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PHYSICS CONTRIBUTION

HYBRID IMRT PLANS—CONCURRENTLY TREATING CONVENTIONAL AND IMRT BEAMS FOR IMPROVED BREAST IRRADIATION AND REDUCED PLANNING TIME

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Purpose: To evaluate a hybrid intensity modulated radiation therapy (IMRT) technique as a class solution for treatment of the intact breast.
Methods and Materials: The following five plan techniques were compared for 10 breast patients using dose–volume histogram analysis: conventional wedged-field tangents (Tangents), forward-planned field-within-a-field tangents (FIF), IMRT-only tangents (IMRT tangents), conventional open plus IMRT tangents (4-field hybrid), and conventional open plus IMRT tangents with 2 anterior oblique IMRT beams (6-field hybrid).
Results: The 4-field hybrid and FIF achieved dose distributions better than Tangents and IMRT tangents. The volume of tissue outside the planning target volume receiving ≥110% of prescribed dose was largest for IMRT tangents (average 158 cc) and least for 6-field hybrid (average 1 cc); the FIF and 4-field hybrid were comparable (average 15 cc). Heart volume ≥30 Gy averaged 13 cc for all techniques, except Tangents, for which it was 32 cc. Average total lung volume ≥20 Gy was 7% for all. Contralateral breast doses were <3% for all. Planning time for hybrid techniques was significantly less than for conventional FIF technique.
Conclusions: The 4-field hybrid technique is a viable class solution. The 6-field hybrid technique creates the most conformal dose distribution at the expense of more normal tissue receiving low dose. © 2005 Elsevier Inc.

IMRT breast techniques, Breast irradiation, Hybrid IMRT.

INTRODUCTION

Radiation therapy is an established component in the care of patients afflicted with breast cancer. As an adjunct to both surgery and chemotherapy, radiation therapy provides a survival advantage for lymph node–positive breast cancer patients (1) and a benefit in improving local control for all patients (2). In selected patients of limited constitutional status, radiation therapy can be the sole locoregional modality of care.

Anatomically, the breast presents a very challenging geometry for radiation therapy. For locoregional disease control, a minimal dose to all breast tissue is required. For good cosmetic results, dose homogeneity within the breast must be maximized and "hot spots" outside the target tissue minimized. Because most patients have a long life expectancy, doses to the lung and heart must be kept low to avoid long-term complications. Another restriction is dose to the contralateral breast, out of concern for possible induced second malignancies.

Seminal studies (1, 2) demonstrating a survival benefit to breast cancer patients treated with radiation therapy used two-dimensional planning. Single isodose distributions through the isocenter provided the infrastructure for evaluating the role of radiation therapy in this disease. However, the full extent of the dose heterogeneity on the breast and the location and magnitude of the hot spots with conventional wedged-field tangents have become appreciated only as 3D treatment planning with CT scans obtained in the treatment position have become common for breast patients. With this conventional treatment strategy, areas of maximum dose often are located in tissues outside of the intended target. Advances in multileaf collimator (MLC) use have helped compensate for these effects with the use of forward- or inverse-planned intensity modulated radiation therapy (IMRT) fields. These provide the radiation oncologist an opportunity to optimize treatment to the target and to develop conformal avoidance of normal tissue.

Several groups have reported on the improvement in dose homogeneity that may be achieved by using several MLC-formed subfields (3–9). Commonly referred to as forward-planned IMRT, this technique improves the dose homogeneity throughout the breast and reduces the magnitude of the hot regions outside the target region. It also reduces the maximum dose to the ipsilateral lung. The primary disad-

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vantage of these techniques is the increased treatment planning time, because defining the shape and number of subfields is an iterative process.

Inverse-planned IMRT offers the potential of extremely conformal dose distributions for many disease sites. The conformal and avoidance dose distributions are achievable by rapidly varying the fluence intensities of multiple beams from multiple angles. However, for breast treatments, the optimal beams for minimizing dose to the nearby normal tissues (lung and heart) are the nearly opposed tangent fields that geometrically avoid them. Success with IMRT may be limited by this geometry. Several groups have investigated the use of IMRT for intact breast (10–14).

We too have investigated IMRT for breast irradiation and have developed a class solution that applies to both sides and all sizes and shapes of intact breast. By combining open conventional tangent beams with IMRT beams from the same medial and lateral angles, dose distributions that are superior to those of conventional tangents and IMRT-only tangents can be readily achieved. Even more conformal dose distributions can be achieved by adding anterior oblique IMRT beams, but at the expense of greater volumes of normal tissues receiving low doses. This approach meets our goal of using inverse planning to reduce treatment planning time, compared to our conventional techniques, and minimizing the set of optimization constraints. This method produces consistent results with less dependence on the advanced skills of the treatment planner and is a class solution for very common treatments.

METHODS AND MATERIALS

Five patients from each of the left- and right-sided treatment site groups were selected. The range of breast volumes for patients in each group was typical of those usually encountered. The patients were immobilized in a custom α-cradle device and had CT scans performed in the treatment position. Scans were transferred to the treatment planning computer (Varian Eclipse version 7.1.35; Varian Medical Systems, Palo Alto, CA), and the breast tissue (clinical target volume) [CTV]) was defined by a radiation oncologist. The contralateral breast, right lung, left lung, and heart tissues were delineated on the CT scans. Breast volumes ranged from 370 to 1600 cc, separations from 17 to 27 cm.

The following considerations were used by the radiation oncologist in delineating the breast CTV. With the use of anatomic references, the CTV is generally defined superiorly by the inferior aspect of the clavicular head and inferiorly by the inframammary fold as identified on skin reconstruction and physical examination. Medially, the CTV is limited by the sternum and is generally delineated 2 cm medial to the edge of the sternum. Laterally, the breast tissue is identified in the midaxillary line. Exceptions to these anatomic references are made by the physician on a case-by-case basis based on the physical examination and image assessment.

A breast planning target volume (PTV) was defined as the breast CTV plus a margin of 0.5 cm. It was modified to include only intersection with the body contour to facilitate evaluation of dose–volume histograms. Treatment beams maintained “flash” necessary to assure coverage of the treatment area as defined by the unmodified PTV.

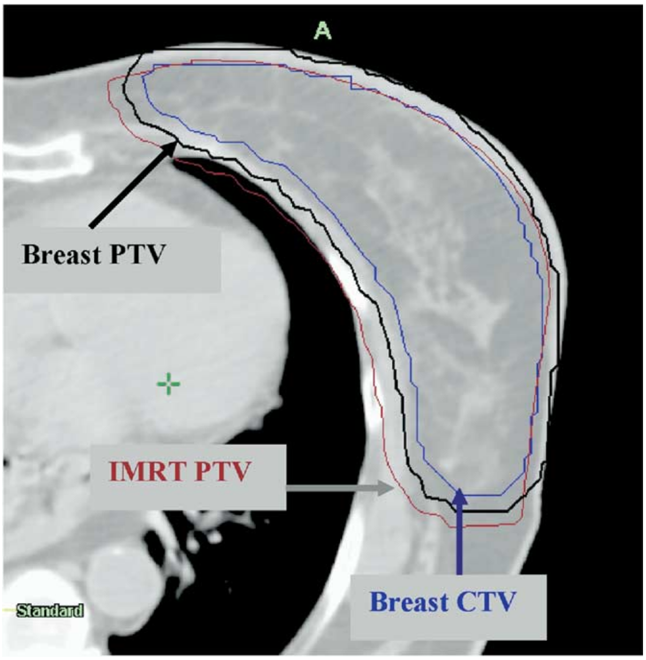

Fig. 1. For IMRT planning, the breast PTV contour (dark gray) is modified to create an IMRT PTV (contour line) that facilitates achieving good coverage of the breast PTV using the optimization algorithm. IMRT = intensity modulated radiation therapy; PTV = planning target volume; CTV = clinical target volume.

A planning volume, the IMRT PTV, was defined to facilitate inverse planning optimization. It was created with a margin of 0.5 cm on the breast PTV and then modified to exclude 0.5 cm of the buildup region near the skin (See Fig. 1). This additional margin pushes the high-dose gradient produced by IMRT plans farther away from the edge of the PTV to reduce the effect of day-to-day variability in patient setup on actual PTV coverage. Excluding the region near the skin guides the optimization algorithm away from attempting to achieve full dose in the buildup region. Once optimization on the IMRT PTV was complete, normalization of the plan was based on coverage of the breast PTV.

The body was delineated on the CT scans, and Boolean operations were used to construct a modified body volume that excluded breast tissue with a 0.5-cm margin. Dose–volume histograms of this tissue outside the breast (V_{OB}) were used to characterize doses to nontarget tissue within the radiation fields.

For each patient, 5 treatment plans were developed to treat the breast to 45 Gy using 6 MV photon beams. All 5 plans for each patient used the same isocenter and tangential beam angles. Typical beam's-eye–views for medial beams are illustrated in Fig. 2.

The first plan (Tangents) was a conventional breast treatment using medial and lateral tangential rectangular beams with wedges. In this article, this plan is considered to be the standard to which others are compared. All other plans were normalized to achieve isodose coverage of the breast tissue at least as good as the tangent plan.

The second plan (field-within-a-field [FIF] tangents) was a manually developed field-within-a-field treatment (or forward-planned IMRT). This is the technique routinely used in our clinic to reduce hot spots and to increase the dose homogeneity to the breast (3). Wedges are used, and the radiation areas of medial and

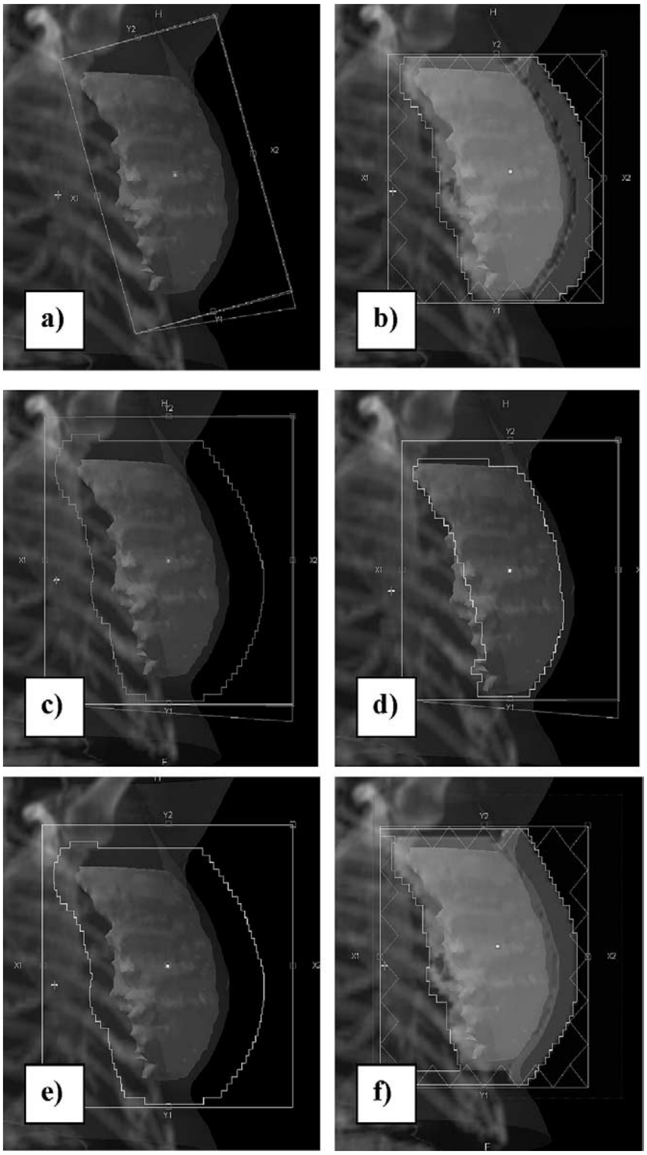

Fig. 2. Beam's-eye–views of medial beams for plans. The gray volume is the PTV. Beam edges defined by the collimators and static field MLCs are shown. For IMRT, the gray extending beyond the PTV is the fluence. Shown are medial beams for (a) Tangents, (b) IMRT tangents; (c) open portion and (d) reduced field of the FIF technique; (e) open portion and (f) IMRT portion of hybrid plans. IMRT = intensity modulated radiation therapy; FIF = field-within-a-field tangent; MLC = multileaf collimator; PTV = planning target volume.

lateral fields are defined with an MLC shaped to give a 1.0-cm margin on the breast volume. Subfields are designed to reduce hot spots created by the primary fields. This process is repeated until a good plan is achieved. For each of the cases here, one set of subfields was sufficient for each of the medial and lateral beams (a total of 4 fields). Approximately 90% of the dose is delivered by the primary tangents and 10% by the subfields.

The IMRT plans were developed using the Varian Medical Systems Eclipse/Helios treatment planning system with the optimization constraints shown in Table 1. All plans were developed for a 6 MV beam on a 2300C/D accelerator with a Millennium 120 MLC from Varian. Although Eclipse/Helios allows the planner to

Table 1. Optimization parameters used in Eclipse/Helios in this study for all plans involving intensity modulated radiotherapy

Treatment site	Tissue limit	Limit	Dose (Gy)	Priority
Right breast	Breast	Min.	45	100
		Max.	47	50
Left breast	Breast	Min.	45	100
		Max.	47	50
	Heart	Max.	35	70

interactively monitor and change the constraints as the optimization proceeds, we adhered to the set of constraints indicated. This allowed testing the hypothesis that a simple class solution could be developed that is advantageous compared to manual planning methods.

The third plan (IMRT tangents) consisted of medial and lateral tangent IMRT beams; i.e., the wedges were removed from the standard tangent fields, and these beams were optimized for IMRT delivery. With Eclipse/Helios, the relative weights of the IMRT beams cannot be modified. Although the treatment planning system allows for modification of fluence patterns to control hot spots, this feature was not used in the study. Manual adjustment of the fluence to avoid creation of hot and cold spots in the dose distribution requires skilled effort not consistent with our objective of investigating broadly applicable class solutions.

The fourth plan (4-field hybrid) combined conventional and IMRT beams. The conventional medial and lateral primary beam MLCs designed for the FIF tangents were used without wedges. These were supplemented with a pair of IMRT tangents. The relative weights of the conventional beams were manually modified to achieve dose coverage similar to that of the tangents plan; typically ~83% of the dose was delivered from conventional beams.

The fifth plan (6-field hybrid) added 2 anterior oblique IMRT beams to the 4-field hybrid plan. Angles for these beams were selected to reduce hot spots created outside the breast tissue in the entrance regions of the tangent beams and were approximately 45° from the nearest tangent beam. The relative weights of the conventional and IMRT fields calculated by the optimization algorithm were accepted; typically ~20% of the dose was delivered with conventional beams.

Tissue heterogeneity was accounted for in dose calculations using the Batho power law correction. Tangent beam plans were normalized such that the prescribed dose (45 Gy) was received by 95% of the breast PTV. All other plans were normalized to achieve coverage at least as good as that of tangent beams.

Total monitor units were tabulated for each plan. The ratio for each plan of total monitor units to those for the Tangents plan was calculated for each patient. Results are summarized in Table 9.

Isodose contour distributions of the different plans were evaluated and compared. Cumulative dose–volume histograms were calculated for the target volumes and normal structures. Quantitative data were extracted from the dose–volume histograms. Maximum doses were determined as the dose associated with the hottest 1 cc of tissue. This prevented exaggeration of maximum values when 1 or 2 voxels had a large value. The maximum dose and the volume of heart receiving >30 Gy were determined. The 30 Gy dose level was selected, because retrospective analyses of patients treated for breast cancer (15) and for Hodgkin's disease (16, 17) have shown that the probability of mortality resulting from radiation damage is low for doses less than 30 Gy. Maximum

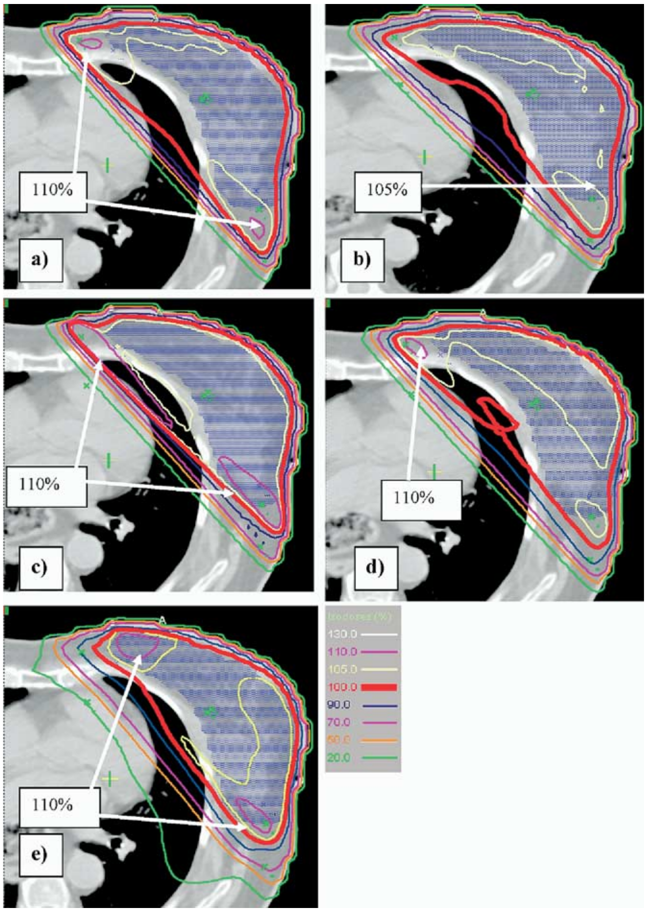

Fig. 3. Typical isodose distribution at the central axis plane for (a) Tangents, (b) FIF tangents, (c) IMRT tangents, (d) 4-field hybrid IMRT, and (e) 6-field hybrid IMRT. The regions of highest dose are indicated. FIF = field-within-a-field tangents; IMRT = intensity modulated radiotherapy.

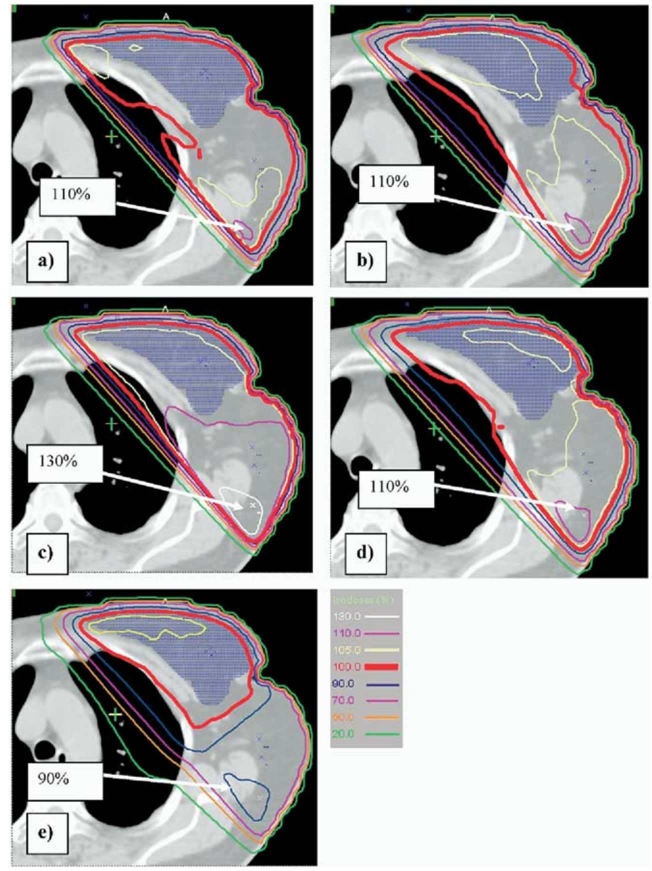

Fig. 4. Typical isodose distribution at the plane of the axilla for (a) Tangents, (b) FIF tangents, (c) IMRT tangents, (d) 4-field hybrid IMRT, and (e) 6-field hybrid IMRT. The regions of highest dose are indicated. FIF = field-within-a-field tangents; IMRT = intensity modulated radiotherapy.

doses to the heart were determined; low doses to the heart were evaluated by determining the volume receiving >5 Gy. In the lungs, the mean lung doses were determined, because studies (18–20) have shown a correlation between radiation pneumonitis and mean lung dose. The volume of lungs receiving >20 Gy was also determined. In the contralateral breast, the mean dose and the dose associated with the hottest 5% of the contralateral breast tissue were tabulated. Low doses in the body were evaluated by comparing the total volume of tissue receiving at least 10 Gy. A major goal of these plans was to reduce the hot spots in the soft tissue surrounding the breast. These regions were investigated by evaluating the volume of tissue outside the breast receiving >100% and >110% of the prescribed dose; the maximum dose was also determined. A Student's *t* test was used for computing *p* values and for comparing differences in mean values at a 0.025 significance level.

RESULTS

Typical results for the isodose distributions of each of the 5 plans examined in this study are shown in Figs. 3 at the level of the central axis and Fig. 4 at the level of the axilla. The rectangular fields of tangent beam plans encompassed a large volume of tissue outside the breast and created hot spots in the medial and lateral entrance regions. These hot spots are generally located where the patient is radiographically "thinner" than on the central axis, near the lungs (because of their low density compared to surrounding tissue), near the apex of the breast, and the axilla, where the physical thickness is less. FIF tangents improved on dose homogeneity by blocking out high-dose regions for a fraction of the total dose. Using MLCs to conform the radiation fields to the breast tissue reduced the volume of tissue irradiated outside the breast. Manually designing these FIF tangent beams was an iterative process that required ~1–2 hours, depending on the morphology of the breast target.

Intensity modulated radiation therapy tangents reduced the volume of tissue irradiated but generally created hot regions worse than encountered with traditional Tangents. Generally, inverse-planned IMRT beams achieve excellent conformality with beams using nonopposed directions and distributed around the plane of the target but do not do well with the two limited, nearly opposed, angles of the tangents.

The 4-field hybrid technique allowed the majority of dose to be delivered with open conventional beams and used IMRT beams to even out the distribution. The dose distri-

Table 2. Dose characteristics of the PTV (breast) of the five planning strategies include the mean dose and dose homogeneity for right- and left-sided patient groups

Treatment site	Technique	Mean PTV dose (%)	V_{110} (%)
Right breast	Tangents	105 ± 2	4 ± 5
	FIF tangents	104 ± 2	2 ± 3
	IMRT tangents	105 ± 1	2 ± 5
	4-field hybrid	104 ± 2	3 ± 6
	6-field hybrid	103 ± 1	0.1 ± 0.2
Left breast	Tangents	103 ± 2	2 ± 3
	FIF tangents	102 ± 2	1 ± 2
	IMRT tangents	104 ± 3	2 ± 2
	4-field hybrid	102 ± 3	2 ± 3
	6-field hybrid	101 ± 3	1 ± 2

Abbreviations: PTV = planning target volume; FIF = field-within-a-field tangents; IMRT = intensity modulated radiation therapy.

butions were similar to FIF tangent distributions but required only ~15 minutes to plan. The 6-field hybrid technique dramatically reduced the hot regions and made a more conformal dose distribution around the breast tissue. However, it increased the volume of tissues outside the breast that received low doses.

Table 2 shows that the mean doses delivered to the breast tissue are similar among techniques for each of the left- and right-sided patient groups. Mean values for each of the two groups are not significantly different among the techniques. Dose homogeneity, as measured by the volume of PTV receiving >110% dose, is also similar among the techniques.

The mean doses to the ipsilateral and contralateral lungs for each of the techniques are shown in Table 3. The mean lung doses for the 6-field hybrid technique were significantly higher than for the other techniques by ~8% ($p <$ 0.015). In none of the plans did the contralateral lung receive 20 Gy. There was little difference among the plans with respect to the volume of ipsilateral lung that received

Table 3. The mean doses to lungs for each of the treatment techniques

		Mean dose (%)	
Treatment site	Technique	Right lung	Left lung
Right breast	Tangents	17 ± 6	0.7 ± 0.3
	FIF tangents	16 ± 6	0.4 ± 0.2
	IMRT tangents	13 ± 7	0.4 ± 0.2
	4-field hybrid	15 ± 7	0.4 ± 0.2
	6-field hybrid	26 ± 7	7 ± 0.7
Left breast	Tangents	0.6 ± 0.1	18 ± 5
	FIF tangents	0.5 ± 0.2	15 ± 7
	IMRT tangents	0.5 ± 0.2	14 ± 5
	4-field hybrid	0.5 ± 0.2	15 ± 7
	6-field hybrid	7 ± 0.4	25 ± 6

Abbreviations: FIF = field-within-a-field tangents; IMRT = intensity modulated radiation therapy.

Table 4. The volumes of the ipsilateral lung that received at least 20 Gy from each of the treatment techniques

Technique	Right breast	Left breast
Tangents	188 cc ± 74 cc	173 cc ± 50 cc
FIF tangents	180 cc ± 60 cc	151 cc ± 65 cc
IMRT tangents	129 cc ± 70 cc	120 cc ± 51 cc
4-Field hybrid	160 cc ± 78 cc	149 cc ± 61 cc
6-Field hybrid	183 cc ± 83 cc	167 cc ± 65 cc

Abbreviations as in Table 3.

20 Gy, as shown in Table 4. Fig. 5 shows the average lung volume receiving ≥20 Gy ranges from 6% to 8% among the techniques, and are not significantly different.

Doses to the heart are characterized in Table 5. Figure 6 shows that only the 6-field hybrid technique delivered more than 5 Gy to portions of the heart (average 42%). The maximum dose to the heart for the 6-field hybrid technique of 10 Gy (22.7%) was significantly larger than that delivered by the other techniques: ~4.6 Gy (8.4%) (p = 0.001). For left-sided breast treatments, all of the techniques treated portions of the heart to more than 30 Gy. The conventional tangents plan treated the largest volume to >30 Gy (32 cc average) and had the highest maximum heart dose, 46 Gy (103%) average. The lowest maximum heart doses, 36 Gy (80%), were achieved with the 6-field hybrid technique ($p <$ 0.14). Figure 7 shows that the percentage of heart receiving ≥30 Gy was low for all techniques (1.5–5.4%). The IMRT tangents and 6-field hybrid techniques demonstrated improvement over the conventional Tangents technique. In the low-dose region, the 6-field hybrid technique delivered at least 5 Gy to 69% of the heart volume on average compared to ~11% for the other techniques.

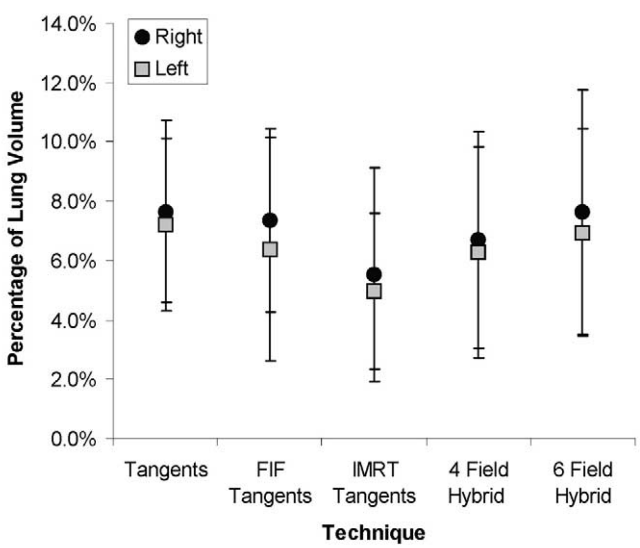

Fig. 5. Percentage of the total lung volume receiving >20 Gy for (circle) right-sided and (square) left-sided breast for the different techniques. Error bars are 1 standard deviation. FIF = field-within-a-field tangents; IMRT = intensity modulated radiotherapy.

Table 5. Characteristics of the dose to the heart for each of the treatment techniques. The volume of the heart that receives 5 Gy and 10 Gy are tabulated; the maximum dose is to a 1-cc volume and is expressed as a percentage of the prescription dose

Treatment site	Technique	$V > 5$ Gy (cc)	$V > 30$ Gy (cc)	Max. dose (%)
Right breast	Tangents	0.2 ± 0.4	0.0 ± 0.0	9 ± 2
	FIF tangents	0.0 ± 0.0	0.0 ± 0.0	9 ± 1
	IMRT tangents	0.0 ± 0.0	0.0 ± 0.0	8 ± 1
	4-Field hybrid	0.0 ± 0.0	0.0 ± 0.0	8 ± 1
	6-Field hybrid	199 ± 33	0.0 ± 0.0	23 ± 7
Left breast	Tangents	75 ± 34	32 ± 15	103 ± 3
	FIF tangents	62 ± 22	15 ± 14	87 ± 13
	IMRT tangents	63 ± 34	9 ± 6	88 ± 11
	4-Field hybrid	65 ± 20	17 ± 11	90 ± 8
	6-Field hybrid	417 ± 98	12 ± 8	80 ± 5

Abbreviations as in Table 3.

The volumes of soft tissue outside the breast (V_{OB}) that received prescription or higher doses are detailed in Table 6. The FIF technique reduced the volume of tissue that received prescription dose ($V_{OB} \geq 100\%$) by an average of 55% compared to conventional tangents. Similar results were obtained for the 4-field hybrid technique, which showed an average 53% reduction. The 6-field hybrid demonstrated an average reduction in $V_{OB} \geq 100\%$ of 85%. The highest maximum doses were produced by the IMRT tangents–only plans, and the lowest maximum doses were with the 6-field hybrid techniques. The maximum dose for the IMRT tangents was significantly higher (~30%) than the for the other plans. Similarly, the volume of tissue receiving ≥110% was significantly higher for the IMRT tangents than for all other plans, whereas the lowest values were obtained by the 6-field hybrid technique. IMRT tangents treated ~120 cc more tissue to 110% doses than other techniques.

The amount of irradiated tissue outside the breast (V_{OB}) varies with the breast size and morphology as well as with treatment technique. In Fig. 8, the volume of tissue outside the target that receives at least 100% of the prescribed dose is plotted as a percentage of the breast volume for the different techniques. Examining V_{OB} as a percentage of the breast volume helps focus on variations in volumes as a result of technique alone. Figures 9 shows the data for $V_{OB} \geq 100\%$ and Fig. 10 for $V_{OB} \geq 110\%$. For V_{OB} there was no significant difference between FIF and 4-field hybrid techniques. The lowest values were obtained for the 6-field hybrid technique: $V_{OB} \geq 110\%$ at an average of 0.6% of the breast volume.

The mean doses to the contralateral breast were no greater than 3.3% for all techniques, as shown in Table 7. The 1.3–1.8% increase in the mean dose for the 6-field hybrid technique as compared to Tangents was small but may be significant. The largest dose seen by at least 5% of the breast tissue D_5 was 3.1–4.1% for techniques other than the 6-field hybrid. That technique increased the dose by 3.1% when compared to tangents.

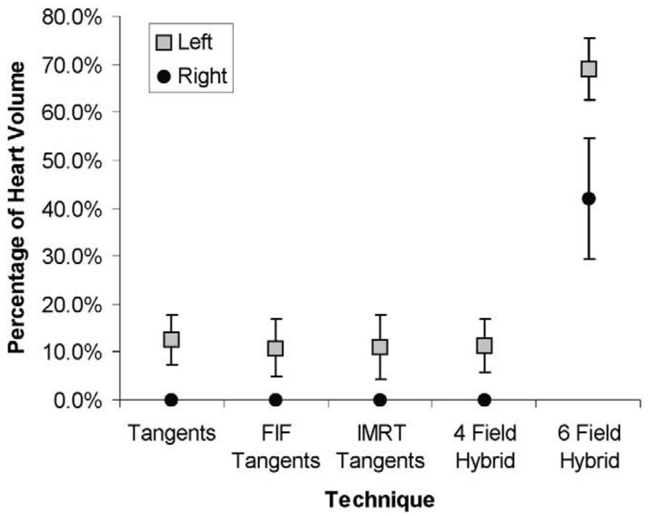

Fig. 6. Percentage of the heart volume receiving >5 Gy for (circle) right-sided and (square) left-sided breast. Error bars are 1 standard deviation. FIF = field-within-a-field tangents; IMRT = intensity modulated radiotherapy.

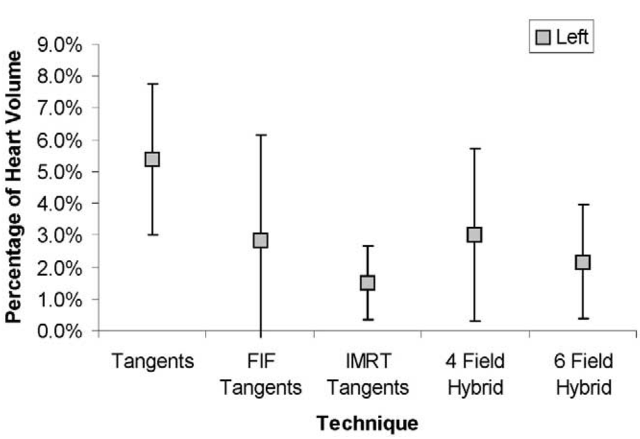

Fig. 7. Percentage of the heart receiving >30 Gy for left-sided breast treatments with different techniques. Right-sided breast treatments did not deliver heart doses >30 Gy. Error bars are 1 standard deviation. FIF = field-within-a-field tangents; IMRT = intensity modulated radiotherapy.

Table 6. Characteristics of dose to the soft tissue surrounding the breast for the different techniques

Treatment site	Technique	V>100% (cc)	V>110% (cc)	Max. dose (%)
Right breast	Tangents	437 ± 220	37 ± 46	112 ± 2
	FIF tangents	221 ± 179	22 ± 31	110 ± 6
	IMRT tangents	362 ± 162	144 ± 119	141 ± 18
	4-field hybrid	260 ± 139	20 ± 28	113 ± 40
	6-field hybrid	70 ± 41	0.0 ± 0.0	104 ± 1
Left breast	Tangents	587 ± 353	52 ± 74	113 ± 4
	FIF tangents	234 ± 179	12 ± 17	110 ± 4
	IMRT tangents	367 ± 188	180 ± 160	148 ± 21
	4-Field hybrid	208 ± 128	9 ± 14	111 ± 3
	6-Field hybrid	69 ± 55	1 ± 3	106 ± 4

Abbreviations as in Table 3.

Table 8 indicates that the volume of tissue in the body receiving ≥10 Gy ranged from 1306 to 1989 cc, corresponding to 1.5 to 2.3 times the average breast volume. Differences among the techniques were not significant. There were significant differences between the 6-field hybrid technique and the others in the relative distribution of low dose and high dose within this range.

The total number of monitor units was similar to that for Tangents for the FIF tangents and the 4-field hybrid technique. Table 9 shows the average ratio of total monitor units for each technique relative to the total for Tangent beams. The difference between FIF tangents and 4-field IMRT was not significant and was similar to Tangents alone. The IMRT tangent and 6-field hybrid plans both demonstrated total monitor units ~2.3 times larger than for Tangents.

DISCUSSION

By combining inverse-planned IMRT beams with conventional open beams, dose distributions for breast treatment are achieved that are better than conventional tangential treatments and better than IMRT-only treatments. Dose uniformity to the target issue is improved, and "hot" regions outside the target are reduced. With 4-field (open and IMRT tangents) hybrid plans, the dose distributions are comparable to those with field-within-a-field, or forward-planned IMRT, techniques but achieved with significantly less planning time. By adding 2 anterior oblique IMRT beams (6-field hybrid), dose conformality is improved even more.

The patients selected for this study represented the range of sizes encountered in the clinic. The separations varied from 17 cm to 27 cm; both left- and right-sided treatments were investigated. As expected, the improvement in dose distribution was greater for the larger patients, for whom the hot regions are greater with conventional tangential treatments.

All plans reported here were calculated with dose heterogeneity. The plans considered standard for this study were conventional tangent fields with wedges selected to optimize the dose uniformity to the target tissue. The field-within-a-field plans were developed as is routine in our clinic (3) and are similar to those reported by others (4–9).

The inverse-planned IMRT plans were developed on the Varian Eclipse system with the Helios optimization algo-

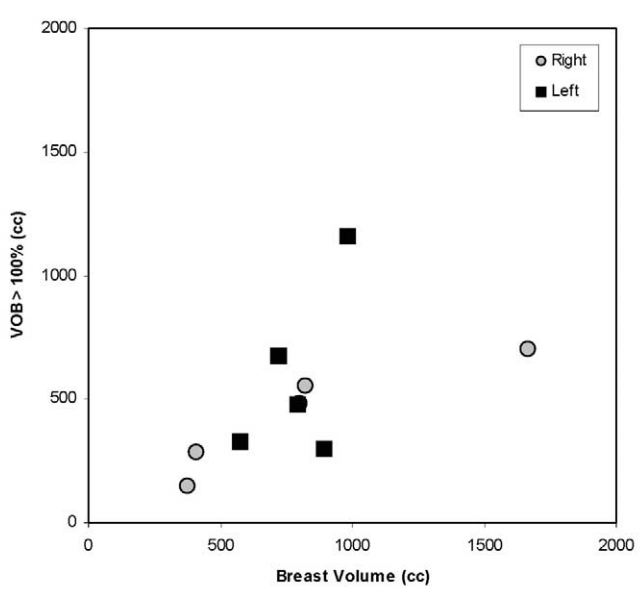

Fig. 8. The volume of tissue outside of the breast planning target volume [PTV], V_{OB}, that received at least the prescription dose (100%) plotted vs. the PTV volume.

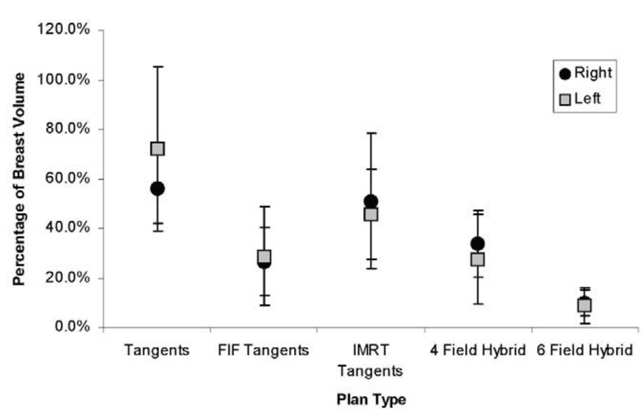

Fig. 9. The volume of tissue outside of the breast that received full dose, V_{OB} ≥100%, for (circle) right-sided and (square) left-sided breast treatments is shown as a percentage of breast target volume, planning target volume [PTV]. FIF = field-within-a-field tangents; IMRT = intensity modulated radiotherapy.

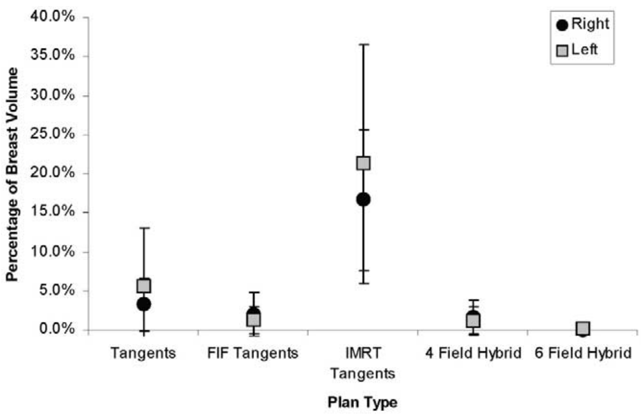

Fig. 10. The percentage of tissue outside of the breast that receives >110% prescription dose (V_{OB} ≥110%) for (circle) right-sided and (square) left-sided breast is plotted as a percentage of breast target volume. FIF = field-within-a-field tangents; IMRT = intensity modulated radiotherapy.

rithm. In the IMRT plans with tangents only, the hot regions were excessive. The plans developed for left-sided treatments included a low-priority constraint on the dose to the heart; this constraint tended to reduce the dose to the ipsilateral lung but increased the dose inhomogeneity in the PTV as compared to the right-sided plans.

The inverse planning algorithm produces steep dose gradients at the interface of the beam edge and the target that result in excellent dose distributions for multiple beams arranged throughout 2π for coplanar beams or $\sim 3\pi$ solid angle for noncoplanar beams. The quasi-opposed beams of a tangent plan are essentially a one-dimensional beam arrangement, and, in this case, the doses required to produce the steep gradient are problematic. With skill and time, a planner can reduce the magnitude of these hot spots using advanced techniques. However, this is opposite to the goal of using inverse planning to improve upon conventional techniques for dose coverage, efficiency, and reduced dependence on planner skill to achieve levels of consistency

Table 7. The mean doses to the contralateral breast as a percentage of the prescribed dose

Treatment site	technique	Mean dose (%)	D_5*(%)
Right breast	Tangents	1.5 ± 0.4	4.1 ± 1
	FIF tangents	1.3 ± 1	4.1 ± 2
	IMRT tangents	1.3 ± 1	3.5 ± 2
	4-field hybrid	1.2 ± 2	3.7 ± 2
	6-field hybrid	3.3 ± 1	7.1 ± 2
Left breast	Tangents	1.0 ± 0.4	3.5 ± 1
	FIF tangents	1.0 ± 0.2	3.4 ± 0.4
	IMRT tangents	0.9 ± 0.3	3.2 ± 1.0
	4-field hybrid	0.9 ± 0.2	3.1 ± 0.4
	6-field hybrid	2.3 ± 1.0	6.6 ± 2

Abbreviations as in Table 3.
* The dose received by the hottest 5% of the volume is abbreviated as D_5.

Table 8. The average volume of the body that receives at least 10 Gy for the various techniques

Treatment Site	Technique	V >10 Gy (cc)
Right breast	Tangents	1854 ± 584
	FIF tangents	1550 ± 588
	IMRT tangents	1387 ± 454
	4-field hybrid	1460 ± 608
	6-field hybrid	1989 ± 827
Left breast	Tangents	1756 ± 660
	FIF tangents	1561 ± 415
	IMRT tangents	1306 ± 286
	4-field hybrid	1542 ± 397
	6-field hybrid	1953 ± 340

Abbreviations as in Table 3.

necessary for broad application of IMRT to breast treatments.

The FIF plans developed here are comparable with respect to dose uniformity to the target volume, reduction of hot regions, and doses to ipsilateral lung and heart to those reported in the literature. Lo *et al.* (3) reported that the FIF technique reduced the magnitude of maximum hot spots, significantly reduced their volume in the breast, and moved them from lung or soft tissue into the breast tissue. Zackrisson *et al.* (6) found that the volume outside the target that received >105% dose was approximately half with the FIF techniques as compared to conventional tangents. Chang *et al.* (7) found increased dose uniformity to the breast with forward-planned FIF when irradiating a breast phantom; they did not expressly address the volume of soft tissue receiving excessive dose. Evans *et al.* (4) reported essentially no volume receiving >105% dose when using the FIF techniques as compared to conventional tangents, where up to 15 cc received such doses. Meier *et al.* (9) reported comparable dose coverage to the target with significantly reduced volumes (3% vs. 23%) for the FIF vs. conventional techniques. In the study reported here, the volume receiving >110% dose was reduced by about 2.5 times, from an average of 44 cc to 17 cc.

The dose uniformity to the PTV was comparable for all techniques in our study with mean doses ranging from 101% to 105%. The PTV volume receiving high doses (>110%) was slightly reduced for the 6-field hybrid tech-

Table 9. The ratio of total MUs for all fields for each technique to total MUs for the standard tangents technique. The average total MUs for the standard tangent field plans was 270 ± 27.5 MU

Technique	Ratio of total MUs (technique/tangents)
FIF tangents	1 ± 0.10
IMRT tangents	2.3 ± 0.5
4-field hybrid	1.1 ± 0.1
6-field hybrid	2.4 ± 0.50

Abbreviations: MU = monitor unit; FIF = field-within-a- field tangents; IMRT = intensity modulated radiotherapy.

nique from 2% to 1%. These results are comparable to those reported in the literature. Hong *et al.* (10) found an improvement of ~8% in the superior and inferior regions of the breast with IMRT tangents as compared to conventional fields, though the authors noted a decrease of ~4% coverage in the medial and lateral regions. Donovan *et al.* (5) reported that the volume receiving >105% dose was reduced from 15.9% with conventional tangents to 5.0% with their GE target 2 IMRT plans. Fogliata *et al.* (13) used an equivalent uniform dose to quantify the dose uniformity. They found that the equivalent uniform dose for 2-field IMRT plans was 47.1 Gy as compared to 49.4 Gy for conventional tangents. Mihai *et al.* (11) reported essentially the same maximum dose but a reduction in the volume receiving >105% and >110% with IMRT plans as compared to FIF plans. Hurkmans *et al.* (12) found essentially no difference in dose uniformity between the IMRT plans and the conventional plans. Vicini *et al.* (21) evaluated the number of segments required to achieve various percentages of irradiated volume receiving >15%, >10%, and >5% dose; overall, they were able to achieve their goals with 6–12 subfields.

The lung and the heart (particularly for left-sided treatments) are the primary organs of concern. Comparing the 4-field hybrid, the FIF, and the conventional tangent techniques, the mean dose to the ipsilateral lung is 15%, 16%, and 17%, respectively, on the right and 0.5%, 0.5%, and 0.6%, respectively, on the left (where heart constraints were imposed). The volume of ipsilateral lung that received 20 Gy averaged 150 cc, 165 cc, and 180 cc, respectively. Hence, the FIF plans and IMRT plans achieve a reduction in the volume of lung treated to significant doses. The 6-field hybrid plan increases the mean ipsilateral lung dose by about 10%, or 4.5 Gy, as compared to the other techniques. The dose to the heart for left-sided treatments is also reduced with the 4-field hybrid technique as compared to conventional tangents. The volume of heart receiving >30 Gy is reduced by more than half for the FIF, 4-field hybrid, and 6-field hybrid IMRT plans as compared to the conventional tangents. However, with the 6-field hybrid plan, the volume of heart receiving low dose is significantly greater than from any of the other techniques.

These results for the lung and heart are in agreement with other reports. For example, Hong *et al.* (10) found the volume of ipsilateral lung receiving the prescription dose decreased 30% with IMRT plans as compared to conventional tangents. They reported that the dose encompassing 20% of the coronary artery region decreased from 36 Gy with conventional to 27 Gy with IMRT plans. Fogliata *et al.* (13) noted a reduction in lung dose with IMRT; the volumes of ipsilateral lung receiving 20 Gy were reduced from 24% with conventional to 20% with IMRT, and the volume receiving 90% of prescription dose dropped from 18% with conventional to 10% with IMRT. For the heart, they reported a 10 Gy reduction in maximum dose with the IMRT plans as compared to conventional. Hurkmans *et al.* (12) calculated a normal tissue complication probability (NTCP) for the lungs and heart. The IMRT plans reduced the NTCP for the heart to 2.0% as compared to 5.9% for conventional plans; for the lungs, a reduction to 0.3% NTCP with IMRT from 0.5% with conventional was calculated.

Dose to the contralateral breast is of interest for breast treatments. In our plans, the mean dose to the contralateral breast is approximately 1% (0.45 Gy) for all plans except the 6-field hybrid, where it is 2.8% (or 1.3 Gy). These values are similar to those reported by others. Hong *et al.* (10) found the conventional treatment to deliver a mean dose of 1.2 Gy (for 46 Gy prescribed) and the IMRT to deliver a mean dose of 0.7 Gy to the contralateral breast. Fogliata *et al.* (13) reported 2% to 3% dose to the contralateral breast for all treatments.

Whole body dose may be a concern, though there are few data to estimate risk. Hall and Wuu (22) estimated the secondary cancers at 10 years might increase from 1% for conventional radiation therapy to 1.75% for IMRT. In this study there was essentially no difference in the whole body volume receiving at least 10 Gy. For lower-dose levels, there may be differences between techniques, but the effects are estimated to be extremely small.

For chemoradiation therapy in treatment of esophageal cancer, Lee *et al.* (23) pointed out the importance of volume of lung tissue receiving at least 10 Gy. They showed similar incidence of complications for more than 40% of lung receiving at least 10 Gy and more than 20% of lung receiving at least 20 Gy. (In this study total lung volume receiving more than 20 Gy was less than 12% for all techniques.) Future studies may find correlations between partial body doses to 10 Gy levels and other levels, but for now there is little data available.

The plans with the IMRT tangent fields only in our study resulted in significantly greater volumes of tissue outside the target receiving >110% dose than with any of the other techniques investigated. To achieve coverage at the medial aspects of the target, the algorithm pumped in fluence in these regions, which resulted in the soft tissues receiving excessive dose. This is not in agreement with other reports in the literature. Hong *et al.* (10) found that the volume of surrounding soft tissue receiving greater than the prescription dose (46 Gy) was reduced by 30% with the IMRT plans developed on the in-house system at Memorial Sloan-Kettering Cancer Center. Fogliata *et al.* (13), using the MDS-Nordian Helax TMS system, did not specifically address this issue, but did report an average improvement in conformity index (defined as the ratio between treated volume at 90% dose level and PTV) from 2.5 with conventional beams to 2.1 with IMRT beams. Mihai *et al.* (11) reported a reduction in the volumes receiving 105% and 110% prescribed dose but did not explicitly state whether these were in or out of the breast tissue.

Some of this difference from other reports may be due to the normalization of the plans. In our study, all plans were normalized such that the breast target volume was included within the prescription (45 Gy) isodose contour. This is the method that we used in our clinic for the conventional wedged-field tangents and also the method that we have continued to use for the FIF technique. Others have used a point at the lung–chest wall interface (10), isocenter (5), mid depth and 1 cm superficial to the deep edge of the chest wall (21), target mean dose (12, 13), and two-thirds the distance between the skin and the base of the tangent fields (11). It is difficult to evaluate the effects these normalizations have on the absolute values reported. However, the general trends for normal tissue reduction with IMRT are consistent. We do note that several of these reported somewhat less coverage with the IMRT plans. For example, Hong *et al.* (10) noted ~4% reduction at the lateral and medial portions; Donovan *et al.* (5) had a reduction of 0.2% of the target volume receiving 95% dose with the IMRT plans.

Combining conventional open tangent beams and IMRT tangent beams in the 4-field hybrid plan achieved a significant reduction in the magnitude of the hot regions outside the target as compared to conventional tangents and to IMRT-only tangents. The reduction was comparable to that achieved with the FIF technique plans, but with significantly less planning time. Forward-planned FIF treatments require manual iterations of the MLCs, which can take several hours of an experienced planner's time. The hybrid plans can be optimized within 10–15 min. The tradeoff, of course, is the additional time required to perform the quality assurance on the IMRT beams.

Even better dose conformation than with the 4-field hybrid plan may be achieved by adding 2 anterior oblique IMRT beams. This arrangement allows significant further reduction of the dose to the soft tissue outside the target and some reduction in the volume of heart exposed to high dose. The tradeoff is increased low dose to more of the lung, the heart, and the contralateral breast. Whether or not these increases of low dose have any clinical significance with respect to long-term complications or induction of secondary cancers is not known. As with IMRT plans in other areas of the body, the decision on how to balance the risks of low dose levels against high dose levels when evaluating a planning approach is a clinical judgment by the physician.

CONCLUSIONS

A goal of this technique was to reduce overall planning time for breast IMRT. The value of this objective is that time is freed up so that skilled treatment planners can concentrate their abilities on other cases not easily addressed by class solutions. For clinics with limited planning resources, this facilitates improved treatment as compared to that with conventional Tangents.

The baseline time required of any CT-based planning (non-IMRT or IMRT) for tissue delineation is not affected. Normal tissues (e.g., lung and heart) and the breast CTV must be defined to allow evaluation of the dose–volume histograms. Initially, learning to delineate the breast CTV requires additional time and educational commitment from the physician. We find that once our physicians have gained experience, it takes less than 10 minutes to define the breast CTV.

Combining the relatively broad penumbra and slowly varying dose distribution of conventional beams with the sharp dose gradients and rapidly changing intensities of IMRT beams produces a hybrid planning approach that requires a minimum set of optimization objectives to rapidly converge on a clinical solution superior to that with conventional tangents and IMRT-only tangents. The results are comparable or superior to forward-planned field-within-a-field techniques, with the advantage of requiring significantly less planning time.

In this hybrid technique, the open and IMRT tangent beam angles are the same. This effectively creates an IMRT beam that allows the user to specify the degree of intensity modulation relative to the dose at isocenter. The open beam is essentially just one additional segment in the leaf sequences defined for the IMRT beam. The hybridization places the spatial intensity modulation on top of an intensity plateau defined by the open beam. This approach could be incorporated directly into IMRT algorithms. In the meantime, a hybrid beam arrangement is a practical implementation.

The 4-field hybrid technique consists of medial and lateral open conventional beams and IMRT beams from the same tangential angles. With this approach, dose uniformity to the target volume is increased, and the dose to the heart, ipsilateral lung, and soft tissue surrounding the target are reduced compared to conventional wedged-field tangent treatments. This approach automates the forward-planned field-within-a-field technique and provides a class solution that can be easily implemented and rapidly planned. The disadvantage is additional time required for the quality assurance of the IMRT beams.

Improvements in conformality and uniformity of dose to the target volume may be achieved by adding 2 anterior oblique IMRT beams to the 4-field hybrid technique. The addition of these fields increases the dose homogeneity to the breast target volume and significantly decreases the regions of high dose in the surrounding soft tissue. The tradeoff to this degree of optimization to the breast and soft tissues is an increased volume of heart and lung that receives low dose. The clinical significance of these low doses, resulting in an increase in integral dose to the patient, is not established. Tracking the clinical outcomes of patients treated with these techniques will help determine the significance of integral dose and to what degree it should serve as a coefficient to developing the radiation therapy care plan.

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