Breast radiotherapy in the prone position primarily reduces the maximum out-of-field measured dose to the ipsilateral lung

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Purpose: To quantify the potential advantages of prone position breast radiotherapy in terms of the radiation exposure to out-of-field organs, particularly, the breast or the lung. Several dosimetric studies have been reported, based on commercial treatment planning software (TPS). These TPS approaches are not, however, adequate for characterizing out-of-field doses. In this work, relevant out-of-field organ doses have been directly measured.
Methods: The authors utilized an adult anthropomorphic phantom to conduct measurements of out-of-field doses in prone and supine position, using 50 Gy prescription dose intensity modulated radiation therapy (IMRT) and 3D-CRT plans. Measurements were made using multiple MOSFET dosimeters in various locations in the ipsilateral lung, the contralateral lung and in the contralateral breast.
Results: The closer the organ (or organ segment) was to the treatment volume, the more dose sparing was seen for prone vs supine positioning. Breast radiotherapy in the prone position results in a marked reduction in the dose to the proximal part of the ipsilateral lung, compared with treatment in the conventional supine position. This is true both for 3D-CRT and for IMRT. For IMRT, the maximum measured dose to the lung was reduced from 4 to 1.6 Gy, while for 3D-CRT, the maximum measured lung dose was reduced from 5 to 1.7 Gy. For the proximal part of the ipsilateral lung, as well as for the contralateral lung and the contralateral breast, there is little difference in the measured organ doses whether the treatment is given in the prone or the supine-position.
Conclusions: The decrease in the maximum dose to the proximal part of the ipsilateral lung produced by prone position radiotherapy is of potentially considerable significance. The dose-response relation for radiation-induced lung cancer increases monotonically in the zero to 5-Gy dose range, implying that a major decrease in the maximum lung dose may result in a significant decrease in the radiation-induced lung cancer risk. [http://dx.doi.org/10.1118/1.3700402]

Key words: prone breast, lung dose, secondary cancer, low dose measurements, breast cancer

I. INTRODUCTION

Radiation therapy inevitably results in radiation exposure to normal healthy organs, potentially subjecting them to an increased risk of a radiation-induced second cancer.[1] As patients who undergo radiotherapy are being treated at a younger age and are living for increasingly long times post-radiotherapy, the issue of radiation-induced second cancers has become increasingly pertinent.[2,3] In particular, long term survival after breast cancer diagnosis has increased markedly in the last decade: 15-year relative survival in the United States after breast cancer diagnosis is now 75%,[4] up from 58% in 2001. This is due not only in part to earlier detection but also to improved treatment options.[5,6]

For radiotherapy of the breast, the main concerns in terms of radiation-induced second cancers are for the lung and the breast.[2,7–10] There has been considerable focus, therefore, on techniques which result in reduced dose to these organs. One such technique is to treat the patient in the prone position, so that the distance between the ipsilateral breast and other organs is greater than for the standard supine position.[11] Prone position radiotherapy is now being used with conformal

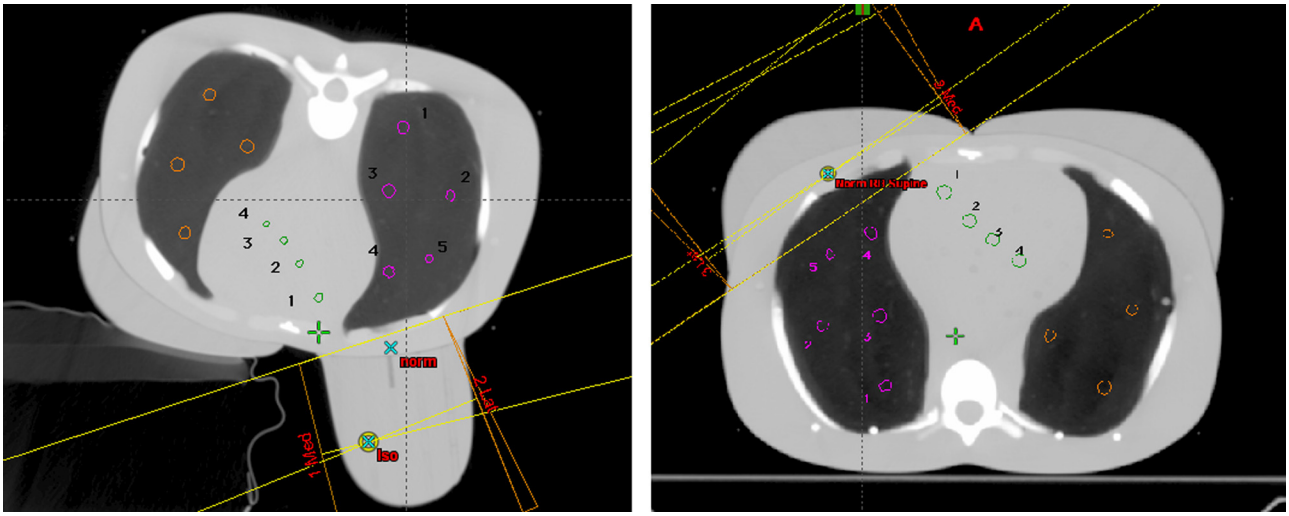

FIG. 1. CT of phantom in prone and supine position with treatment fields and MOSFET positions.

radiotherapy[12] and intensity modulated radiation therapy (IMRT),[13,14] as well as TomoTherapy (Ref. 15) and proton therapy.[16]

To quantify the potential advantages of prone position breast radiotherapy in terms of the radiation exposure to out-of-field organs, several dosimetric studies have been reported, based on calculations made with commercial treatment planning software.[17–23] It is now well established, however, that commercial treatment planning software is not adequate for characterizing out-of-field doses. For example, Howell *et al*. recently reported an average of 40% discrepancies compared with measured doses for out-of-field distances ranging from 37 to 112 mm from the edge of the treatment volume.[24]

In this study, therefore, we have measured out-of-field organ doses using multiple MOSFET dosimeters in an anthropomorphic phantom. Because of the dominant significance of the lung and breast in terms of second cancers after breast radiotherapy, we have focused on these organs. We utilized an anatomically modified adult anthropomorphic phantom to conduct experimental measurements of out-of-field doses after prone and supine irradiations, and for IMRT and 3D-CRT. Measurements were made at multiple locations in the ipsilateral lung, the contralateral lung, and in the contralateral breast.

II. MATERIALS AND METHODS

II.A. The anthropomorphic phantom

An adult ATOM anthropomorphic phantom[25] manufactured by CIRS (ATOM 701; CIRS, Norfolk, VA) was used for all experiments. The phantom is made of several tissue-equivalent plastics which simulate several different body tissues, including bone, lung, breast, and soft tissue, according to an average anatomy. In order to simulate a real patient, the breasts of the phantom were replaced with custom attachments representative of 50–50 breast tissue (50% glandular tissue and 50% adipose tissue). Two custom breast models were created by reconstructing the volume of the breast using prone and supine CT simulator scans of an actual patient (Fig. 1).

The phantom is comprised of 25 mm thick slices (Fig. 2). Each slice contains multiple 5 mm diameter through holes, whose locations are optimized for dosimetry in 19 organs in the body. When making measurements, the holes are filled with tissue-equivalent plugs that hold MOSFET radiation detectors.

The ATOM anthropomorphic phantom is rigid and cannot adequately reproduce the positional and volumetric changes of the heart and lung. These changes are particularly relevant to left breast cancer, because of the frequent heart shift toward the chest wall when prone, making this model inadequate and possibly misleading for left breast cancers. Therefore, we chose to simulate a right breast irradiation case.

Doses in multiple organs were measured in this study: ipsilateral lung (5 detectors), treated breast (4 detectors), contralateral breast (12 detectors), and contralateral lung (4 detectors). The positions remained the same over all treatment plan calculations and measurements, except for the

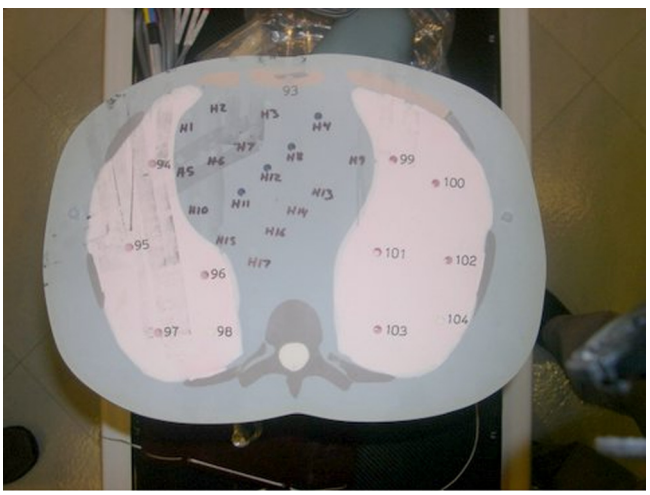

FIG. 2. Picture of one slice of the phantom. Marks indicate MOSFET positions.

FIG. 3. Pictures of phantom in prone position on mattress.

treated breast. Since two different attachments were used to simulate the treated breast in prone and supine setup, the positions of the MOSFET detectors in the breast were changed consistently (Fig. 1).

II.B. Simulation and planning

CT-scans of the phantom in both the prone and supine positions were obtained, using a 16 slice GE LightSpeed CT scanner with 2.5 mm slice thickness. For the supine position, the phantom was placed directly on the table. For the prone position, the phantom was placed on a custom-made NYU positioning mattress.[12,26] The mattress allows the breast to hang away from the chest wall. The prone setup is shown in Fig. 3.

The PTV is defined as the entire breast volume acquired in prone or supine position delineated by opposed tangential fields placed by the physician. For both prone and supine setups, beam placement, angles, and field sizes were determined using the following clinical criteria: borders of the fields were set medially at midsternum, laterally at the anterior edge of latissimus dorsi, superiorly at the bottom of the clavicular heads, and inferiorly 2 cm from the inframammary fold.

For this study, prone and supine whole breast plans were created in VARIAN'S ECLIPSE TPS Version 8.5 (AAA 8.2.23 calculation model) using both IMRT (sliding window) and 3D techniques. Both sets of plans utilized the same simple tangential field arrangement. 3D plans used tangential beams with enhanced dynamic wedges and MLC field shaping. The beam arrangements were the same for the IMRT and 3D plans and can be seen in Fig. 1. All plans were generated to deliver a 18 Gy prescription dose to 95% of the PTV volume. This was chosen to maintain a reproducibility of 3% or less and yet limit the total dose to the MOSFET detectors due to their finite lifetime.

The acceptance criteria for the plans were 95% of the PTV received the full prescription dose and that the maximum dose (which encompassed >1 cc volume) was $<108\%$.

II.C. The MOSFET dosimetry system

Twenty MOSFET (Refs. 27 and 28) dosimeters (TN-502RD, Best Medical, Ottawa, Canada) were simultaneously used for the dose measurements. They were attached to an AutoSense reader (TN-RD-15, Best Medical, Ottawa, Canada) with four bias supplies (TN-RD-22, Best Medical, Ottawa, Canada) set to high sensitivity. Two group calibration factors were created and applied to the dosimeters, one for in-field measurements and one for out-of-field measurements. Based off in-house calibrations and specifications from the manufacture, these dosimeters have a linear dose-response and a reproducibility between 3% and 0.8% for doses between 20 and 200 cGy. The target dose to the breast was chosen to deliver a minimum of 20 cGy to all of the dosimeters. The dose prescriptions mentioned above were chosen to ensure a dose of 20 cGy was reached for most data points.

The MOSFETs have angular dependability of approximately 3%. While this affects the uncertainty in the absolute dose levels, it does not change the ratios of the doses between treatment modalities at the same MOSFET position. This is because the MOSFETs did not move between irradiations and their orientation did not change in relationship to the treatment beams. In addition, the MOSFETs stayed in the same position and orientation when switching from prone to supine treatments. Their angular relationships did not change. By taking the sum of the squares of the angular dependency and dose rate response, the accuracy of the relative doses was approximately 3.1% for the low dose regions and 1.3% for the high dose regions when comparing the same MOSFET position and 4.4% and 3.3% for the absolute dose comparison to all positions. Mulitple dose points dropped below the 20 cGy level. It is estimated that the linear dose-response and a reproducibility is 5% for those points. This would suggest an relative dose accuracy of 5% and a 6% absolute dose accuracy for those points under 20 cGy.

II.D. Treatment setup and measurement

The phantom was setup on the treatment table in the same position as in the planning CT with the help of BB markers and lasers. The phantom was first setup and treated in the supine position with the 3D plan and then the IMRT plan. The MOSFETs were read out after executing each plan. This process was then repeated for the prone position. The same MOSFET was used in the same phantom position for each irradiation.

The number of MUs for the prone 3D and IMRT plans were 1962 and 6786, whilst the number of MUs were 2286 and 7002 for the supine 3D and IMRT plans, respectively. Since the MUs delivered were chosen to obtain a certain accuracy from the dosimeters, the measured doses were subsequently adjusted to match a standard 50 Gy prescription dose. Each set of measurements were scaled to give 50 Gy to 95% of the PTV.

III. RESULTS

III.A. Ipsilateral lung

Dose to the lung showed a strong dependence on distance from the field edge. Figure 4 shows the dose to the ipsilateral lung at five locations; 1, 2, and 3 being far away from the field edge and 4 and 5 being closer. For supine 3D technique, the dose to the lung was 56.0 cGy (1.1% of the prescription dose) and 518.2 cGy (10.4%) for points 1 and 4, respectively, while the dose from the prone 3D technique was 48.8 cGy (1.0%) and 182.5 cGy (3.6%) of the maximum for points 1 and 4, respectively. For the supine IMRT technique, the dose was 51.0 cGy (1.0%) and 418.5 cGy (8.4%) for points 1 and 4, respectively, while the dose from the prone IMRT technique was 53.2 cGy (1.1%) and 173.3 cGy (3.5%) of the maximum for points 1 and 4, respectively.

III.B. Contralateral lung

Doses to the contralateral lung were much lower than to the ipsilateral lung. Figure 5 shows the measured dose to the lung for four points; 1, being farthest away from the field edge, 2 and 3 being a middle distance, and 4 being closest. For supine 3D technique, the dose to the lung was 28.0 cGy (0.6%) and 49.8 cGy (1.0%) for points 1 and 4, respectively, while the dose from the prone 3D technique was 18.9 cGy (0.4%) and 51.9 cGy (1.0%) of the maximum for points 1 and 4, respectively. For the supine IMRT technique, the dose was 28.0 cGy (0.6%) and 38.7 cGy (0.8%) for points 1 and 4, respectively, while the dose from the prone IMRT technique was 24.0 cGy (0.5%) and 50.0 cGy (1.0%) of the maximum for points 1 and 4, respectively.

III.C. Contralateral breast

The dose to the contralateral (CL) breast did not vary much with technique or positioning. The average doses to the CL breast from the supine and prone 3D plans (% of 50 Gy prescription dose) were 127 cGy (2.5%) and 145 cGy (2.9%), respectively. For IMRT supine and prone plans, the doses to the CL breast were 111 cGy (2.2%) and 109 cGy (2.2%), respectively. The doses ranged from 56.9 to 210.5 cGy, 56.9 to 240.7 cGy, 60.4 to 177.0 cGy, and 39.7 to 172.9 cGy for prone 3D, supine 3D, prone IMRT, and supine IMRT, respectively. The average doses by quadrant and the total breast average doses are displayed in Figs. 6(a)–6(d). As expected from the vicinity of the tangent field edges, medial quadrants of the CL breast received more dose than the lateral quadrants, similar to the results achieved in William *et al.*[10]

III.D. IMRT vs 3D-CRT

Overall, the measured out-of-field organ doses were surprisingly similar between IMRT and 3D-CRT, rarely

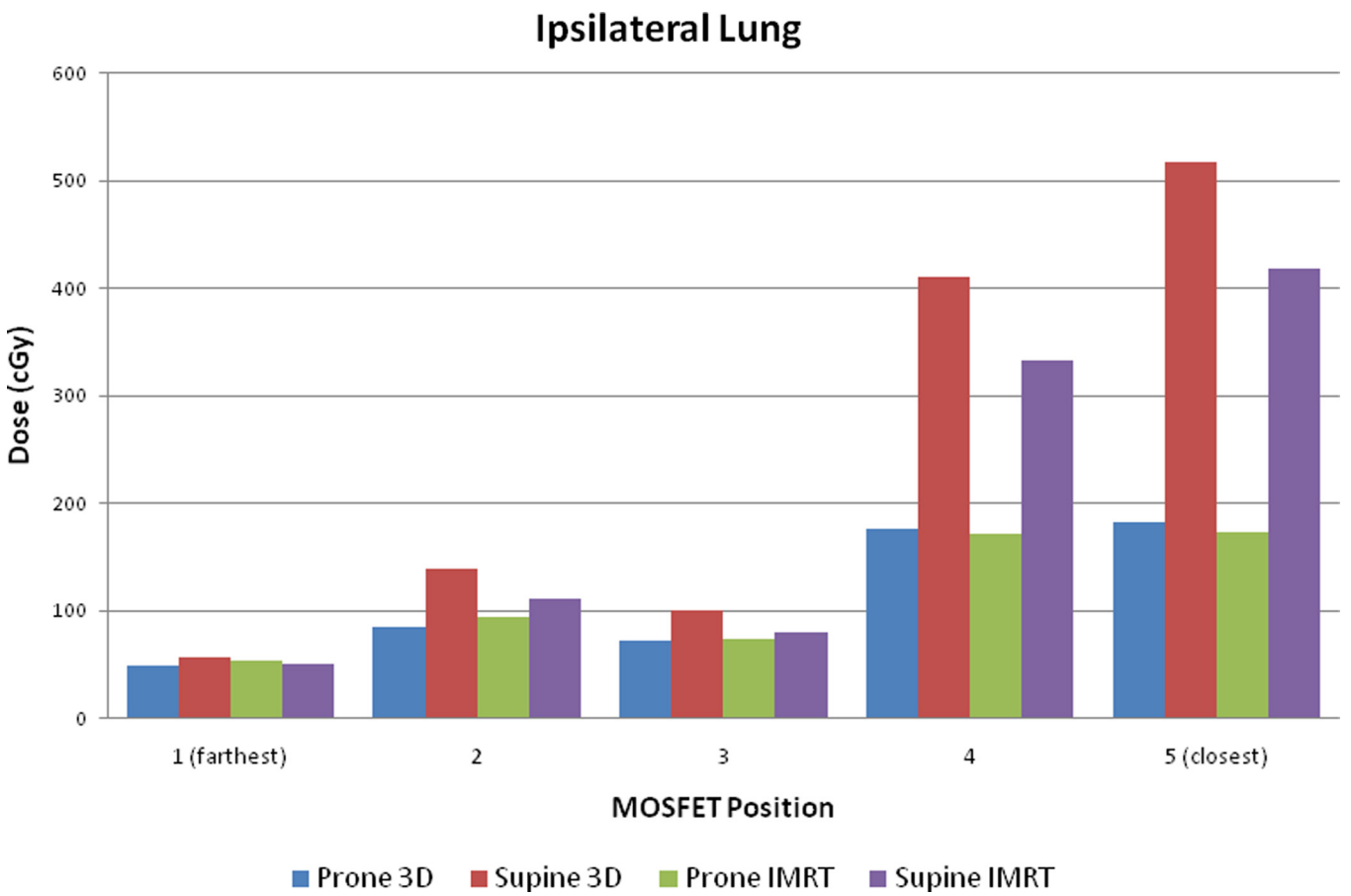

FIG. 4. Dose measurements at five locations in the ipsilateral lung from plans with a 50 Gy dose prescription using four different treatment techniques. 50 cGy is equal to 1% of the prescription dose.

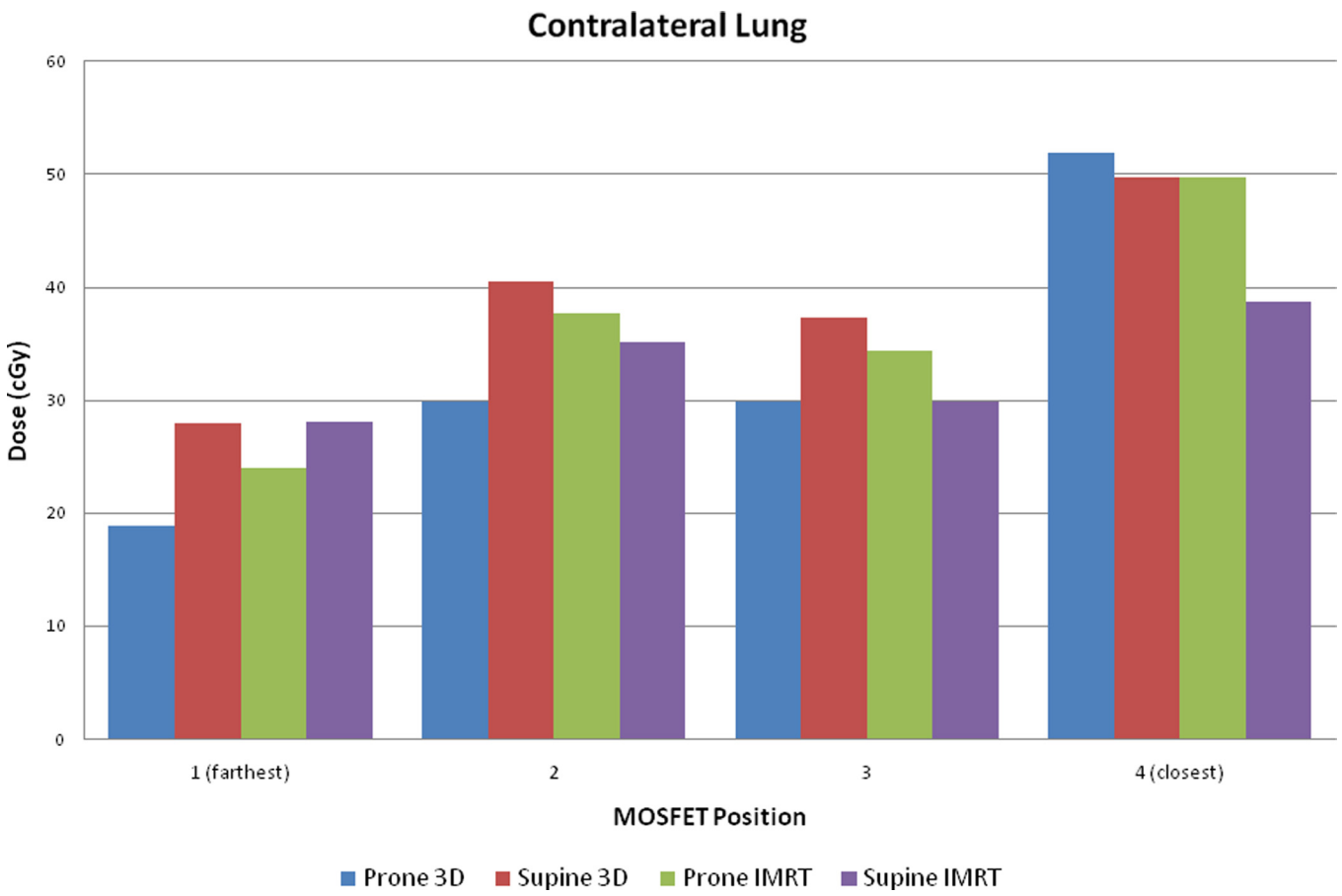

FIG. 5. Dose measurements at four locations in the contralateral lung from plans with a 50 Gy dose prescription using four different treatment techniques. 50 cGy is equal to 1% of the prescription dose.

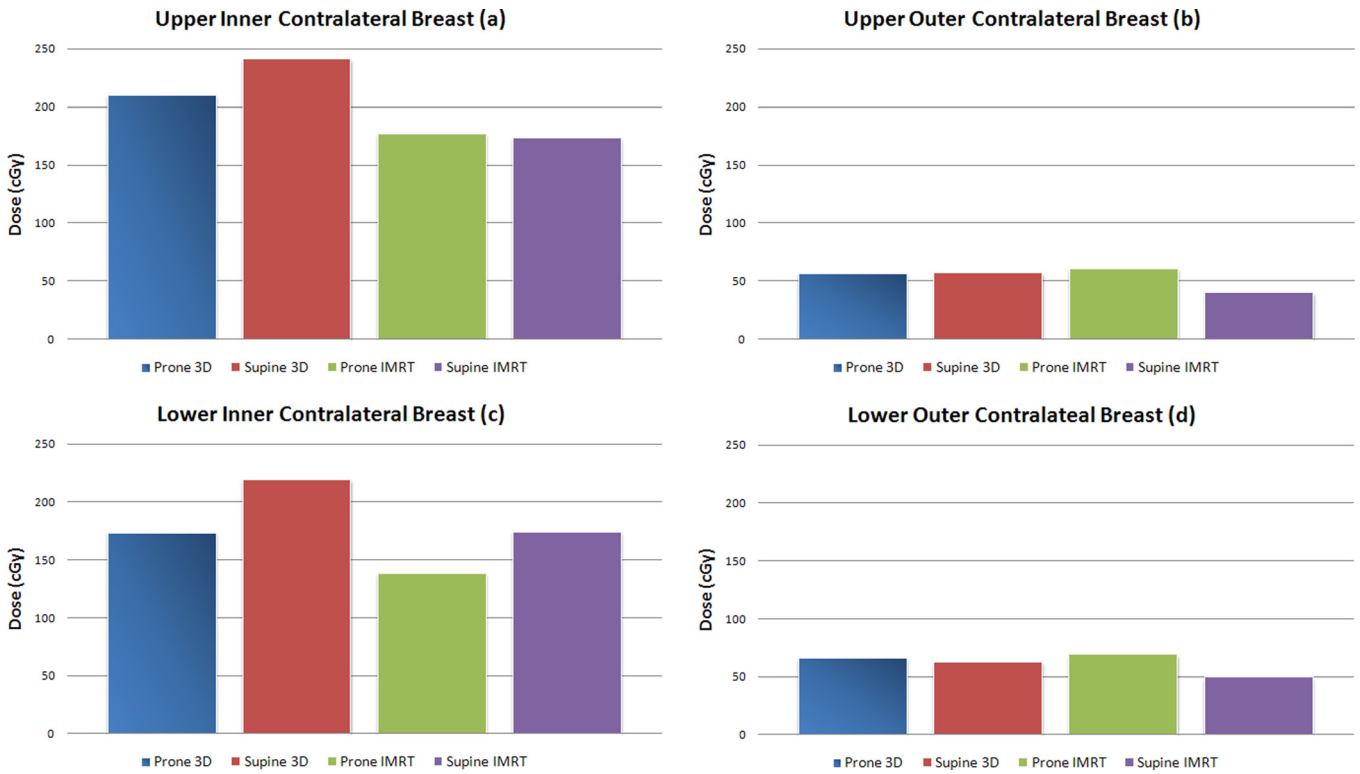

FIG. 6. Dose to the contralateral breast dose by quadrant for 3D and IMRT plans in both the prone and supine position: (a) Upper inner, (b) upper outer, (c) lower inner, and (d) lower outer. Doses (cGy) for plans with a 50 Gy dose prescription. 50 cGy is equal to 1% of prescription dose.

different by more than 1% of the Rx dose, even thought the number of monitor units (beam-on time) increased by a factor of 3.1–3.5 for IMRT. The lowest doses measured were 0.5% of the Rx. This is well above the expected 0.1% from leakage for 3D-CRT and 0.35% for IMRT if you take into account the 3.5× MUs delivered by IMRT. The likely explanation is that the doses from the collimator and internal scatter dominate over leakage at this intermediate distance.

IV. DISCUSSION

The prone position generally includes less volume of the ipsilateral lung in the field. This not only contributes to a much smaller high dose region near or in the field but also to the dose in the lung outside the field. This is consistent with our own and other groups experience.[20,29,30] The measured doses in the phantom showed a definite decrease from supine to prone position for the nearest point (location 1) with both treatment technique but much smaller changes for the most distant point (location 4).

Dose to points in the contralateral lung was the comparable for the prone and supine positions. They ranged from 0.5% to 1.0%, depending on position in the lung. All of the points were more than 10 cm away from the field edge. Therefore their expected doses were very low.

Since no direct beams traverse the contralateral breast for any of the techniques, the doses remained relatively low in all the studied setups. The results show that whole contralateral breast receives 50–100 cGy for a typical treatment, whereas the medial parts receive around 200 cGy (∼4% of prescription dose), regardless of positioning. These results are similar to those reported by Burmeister *et al.*[31] who found that IMRT delivered approximately 4% of the prescription dose to the medial surface of the contralateral breast in the supine position.

V. CONCLUSIONS

The major finding of this work was the closer the organ (or organ segment) is to the treatment volume, the more dose sparing was seen for prone vs supine positioning. The findings of this work are important in breast radiotherapy because treatment in the prone position results in a marked reduction in the dose to the proximal part of the ipsilateral lung, compared with treatment in the conventional supine position. This is true both for 3D-CRT and for IMRT. For the distal part of the ipsilateral lung, as well as for the contralateral lung and the contralateral breast, there is little difference in the measured organ doses whether the treatment is given in the prone or the supine position.

We and several other authors have suggested that breast radiotherapy in the prone position will also result in a decreased dose to the heart.[11,20] This is of potential significance because there is persuasive, if not definitive, evidence that cardiac dose as low as 1 to 2 Gy may increase the lifetime risk of cardiovascular disease.[8,32,33] We did measure cardiac doses in our anthropomorphic phantom and found decreased doses for the distal part of the heart when prone, ranging from differences of 15% for IMRT to 30% for 3D-CRT compared to supine. However, a nondeformable phantom is not the appropriate tool for assessing cardiac doses in the prone vs supine positions, as the heart undoubtedly changes its relative position between these two scenarios.

The major decrease in the dose to the proximal part of the ipsilateral lung is, however, of potentially considerable significance. For IMRT, the maximum measured dose to the lung was reduced from 4 to 1.6 Gy, while for 3D-CRT the maximum measured lung dose was reduced from 5 to 1.7 Gy. Analyses of second cancer risks suggests that the dose-response relation for radiation-induced lung cancer increases monotonically in the zero to 5 Gy dose range,[1] implying that a major decrease in the maximum lung dose will result in a significant decrease in the radiation-induced lung cancer risk.

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