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Clinical Investigation: Breast Cancer

Impact of Internal Metallic Ports in Temporary Tissue Expanders on Postmastectomy Radiation Dose Distribution

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Summary

This study evaluates the impact of the internal metallic port (IMP) contained within tissue expanders on the radiation dose distribution in post-mastectomy radiation therapy plans. Heterogeneity corrected treatment plans were calculated on 24 previously planned patients to simulate doses with and without the IMP. We find that the presence of the IMP decreased the dose to the clinical target volume by an average of 11.7% and therefore warrants more careful evaluation of treatment plans.

Purpose: Temporary tissue expanders (TTE) with an internal magnetic metal port (IMP) have been increasingly used for breast reconstruction in post-mastectomy patients who receive radiation therapy (XRT). We evaluated XRT plans of patients with IMP to determine its effect on XRT dose distribution.

Methods and Materials: Original treatment plans with CT simulation scans of 24 consecutive patients who received XRT (ORI), planned without heterogeneity corrections, to a reconstructed breast containing an IMP were used. Two additional treatment plans were then generated: one treatment plan with the IMP assigned the electron density of the rare earth magnet, nickel plated neodymium-iron-boron (HET), and a second treatment plan with the IMP assigned a CT value of 1 to simulate a homogeneous breast without an IMP (BRS). All plans were prescribed 50 Gy to the reconstructed breast (CTV).

Results: CTV coverage by 50 Gy was significantly lower in the HET (mean 87.7% CTV) than in either the ORI (mean 99.7% CTV, $P<.001$) or BRS plans (mean 95.0% CTV, $P<.001$). The effect of the port was more pronounced on CT slices containing the IMP with prescription dose coverage of the CTV being less in the HET than in either ORI (mean difference 33.6%, $P<.01$) or BRS plans (mean difference 30.1%, $P<.001$). HET had a less homogeneous and conformal dose distribution than BRS or ORI.

Conclusion: IMPs increase dose heterogeneity and reduce dose to the breast CTV through attenuation of the beam. For optimal XRT treatment, heterogeneity corrections should be used in XRT planning for patients with TTE with IMP, as the IMP impacts dose distribution.

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Introduction

Immediate reconstruction after mastectomy in breast cancer patients may markedly improve a woman's quality of life by enhancing body image, cosmetic outcome, and overall psychological well-being (1, 2). However, in patients requiring postmastectomy radiation therapy (PMRT), irradiating a fully reconstructed breast may lead to complications including capsular contracture, infection, extrusion, and development of seroma (3). Reconstruction may also impair radiation (XRT) delivery (4-6), resulting in an inadequate dose to the chest wall and internal mammary lymph nodes and an excess dose to the heart and lungs (5).

Frequently, in cases in which a patient requires PMRT or where the role of XRT is uncertain before mastectomy, a temporary tissue expander (TTE) is placed at the time of oncologic surgery. Several institutions, including Emory University, use a delayed reconstruction approach, whereby a patient receives a TTE at the time of mastectomy, allowing for maintenance of the breast skin envelope while awaiting assessment of the final pathology (7). If a patient is recommended PMRT, XRT is delivered to the chest wall with the TTE in place. The volume of saline within the TTE may be adjusted before simulation to optimize XRT delivery. Other patients not needing PMRT proceed immediately to permanent implant exchange after tissue expansion.

Increasingly, reconstructive surgeons are using TTE with internal metallic ports (IMP), through which saline is injected for gradual expansion of the surrounding skin. Easily localized by an external magnet, the IMP allows convenient access for saline injections. Once fully expanded, the TTE is exchanged for a permanent implant. These novel internal ports have presumably decreased infection rates over previous expanders with external ports. However, the impact of the IMP on radiation dose distribution and subsequent clinical outcome is unclear. Furthermore, the IMP is made out of nickel-plated neodymium-iron-boron alloy, and there are concerns over whether modern XRT planning software may accurately depict the dose around this high Z material. We hypothesized that the presence of the IMP would decrease the dose to the clinical target volume and potentially affect dose to nearby organs at risk.

Methods and Materials

After obtaining institutional review board approval, the medical and radiation records of 24 consecutive postmastectomy breast cancer patients who underwent TTE placement and postoperative XRT at Emory University were reviewed. Beginning in 2007, Emory University reconstructive surgeons adopted TTE with IMP into their routine practice. For the purposes of this study, we included stage 0 to III breast cancer patients who received PMRT to TTE with IMPs between the years 2007 and 2009. All patients underwent mastectomy and immediate reconstruction with placement of a TTE containing an IMP, followed by XRT. The most commonly used TTE with integrated magnetic port, manufactured by Dermaspan (Specialty Surgical Products, Victor, MT), contains a nickel-plated neodymium-iron-boron disc magnet. Twenty patients had axillary lymph node dissections, whereas 4 patients underwent sentinel lymph node biopsy only. Eleven patients received neoadjuvant chemotherapy, 11 received adjuvant chemotherapy, and 2 did not receive any chemotherapy.

All patients underwent CT simulation for radiation treatment planning purposes. The original treatment plans (ORI) were generated in the Eclipse Planning system (Varian Medical Systems, Palo Alto, CA) without heterogeneity corrections. In all women, the chest wall and reconstructed breast with IMP were treated with opposed tangents using 6-MV and/or 18-MV photons to 50 Gy at 2 Gy per fraction. No patients were treated with electrons. Dose was modulated according to physician preferences for optimizing dose distribution, with plans being delivered with dynamic wedges in 22 patients and field-in-field technique in 2 patients. For the purposes of this study, the breast clinical target volume (CTV) was defined as the volume encompassed by the original prescription isodose line on the delivered treatment plan.

Two additional plans were then generated per patient using identical targets and avoidance structures. The convolution superposition heterogeneity correction algorithm within the Eclipse planning software (anisotropic analytic algorithm [AAA]) was applied to each plan; dose distribution was recalculated using the original treatment fields, prescription, and monitor units. The IMP was identified by adjusting the window and level of the scan until the size of the IMP on the scan matched its physical dimensions. The first plan (BRS) was created assigning the IMP and surrounding scatter a CT number equivalent to soft tissue, so as to simulate a breast mound without an IMP while taking into account the bone and lung tissue densities within the radiation fields. As the heterogeneity correction model AAA has not been validated for high Z material, we recognized that AAA may not accurately model the impact of the high Z material magnet on dose distribution. Therefore, we used a series of phantom and film dosimetry measurements. Percent depth dose (PDD) measurements were taken using gafchromic film with the IMP positioned at the top of the film in 2 different orientations (perpendicular to the beam/film and parallel to it). A PDD curve was acquired for the IMP in the 2 different positions using a 6-MV beam and 10 $\times$ 10-cm field size. A virtual phantom was then created within Eclipse to emulate the IMP and film setup that was used for the film PDD curve generation. The electron density of the IMP volume in Eclipse was then adjusted and recalculated using the AAA algorithm with heterogeneity corrections turned on until the calculated PDD matched the values from the film. For both IMP orientations, this value of the electron density relative to water was 11.8. With this value, the film measured and Eclipse calculated values along the PDD curve match within 3% for a 6-MV beam, whereas they are within 10% for an 18-MV beam. This discrepancy is due to a significant difference in the interactions in metal between 6- and 18-MV photons (Fig. 1). To examine the effect of the IMP on dose distribution, a second plan (HET) was thus calculated with the IMP assigned a CT number that corresponded to a relative electron density of 11.8, recognizing the limitations of current treatment planning software.

The 3 plans (ORI, BRS, and HET) were compared using mean values calculated from dose-volume histogram data for clinically significant parameters. Dose heterogeneity was assessed using the following equation: Inhomogeneity coefficient = (D5%-D95%)/D95%. A more homogeneous plan is indicated by a value closer to 0. A conformation number was used to assess the amount of normal tissue receiving at least 95% of the prescribed dose and the

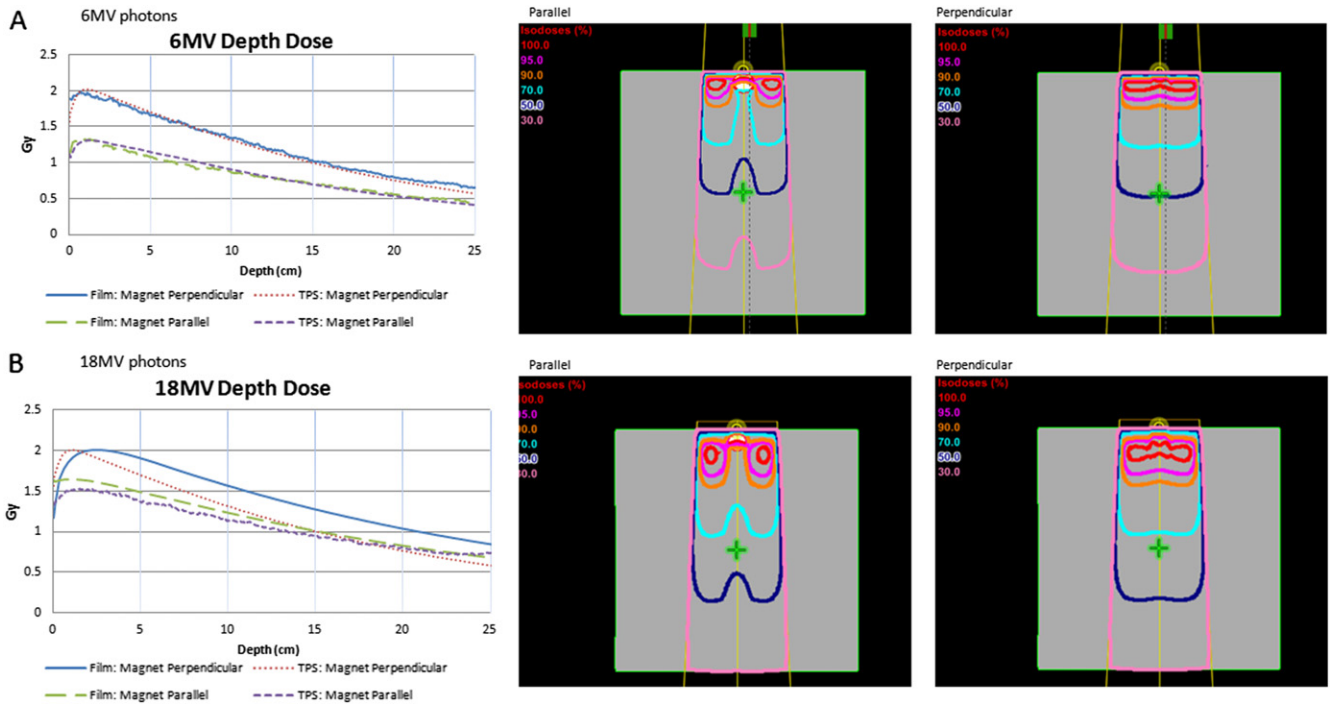

Fig. 1. (a) Film and treatment planning system (TPS) with heterogeneity correction depth dose with magnet 100 SSD to water surface and delivery of 200 MU with 6-MV photons in a 10 × 10-cm field. The TPS used an experimentally determined electron density relative to water of 11.8 for the IMP. (b) Film and TPS depth dose with heterogeneity correction depth dose with magnet 100 SSD to water surface and delivery of 200 MU with 18-MV photons in a 10 × 10 cm field. The TPS used an experimentally determined electron density relative to water of 11.8 for the IMP.

amount of tissue within the CTV that does not receive this dose. The following conformation number was used to compare the dose conformality of each plan: Conformation number = (PTV_{ref} x PTV_{ref})/(PTV × V_{ref}), where PTV_{ref} is the volume of PTV receiving a reference dose, the PTV is the absolute volume of the PTV, and the V_{ref} is the volume receiving a reference dose (8, 9). Differences in mean values were compared using Wilcoxon signed-rank test, with P values $\leq$.05 considered significant. Statistical analysis was performed using SPSS Statistics 19 software (SPSS Inc., Chicago, IL).

After completing XRT treatment, all patients were subsequently followed with at least physical examination and mammography. Positron emission tomography (PET) scans and/or magnetic resonance imaging (MRI) scans were obtained when clinically indicated.

Results

Patient, tumor, and treatment characteristics

The median follow-up period was 3.3 years (range, 1.0-5.0 years). Median patient age was 44 years at diagnosis (range, 31-62 years). Tumor characteristics are described in Table 1. Among patients receiving adjuvant chemotherapy (n = 11), median time from surgery to XRT was 201 days (range, 152-239 days). Alternatively, for patients who received either neoadjuvant chemotherapy (n = 11) or no chemotherapy (n = 12), median time from surgery to XRT was 57 days (range, 26-75 days). Among patients who received neoadjuvant chemotherapy or no chemotherapy, an average of 333 days (range, 225-504 days) elapsed between TTE placement and permanent implant exchange. In patients receiving adjuvant chemotherapy, an average of 578 days (range, 377-665 days) passed between the 2 procedures.

Table Patient characteristics

Patient characteristics	n (%)
Tumor laterality	
Left	12 (50)
Right	12 (50)
Stage	
DCIS	1 (4)
IIB	7 (29)
IIIA	10 (42)
IIIB	1 (4)
IIIC	3 (12)
Recurrent	2 (8)
T stage	
Recurrent	2 (8)
DCIS	1 (4)
T1	5 (20)
T2	7 (29)
T3	6 (24)
T4	3 (12)
N stage	
Recurrent	2 (8)
N0	4 (16)
N1	9 (38)
N2	7 (295)
N3	2 (8)

Abbreviation: DCIS = ductal carcinoma in situ.

Dosimetric characteristics

Breast CTV coverage

The mean percent CTV coverage was significantly lower in the HET plans (mean, 87.7%; range, 60.2%-99.4%) than in either the ORI (mean, 99.7% CTV; range, 99.6%-99.7%) or BRS plans (mean, 95.0% CTV; range, 81.4%-99.1%), $P<.001$ for all comparisons (Fig. 2). The largest difference in percent CTV coverage by 50 Gy between the ORI and HET in 1 patient was 39.4% (mean difference, 11.7%; range, 0.2%-39.4%), with the HET plan having poorer coverage. The mean percent CTV coverage was also significantly lower in the BRS plans than in the ORI plans ($P<.001$). This effect was most pronounced on CT slices containing the IMP, for which the ORI plan overestimated breast CTV coverage by as much as 75.6% (mean difference, 33.6%; range, 0.5-75.6, $P<.001$) in comparison to the HET plan (Fig. 3). Similarly, on these same CT slices, the BRS plans overestimated the coverage of the breast CTV by as much as 61.1% (mean difference. 30.1%; range, 0.5%-32.2%; $P<.001$) in comparison to the HET plans. An example of difference in dose distribution between the BRS and HET plans for 1 patient is shown in Fig. 4.

Avoidance structures

In all the patients studied, the mean lung V20 was higher in the BRS plan at 10.3% (range, 4.3%-18.7%) than the ORI plan at 9.6% (range, 3.0%-18.0%) or the HET plan at 10.2% (range, 3.1%-18.7%). Although the HET and BRS plans both modeled the true density of the lung and bone in the treatment fields, the HET plans had lower mean lung V20 than the BRS plans due to attenuation of the beam by the IMP in the HET plan ($P<.001$). At doses below V20, the ORI underestimated the lung dose delivered compared with the BRS and HET plans because of the ORI planning being calculated without heterogeneity corrections (Fig. 5a).

For women with left-sided breast cancers, there were no appreciable differences between the plans in cardiac V5, V10, or V20 (Fig. 5b).

Dose distribution

The percentage of breast CTV receiving more than 50 Gy was greater in both the BRS and HET plans in comparison to the ORI plan. The HET plans had the most heterogeneous dose distribution, with a mean inhomogeneity coefficient of 0.14 (range, 0.10-0.22). The mean inhomogeneity coefficient of the ORI plans and BRS plans was 0.09 (range, 0.05-0.14) and 0.10 (range, 0.07-0.16), respectively. Dose distribution was less conformal in the HET than in the BRS and ORI plans. The mean conformation number was 0.98 (range, 0.0.65-1.33) for the HET vs a mean conformation number of 0.99 (range, 0.0.72-1.16) in the BRS plans. The mean conformation number for ORI plans was 1.04 (range, 0.95-1.16).

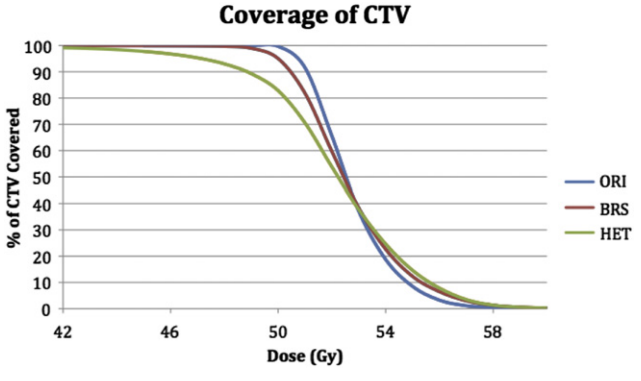

Fig. 2. Dose-volume histograms comparing mean CTV coverage values of original (ORI), breast without IMP (BRS), and breast with IMP (HET) plans.

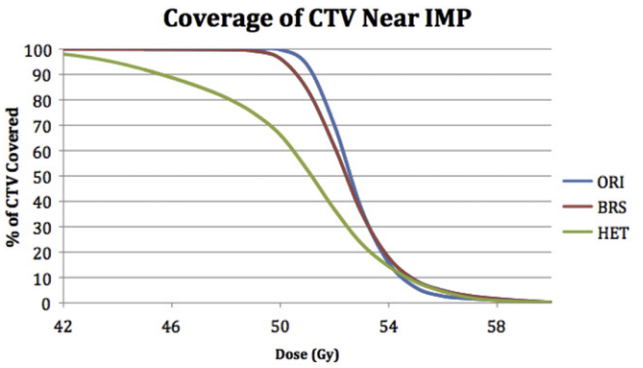

Fig. 3. Dose-volume histograms comparing mean CTV coverage near IMP values of original (ORI), breast without IMP (BRS), and breast with IMP (HET) plans.

Clinical outcome

In our patient cohort, with a median follow-up of 3.3 years, the 3-year locoregional control rate was 91.7% and overall survival was 81.3%.

Side effects

In all, 21 of the 24 patients underwent TTE exchange for permanent implant with a median time from completion of XRT to exchange surgery of 395 days (range, 225-665 days). Four patients had complications after reconstruction necessitating surgical intervention under general anesthesia; 2 patients had complications involving the TTE, and the remaining 2 patients had complications regarding the permanent implant. Three of the 4 patients required removal of their breast prosthesis; 2 had infection of the TTE, and 1 had rupture of the permanent implant. Other reasons for surgical intervention included necrosis of overlying flap and chronic wound drainage. In addition, 2 patients required fat injections for improvement of symmetry and cosmesis.

Discussion

As has been found in previous studies, our study suggests that treatment planning without the use of heterogeneity corrections overestimates the homogeneity of the dose delivered to the entire breast CTV while underestimating the dose to the lungs (10-12). Our data suggest that the IMP independently affects dose distribution by attenuating the beam in all 24 of our patients who received XRT to a TTE. In addition to decreasing dose to the breast CTV, the IMP increases heterogeneity.

Although heterogeneity corrections in treatment planning are not always reliable with high Z material, we found that the breast CTV dose coverage is significantly lower in plans with IMP in

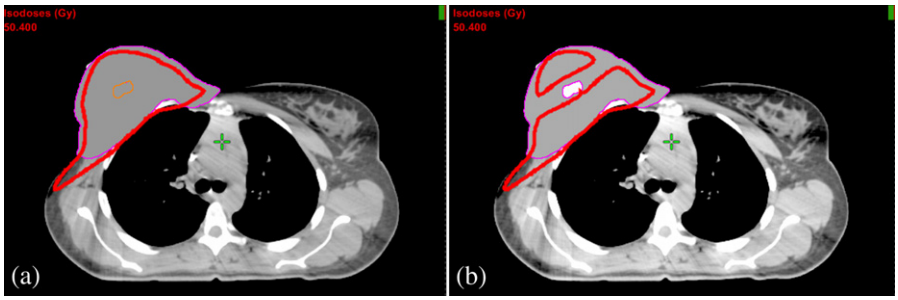

Fig. 4. Example of isodose distribution. (a) Breast (BRS) plan with heterogeneity correction and IMP and surrounding scatter assigned soft tissue density. (b) Heterogeneous (HET) plan with heterogeneity correction and IMP set to high electron density material and surrounding scatter assigned soft tissue density.

place after inputting CT values matching film dosimetry. Although heterogeneity algorithms vary widely between treatment planning systems, we used the available Eclipse software at our institution, which is used in an estimated 40% of XRT centers throughout the United States (Varian Medical Systems, Personal Communication). To verify the assigned electron density to the IMP, we performed film dosimetry. This experiment was replicated virtually within Eclipse, applying the AAA, recognizing that this may not truly present the interaction of photons with high Z metal, particularly in the region near the metal. Although the electron density relative to water of the magnet is closer to 6.6, we found that when the IMP was assigned a value of 11.8, the 6-MV dose distribution matched the film dose at all depths and orientations of the IMP. However, the 18-MV dose distribution is highly variable in the build-up region and cannot be corrected for in the same manner.

Like other studies, we also determined that the effect of the IMP on dose distribution was most significant on CT slices where the IMP was present (13-15). Our study showed that the dose on the HET plan was attenuated by as much as 39.4% when compared with the ORI plan, and as much as 31.2% when compared with the BRS plans. Similarly, a previous study showed that dose was attenuated 6%-22% in phantoms using film dosimetry and up to 15% in patients using TLD measurements (16). When the IMP was oriented parallel to the XRT beam, the IMP had a greater effect on patient dose. A very small percentage of dose was delivered with 18-MV photons in a few select patients in our study, and there was no appreciable difference in dose attenuation in these patients, given our small numbers.

The clinical implications of treating patients with IMP remain unknown. In our study, with a short follow-up period, the local control rate was 91.7% and did not appear to be adversely affected by the reduced XRT dose coverage to the breast CTV or the increased variances in dose distribution. Results from our study suggest that if heterogeneity corrections are not used in planning, the ORI plans display good coverage of the CTV but overestimate the XRT dose coverage. In plans that model the true density of the IMP, the CTV coverage may be decreased by as much as 39.4% by the IMP, lowering the actually delivered dose per fraction from 2.0 Gy-1.21 Gy, which is below the standard fraction sizes recommended by National Comprehensive Cancer Network of at least 1.8 Gy per day for treatment of breast cancer (16). This effect would be greater if the patients were prescribed 50.4 Gy at 1.8 Gy per fraction, resulting in 1.09 Gy being delivered on a daily basis. In addition, doses modeled by TPS may not be consistent on a daily basis, as the IMP lies within a small pocket of the TTE and has the potential to migrate within a small volume throughout a treatment course potentially affecting dose distribution unpredictably. In addition, daily set up error and changes in the breast through a protracted course of treatment, may increase the uncertainty of dose delivery and is unlikely to mitigate large effects on dose distribution caused by the IMP. Advances in technology, such as VisionRT (VisionRT Inc, Columbia, MD) and use of body molds may decrease this, but will not eliminate the uncertainty completely. Longer follow-up, however, is needed to determine whether the potential reduction in daily dose and the variances in dose distribution negatively affect cancer control.

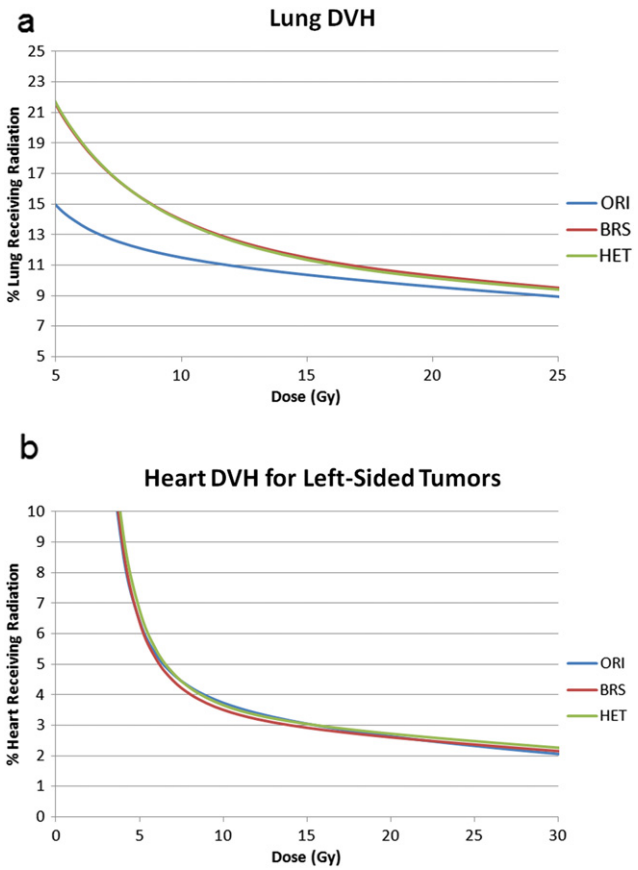

Fig. 5. (a) Dose-volume histograms comparing mean lung values of original (ORI), breast without IMP (BRS), and breast with IMP (HET) plans. (b) Dose-volume histograms comparing mean heart values of original (ORI), breast without IMP (BRS), and breast with IMP (HET) plans, where BRS and HET curves are superimposed.

Although local control rates appear to be unaffected by the presence of the IMP, there is the theoretical risk of increased complications due to the dose heterogeneity caused by the port. Previous studies have shown that doses greater than 105% may increase rates of acute XRT dermatitis, fibrosis, marked changes in breast cosmesis, and poorer overall cosmetic outcome (17, 18). Presumably, backscatter from the IMP would increase the variance in dose distribution further and has the potential to increase the maximum dose of the treatment plans. However, a previous study attempting to quantify backscatter using TLDs showed that backscatter using a 6-MV photon beam is minimal except within 2 mm of the IMP (13), and that altered dosimetry in the region of the metallic device did not appear to contribute the complication rates in women receiving XRT to TTE implants. Although the mean Dmax in all 3 plans in our study were not significantly different, there was more dose heterogeneity in the HET and BRS plans than in the ORI plans without taking into account backscatter, which is poorly modeled by our current planning system. Similar to other series reporting reconstruction failure of 15%-21%, we found an 18% complication rate, necessitating surgical removal of either the TTE or the permanent implant (3, 4, 19). In our small series of patients with limited follow-up (4 of the 24 patients have not yet proceeded to the final stage of reconstruction), there did not appear to be a relationship between the XRT dose distribution, Dmax, or inhomogeneity coefficient and development of a complication. Nevertheless, use of modern treatment techniques with either IMRT or forward-based field in field planning has the potential to improve homogeneity and dose coverage with dose painting or modulated beams specifically tailored to improving the dose distribution around the IMP.

Conclusion

In conclusion, the IMP within the TTE has an impact on dose distribution. Our findings suggest that clinicians should exercise caution when relying on modern treatment planning software with dose calculation algorithms that have not been validated for high Z materials such as the IMP. In our study, we conducted phantom and film measurements to arrive at a more accurate CT value for the IMP, which provided a more realistic effect of the magnet on the dose modeled by Eclipse software using AAA with heterogeneity corrections. In light of its affect on XRT dose, further studies evaluating the long-term clinical impact of IMPs on cancer control and complication rates are warranted. Alternative forms of reconstruction, which may eliminate the need for a TTE with IMP, may be needed and explored within a multidisciplinary team.

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