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A quantitative investigation of the impact roll has on the percent change in position of breast phantoms of various volumes

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Abstract

The purpose of this study was to evaluate the effect of phantom size and level of roll on the percent change in position and percent of planned treatment volume (PTV) receiving prescription dose of breast phantoms. Due to their non-rigid physical properties, breasts being treated for radiation therapy are vulnerable to positional variability following a roll adjustment. Cone Beam Computed Tomography (CBCT) scans are commonly used to verify anatomical breast position, but they are not always reacquired after a roll correction is made. Treating a volume at a different position has the potential to compromise the intended dose distribution. Factors like roll amount and breast size can contribute to the extent of positional change. A quantitative assessment of these factors on breast phantoms may be helpful for clinics who are determining whether to use large roll corrections for patients receiving breast cancer radiation treatment. It can also assist clinics in deciding the amount of roll that should require re-imaging prior to radiation treatment. The study is a prospective analysis using 3 fabricated breast phantoms with volumes corresponding to 34D, 34E and 34F cups. Each phantom was scanned at a 0-degree baseline position. The phantoms were then scanned 5 times each with 3, 6 and 10 degrees of roll added. MIM was used to correct the orientation of each angled scan to match that of the baseline scan. Contours for the phantom externals of each angled scan were created on the orientation-adjusted data to isolate the settling motion for ease of statistical analysis. Differences in position were calculated with Raystation region of interest (ROI) algebra tool. The primary outcome measure was the percent change in the position. Secondly, a three dimensional (3D) parallel opposed photon plan was created for the phantoms on the baseline scan. The scan was recalculated for each angled scan's phantom external contours. The change in percent of PTV volume covered by prescription dose was recorded as the secondary outcome measure. The results did not indicate

statistically significant differences in the percent change in phantom position or percent change in PTV receiving prescription dose based on different sized phantoms. The results did, however, indicate statistically significant higher percent change in phantom position with larger roll angles. Statistically significant changes in PTV receiving prescription dose were only found between 3 and 6 degrees of roll. Nevertheless, there was only a 0.99% difference between medians which is not clinically significant. The amount of roll applied to a breast phantom has a significant impact on percent change of position. This may indicate that applying roll to a breast cancer patient can change the position of the affected breast. Whether applied manually or using a 6 degree of freedom (DOF) couch, re-taking CBCTs may be beneficial to ensure optimal breast position prior to radiation treatment. Even though this study did not conclude significant differences in percent change of PTV receiving prescription dose using a 3D tangent photon plan, further research should be conducted to explore the dosimetric impacts for proton plans.

Introduction

Breast cancer has been a part of human knowledge for a very long time. The Edwin Smith Surgical Papyrus is a medical text written between 2,500 and 3,000 before common era (BCE) that contains the earliest descriptions [1]. The use of surgery as modern treatment for breast cancer has been around since William Halsted performed the first radical mastectomy in 1882 [1]. However, the implementation of radiation therapy for breast cancer treatment was not attempted until over half a century later. Radiation therapy was first used adjunctively to surgery for breast cancer treatment in 1937 [1]. With the intent of sparing the breast tissue in mind, radium needles were placed into the cavity following surgical tumor removal [1]. Radiation therapy and other treatment modalities for breast cancer have significantly improved in the last several decades. The improvements and widespread availability are much needed because of how common breast cancer is.

According to the American Cancer Society, breast cancer is the most common female cancer in America and is the second leading cause of death from cancer in women, only surpassed by lung cancer [2]. About 1 in 10 of all women will develop breast cancer at some point in their lives [3]. Radiation therapy is commonly used following a lumpectomy and/or axillary dissection, for treatment of recurrence to the primary mastectomy, and for palliation of symptomatic metastatic breast cancer [2]. The type of radiation therapy technique that is chosen for each patient depending on the diagnosis, extent of the disease, and the patient's anatomy. The most important factor at diagnosis when it comes to the survival rate and the determination of the type of treatment is the presence and extent of axillary metastasis [3]. Often, a radiation therapy treatment course is determined to be beneficial. If so, a patient is simulated in a specific

treatment position before treatment begins. There are several factors that affect how a patient is positioned.

The way a patient is positioned is affected not only by the type of radiation treatment to be administered, but also the characteristics of the breast. These characteristics include variations in volume, shape, stability, and firmness. Whether a breast is more pendulous or archetypal is another consideration. Patients can be positioned supine, prone or decubitus with the effected arm usually raised above the head and face turned away from the involved side [3]. Many patients prefer to raise both arms for comfort. Treatment position may also vary due to a patient's physical limitations. With those factors in mind, the position and immobilization devices for each patient are chosen during computed tomography (CT) simulation. The devices are adjusted or constructed with the patient in a straight and level position on the CT table. Alignment lasers projected from the wall and ceiling in the CT simulation room assist therapists in marking the patient's position relative to the CT table. The lasers from above and the left and right laterals converge to a single midline point within the patient. Therapists align the lasers to an area near the disease site that is stable, meaning each laser is projected on a consistent, non-mobile surface of the patient's body. The three points are marked where the lasers cross by the therapist, usually via tattoo.

After the simulation and treatment planning processes are complete, the patient returns for treatment. One of the most important responsibilities of a radiation therapist in the treatment room is ensuring the patient position is reproduced to match the position from the original planning CT. Therapist uses the alignment lasers in the treatment room to ensure they converge on the marks that were placed in CT. A patient will never lay down the exact same way twice. The therapists traditionally make manual adjustments to correct for the slight positional

variations. This can include sliding, rolling, or rotating a patient. Recently, technology has evolved allowing the patient positioning system (PPS) to correct for these variations.

Companies have designed a PPS with pitch and roll capabilities within the last several years. Recently, table shifts to correct for pitch and roll have been regularly applied for a variety of treatments in the clinical setting. However, medical physicists and other professionals in the field of radiation oncology debate on which of the different anatomy sites and modalities of treatment justify the use of a couch robotics for daily treatment. Some argue that only stereotactic radio surgery (SRS) brain treatment currently has significant clinical data proving the justification of its use due to the stability of its location [4]. A primary concern for such argument is the patient's leaning or sliding because of applying a pitch or roll to the PPS. The extent of this movement can be assessed and corrected with further imaging, but that can ultimately lead to longer table time and more image exposure than necessary. Breast tissue also has the potential to move or settle independently of the patient. This situation is witnessed regularly by radiation therapists.

In the realm of radiation therapy, it is widely known that breasts can vary significantly in position from day to day. A patient’s breast tissue can fall differently each time the patient assumes their treatment position. This is often observed by radiation therapists while taking the first setup image prior to treatment. A significant change in the breast tissue position can also be likely observed after manually rolling a patient. It is very possible that same settling effect can result from applying a large table roll and not necessarily from the patient leaning or sliding. The extent of these variations in breast position are important to consider because of the impact they can have on the quality of a plan. For a 3D plan, therapists are responsible for ensuring flash around the breast tissue. Flash is the opening of the field beyond the patient exterior for motion,

see figure 1 in appendix. Flash is visible by a light field. The light field is projected on the patient from the gantry in treatment position and represents the volume that will be irradiated along with the margin for movement. When checking flash, the field light that corresponds to the treatment field should encompass the entire breast with a margin. The margin creates the flash on the wall, floor or ceiling opposite of the gantry head. From day to day, the flash margin around a breast can differ. Variations in setup including roll can prevent the flash from extending around the entire breast. This could result in a fraction being delivered that does not cover the full treatment volume if unnoticed by the therapists. This situation represents one example of how an altered breast position can lead to non-ideal dose delivery. Even if the flash does fully cover the PTV, changes in position could still cause the dose to differ. Different types of radiation may yield larger dose differences due to positional variations than others.

Different modalities of radiation display unique dose deposition characteristics. For a proton therapy treatment, breast tissue position is even more crucial. Protons have a very specific depth at which they deposit dose. The depth for each proton beam corresponds to the beam energy [5]. The depth of delivery corresponding to each energy creates a very thin Bragg Peak [6]. In order to biologically reflect the dose delivery of a treatment plan, protons should travel through roughly the same thickness of tissue day to day. When a breast is positioned in a way that was different from the planning CT, it could cause some variations in the thickness of tissue that the protons travel through. This has the potential to compromise the quality of the treatment. However, the extent of the dosimetric differences resulting from these examples likely vary depending how much a breast independently moves after applying roll. The variation in the amount of movement following a roll can differ from one breast to another depend on the physical characteristics of a breast.

The characteristics contributing to the stability and mobility of a given breast can vary substantially from patient to patient. Breasts come in many different shapes and sizes. The volume of a breast is less dependent on the amount of glandular tissue, fibrous tissue, and ducts, but rather the amount of fat around the glandular tissue [7]. Two important factors that relate to a breast's position are density and firmness. The density and firmness of breast tissue corresponds to the concentration of tissue subcategories [8]. A breast would be considered dense if it has a high concentration of fibrous or glandular tissue compared to the concentration of fat [8]. Typically, breasts become less dense with age, although in some women, breasts tissue density does not change much at all over time [8]. In general, breast density ranges from 0.93-1.04 grams (g) per cubic centimeter (cc) [8]. For this study, phantoms were used. This study examined movement of phantoms with a 1 g/cc density for consistency purposes. Breast density is not the only factor in stability and firmness. Since stability and firmness ultimately correspond to the positional variation, this study will not likely be representative of every breast. A study to quantify whether change in position caused by applying table roll for these phantoms will explore the concept.

Thus, posing the question: For breast phantoms, is median percent change in position affected by phantom size or degree of roll? So far there have not been any studies to quantify the extent of the independent settling movement of breast phantoms following a manual roll or table shift. This type of data could be supplemental for clinics in determining whether or not to use large roll corrections for breast treatments. This study does not intend to establish a range of tolerance. Rather, this study will simply investigate the independent settling of breast phantoms resulting from varying angles of roll and the impact that breast phantom size has on the extent of that positional variation.

Literature Review

In 2013, Varian introduced the PerfectPitch, a 6 degrees of freedom (DOF) couch system [4]. Traditional treatment couch systems can move left or right (x), in or out (y), and up or down (z). In addition to the movements a traditional treatment table can perform, the new treatment table can perform three new types of movement: roll, pitch, and yaw. Roll refers to leaning one side of the body towards the floor and the other side towards the ceiling. Pitch refers to tilting a patient's feet toward the floor and head toward the ceiling or vice versa. Yaw refers to twisting or oscillating around a vertical axis. Before this technology, therapists had to manually reposition patients. The adjustments were not always accurate and could not be quantified, so the field embraced the new technology. Roll corrections are used widely for a variety of radiation therapy treatments. However, since it was released, there is still two sides to the argument of which anatomy and types of treatment justify the use of roll table corrections.

According to professionals like Dr. Christopher F. Njeh, the potential benefit is surpassed by the loss of tabletop leveling, which can lead to a patient sliding or leaning and creates too much setup uncertainty for most treatments [9]. However, he admits a strong setup advantage for stereotactic radiotherapy for several reasons including the small target, high dose, and proximity to organs at risk [9]. Professionals on the other side of that argument like Karen Snider, MS, contends the use of 6DOF couches for conventional treatments to limit setup deviations [9]. This study could be supplemental in oncology professionals determining if they think applying roll to a 6DOF couch is preferred for breast patients.

In 2015, the British Institute of Radiology conducted a study shortly after commissioning a 6DOF couch by collecting data on every brain, lung, liver, pancreas, and prostate patient for the first 6 months of its use [10]. The daily images were assessed to try to infer which treatment

sites pitch and roll compensations should be required [10]. They found that even though brain patients benefit the most, pitch and roll corrections improved patient set-up in all treatment sites [10]. This sounds promising, but it does not take into account the independent breast movement that could occur as a result of applying roll while setting up a breast cancer patient. Going a step further and considering the independent positional variation of breast tissue after applying roll could be help determine whether the usage of table or manual roll is preferred.

Subsequently, a study was done using 25 patients to compare the setup accuracy for tangential breast radiotherapy among three different imaging methods and tested the relationship between setup errors and breast size [11]. They concluded that a significant relationship does exist between size and setup error citing patients with larger breasts tend to yield more positional variation [11]. To help combat this problem, treating patients with large or pendulous breasts in the prone position has slowly become more common to decrease acute and late toxicities [12]. These studies help confirm the benefit of pitch and roll corrections for various pathologies and provides us with proof that larger breasts tend to set up less consistently. However, none of these studies address the independent settling movement that results from applying a roll correction to the couch.

This study will build off previous breast cancer localization studies and studies about 6 degrees of freedom couches with the intent to determine whether roll impacts breast phantom positioning. This study will measure variations in the positioning of fabricated breast phantoms following roll application at varying degrees. The data will be analyzed using Statistical Package for the Social Sciences (SPSS) software. Since stability and firmness ultimately correspond to the positional variation that accompanies setup discrepancy, this study will not likely be

representative of every breast. Rather, this study aims to quantify changes in position of fabricated breast phantoms.

Primary null hypothesis (H_o1): Median percent change of breast phantom position does not differ depending on phantom size or level of roll.

Primary alternative hypothesis (H_a1): There is at least one difference in median percent change of breast phantom position depending on phantom size or level of roll.

In addition, this study will also contain a planning comparison component to explore the dosimetric effects resulting from phantom position change. The dosimetric evaluation of differences occurring from phantom size and level of angle could provide insight on how real breast treatments may vary in the presence of roll-induced positional change. A plan will be created for the initial scan with the phantoms at 0 degrees of roll. The same plan will be recalculated for each rolled scan and the percent change in PTV prescription coverage will be used as the secondary outcome measure.

Secondary null hypothesis (H_o2): Median percent change in PTV prescription coverage of breast phantoms does not differ depending on phantom size or level of roll.

Secondary alternative hypothesis (H_a2): There is at least one difference in median percent change in PTV prescription coverage of breast phantoms depending on phantom size or level of roll.

Methods and Materials

Study Design

This is a prospective study of three breast phantoms of various volumes. The study was approved by a midwestern institutional review board (IRB) office under the exempt application

category since it uses no patient data. The study was also approved by the IRB office at Grand Valley State University under the same category. All phases of research were conducted and assessed in the physics, imaging, and therapy departments of the radiation oncology center. Percent change of phantom position was the primary outcome measure. International Business Machine's (IBM) SPSS software was used to plot the data and attain the necessary statistical output. Secondly, a 3D tangential parallel opposed treatment plan was created to explore the dosimetric effects resulting from positional change. The percent of PTV receiving at least 5,000 centigray (cGy) (V50) was the secondary outcome measure. IBM's SPSS software was used to plot the data and attain the necessary statistical output.

Phantom Fabrication

The phantoms were created with water balloons filled with varying volumes that correspond to cup sizes of 34D, 34E and 34F. The volumes that correspond to those cup sizes are roughly 590 cc, 710cc and 850cc, respectively [13]. The diameters corresponding to those cup sizes are approximately 13.1 centimeters (cm), 14 cm and 14.8cm, respectively [13]. Phantoms were created to replicate those values. Using breast phantoms was a good way to rule out patient movement error and solely focusing on the change in position of the breast phantoms caused by roll-induced settling only. The breast phantoms were roughly tissue equivalent in density to human breast tissue at a value of 1.00 g/mililitre (ml). The viscosity and texture were mediated by adding Thick-IT nectar dietary thickener to the water used for the phantoms. The water was added to the phantoms using a turkey baster. The baster had a capacity of 30cc. Different ratios of Thick-IT and tap water were concocted until the viscosity and texture of the phantoms roughly equated those of real breasts.

Next, they were mounted to a stable foam board with 3M mounting tape fixed securely around the parameter of each phantom. All of the phantoms were created using the same 34" party balloons. The F phantom was more high set and firmer since it was filled with the largest volume. Conversely, the D phantom was less taut and more low set. Special measures were taken to correct this variation by mounting the phantoms in a way to achieve the appropriate diameters that corresponded to the desired cup sizes. The excess edges of the balloons were carefully folded under the rest of the phantom and taped to the board. The amount of excess balloon had to be adjusted a few times before the optimal dimeters of the phantoms were achieved. As a result, the volumes, the diameters, viscosities, densities, and shapes of the phantoms roughly matched their respective cup sizes, see figure 2 in appendix.

Once the optimal phantoms were created and secured to the mounting board, several metallic markers were taped along the center of the board superiorly and inferiorly to each phantom to assist in laser alignment in the CT room. More markers were taped 20cm laterally on both sides of the superior and inferior most markers. These were placed to assist in orientation matching during the image registration process. Next, wedges were created to give the mounting board 3, 6 and 10 degrees of roll. Since the width of the board was 20 inches and the desired angles of roll were predetermined, the trigonometric formula to find the opposite side of a right triangle was used to calculate the optimal wedge thickness, see figure 3 in appendix. This formula was given by:

$$Sin(a) = \frac{opposite}{hypotenuse}$$

Where (a) is the desired angle and the 20-inch width of the mounting board is the hypotenuse. The formula was used to calculate the appropriate thickness of 1.05 inches for the desired wedge thickness corresponding to 3 degrees of roll. The formula was also used to find the desired

wedge thicknesses of 2.1 inches for a 6-degree angle and 3.5 inches for a 10-degree angle. A razor knife was used to create the wedges by carefully cutting strips from a firm foam board for each of the three desired thicknesses.

Simulation

After fabrication of all required supplies, an initial CT was acquired with the mounting board lying flat with zero degrees of roll to form a baseline position for the phantoms. Next, CT scans were acquired for each roll value by placing the corresponding wedge under one side of the mounting board along the outer edge. For each angle, the wedge was carefully positioned perpendicular to the table. This created a right angle of the wedge with the table, ensuring the angle of the board was consistent with the value calculated from the trigonometric formula, see figure 3 in appendix. This process was repeated to acquire one CT scan of the phantoms at each angle. The positions were then re-created for each angle to acquire four more scans at each angle. This provided a total of sixteen scans: one 0-degree scan, five 3-degree scans, five 6-degree scans and five 10-degree scans. All 16 scans were then sent from the CT scanner console to MIM, the medical image processing software.

Image Processing

The external surfaces of each phantom in the initial baseline scan were delineated with MIM's external definition tool. The resulting contours were renamed to D0_ext, E0_ext and F0_ext to match their corresponding phantom size and to indicate the 0-degree baseline position. Next, the first scan with the mounting board at three degrees of roll was brought into the same MIM session as the baseline scan. This image data was then fused to the baseline scan using the rigid fusion tool. The decision was made to adjust the orientation of the angled scan to match that of the baseline scan. This allowed the variation in position due to roll induced settling

to be isolated and easily quantified. The image orientation editor tool was used to match the orientation of the baseline scan for pitch, roll, rotation, x, y and z. The markers taped to the corners of the board and along the center of the board made the orientation matching process easy to accomplish.

The image data was overwritten and saved to reflect the changes in orientation after the orientation of the two CTs agreed. Contours for each phantom were delineated on corrected CT using the external definition tool to maintain delineation integrity. Each contour was named appropriately according to the phantom size and angle. For this scan, the contours were named D3_ext_1, E3_ext_1 and F3_ext_1. The transfer contours tool was used to transfer those contours to the baseline scan. It was then easy to visualize the difference between the position of the breast in the presence and absence of roll, see figure 4 in appendix. The procedure above was followed to create orientation-corrected contours for all remaining CT scans. Finally, the expansion/contraction tool was used to contract the surface of each external contour by 3mm in all directions to create PTV contours. As a result, the baseline scan contained all of the imaging data and contours necessary to conduct this study.

After all contours were transferred and saved to the baseline scan, they were exported to Raystation Treatment Planning System. Raystation was used to quantify the change in position resulting from the presence of roll. The volumes of the baseline phantom external contours for D, E and F were recorded as 563.10cc, 716.42cc and 887.39cc respectively. Under the patient modeling interface of Raystation, the region of interest (ROI) algebra tab was used to create intersection contours between the baseline external contours and each roll-adjusted external contour. The intersection function creates a contour at areas where 2 contours overlap. The values for the volumes in cc of each intersection contour were recorded for each data point.

Those values were subtracted from the initial phantom volumes from the scan at 0 degrees. The resulting values were finally divided by the initial phantom volumes to obtain our primary outcome measure: percent change.

Planning

To get a glimpse at how these subtle positional changes can affect the dosimetric outcomes, a 3D breast plan with parallel opposed beams was created. The plan was loaded with three beam sets. Each beam set corresponded to a phantom. The isocenter for each beam set was placed at the center of the PTV contour. The isocenter's z-coordinate was manually adjusted for each contour by changing the z-value until it was located 3mm from the posterior edge of the external contour. Next, two fields were added with gantry angles at 90 and 270 degrees. The isocenter's x-coordinate was adjusted to balance the source-to-skin distance (SSD) for both fields. The treat & protect tool was then used to allow the field edge to have 5mm of margin around the PTV's posterior surface and 2 cm of flash around the PTV's anterior, superior, and inferior surfaces. The multi leaf collimator (MLC) was set to the specified margin with the conform MLC tool. This 3D field-in-field (FIF) plan was like a conventional 3D breast plan with matching tangential divergence and appropriate flash margins. The FIF technique was utilized by creating control points for the tangent fields. Carefully, the beam weights and MLCs were manipulated until 95% of the volume of each PTV was covered by the arbitrary 5,000 cGy prescription and zero volume was covered by 5250cGy or 105% of the prescription, see figure 5 in appendix. The process above was repeated for each beam set until the beams satisfied those these treatment goals for each phantom's PTV.

Finally, the dosimetric data was ready to be collected. Each external contour's density was set to 1g/mL by overriding the material to water. For the first 3-degree scan, the external

contours had to be set to external to enable Raystation to calculate the plan using only those contours. The recalculate button was pushed and the resulting dose statistics were recorded. The dose distribution and statistics displayed some obvious differences, see figure 6 in appendix. This process was repeated for each scan's externals. PTV receiving 100% prescription, PTV receiving >105% prescription and max point dose (Dmax) was recorded for each phantom in all 16 scans. All data for positional change and dosimetric variation was transferred into an excel sheet.

Results

Two-way analysis of variance (ANOVA) test is a statistical method used to compare means of a numeric dependent variable between groups constructed from two independent variables [14]. It can also find an interaction between independent variables and possibly the main effects or simple effects [14]. For this study, it would assist in assessing the primary outcome measure and determine if the percent change in position of breast phantoms is affected by cup size and/or level of roll and how they interact. Certain data assumptions must be met to use ANOVA tests: samples must come from normal populations and populations must have equal variance [14]. When data does not meet the assumptions for ANOVA testing, non-parametric tests should be used.

In this study, nonparametric tests were used since the normality assumptions were not met. First, G*Power 3.1 determined a minimum sample size of n=80 needed for 9 groups, 2 covariates, large effect size F=0.4, 0.8 power, 4 degrees of freedom and an alpha error probability of 0.05, see figure 7 in appendix. Also, the boxplots revealed large differences between inter quartile ranges and lots of skewness, see figure 8 in appendix. Lastly, the

histograms were not normally distributed, see figure 9 in appendix. A non-parametric or distribution free test does not assume anything about the underlying normality of the data distribution [15]. Nonparametric tests are often used for small sample sizes and can perform well with non-normal continuous data if you have 15 items in each group [15]. Kruskal-Wallis analysis of variance test was used to compare the medians among the three levels of roll and three sizes of phantoms. A post-hoc analysis was done by obtaining a Mann-Whitney test output to compare each pair of groups. Bonferroni's adjustment was used to determine an appropriate significance level. The alpha value of .05 was divided by three, giving us a significance level of 0.0167 as our Mann-Whitney p-value comparison. The statistical output allowed us to rank the affect each phantom size had on the percent change via pairwise comparisons. The same non-parametric process was repeated for the level of roll.

Change in Position

The primary goal of this study was to measure the percent change in breast phantom position depending on three phantom sizes and three different angles. By matching the mounting board orientation of the rolled scans to that of the initial scan, there was a clear and quantifiable difference in position change because of roll. The external definition tool on MIM was used to generate external contours while maintaining integrity for each phantom on each individual CT scan. Correcting the orientation of the rolled scans to match that of the non-angled baseline scan allowed use of ROI algebra to create intersection contours in areas where each angled external contour overlapped with its external from the initial scan. The percentage of the volume not overlapping was recorded and used as our change_position dependent variable. The data appeared to display a trend of larger change in position with a greater angle of roll.

Size

For the D phantom, the change in position for all angles ranged from 4.11% to 6.04%, with a median change of 4.66% and a mean change of 4.972%. For the E phantom, the change in position for all angles ranged from to 2.64% to 6.28%, with a median change of 4.03% and a mean change of 4.3153%. For the F phantom, the change in position for all angles ranged from to 2.77% to 4.93%, with a median change of 4.51% and a mean change of 4.122%. A Kruskal-Wallis Test was performed and indicated no significant difference in median percent change in breast phantom position among different phantom sizes, chi-squared (X^2) = 5.126, p = 0.077, see table I in appendix. No post-hoc test was necessary.

Roll

At 3 degrees of roll, the change in position for all phantom sizes ranged from 2.64% to 4.55%, with a median change of 3.53% and a mean change of 3.5327%. At 6 degrees of roll, the change in position for all phantom sizes ranged from 3.94% to 5.04% with a median change of 4.46% and a mean change of 4.4287%. At 10 degrees of roll, the change in position for all phantom sizes ranged from 4.64% to 6.28%, with a median change of 5.61% with a mean change of 5.53%. A Kruskal-Wallis Test was performed and indicated a significant evidence of at least one difference in median percent change in breast phantom position among different levels of roll, X^2 = 33.238, p = <0.001 which is < 0.05, see table II in appendix. Post-hoc analysis was justified for pair-wise comparisons of all three groups.

The Bonferroni's adjustment indicated a significance level of 0.0167 for a Mann-Whitney test p-value comparison after dividing the significance level of 0.05 by 3. Sufficient evidence of a difference in median percent change in position was found between 3 and 6 degrees of roll, p = 0.001 < 0.0167, see table III in appendix. The median change in position from 6 degrees of roll was greater than the median change in position from 3 degrees of roll. Sufficient evidence of a

difference in median percent change in position was also found between 3 and 10 degrees of roll, $p = .001 < 0.0167$, see table III in appendix. The median change in position from 10 degrees of roll was greater than the median change in position from 3 degrees of roll. Furthermore, sufficient evidence of a difference in median percent change in position was also found between 6 and 10 degrees of roll, $p = 0.001 < 0.0167$, see table III in appendix. The median change in position for 10 degrees was higher from 10 degrees of roll than the median change in position from 3 degrees of roll.

Change in Dose

The secondary goal of this study was to measure the change in percent of PTV prescription coverage resulting from change in breast phantom position as a resut of varying phantom sizes and roll angles. Recalculating the initial plan on the orientation adjusted contours from each rolled scan allowed the changes in dose to only reflect those caused by tissue settling. The value for each PTV receiving 100% prescription dose was recorded to an excel sheet. From each recorded value, the value for percent of PTV receiving 100% prescription for the initial plan, 95% was subtracted. This value was recorded as our secondary outcome measure change_dose and used as a dependent variable in the STSS non-parametric tests. The data did not appear to display a trend.

Size

For the D phantom, the change in percent PTV prescription coverage at all degrees of roll ranged from -0.05% to 3.22%, with a median change of 1.96% and a mean change of 1.441%. For the E phantom, the change in percent PTV prescription coverage at all degrees of roll ranged from -1.69% to 0.71%, with a median change of 0.25% and a mean change of -0.126%. For the F phantom, the change in percent PTV prescription coverage at all degrees of roll ranged from -

1.27% to 1.65%, with a median change of 0.2% and a mean change of 0.2527%. A Kruskal-Wallis Test was performed and indicated sufficient evidence of at least one difference in median percent change in PTV prescription coverage among different phantom sizes, $X^2 = 6.733$, $p = 0.035$ which is < 0.05, see table IV in appendix. Post-hoc analysis was justified for pair-wise comparisons of all three groups.

The Bonferroni's adjustment indicated a significance level of 0.0167 for a Mann-Whitney test p-value comparison. Insufficient evidence of a difference in median percent change in PTV prescription coverage was found between D and E phantoms, $p = 0.019 > 0.0167$, see table V in appendix. The evidence of a difference in median percent change of PTV prescription coverage was also insufficient between D and F phantoms, $p = .045 > 0.0167$, see table V in appendix. Furthermore, insufficient evidence of a difference in median percent change in PTV prescription coverage was also found between E and F phantoms, $p = 0.486 > 0.0167$, see table V in appendix.

Roll

At 3 degrees of roll, the percent change of PTV prescription coverage for all phantom sizes ranged from -0.96% to 0.33%, with a median change of 0.06% and a mean change of -0.128%. At 6 degrees of roll, the change in PTV prescription coverage for all phantom sizes ranged from 0.25% to 2.43% with a median change of 1.05% and a mean change of 1.117%. At 10 degrees of roll, the change in PTV prescription coverage for all phantom sizes ranged from -1.69% to 3.22%, with a median change of -0.12% with a mean change of 1.736%. A Kruskal-Wallis Test was performed and indicated a significant evidence of at least one difference in median percent change in PTV prescription coverage among different levels of roll, $X^2 = 11.866$,

p = 0.003 which is < 0.05, see table VI in appendix. Post-hoc analysis was justified for pair-wise comparisons of all three groups.

The Bonferroni's adjustment indicated a significance level of 0.0167 for a Mann-Whitney test p-value comparison. Sufficient evidence of a difference in median percent change in PTV prescription coverage was found between 3 and 6 degrees of roll, p = <0.001 which is < 0.0167, see table VII in appendix. The median change in PTV prescription coverage from 6 degrees of roll was greater than the median change in PTV prescription coverage from 3 degrees of roll. Insufficient evidence of a difference in median percent change in PTV prescription coverage was also found between 3 and 10 degrees of roll, p = 0.935 > 0.0167, see table VII in appendix. Furthermore, insufficient evidence of a difference in median percent change in PTV prescription coverage was also found between 6 and 10 degrees of roll, p = 0.217 > 0.0167, see table VII in appendix.

Discussion

The purpose of this study was to evaluate the effect of phantom size and level of roll on the percent change in position and PTV receiving prescription dose of breast phantoms. Under the right circumstances, the settling response of a breast phantom in the presence of roll could be similar to that of a real breast for a patient receiving radiation therapy. Changes in the daily breast position has the potential to compromise the integrity of a breast cancer treatment and result in delivery of a different dose to the PTV than planned. Breasts certainly have the potential to settle differently on a daily basis while applying 6DOF table roll or manual roll. The independent settling of breast tissue that occurs when a roll is applied should be considered while aligning a patient in order to deliver an optimal treatment. The size of a breast and the level of

roll are both factors that could contribute to the extent of percent change in position and percent change in PTV receiving prescription dose of a breast. This study attempted to quantify how much phantom size and level of roll contribute to those changes. The results of this study on breast phantoms may help future researchers quantify how real breasts behave under the same circumstances.

Change in Position

Size was not found to be a significant factor affecting the percent change in position of a breast phantom. The quantity of rolled phantom volumes that did not overlap the baseline scan seemed to be fairly proportional among the different phantom sizes. On the other hand, the percent change in phantom position did significantly differ depending on the level of roll. As anticipated, the percent change in breast phantom position was larger for 6 degrees of roll than 3 degrees of roll. It was also larger for 10 degrees of roll than 6 degrees of roll. The changes of breast phantom position resulting from roll are important to consider because of the implications they may have for real breasts. If roll is applied to a patient before treatment, it could result in undesirable positioning if the position is not further verified before delivering a radiation treatment. Thus, undesirable positioning may lead to undesirable dose delivery.

Change in Dose

The Kruskal-Wallis Test indicated sufficient evidence of at least one difference in median percent change in PTV prescription coverage due to phantom size at all three levels of roll. However, the Mann-Whitney tests did not find any significant differences in median percent change in PTV prescription coverage among the three pairs of comparisons. Likewise, the Kruskal Wallis test displayed sufficient evidence of at least one difference in median percent change in PTV receiving prescription dose due to level of roll. The Mann-Whitney output only

displayed on significant difference between medians for 3 and 6 degrees of roll. Arguably, this 0.99% would not be considered a clinically significant difference.

Limitations and future research

There were several limitations of this study. During fabrication of the breast phantoms, the densities, viscosities and surface tensions were estimated by hand. The dynamic properties likely differ from real breasts. Elastography ultrasound breast phantoms and needle breast biopsy phantoms are available for purchase and would likely reflect physical behaviors of real breasts, but the prices exceeded the budget for this project. Using a more realistic phantoms will allow for more useful data and have results more applicable to breast patients. Another limitation of this study was failing to use human subjects. The same prospective study using human subjects to acquire the imaging data will yield the most optimal and useful results for the primary outcome measure.

There were also some limitations pertaining to the dosimetric secondary goal. A photon plan was created for the dosimetric comparison component of this study since it was the available modality. Compared to photons, the dosimetric impact of protons are more depth dependent. Performing this portion of the study using a proton plan will likely yield more significant dosimetric differences.

Future research could include the human participation or the use of phantoms that are more like real breasts. This would allow collection of more realistic and useful data for percent change in position because of roll. The dosimetric differences would vary between patients due to differing patient anatomy. Density and surface angle upon entry both have the potential to impact dose deposition. Surface guided radiation therapy could be used as a position variation reference tool for future research that involves human participation. Future research could also

include proton plan comparisons to assess the impact altered breast position induced by roll has on percent of PTV receiving prescription dose. For a study involving human participants, a large enough sample size could allow for a regression statistical analysis. This could allow for researchers to establish a linear relationship between the independent and dependent variables and allow a dependent variable value to be predicted based on the independent variables.

Conclusion

One of the most important factors in the quality of a radiation treatment is the patient position, setup and reproducibility. Traditionally, therapists will make manual adjustments to correct for the slight positional variations. A patient that has been manually corrected for a roll variation will typically have their position verified by a CBCT prior to treatment. However, that is not always true for roll corrections that are applied using a 6DOF couch. Breasts are particularly vulnerable to positional changes following a dynamic movement like roll. Thus, oncology professionals should be cautious of independent settling of breast tissue after rolling a patient whether manually or using a 6DOF couch.

Several factors potentially contribute to the physical response in position of breast phantoms in the presence of roll. Among those are phantom size and level of roll. This study showed that phantom size did not significantly impact median percent change in position. However, this study did show a significant difference in the median percent change of position depending on the level of roll. For 3, 6 and 10 degrees of roll, the median percent change in phantom position was highest for 10 degrees of roll and lowest for 3 degrees of roll.

Recalculating the plan created for the phantoms at the initial 0 degree of roll position on the rolled scans produced some noticeable dosimetric variation. However, the amount of

dosimetric differences did not appear to follow any order. In fact, none of the means among all 9 pairs of data reached a 2% change in percent PTV prescription coverage. The only significant median difference in percent PTV coverage found by the Kruskal Wallis and Mann Whitney tests were between the medians of 3 and 6 degrees of roll. Even then, the differences in those medians only amounted to a difference of 0.99% PTV prescription coverage. This would not likely be considered an insignificant difference in the opinion of an Oncologist or Physicist.

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Appendix

Table I. Kruskal Wallis output for percent change of phantom position depending on phantom size.

Size (cup)	N	Mean Rank
D	15	29.27
E	15	19.73
F	15	20.00

Kruskal-Wallis H	5.126
df	2
Asymp. Sig.	0.077

Table II. Kruskal-Wallis output for percent change of phantom position depending on level of roll.

Roll (degrees)	N	Mean Rank
3	15	9.67
6	15	22.07
10	15	37.27

Kruskal-Wallis H	33.238
df	2
Asymp. Sig.	<0.001

Table III. Mann-Whitney output for percent change in phantom position depending on level of roll.

Roll (degrees)	N	Mean Rank	Sum of Ranks
3	15	9.67	145.00
6	15	21.33	320.00
Sig.		<0.001	
3	15	8	120.00
10	15	23	345.00
Sig.		<0.001	
6	15	8.73	131.00
10	15	22.27	334.00
Sig.		<0.001	

Table IV. Kruskal-Wallis output for %change in PTV prescription dose depending on phantom size.

Size (cup)	N	Mean Rank
D	15	30.00
E	15	18.10
F	15	20.90
Kruskal-Wallis H	6.733	
df	2	
Asymp. Sig.	0.035	

Table V. Mann-Whitney output for %change in PTV prescription dose depending on phantom size.

Roll (degrees)	N	Mean Rank	Sum of Ranks
D	15	19.27	289.00
E	15	11.73	176.00
Sig.		<0.001	
D	15	8	120.00
F	15	23	345.00
Sig.		<0.001	
E	15	8.73	131.00
F	15	22.27	334.00
Sig.		<0.001	

Table VI. Kruskal-Wallis output for %change in PTV prescription dose depending on level of roll.

Roll (degrees)	N	Mean Rank
3	15	15.83
6	15	32.03
10	15	21.13
Kruskal-Wallis H	11.866	
df	2	
Asymp. Sig.	0.003	

Table VII. Mann-Whitney output for %change in PTV prescription dose depending on level of roll.

Roll (degrees)	N	Mean Rank	Sum of Ranks
3	15	8.5	127.5
6	15	22.5	337.5
Sig.		<0.001	
3	15	17.53	263.0
10	15	13.47	202.0
Sig.		0.206	
6	15	15.33	230.0
10	15	15.67	235.0
Sig.		0.917	

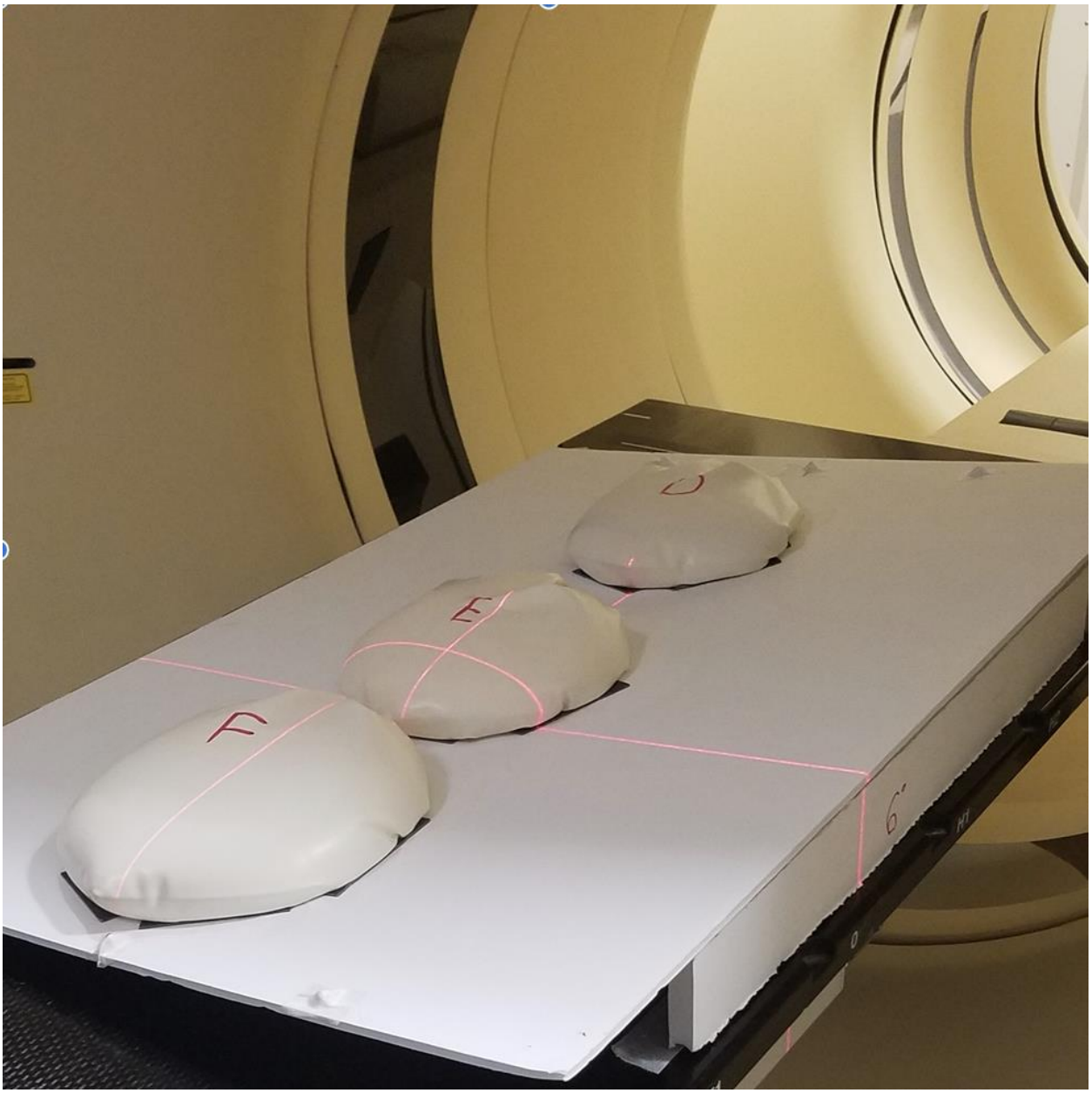

Figure 1. Photograph of breast phantoms fixed to the mounting board positioned at a 6-degree angle.

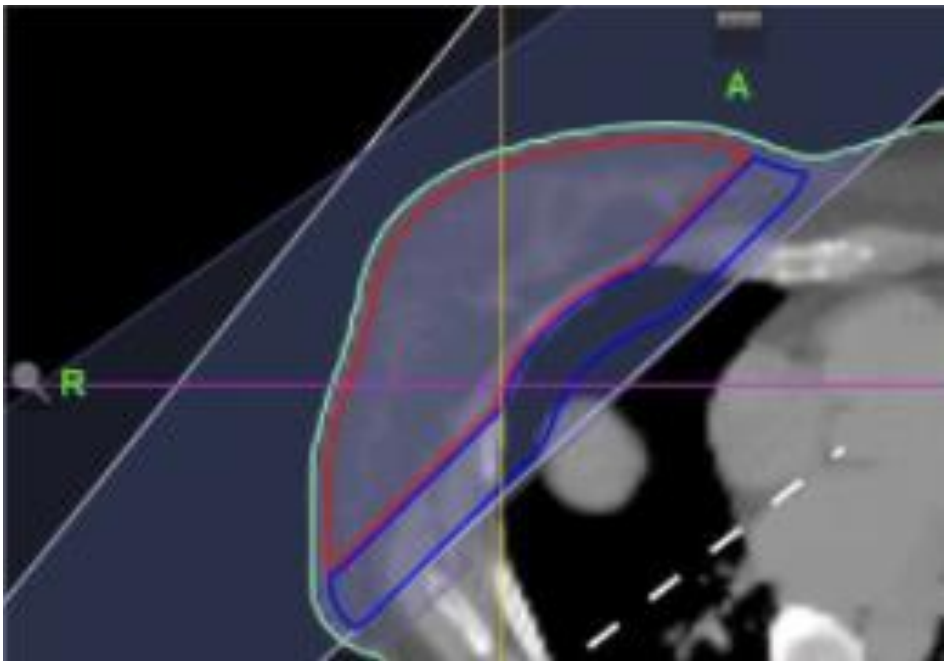

Figure 1. Breast fields shaded blue displaying a flash margin outside of the breast.

Figure 2. The trigonometric formula to calculate the appropriate wedge thickness for each desired angle

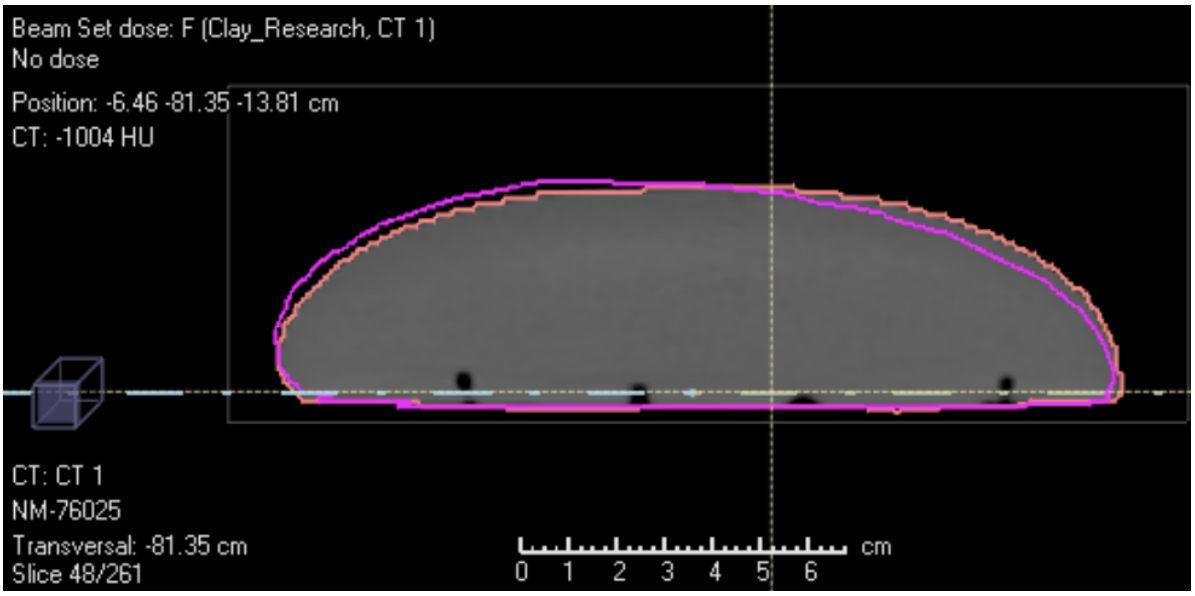

Figure 3. Baseline scan of the F phantom and contour along with the contour from one of the r=3 scans.

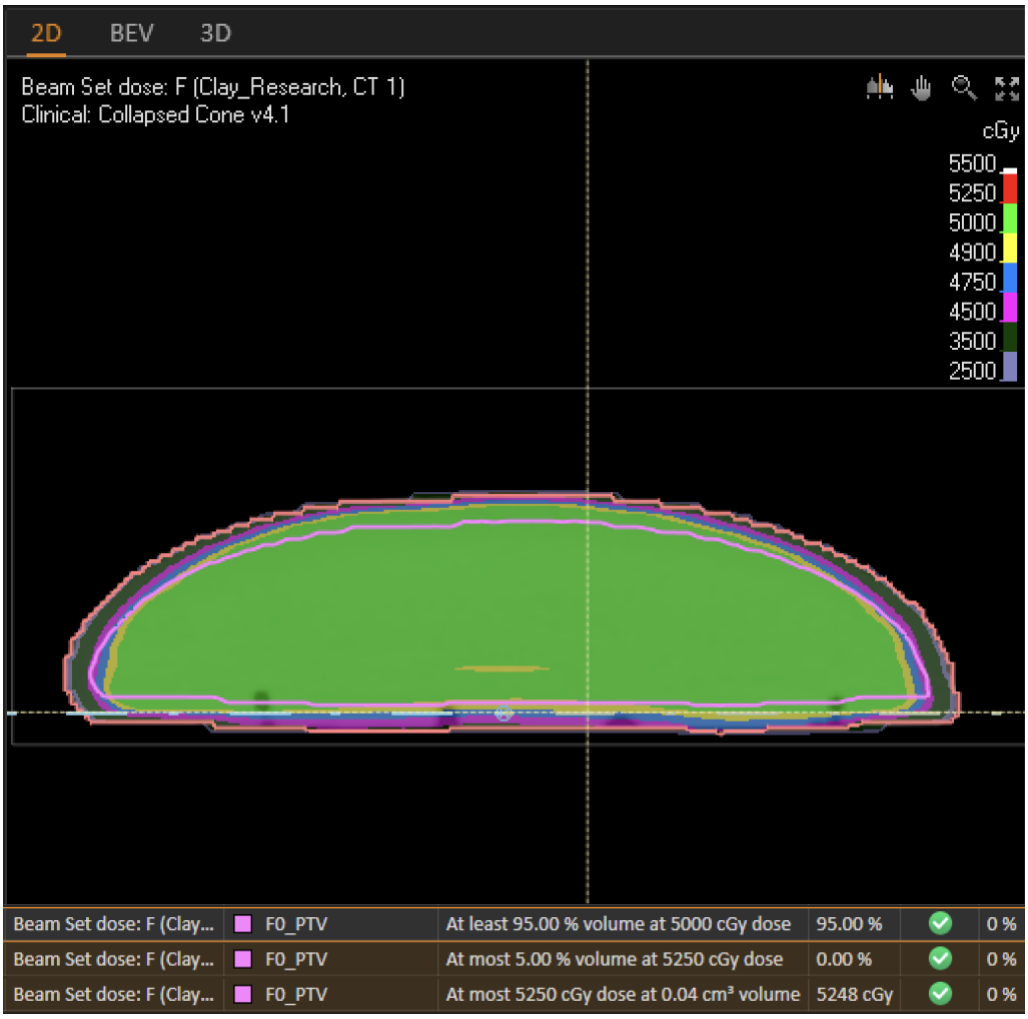

Figure 4. Screenshot of a slice from the initial plan created for the F phantom with 0 degrees of roll.

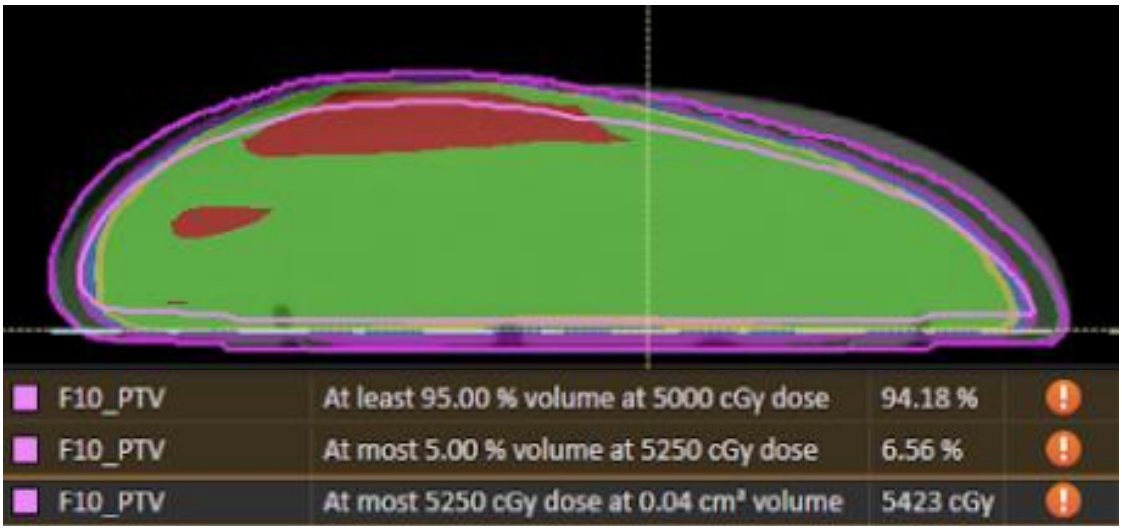

Figure 5. Dose distribution after recalculating the initial plan on the F phantom at 10 degrees of roll.

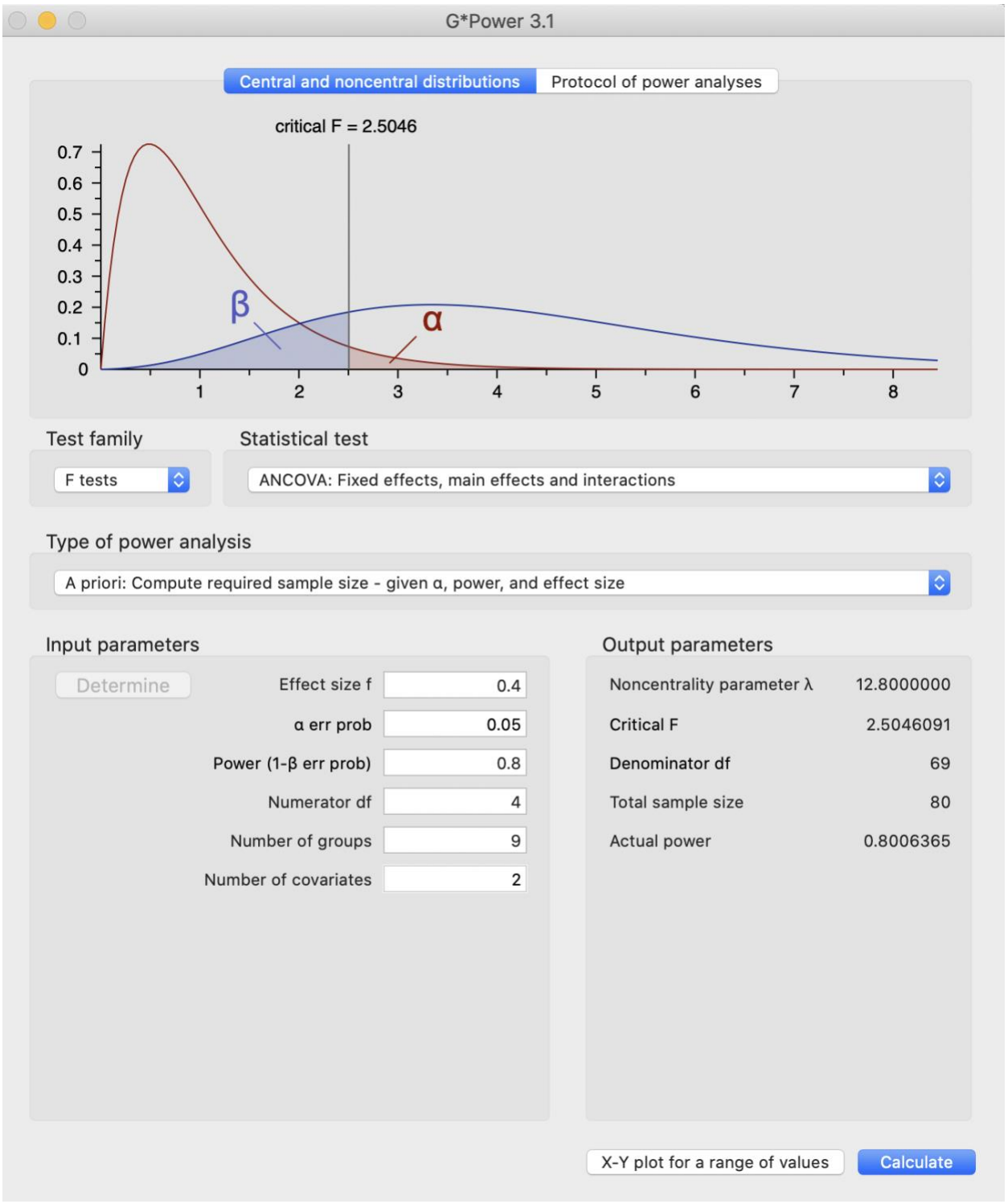

Figure 6. G*Power sample size results displaying a minimum sample size of 80.

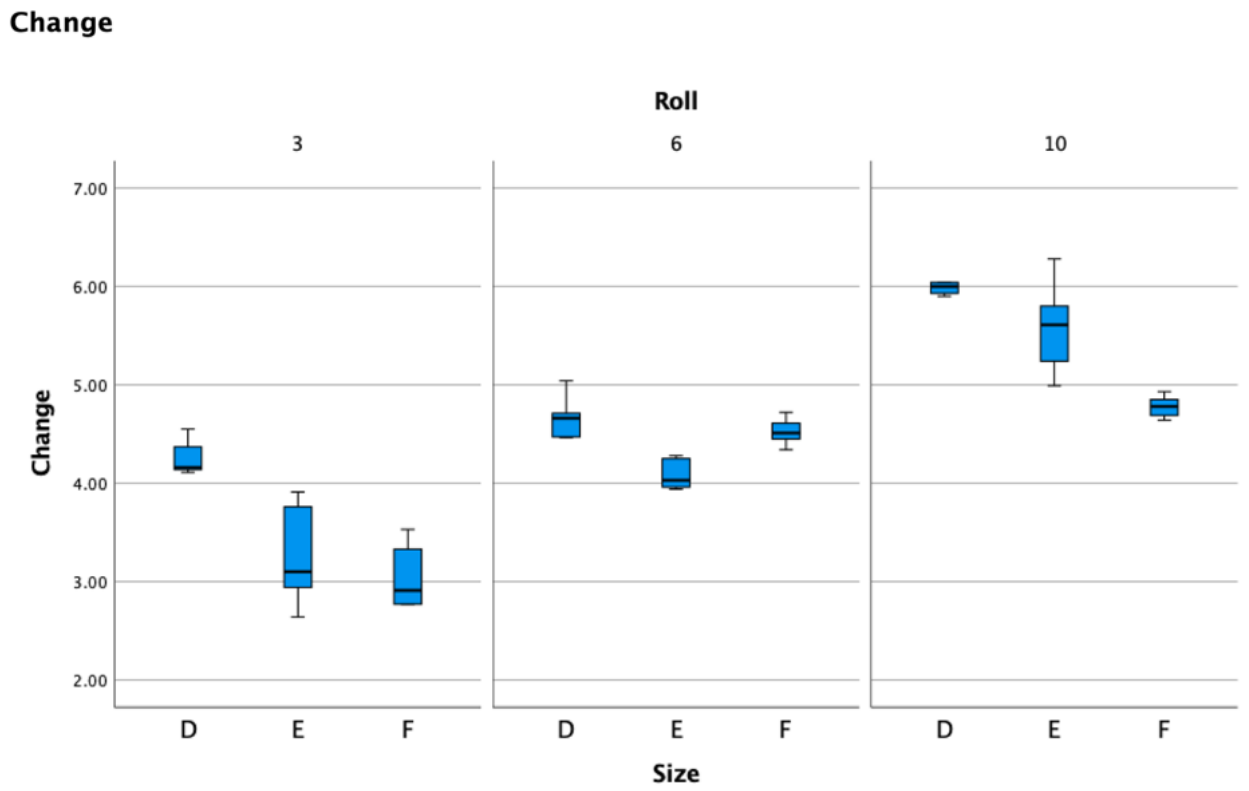

Figure 7. Box plots for percent change in phantom position with factors paneled by columns.

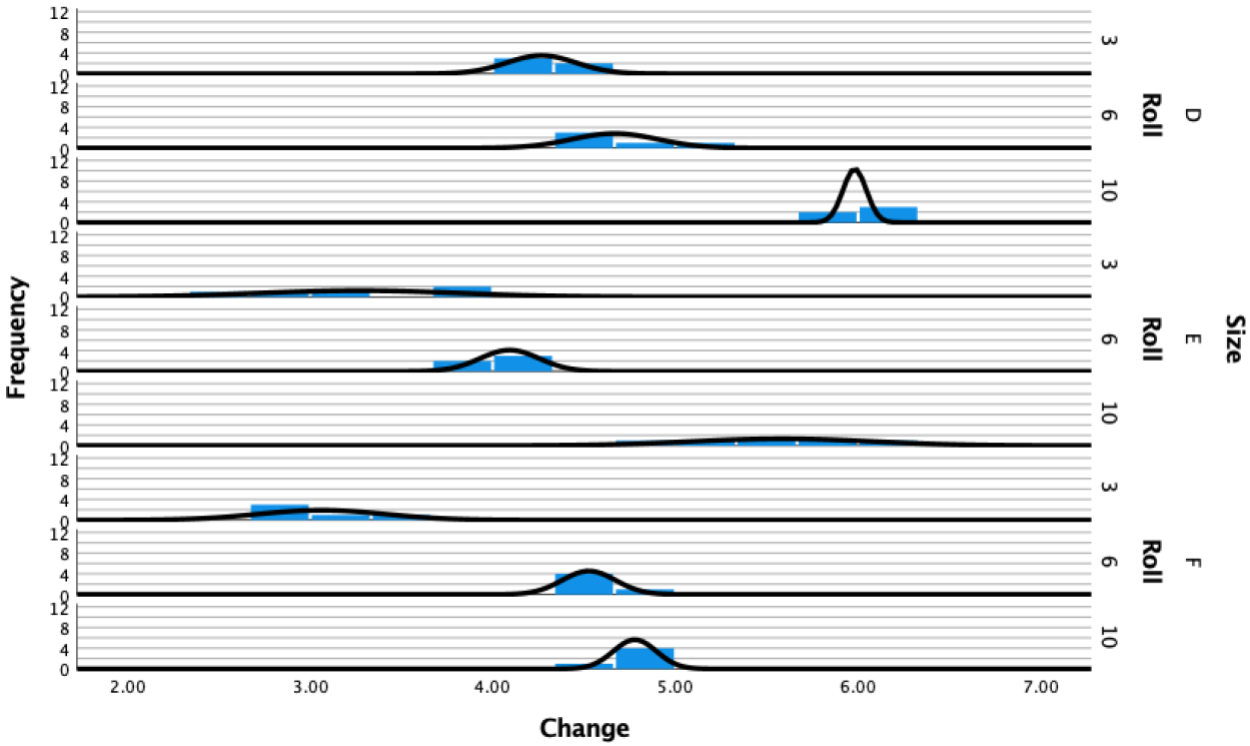

Figure 8. Histograms for percent change in phantom position with factors paneled by rows.