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CLINICAL INVESTIGATION **Breast**

COMPARISON OF THREE CONCOMITANT BOOST TECHNIQUES FOR EARLY-STAGE BREAST CANCER

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Purpose: Whole breast radiotherapy (RT) followed by a tumor bed boost typically spans 5–6 weeks of treatment. Interest is growing in RT regimens, such as concomitant boost, that decrease overall treatment time, lessening the time/cost burden to patients and facilities.

Methods and Materials: Computed tomography (CT) scans from 20 cases were selected for this retrospective, dosimetric study to compare three different techniques of concomitant boost delivery: *(1)* standard tangents plus an electron boost, *(2)* intensity-modulated RT (IMRT) tangents using custom compensators plus an electron boost, and *(3)* IMRT tangents plus a conformal photon boost. The equivalent uniform dose model was used to compare the plans.

Results: The average breast equivalent uniform dose value for the three techniques (standard, IMRT plus electrons, and IMRT plus photons) was 48.6, 47.9, and 48.3, respectively. The plans using IMRT more closely approximated the prescribed dose of 46 Gy to the whole breast. The breast volume receiving >110% of the dose was less with the IMRT tangents than with standard RT ($p = 0.037$), but no significant difference in the maximal dose or other evaluated parameters was noted.

Conclusion: Although the IMRT techniques delivered the prescribed dose with better dose uniformity, the small improvement seen did not support a goal of improved resource use. © **2006 Elsevier Inc.**

Intensity modulation, Concomitant, Boost, Radiotherapy, Breast.

INTRODUCTION

Breast conservation has been widely accepted in the treatment of women with early-stage breast cancer on the basis of randomized, controlled trial data demonstrating that whole breast radiotherapy (WBRT) after conservative surgery reduces local recurrence rates and produces survival rates comparable to those of more aggressive surgery (1, 2). The optimal schedule and technique for radiation delivery remains an area of controversy and considerable interest. The standard method has typically used opposed tangents within a 5–6-week period of daily treatment. Decreasing the overall treatment time and, therefore, the cost/inconvenience to the patient and radiation oncology department is particularly attractive. Whelan *et al.* (3) completed a randomized trial comparing standard dose fractionation (50 Gy in 25 fractions) to accelerated WBRT (42.5 Gy in 16 fractions). At 5 years, no statistically significant difference was found between the schedules with regard to local control or cosmesis. The shorter fractionation schedule decreased the use of limited physical and financial resources and increased access for those patients with logistical difficulties. Thus far, this fractionation schema does not appear to have gained widespread acceptance in the United States, perhaps because of the lack of a tumor bed boost.

The addition of a tumor bed boost after WBRT has been shown to improve local control, albeit at increased cost with regard to resources and cosmetic outcome (4–7). The tumor bed boost has become standard in the United States and Europe. It typically consists of five to eight treatments that are restricted to the tumor bed after WBRT.

One way to reduce the overall treatment time, yet maintain the tumor bed boost, is to deliver the boost concomitantly with the whole breast treatment, shortening the overall treatment time by 1.5 weeks. Dividing the boost into 23 fractions will result in a daily tumor bed dose of 261 cGy, which was proven to be a safe and effective fractionation for the whole breast in the Canadian trial (3). Although still longer than the shortened fractionation (16 fractions) used by Whelan *et al.* (3), this approach has the advantage of incorporating the boost dose standard in the United States.

Even while efforts are underway to reduce resource use

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safely by shortening fractionation schemas, interest has been increasing in using sophisticated techniques such as intensity-modulated RT (IMRT) to improve cosmesis and minimize other breast RT sequelae. Although IMRT is feasible and results in excellent dose homogeneity, it requires significantly more resources. Nonetheless, the improved dose homogeneity may compensate for the higher dose per fraction delivered to the tumor bed during a concomitant boost approach. Thus, the extra resources necessary for IMRT may be offset by allowing shorter fractionation schedules.

The purpose of our study was to evaluate the dosimetric outcomes of several different methods of concomitant boost delivery to determine the magnitude of benefit of IMRT over conventional treatment in the setting of a concomitant boost. Three concomitant boost delivery methods were designed: *(1)* standard opposed tangents using a lateral physical wedge for dose homogeneity plus an electron boost field, *(2)* IMRT tangents plus an electron boost field, and *(3)* IMRT tangents plus a four-field (right) or five-field (left) conformal boost based on the partial breast irradiation model as described previously (8).

METHODS AND MATERIALS

This study was conducted in accordance with the ethical standards of the overseeing University of North Carolina (UNC) Institutional Review Board and the Helsinki Declaration of 1975 (revised 1983).

The archived computed tomography (CT) scans of 19 patients (20 breasts) treated for breast cancer in the Department of Radiation Oncology at UNC were selected at random for this retrospective, dosimetric study. Women who had undergone breast-preserving surgery and CT for RT planning were chosen from the patient populations of the co-investigators. Three different techniques for concomitant boost delivery were designed for each patient and retrospectively compared using an in-house treatment planning system (PLan University of North Carolina; PLUNC).

Data acquisition

Each patient underwent CT simulation in the treatment position (supine, ipsilateral arm above head). Radiopaque contrast material was placed at the superior, inferior, medial, and lateral limits of the clinically palpable breast tissue. Four patients had the superior marker placed for treatment of a supraclavicular field (not included in this study), and one with bilateral breast cancer did not have a medial marker placed. These missing clinical data points were determined from the location of breast tissue on CT. CT images of the chest were acquired and transferred to PLUNC.

Target definition

Anatomic information from the CT scan was used to define the volumes at risk and normal structures. The breast volume was initially delineated using the clinical radiopaque markers and breast CT appearance. Tangential fields were designed using these clinical parameters, and the target breast volume was then more precisely defined as the tissue encompassed by these tangential fields minus a 1-cm margin from the posterior beam edge and 0.5-cm margin from the skin edge. The margins were chosen to be in keeping with published data (9–11) and our standard institutional practice. The tumor bed boost volume was defined as the area of architectural distortion combined with, when present, the location of surgical clips. An additional contour was created consisting of the target breast volume less the tumor bed volume. This eliminated the tissue targeted to receive the concomitant boost and allowed a separate analysis of the effective dose received by the tissue surrounding the tumor bed, hereafter referred to as the clinical target volume. Finally, the ipsilateral lung was contoured, as was the cardiac silhouette (root of the great vessels to the apex), in those patients with left-sided breast cancer.

Treatment planning

Opposing tangents were constructed using radiopaque clinical markers in conjunction with the breast tissue appearance on CT. The tangents were designed so that the posterior beam edges passed through the medial and lateral clinical markers in a nondivergent fashion. The beam setup design was aimed at achieving a balance between target coverage and dose sparing to the ipsilateral lung and contralateral breast. A dose of 46 Gy in 2-Gy fractions was prescribed to a normalization point on the central CT slice 2 cm from the posterior border of the tangent fields, as is standard at UNC. If such a defined point was within the lung parenchyma, it was moved anteriorly toward the chest wall–lung interface. Separations between the medial and lateral chest wall were measured at the central CT slice. This basic beam setup was used to create tangent treatment plans using wedges and IMRT.

To create the tangents for the conventional concomitant boost plan, a physical wedge was used in the lateromedial field to improve dose homogeneity. The isodose lines representing 110% and 115% of the prescribed dose were used to visualize regions of overdose within the breast. Wedge orientation and degree were introduced to minimize and evenly distribute these regions. Medial wedges were not used to minimize scatter dose to the contralateral breast. For the IMRT tangents, the index-dose gradient minimization algorithm (12) was used for dose optimization. Optimization priority was given to target volume dose uniformity. At our institution, IMRT is delivered using compensators or step-and-shoot IMRT with multileaf collimators (MLCs). Because most breast cancer patients are treated with compensator IMRT, this method was used for investigation of dosimetry outcomes in this study (13). The ipsilateral lung and heart dose were not restricted in the optimization.

A separate electron boost plan was also created for each patient. The clinical setup originally designed for treatment was used as recorded in the treatment chart. However, the tumor bed defined by the investigator was used rather than that delineated by the treating physician, because the latter was not always available. In 2 patients, the investigator defined tumor was somewhat underdosed by the electron plan reported in the treatment chart. For one of the patients, the retrospectively created plan was changed to include 0.5 cm of bolus; for the other, the electron energy was decreased from the original prescription energy. In 4 patients, the investigator-contoured tumor bed required a 15-cm cone, but a 10-cm electron cone was actually used for treatment. Patients without electron boost data had a boost plan constructed using planning tools in PLUNC such as axial isodose views and patient surface rendering. The investigator-defined tumor bed was encompassed with a 2-cm margin and edited back to accommodate critical structures, as indicated. An electron dose of 14 Gy in 61-cGy fractions was prescribed to the point of maximum dose and delivered at 100-cm source to surface distance (SSD). Electron energy

was chosen to deliver 90% of the prescribed dose to as much of the tumor bed as possible while minimizing the dose to the surrounding normal structures.

Finally, a separate conformal photon boost plan was created using the partial breast irradiation technique described by Baglan *et al.* (8). A 6-MV photon beam was used to design a four-field (right-sided) or five-field (left-sided) boost plan. Because multiple fields were delivered concurrently with WBRT, the margin around the tumor bed was reduced to 1 cm. A 14-Gy dose in 61-cGy fractions was prescribed to the center of the tumor bed. Optimization priority was given to dose uniformity within the tumor bed. The ipsilateral lung and heart were not restricted in the optimization. Dose modulators were acceptable in the medial boost beams, because the gantry angles were typically 10–20° steeper than the whole breast tangents, thereby lessening the concern of contralateral breast scatter dose.

Concomitant boost delivery methods

The tangents modified with wedges, IMRT tangents, electron boost, and conformal photon boost were used in combination to create three different concomitant boost plans for each data set. Each treatment plan consisted only of opposed tangents and a tumor bed boost; nodal basin irradiation was not incorporated. For technique 1, the wedge plan was merged with the electron boost plan to create a conventional concomitant boost delivery method. For technique 2, the IMRT plan was combined with the electron boost plan to form the second boost technique. The final method, technique 3, combined the IMRT tangents with the photon boost for a highly conformal concomitant boost delivery plan. Each technique was designed to deliver 2 Gy to the whole breast, concurrent with 0.61 Gy to the tumor bed, in 23 fractions, for a total dose of 46 Gy to the whole breast and 60 Gy to the tumor bed.

Plan comparisons

The equivalent uniform dose (EUD) model was used to compare the dose to the breast and tumor bed volumes among the three concomitant boost delivery techniques. Conceptually, the EUD model equates an inhomogeneous dose distribution in an anatomic structure to a homogenous dose distribution given in the same number of fractions and total time that generates the same radiobiologic effect. In his original paper, Niemierko (14) described a basic formula for calculating the EUD that can be modified to account for a number of parameters, including tumor volume and dose/fraction. In PLUNC, we implemented the EUD equation (15): $\mathrm{EUD} = (\Sigma_{i=1}^{N} v^i D_i^a)^{1/a}$. This EUD equation does not account for the biologic effect of the dose/fraction. However, the dose–volumetric effect is accounted for by the parameter a, which is defined for normal structures and tumors on the basis of historical data linking the efficacy of the dose delivered to the volume of the treated area (16). It extends from very large numbers in normal tissues that demonstrate a small volume effect (i.e., the radiation dose is important, even if the treated volume is quite small, such as in the spinal cord) to negative numbers in organs or tumors demonstrating a very large volume effect. The latter is true for breast tumor ($a = -7.2$), because the entire volume needs to receive a substantial dose to achieve the endpoint of local control.

We examined the coverage of the whole breast volume in two distinct fashions. First, we looked at the EUD given to the clinical target volume to assess the impact of the concomitant boost on the tissue directly surrounding, but not including, the tumor bed boost volume. Second, we analyzed the entire treated breast represented by the target breast volume. The EUD was also used to assess each of the boost methods independently, as well as incorporated into the concomitant boost techniques.

The magnitude of hot spots, as well as the volume of breast tissue receiving 110% and 115% of the prescribed dose, were assessed by dose–volume histogram analysis. These parameters were evaluated for both conventional and IMRT delivery techniques before the addition of the tumor bed boost. The percent volume of lung and heart (left-sided lesions) receiving 20 Gy was also determined.

Table 1. Breast size related to dose delivery

Separation (cm)	Target breast volume (cm^3)	Wedge volume 110%* (cm^3)	IMRT volume 110%* (cm^3)
19	407.77	44.1	0
17.5	247.32	3.2	0
16	277.66	10.1	0
24	1427.9	30.8	20.8
26	1377.55	0	4.3
28	2271.97	44.6	115.5
21	619.03	45.2	14.9
26.5	1412.39	0	0
26	1541.84	31.3	31
19	537.53	26.1	0
22	892.97	13.1	18.9
19	381.68	0.1	0.2
25	2074.88	22.4	2.9
20	1008.69	58.6	3
21	1213.8	113	10.4
18	426.44	0	0
19	335.09	10.7	0.1
24	1713.83	237.1	88.3
19	531.77	0.1	0
19.5	1341.07	136.3	4.5

Abbreviation: IMRT = intensity-modulated radiotherapy.
* Target breast volume receiving ≥110% of prescription dose.

Statistical analysis

Two-sided 95% confidence intervals (CIs) were used to compare data on the assumption of normally distributed outcome differences in the two comparison groups. Outcomes in the 1 patient with bilateral breast cancer were assumed to be independent.

RESULTS

We included 19 patients (age range, 40–77 years) in this study. Ten malignancies were on the left and 10 on the right. One of the patients had bilateral disease. The separation between the medial and lateral beam entrance points was between 16–28 cm, and the target breast volume spanned 247.32–2271.97 cm^3 (Table 1). The chest separation correlated roughly with increasing breast volume, but the much wider numeric range seen with the target breast volumes may make this a more useful surrogate of breast size. In addition, the target breast volume accounted for occasional discordance between body frame and breast size.

Table 2. Dosimetric characteristics of wedge tangent delivery vs. intensity-modulated radiotherapy

Characteristic	Wedges	IMRT
Three-dimensional maximal dose (%)	116	116
Maximal dose to 1 cm^3 of target breast volume (%)	113	111
Volume 110%* (cm^3)	41	16
Volume 115%† (cm^3)	1	2

Abbreviation: IMRT = intensity-modulated radiotherapy.
* Target breast volume receiving ≥110% of prescription dose.
† Target breast volume receiving ≥115% of prescription dose.

Target breast volume coverage

In evaluating the delivery of opposed tangents alone without the concurrent boost, a subtle improvement in dose homogeneity using IMRT compared with a wedge was revealed (Table 2). This was not seen in the three-dimensional maximal dose, because tangent delivery with either wedge or IMRT resulted in an average hot spot of 116% (95% CI, −3.0 to 3.5). Because the three-dimensional maximum can represent extremely small volumes, the data were also analyzed to determine the maximal dose received by at least 1 cm^3 of breast tissue. A nonsignificant improvement was noted, with wedged tangents delivering an average overdose of 113% and IMRT tangents only 111% (95% CI, −21.8 to 183.7). However, a statistically significant improvement was seen in the ability of IMRT to reduce the breast tissue volume receiving ≥110% of the prescription dose. Modulation with wedges resulted in a 41-cm^3 volume receiving ≥110% of the prescription dose compared with a 16-cm^3 volume with IMRT (95% CI, 1.7–49.5). No obvious consistent correlation was found between breast size and target breast volume receiving ≥110% of the dose with either wedges or IMRT (Table 2). The volume receiving ≥115% of the dose was small with either delivery method: 1 cm^3 with wedges vs. 2 cm^3 with IMRT (95% CI, −3.0 to 1.4). The small improvements in dose homogeneity by reduction of overdosed breast tissue is illustrated in Fig. 1, with a sample dose–volume histogram comparing wedge tangents and IMRT tangents.

Boost volume coverage

Evaluation of the tumor bed coverage using only the boost treatment fields revealed an average EUD (prescription dose, 14 Gy) of 13.3 Gy for the electron boost vs. 13.9 Gy for the photon boost. These results demonstrated that the conformal photon boost was significantly better at delivering a more uniform dose (95% CI, −81.1 to −22.9). This is illustrated in a sample dose–volume histogram (Fig. 2) showing the electron boost with a much broader dose distribution, and a significant portion of that distribution below the prescribed dose.

Concomitant boost

Comparison of the concomitant boost techniques revealed very small improvements in the average clinical target volume dose homogeneity with the IMRT tangents (techniques 2 and 3) compared with the conventional wedge tangents (technique 1), as revealed in an EUD value of 47.9, 48.3, and 48.6 Gy, respectively (Table 3 and Fig. 3a). Although both IMRT tangent techniques resulted in average EUD values that more closely approximated the prescribed dose of 46 Gy, the IMRT tangents with an electron boost showed a significant improvement over conventional tangents (95% CI, 17.5–125.6) and IMRT tangents with a conformal photon boost (95% CI, −79.5 to −18.1). IMRT tangents with a photon boost were not significantly different from the conventional tangents (95% CI, −30.9 to 76.3). This may have been because the beneficial effect of the IMRT tangents on increasing the dose uniformity was masked by the use of multiple fields for the tumor bed boost.

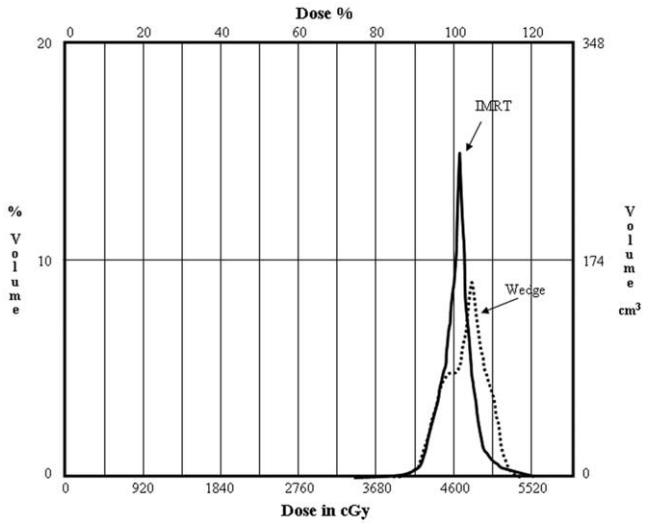

Fig. 1. Sample patient dose–volume histogram illustrating reduction in overdose of target breast volume with delivery of opposed tangents by intensity-modulated radiotherapy (IMRT) vs. wedges.

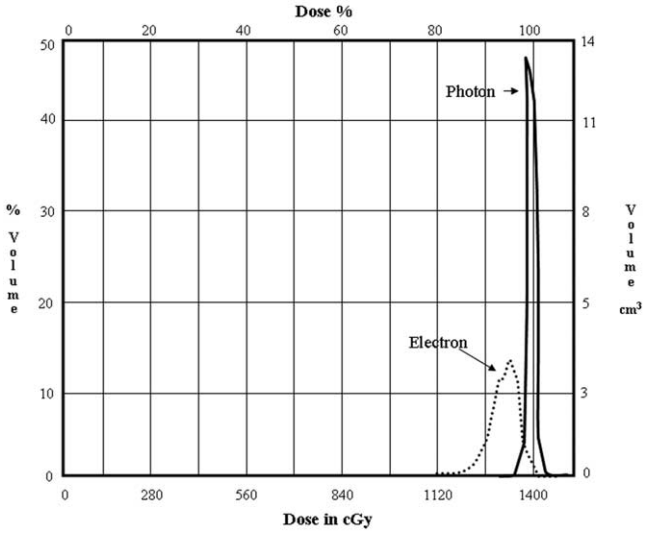

Fig. 2. Sample dose–volume histogram illustrating dose distribution of electron tumor bed boost vs. conformal photon boost.

Table 3. Average equivalent uniform dose values for clinical target volume and tumor bed boost from each of three boost delivery methods

Boost plan	EUD (cGy)	
	Clinical target volume	Tumor boost volume
Standard tangents/electron boost	4857	6005
IMRT tangents/electron boost	4784	5950
IMRT tangents/conformal boost	4834	5996

Abbreviations: EUD = equivalent uniform dose; IMRT = intensity-modulated radiotherapy.

With four or five boost fields, more breast tissue outside of the boost volume receives radiation from the boost treatment. As is illustrated in the sample dose volume histogram (Fig. 3b) IMRT tangent techniques 2 and 3 demonstrate less tissue overdose, but technique 3 has a greater volume of tissue receiving the boost dose.

As expected, the average equivalent doses were slightly increased by the addition of the tissue receiving a greater dose per fraction in the evaluation of the target breast volume (data not shown). However, the results were quite similar in that techniques 2 and 3, which used IMRT for delivery of opposed tangents, achieved an average EUD more closely approximating the prescribed dose, but technique 3 exhibited only marginal improvement.

In the setting of a concomitant boost, excellent tumor bed coverage was obtained, with each technique achieving average EUD values within 50 cGy of the total prescribed dose of 60 Gy (Table 3 and Fig. 3a). However, technique 2 delivered an EUD that was significantly less than either technique 1 (95% CI, 2.2–107.2) or 3 (95% CI, −72.1 to −20.1). Techniques 1 and 3 did not differ significantly (95% CI, −45.1 to 62.3). This result is difficult to explain. However, despite the statistical significance, the absolute differences were quite small, and the clinical benefit of such small improvements is uncertain.

Dose to normal structures

The heart and lung doses were virtually indistinguishable among the three techniques (Fig. 4) and well within the accepted standard of care. The average percentage of lung volume receiving 20 Gy was 14% for all three techniques. Each technique produced an average percent heart volume receiving 20 Gy of 3%.

DISCUSSION

We sought to evaluate the dosimetric outcomes of three different concurrent boost delivery methods in preparation for a phase II clinical trial evaluating the cosmetic outcome of this technique. Our goal was to identify the best technique in terms of dose delivery to the target volume while maintaining acceptable doses to normal structures. Because increasing the dose per fraction could potentially affect cosmesis negatively, choosing the optimal delivery method was particularly important.

One potential way to minimize a negative affect on the cosmetic outcome would be to maximize dose homogeneity in the part of the breast receiving tangential RT only. We found that the IMRT tangents improved dose homogeneity by significantly decreasing the volume of breast tissue receiving ≥110% of the prescribed dose. In a previous study, we compared the dose uniformity obtained with a conventional wedge technique to, among other things, intensity modulation (17). Intensity-modulated techniques using either compensators or MLCs were shown to improve dose uniformity. Based on the results of this investigation, it is unlikely that using MLC IMRT in our dosimetry study

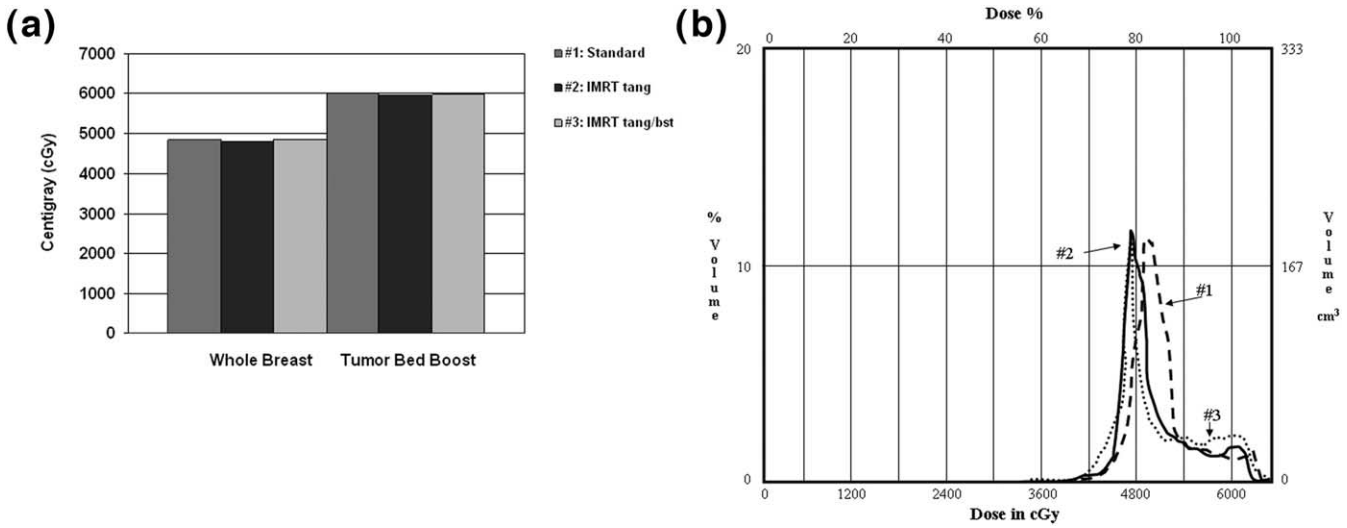

Fig. 3. (a) Comparison of equivalent uniform dose values for clinical target volume and tumor bed boost volume. IMRT = intensity-modulated radiotherapy; tang = tangents; bst = boost. (b) Sample dose–volume histogram comparing coverage of clinical target volume with concomitant boost techniques 1, 2, and 3.

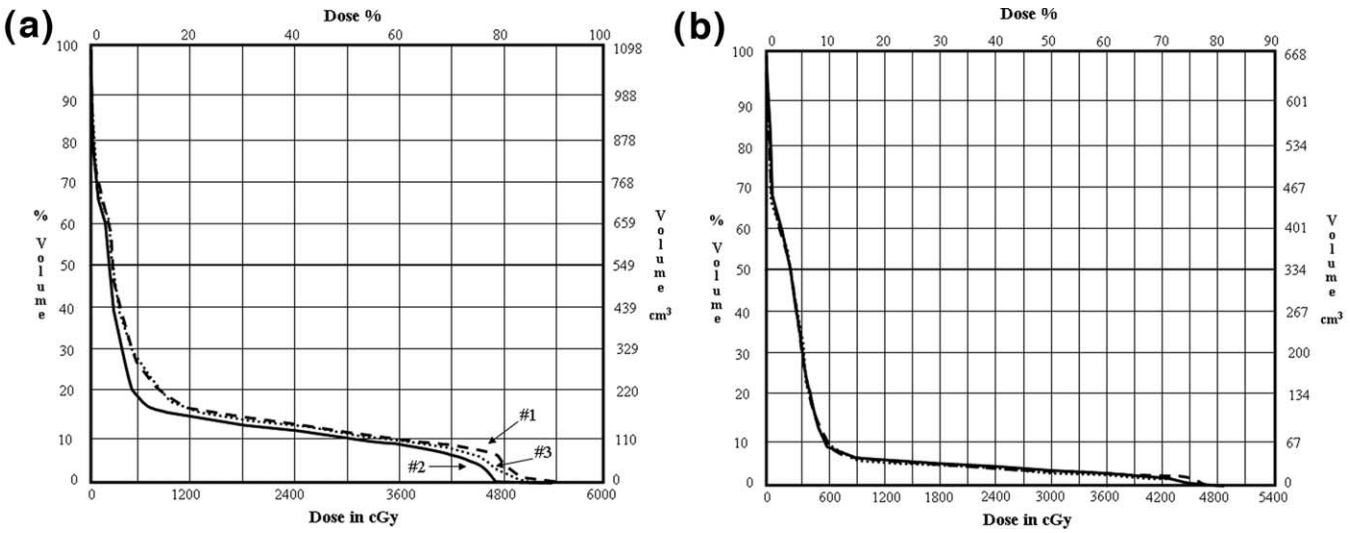

Fig. 4. (a) Sample ipsilateral lung dose–volume histogram comparing concomitant boost techniques 1, 2, and 3. (b) Sample ipsilateral heart dose–volume histogram comparing concomitant boost techniques 1, 2, and 3.

would have changed the current results significantly. Many other studies have also demonstrated an improvement in dose homogeneity with IMRT techniques (11, 18–20). Donovan *et al.* (10) evaluated 300 patients in a randomized trial comparing the clinical outcomes of a conventional wedge technique with those of intensity modulation. A reduction in the volume receiving >105% of the prescription dose was noted from 11.7% with standard technique to 1.0% with IMRT. Mayo *et al.* (9) evaluated the delivery of five different treatment techniques and found improved homogeneity in the treated breast with a six-field IMRT technique. In a series of 95 patients treated with intensity-modulated tangential breast fields, Vicini *et al.* (21) found that no breast volume received 110% or 115% of the prescribed dose. Thus, intensity modulation improves dose homogeneity, and the major portion of this benefit stems from a reduction in the volume of overdosed tissue, often offset by a small increase in the volume of cold tissue.

Although not the primary goal of our study, we also obtained information regarding normal tissue coverage. The volume of irradiated heart and lung was virtually indistinguishable among the three concomitant boost delivery methods evaluated in this study. Admittedly, the IMRT tangents were optimized for target volume uniformity, not for reducing the heart or lung volume. Additionally, the opposed tangential field design may have contributed to the presence of differences among the techniques. However, other studies have also shown minimal differences in heart and lung RT with IMRT vs. conventional therapy. Hurkmans *et al.* (22) compared conventional, conformal, and IMRT techniques and found that the normal tissue complication probability (NTCP) values for radiation pneumonitis was 0.5%, 0.4%, and 0.3% respectively. The cardiac NTCP was reported as 5.9% for conventional, 4.0% for conformal, and 2.0% for IMRT. Another series investigating the use of IMRT and partially wide tangent fields reported comparable cardiac NTCP values but significant improvements in ipsilateral lung NTCP values with IMRT (0 for IMRT vs. 0.7 for partially wide tangent fields) (23). As with dose homogeneity, small improvements of uncertain clinical relevance can be seen with IMRT techniques depending, in part, on the field design.

When we took into account the effect of a concomitant boost, we found that the improved dose homogeneity from IMRT tangents persisted in the breast clinical target volume, despite the addition of a tumor bed boost. However, the improved homogeneity was somewhat offset by the increase in irradiated tissue outside the boost volume with the addition of a conformal photon boost. Several other studies have evaluated the dosimetry of a concomitant boost with varying results. Li *et al.* (24) reported comparably good coverage of the target volume among conventional RT, IMRT, and hypofractionated IMRT (2.8 Gy/fraction to the tumor bed), with decreased lung NTCP values for the IMRT regimens. Thatcher *et al.* (25) investigated a three-dimensional conformal technique with a sequential boost vs. a five-beam IMRT concurrent boost and found that the IMRT plans decreased the regions of overdose within the breast volume but increased the dose to the ipsilateral lung and surrounding structures. Krueger *et al.* (26) evaluated the use of cone IMRT (cIMRT) vs. conventional RT and found that although cIMRT increased the mean dose to the breast relative to the conventional technique, it produced small improvements in the percentage of cardiac volume receiving 30 Gy (2.68% conventional vs. 0% cIMRT) and mean ipsilateral lung dose (8.0 Gy conventional vs. 6.71 Gy cIMRT). Lief *et al.* (27) demonstrated a reduction in the breast volume receiving >105%, >110%, and >118% of the prescription dose from 40%, 25%, and 10% with conventional therapy to 12%, 6%, and 2% with IMRT, respectively, in the evaluation of a 3.3-Gy concomitant boost. These results have not been substantiated to date, in that the subsequent pilot study demonstrated that 37% of the breast volume outside of the boost plus margin received 110% of the prescription dose with IMRT and nearly 4% received 125% (28). Therefore, although

several dosimetric studies have demonstrated a decrease in dose to normal tissues or improved dose homogeneity with IMRT techniques, the optimal clinical implementation of a concomitant boost is still uncertain.

Another complicating factor is that the small gains in homogeneity seen with IMRT may or may not be clinically relevant. For example, only 0.7 Gy separated the equivalent dose values in our comparison of the concomitant boost technique. Very few data exist to correlate the degree of dose homogeneity within the breast to long-term cosmetic outcomes. Breast size has been linked to poor cosmesis, and, although no obvious trend was seen in our data, several studies have reported a correlation between increasing breast size and decreasing dose homogeneity (29–31). However, information directly linking the impact of inhomogeneity on cosmesis is sparse. Taylor *et al.* (31) reported an improvement in cosmetic outcomes associated with the use of compensating filters (designed between 1969 and 1990). Wazer *et al.* (32) noted a maximal dose inhomogeneity of 11.6% and 11.96% was associated with excellent and good cosmetic outcomes, respectively, but a maximal inhomogeneity of 13.22% was associated with fair and poor outcomes. Because the tumor bed boost and a large dose per fraction of a concomitant boost contribute to suboptimal cosmesis (33), improving homogeneity even a little may be relevant, but it is more likely that the major impact on cosmesis will be inclusion of a boost under any circumstances (6, 32).

The above data would seem to suggest that a concomitant boost might result in significantly worse cosmesis, particularly when given with conventional RT. However, the Canadian study by Whelan *et al.* (3) did not substantiate the postulate that a greater dose per fraction given in a conventional manner leads to poor cosmetic outcomes. They demonstrated excellent or good cosmetic outcomes in 76.8% of 1234 patients at 3 and 5 years. These patients received fractions of 2.65 Gy to the entire breast daily delivered with wedged tangents and a dose uniformity of ±7%. Olivotto *et al.* (34) found that 89% of 186 women had excellent/good cosmetic outcomes after receiving 2.75-Gy fractions to a total dose of 44 Gy. In addition, the sacrifice in cosmetic outcomes does result in patient benefit. The European Organization for Research and Treatment of Cancer (4) found a reduction in local recurrence from 7.3% to 4.3% with the addition of boost RT. Romestaing *et al.* (7) also found a statistically significant decrease in the local recurrence rate from 4.5% to 3.6% at 5 years in those receiving a boost.

A final factor to consider is the cost of using IMRT to improve dose homogeneity in the delivery of a concomitant boost. A goal of the concomitant boost technique is to decrease overall resource use by lessening the treatment time by 1.5 weeks. A significant disadvantage to the use of IMRT is the presumed increase in implementation cost. Cocquyt *et al.* (35) recently reported data investigating the economic impact of breast cancer prevention obtained by estimating treatment costs for breast cancer patients. In the analysis of node-negative patients, RT was the second most costly treatment factor of 13 potential costs, including chemotherapy, imaging, and surgery. Although cost was not estimated for the different RT techniques, treatment of a large proportion of patients with IMRT would presumably increase RT expenditures even more. In the radiation oncology department at the UNC, the estimated charge for delivery of tangents with wedges used for dose modulation is $13,000. This includes only the technical and professional costs associated with treatment planning and delivery of the tangents and does not account for the boost dose. The estimated charge for the same treatment delivered with IMRT is approximately $27,000. This estimated financial information is limited in that is was not gathered prospectively but does provide some general insight into the cost effectiveness of various RT delivery techniques.

Two randomized studies have supported a good cosmetic outcome with a large dose per fraction delivered in a conventional manner. In addition, conventional treatment results in exceedingly low pulmonary and cardiac baseline complication rates (36, 37). These two facts, in conjunction with a lack of convincing evidence correlating small gains in dose homogeneity with improved cosmetic outcome and the increased cost of IMRT implementation, make a role for intensity modulation in the delivery of a concomitant boost less likely. Therefore, although breast IMRT certainly has an important application in selected clinical cases, techniques such as a concomitant boost delivered in a conventional fashion would be expected to have a very favorable impact on cost reduction for a far greater number of patients. With the heavy burden to department resources and the cost-intensive nature of IMRT, we believe that the use of IMRT techniques in delivering a concomitant boost is often not necessary. When dose homogeneity ±10% can be obtained with conventional wedges, excellent coverage of the whole breast and tumor bed with a minimal dose to normal tissue is possible with technology that is already widely available, and less costly. Our goal is to proceed with a phase II trial to evaluate prospectively the cosmetic outcome of concurrent boost delivered primarily by standard tangents plus concurrent electron boost.

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