Dosimetric comparison of intensity modulated radiotherapy isocentric field plans and field in field (FIF) forward plans in the treatment of breast cancer

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ABSTRACT

The present study is aimed at comparing the planning and delivery efficiency between three-dimensional conformal radiotherapy (3D-CRT), field-in-field, forward planned, intensity modulated radiotherapy (FIF-FP-IMRT), and inverse planned intensity modulated radiotherapy (IP-IMRT). Treatment plans of 20 patients with left-sided breast cancer, 10 post-mastectomy treated to a prescribed dose of 45 Gy to the chest wall in 20 fractions, and 10 post-breast-conserving surgery to a prescribed dose of 50 Gy to the whole breast in 25 fractions, with 3D-CRT were selected. The FiF-FP-IMRT plans were created by combining two open fields with three to four segments in two tangential beam directions. Eight different beam directions were chosen to create IP-IMRT plans and were inversely optimized. The homogeneity of dose to planning target volume (PTV) and the dose delivered to heart and contralateral breast were compared among the techniques in all the 20 patients. All the three radiotherapy techniques achieved comparable radiation dose delivery to PTV-95% of the prescribed dose covering > 95% of the breast PTV. The mean volume of PTV receiving 105% (V_{105}) of the prescribed dose was 1.7% (range 0-6.8%) for IP-IMRT, 1.9% for FP-IMRT, and 3.7% for 3D-CRT. The homogeneity and conformity indices (HI and CI) were similar for 3D-CRT and FP-IMRT, whereas the IP-IMRT plans had better conformity index at the cost of less homogeneity. The 3D-CRT and FiF-FP-IMRT plans achieved similar sparing of critical organs. The low-dose volumes (V_{5Gy}) in the heart and lungs were larger in IP-IMRT than in the other techniques. The value of the mean dose to the ipsilateral lung was higher for IP-IMRT than the values for with FiF-FP-IMRT and 3D-CRT. In the current study, the relative volume of contralateral breast receiving low doses (0.01, 0.6, 1, and 2Gy) was significantly lower for the FiF-FP-IMRT and 3D-CRT plans than for the IP-IMRT plan. Compared with 3D-CRT and IP-IMRT, FiF-FP-IMRT proved to be a simple and efficient planning technique for breast irradiation. It provided dosimetric advantages, significantly reducing the size of the hot spot and minimally improving the coverage of the target volume. In addition, it was felt that FiF-FP-IMRT required less planning time and easy field placements.

Key words: Breast cancer, contralateral breast, field in field breast plan, intensity-modulated radiation therapy

Introduction

In patients with early breast cancer, local standard therapy is breast-conserving surgery followed by radiotherapy to the whole breast or, in the case of high-risk patients after mastectomy, radiotherapy to the chest wall with or without drainage areas.[1] Continuing information on the complete biological issues in breast cancer, coupled with the input of modern technology, helps to alleviate treatment-related morbidity and to improve the treatment outcome.[2] The radiotherapy techniques in the treatment of breast cancer vary in different institutions, but, in general, the issue of radiation dose delivery to the chest wall after total mastectomy or to the breast following breast conservation surgery remains complex. In the conventional breast irradiation technique, the beam arrangement consists of two opposing tangential glancing portals,[3] which allows acceptable coverage of the breast tissue while minimizing the dose to the adjacent

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critical structures (i.e., ipsilateral lung, contralateral breast, and heart). Physical or dynamic wedges are usually added to these tangential beams in order to compensate for the rapid changes in external contours and to improve the dose uniformity to the entire breast. The risk of contralateral breast cancer has been discussed in recent studies,[4-6] which emphasize the need for reduction of radiation dose to the contralateral breast using physical wedges, avoiding cerroband half beam blocks, and using asymmetric jaws and some form of intensity modulation.[4] Our earlier works had addressed the efficacy of three-dimensional computerized tomography (3D-CT)-based treatment planning and field shaping, as well as better dose conformity by applying multileaf collimator (MLC) optimized tangential beams using field-in-field techniques,[7,8] in achieving better radiotherapy plans. Dose-related morbidity due to irradiation of heart tissue has been reported in a few studies earlier.[9,10] Inversely planned intensity modulated radiotherapy (IMRT) has proved its efficacy in various sites, where there are constraints in dose delivery in general, and restricting minimum dose to critical structures in particular. One of our recent publications had addressed the issue of spatial specificity in dose delivery in the treatment of gastric cancers by applying IMRT plans, thereby achieving significant reduction in the dose to organs at risk (OARs), such as liver, kidney, and spinal cord.[11] Several single-institution studies and two randomized trials for breast cancer have reported that IMRT improves the dose homogeneity and decreases the acute skin toxicity as well as the dose to the contralateral breast compared with conventional tangential techniques with wedges. In these studies, most IMRT plans were created using the field-in-field (or forward-planned [FP] IMRT) technique.[12] Conformal electron irradiation for optimization has also been attempted.[13] The present work aims to compare the dose delivery parameters of the isocentric variable-angle multi-field IMRT plan vis-à-vis other simple plans with parallel opposed tangential fields in the treatment of breast cancer.

Materials and Methods

Patients

The radiotherapy treatment data of 20 patients with left-sided breast cancer treated between October 2009 and March 2010 at the National Oncology Center, Muscat, Oman were selected. Ten patients who underwent mastectomy received a prescribed dose of 45 Gy to the chest wall in 20 fractions. The other 10 patients who had breast-conserving surgery received a prescribed dose of 50 Gy to the whole breast in 25 fractions. Both groups were treated with 3D-CRT. New treatment plans with IMRT were created.

Target volumes

The target volumes (the chest wall or the whole breast) and sensitive structures, such as the heart, ipsilateral lung, contralateral lung, and contralateral breast, were delineated in 5-mm-thick CT slices [Figure 1]. The field borders were clinically defined with radiopaque wires during simulation and also delineated according to the location of the tumor, extent of breast tissue, and adequate set-up margins. The field borders extended up to midline medially, lower border of clavicle superiorly, and laterally and inferiorly 2 cm beyond the palpable breast tissue. To prevent the inverse IMRT planning algorithm from delivering too high a dose to the skin, intact breast and chest wall PTVs were restricted to 5 and 3 mm under the skin surface, respectively, to exclude the build up region from the PTVs.[14]

Treatment planning

Computerized radiation treatment planning system (RTPS) Eclipse (version 6.5, M/s Varian Ag, Palo Alto, USA) was used for treatment planning. On the basis of the FiF-FP-IMRT plans created by combining two open fields with three to four segments in two tangential beam directions, the patients had received radiotherapy using 6-MV photon beams in Clinac 2300-CD (Varian Ag, USA), with millennium 120 MLC as tertiary collimator at 100 cm source to skin distance (SSD). Inversely planned IMRT (IP-IMRT) treatment plans were generated in the CT images of the already treated patients as 'study plans' with sliding window dynamic IMRT employing segmental multi-fields delivery, using Helios optimization software. Eight different beam directions were selected to create IP-IMRT isocentric plans and were inversely optimized. Pencil beam calculation algorithm was used for optimization. Final dose was calculated, with heterogeneity corrections, using Equivalent TAR algorithm after determining the leaf sequencing. The target doses and dose–volume limits restricted for critical structures are listed in Table 1.

Comparison of treatment techniques

Plans of the three different treatment techniques were compared for evaluation of dosimetric parameters. Details of the beam arrangements and objectives of plans are described below:

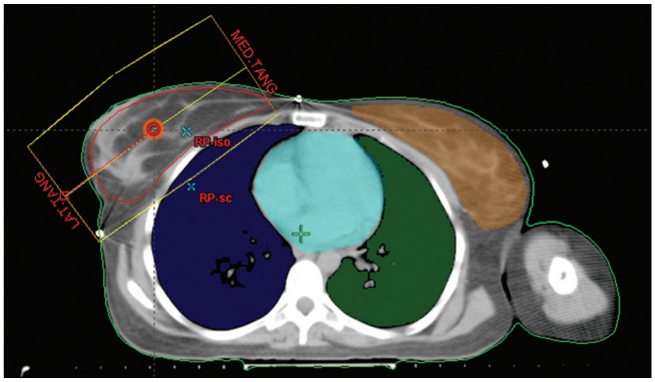


Figure 1: Patient anatomy showing breast planning target volume (PTV) and OARs

3D-Conformal Plan

In this conventional planning technique, the beam arrangement consisted of two parallel opposing tangential beams ensuring the best possible coverage of the breast tissue and minimizing the dose to the adjacent critical structures (i.e., ipsilateral lung, contralateral breast, and heart). The "isocenter" of the treatment machine is positioned at the centre point of the midline joining two parallel opposing fields. Physical or dynamic wedges were then added to both tangential beams in order to improve the dose uniformity to the PTV, and to compensate for the rapid changes in external contours, as shown in [Figures 2 and 3]. Efforts were made to minimize volumes of heart and lung that unavoidably get included within the field borders.

Field-in-Field–Forward-planned–IMRT (FiF-FP-IMRT)

Two open tangential fields were created in this technique, according to the geometry defined during simulation to achieve uniform dose distribution to the breast volume (adequate coverage to the tumor bed), limiting the volume of the heart receiving a dose > 20 Gy not to exceed 5%, minimizing hot spot regions, and limiting dose to the ipsilateral lung and contralateral breast. The " isocenter" of the treatment machine is positioned at the same point as for the 3D-conformal plan. Initially, equal weights were assigned to the two open fields, and the corresponding dose distribution was calculated. By viewing the 95% dose cloud in a beam's eye view projection of the treatment fields, subfields were manually designed to boost the area not included in the dose cloud. The shape of each subfield was iteratively modified with aided visualization of 105% dose clouds in the beam's eye view. The number of subfields varied from three to four. Either 6- or 15-MV photons were selected for the subfields depending on separation of fields.

Inversely planned isocentric IMRT (IP-IMRT)

The IP-IMRT optimized plans were generated to achieve the same objectives described for the FiF-FP-IMRT plan. Eight different photon beam directions from 120 to 300, at intervals of 25 were chosen for this technique [Figure 4]. Beam directions at 120 to 300 remained identical to the initial tangential plans. The "isocenter" of the treatment machine is positioned at the same point as in the 3D-CRT and FiF-FP-IMRT plans. In addition to selection of PTVs 5 mm and 3 mm below the skin, a 5-mm bolus was added to the skin surface as per recommendations.[11]

Table 1: Target doses and dose–volume constraints of the organs at risk

Target or organs of interest	*Goal or constraint dose (%)*
Clinical target volume (CTV)	45 or 50 Gy
Heart	50 volume<5 Gy
	33 volume<10 Gy
	10 volume<20 Gy
	3 volume<40 Gy
Ipsilateral lung	50 volume=0 Gy
	30 volume<5 Gy
	10 volume<20 Gy
Contralateral lung	100 volume=0 Gy

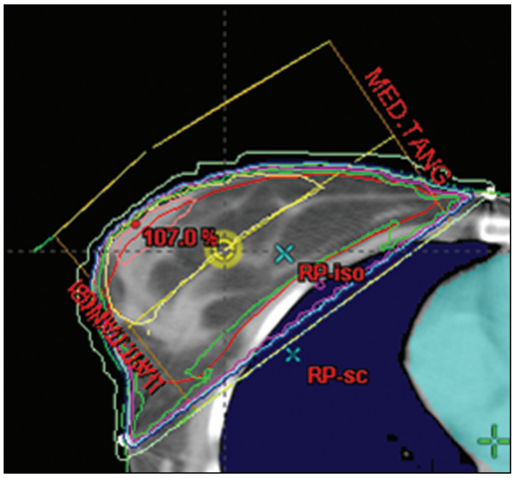


Figure 2: Dose distribution for the two tangential fields without wedges

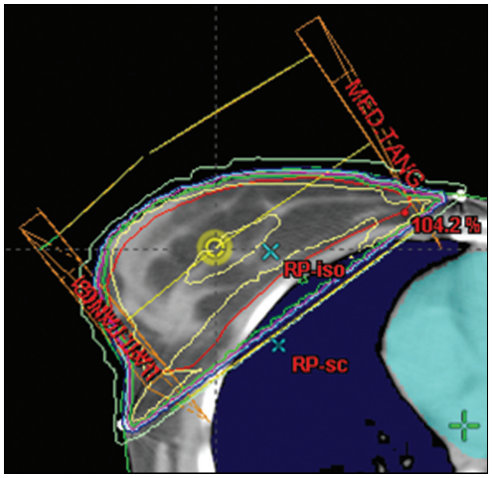
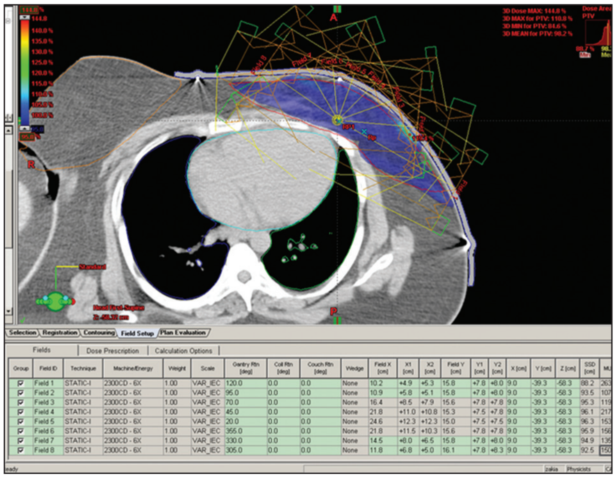


Figure 3: Dose distribution for the two tangential fields with wedges



3D Dose MAX: 144.8 %
3D MAX for PTV: 110.8 %
3D MIN for PTV: 84.6 %
3D MEAN for PTV: 98.2 %

Group	Field ID	Technique	Machine/Energy	Weight	Scale	Gantry Rtn [deg]	Coll Rtn [deg]	Couch Rtn [deg]	Wedge	Field X [cm]	X1 [cm]	X2 [cm]	Field Y [cm]	Y1 [cm]	Y2 [cm]	X [cm]	Y [cm]	Z [cm]	SSD [cm]	MU
☑	Field 1	STATIC-I	2300CD - 6X	1.00	VAR_IEC	120.0	0.0	0.0	None	10.2	+4.9	+5.3	15.8	+7.8	+8.0	9.0	-39.3	-58.3	88.2	263
☑	Field 2	STATIC-I	2300CD - 6X	1.00	VAR_IEC	95.0	0.0	0.0	None	10.9	+5.8	+5.1	15.8	+7.8	+8.0	9.0	-39.3	-58.3	93.5	107
☑	Field 3	STATIC-I	2300CD - 6X	1.00	VAR_IEC	70.0	0.0	0.0	None	16.4	+8.5	+7.9	15.6	+7.8	+7.8	9.0	-39.3	-58.3	95.3	119
☑	Field 4	STATIC-I	2300CD - 6X	1.00	VAR_IEC	45.0	0.0	0.0	None	21.8	+11.0	+10.8	15.3	+7.5	+7.8	9.0	-39.3	-58.3	96.1	217
☑	Field 5	STATIC-I	2300CD - 6X	1.00	VAR_IEC	20.0	0.0	0.0	None	24.6	+12.3	+12.3	15.0	+7.5	+7.5	9.0	-39.3	-58.3	96.3	153
☑	Field 6	STATIC-I	2300CD - 6X	1.00	VAR_IEC	355.0	0.0	0.0	None	21.8	+11.5	+10.3	15.6	+7.8	+7.8	9.0	-39.3	-58.3	95.9	156
☑	Field 7	STATIC-I	2300CD - 6X	1.00	VAR_IEC	330.0	0.0	0.0	None	14.5	+8.0	+6.5	15.8	+7.8	+8.0	9.0	-39.3	-58.3	94.9	135
☑	Field 8	STATIC-I	2300CD - 6X	1.00	VAR_IEC	305.0	0.0	0.0	None	11.8	+6.8	+5.0	16.1	+7.8	+8.3	9.0	-39.3	-58.3	92.5	150

Figure 4: Isocentric IP-IMRT plan with eight photon fields in breast treatments

Evaluation of plans

The treatment plans generated were compared objectively using the dose volume histograms (DVHs) for PTVs and different Organs at Risk (OARs) regions of interest. In the PTV, the values of V_{105}, $V_{99,}$ V_{95}, V_{90}, D_{mean}, D_{max}, homogeneity index (HI), conformity index (CI) were compared for all these three techniques. For lung OAR, the values of V_{mean}, V_5, V_{20}; for heart, V_{mean}, V_5, V_{30}; for ipsilateral lungs, V_{mean} dose value, and V_5, V_2, V_1, $V_{0.6}$, $V_{0.01}$ doses for contralateral breast were evaluated and compared the dose to PTV.

The following parameters were used to evaluate the plans objectively:

1. Relative volume of breast PTV receiving 105% of the prescription dose ($V_{105\%}$) (represent the extension of hot-spot regions within the breast).
2. Mean (D_{mean}) and maximum dose (D_{max}) delivered to the target volume.
3. Target volume receiving 90% and 99% of the dose, ($V_{90\%}$ and $V_{99\%}$).
4. Homogeneity index (HI) in PTV defined by the relation

$$HI = (D_{Max} - D_{Min})/D_{Mean} \qquad .....(1)$$

5. Conformity index (CI) defined as per relation

$$CI = (PTV_{RI}/PTV)\ (PTV_{RI}/V_{RI}) \qquad .....(2)$$

(PTVRI is the 95% of the planning target volume, which should be covered by 95% of the prescribed dose)

6. Relative volume of a given tissue receiving 20 Gy or 30 Gy ($V_{20\,Gy}$ or $V_{30\,Gy}$, respectively) and the mean doses. $V_{20\,Gy}$ for the lungs (combined as one organ) and the $V_{30\,Gy}$ for the heart.
7. Relative volume of the heart and lungs receiving low dose (5 Gy).
8. Relative volume of the contralateral breast receiving dose (0.05, 0.6, 1, 2, and 5 Gy) and the mean dose.

For comparing each parameter, the statistical significance was calculated by *P* value analysis from Student's *t*-test.

Results

Dosimetric characteristics

All the three plans, 3D-CRT, FiF-FP-IMRT, and IP-IMRT, achieved comparable good dose coverage, delivering prescribed dose more than 95% to > 95% of the breast PTV. In all these techniques, 105% of dose (hot regions) was observed in less than 5% of the target volume. Mean volume of PTV breast receiving 105% was 1.7% (range 0-6.8%) for IP-IMRT, 1.9% for FP-IMRT, and 3.7% for 3D-CRT. The results on estimated dosimetric parameters are shown in Table 2.

From Table 2 it can be seen that the 3D-CRT and FiF-FP-IMRT plans had D_{max} in the range 105-108% (mean 107%). For the IP-IMRT plan, D_{max} ranged from 105-117% (mean 111%). The 3D-CRT and FiF-FP-IMRT plans provided comparable HI and CI. The IP-IMRT plan had a better conformity with the same HI. There was no statistical significance in D_{max} between 3D-CRT and FiF-FP-IMRT.

Figures 5a-b show the average dose volume histograms (DVHs) for heart and lungs for the three treatment techniques of breast irradiation. It can be observed that the minimum and mean dose to the heart and lungs are much higher in IP-IMRT than in 3D-CRT and FiF-FP-IMRT. Figures 6a-b illustrate the DVHs for ipsilateral lung and contralateral breast. In these OARs also the minimum and mean doses are much higher for IP-IMRT plans. Figures 7a-b highlight the low-dose distribution compared for the 5 Gy dose level.

It is observed that the volumes receiving low dose (V_{2Gy}) are much larger in the IP-IMRT technique.

Table 2: Comparison of average dosimetric characteristics for planning target volume for the 3D-CRT, FiF-FP-IMRT, and IP-IMRT plans

Measured indices from DVH	*Volumes and doses for three breast irradiation techniques*			*Estimated 'P'values for compared treatment techniques*		
	3D CRT (a)	*FiF-FP IMRT (b)*	*IP-Isocent IMRT (c)*	*a vs. b*	*a vs. c*	*b vs. c*
$V_{95\%}$	96.2 (90.2–99.4)*	97.5 (95.1-99.8)	95.5 (94.1-97.0)	0.13	0.22	0.01
$V_{105\%}$	3.7 (0.0-12.8)	1.9 (0.00-5.3)	1.7 (0.0-7.2)	0.17	0.15	0.42
$V_{90\%}$	97.3 (95.1-98.8)	97.5 (96.3-98.9)	96.3 (94.7-96.8)	0.34	0.03	0.01
$V_{99\%}$	92.3 (87. 8-95.7)	93.5 (89.9-97.0)	92.5 (90.1-98.2)	0.15	0.43	0.17
D_{mean}	100.6 (99.0-101)	100.7 (99.5-102)	99.1 (93.5-101)	0.44	0.03	0.02
D_{max}	107.0 (105-108)**	107.0 (105-108)	111 (105-117)	0.38	0.01	0.01
HI	0.27 (0.16-0.37)***	0.27 (0.15-0.39)	0.29 (0.23-0.38)	0.49	0.25	0.25
CI	0.57 (0.43-0.72)***	0.57 (0.41-7.70)	0.76 (0.22-0.87)	0.49	0.01	0.01

(V95% =relative volume of breast PTV receiving 95%, D_{max}=maximum dose delivered to breast PTV) (HI=Homogeneity index; CI=Conformity index)

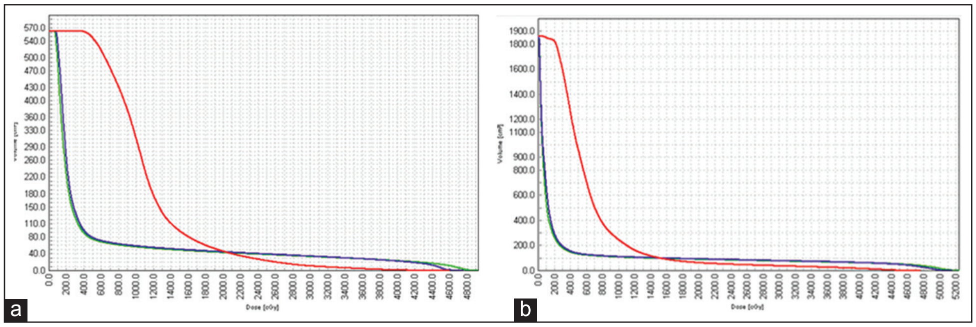
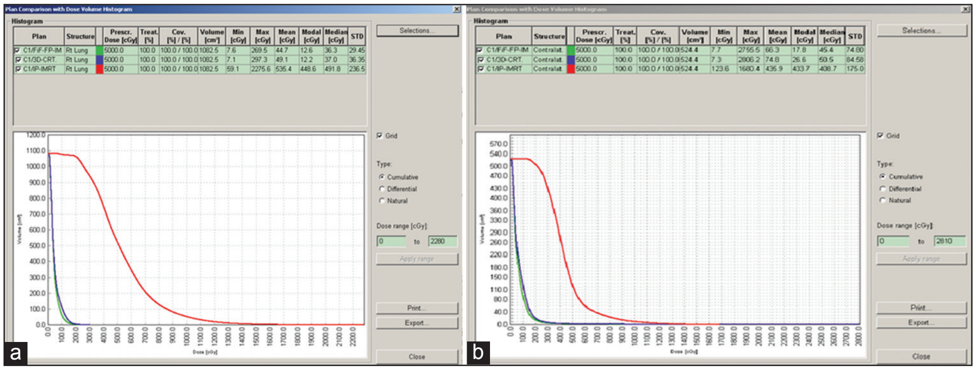


Figure 5: (a) Mean DVH for Heart for three plans, (b) Mean DVH for Lungs for three Plans



Plan	Structure		Prescr. Dose [cGy]	Treat. [%]	Cov. [%] / [%]	Volume [cm³]	Min [cGy]	Max [cGy]	Mean [cGy]	Modal [cGy]	Median [cGy]	STD
☑ C1/FiF-FP-IM	Rt Lung	🟩	5000.0	100.0	100.0 / 100.0	1082.5	7.6	269.5	44.7	12.6	36.3	29.45
☑ C1/3D-CRT.	Rt Lung	🟦	5000.0	100.0	100.0 / 100.0	1082.5	7.1	297.3	49.1	12.2	37.0	36.35
☑ C1/IP-IMRT	Rt Lung	🟥	5000.0	100.0	100.0 / 100.0	1082.5	59.1	2275.6	535.4	448.6	491.8	236.5

☑ Grid

Type:
● Cumulative
○ Differential
○ Natural

Dose range [cGy]
0 to 2200

Plan	Structure		Prescr. Dose [cGy]	Treat. [%]	Cov. [%] / [%]	Volume [cm³]	Min [cGy]	Max [cGy]	Mean [cGy]	Modal [cGy]	Median [cGy]	STD
☑ C1/FiF-FP-IM	Contralat.	🟩	5000.0	100.0	100.0 / 100.0	524.4	7.7	2755.5	66.3	17.8	45.4	74.80
☑ C1/3D-CRT.	Contralat.	🟦	5000.0	100.0	100.0 / 100.0	524.4	7.3	2806.2	74.8	26.6	50.5	84.58
☑ C1/IP-IMRT	Contralat.	🟥	5000.0	100.0	100.0 / 100.0	524.4	123.6	1680.4	435.9	433.7	408.7	175.0

☑ Grid

Type:
● Cumulative
○ Differential
○ Natural

Dose range [cGy]
0 to 2810

Figure 6: (a) Mean DVH for Ipsilateral lung, (b) Mean DVH for contralateral breast

Table 3: Comparison of average dosimetric characteristics for organs at risk for 3D-CRT, FiF-FP-IMRT and IP-IMRT plans

OAR	*Measured Indices from DVH*	*Volumes and doses for three breast irradiation techniques*			*Estimated 'P' values for compared treatment techniques*		
		3D CRT (a)	*FiF-FP IMRT (b)*	*IP-Isocent IMRT (c)*	*a vs. b*	*a vs. c*	*b vs. c*
Lungs**	V_{5Gy}	7.3 (2.4–13.0)	7.1 (2.2-12.7)	39.8 (9.1-61.0)	0.32	<0.0001	<0.0001
	V_{20Gy}	4.6 (1.0–8.9)	4.5 (0.9–9.0)	2.9 (0.2-5.7)	0.48	0.002	0.098
	D_{MEAN}	6.0 (2.3–10.1)	5.8 (0.0–14.3)	12.3 (8.9–15.9)	0.42	0.0001	0.0001
Heart	V_{5Gy}	6.1 (0.0–14.6)	5.8 (0.0–14.3)	72.9 (14.0–99.4)	0.47	<0.00001	<0.00001
	V_{30Gy}	2.0 (0.0–6.0)	2.0 (0.0–5.9)	0.5 (0.0–1.9)	0.49	0.08	0.08
	D_{MEAN}	5.6 (1.0–11.0)	5.2 (1.7–10.1)	16.6 (7.7–27.6)	0.44	<0.00001	<0.00001
Ipsilateral lung	D_{MEAN}	0.9 (0.5–1.4)	0.8 (0.5–1.2)	8.8 (6.1–12.2)	0.43	<0.00001	<0.00001

The comparison of the average dosimetric parameters for OARs for the three treatment techniques are shown in Table 3. The 3D-CRT and FiF-FP-IMRT plans were equivalent in sparing critical organs. For the IP-IMRT planning technique, the average $V_{20\ Gy}$ for the lungs and the mean $V_{30\ Gy}$ for the heart were found to be less than that in the 3D-CRT and FiF-FP-IMRT plans. In addition, D_{mean} for heart and lungs were higher for IP-IMRT than for FiF-FP-IMRT and 3D-CRT. The low-dose volumes ($V_{5\ Gy}$) in the heart and lungs were larger in the IP-IMRT than in the other techniques. The value of the mean dose to the ipsilateral lung was higher for IP-IMRT than the values for the FiF-FP-IMRT and 3D-CRT. The relative volume of contralateral breast receiving low doses (0.01, 0.6, 1, and 2Gy) [Table 4] was significantly lower for the FiF-FP-IMRT and 3D-CRT plans than for the IP-IMRT plan.

Although the differences between 3D-CRT and FiF-FP-IMRT planning techniques were not statistically significant, a small increase in the dose to OARs was present in the 3D-CRT plans.

Discussion

The present work was aimed to compare the planning and dose delivery efficiency among three techniques of radiotherapy to the chest wall/breast, namely 3-dimensional conformal radiotherapy (3D-CRT), field-in-field-forward planned-intensity modulated radiotherapy (FiF-FP-IMRT), and inverse planned-intensity modulated radiotherapy (IP-IMRT). Table 1 shows that the FiF-FP-IMRT results are comparable to the 3D-CRT technique in terms of

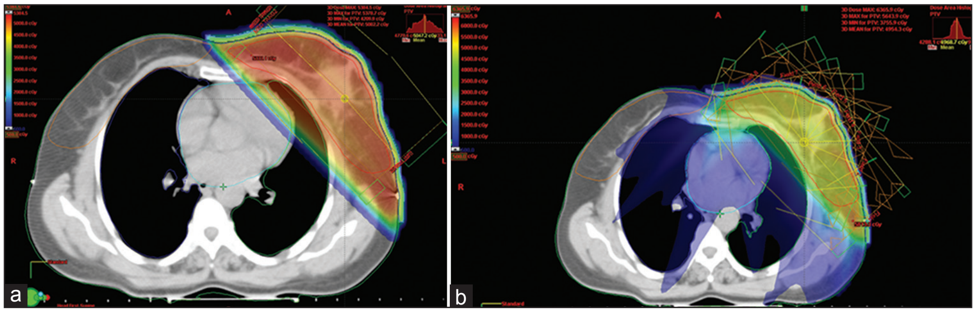


Figure 7: (a) 5Gy dose distribution for the 3D-CRT and FiF-FP-IMRT plans, (b) 5Gy dose distribution for the IP-IMRT treatment plan

Table 4: Comparison of average dosimetric characteristics for contralateral breast for 3D-CRT, FiF-FP-IMRT, and IP-IMRT plans

OAR	*Measured indices from DVH*	*Volumes and doses for three breast irradiation techniques*			*Estimated 'P' values for compared treatment techniques*		
		3D CRT (A)	*FiF-FP IMRT (B)*	*IP-Isocent IMRT (C)*	*A vs. B*	*A vs. C*	*B vs. C*
Contralateral breast	$V_{0.01Gy}$	98.5 (86.3–100)	97.8 (80.0-100.0)	100.0 (100-100)	0.50	0.49	0.48
	$V_{0.6Gy}$	33.3 (9.9–56.9)	27.5 (5.2–47.2)	98.0 (80.2–100)	0.39	0.09	0.07
	V_{1Gy}	16.9 (2.3–38.8)	12.0 (0.0–27.9)	90.6 (56.4–100)	0.32	0.04	0.03
	V_{2Gy}	3.9 (0.0–13.3)	3.0 (0.0–11.0)	66.0 (25.7–96.4)	0.34	<0.00001	<0.00001
	V_{5Gy}	1.0 (0.0–4.8)	1.0 (0.0–4.4)	9.2 (0.8-25.1)	0.47	0.02	0.02
	D_{MEAN}	1.6 (0.6–3.5)	1.4 (0.5-3.0)	6.2 (3.00–9.1)	0.30	<0.00001	<0.00001

breast coverage, delivering 95% of the prescribed dose to > 95% of the breast PTV, the mean dose delivered to the breast PTV and the hot-spot regions. However, in the IP-IMRT plans, the mean maximum doses were more than 110% of the prescribed dose. The results of our study match with other similar studies.[14,15] The authors of this study[14] have opined that the treatment plan with $IMRT_{photons}$ is inferior to 3D-CRT technique, because with 3D-CRT technique the mean radiation doses to the heart, contralateral breast, and lung doses are comparatively less for same PTV coverage and similar OAR shielding. They[14] applied 5-mm-thick bolus on chest wall in each photon beam inferior to match line. We have used a bolus for our IMRT study plans based on the recommendations from earlier work.[13] Efficacy of FIF technique versus plain tangential field is clearly brought out by Sasaoka and Futami.[16] The field-in-field technique significantly reduced the maximum dose, the volumes receiving > 107% of the prescription dose, and the HI for the PTV for dose evaluation compared with the tangential field technique. For each dosimetry of the OARs, excluding the contralateral breast, the field-in-field technique significantly reduced the maximum dose and the volumes receiving > 10, 30, and 50 Gy of the prescribed dose. The volume receiving < 1 Gy of the prescription dose for the contralateral breast was significantly decreased using the field-in-field technique. In addition, the dose distribution using the field-in-field technique in the target volume was less sensitive to the effects of breast motion during normal breathing. In the clinical outcome, the field-in-field technique significantly reduced the Radiation Therapy Oncology Group (RTOG) grade II acute skin toxicity compared with the tangential field technique (3.1 vs. 10.6%).

The 3D-CRT and FiF-FP-IMRT techniques required fewer monitor units (MU) to deliver a given dose, compared with IP-IMRT. In the IP-IMRT, the number of MUs is found to be about four times greater than in the FiF-FP-IMRT plans (1160 MU vs. 293 MU), and about three times greater than in the 3D-CRT plans (1160 MU vs. 443 MU). The afore-mentioned comparison also implies that the Full-size tableMUs for FiF-FP-IMRT tangent plans were less than those for 3D-CRT (443 MU and 293 MU, respectively) because of the use of wedges in the 3D-CRT.

Increased MU results in excess of machine and treatment times (for a dose rate of 300 MU/min), as well as higher machine leakage and total body stray radiation dose. The IP-IMRT for breast treatment is time consuming and requires advanced planning skills. The average planning time to generate the IP-IMRT plans was 45-60 min, whereas the 3D-CRT took about 20-30 min and the FiF-FP-IMRT 15-20 min. In contrast to the 3D-CRT and FiF-FP-IMRT plans, the IP-IMRT required verification of pretreatment patient-specific QA measurements. The additional QA time must be taken into account when considering the total workload per plan. Compared with the IP-IMRT and 3D-CRT plans, the higher-quality FiF-FP-IMRT plans are likely to be generated in a shorter time without requiring a high level of planning ability.

When we attempted to decrease dose to the OARs, the maximum dose increased to the hot-spot regions, which were small regions near the surface of the skin as shown in Figure 8. This may be because of the limitation of the dose optimization algorithm. In some IMRT studies,[13] doses up to 130% (60 Gy) were accepted in the breast PTV in attempt to minimize the dose delivered to the OARs. Furthermore, compared with IP-IMRT, the 3D-CRT and FIF-FP-IMRT plans resulted in a significantly smaller hot spot within the breast volume ($V_{105\%}$). This may have impact on improved cosmetic outcomes.

The 3D-CRT and FiF-FP-IMRT plans provided almost the same HI and CI (*P* values: 0.50, 0.49, respectively), whereas the IP-IMRT plans had less HI, but better CI since this plan had more than two tangential fields [Table 2]. The 3D-CRT and FiF- FP-IMRT plans were also equivalent in sparing sensitive structures. It can also be seen that the average DVHs for the critical structures were nearly identical in the FP-IMRT and 3D-CRT plans [Figure 5 a-b].

Although the mean volume of the lung (both lungs combined as one organ) receiving 20 Gy ($V_{20\ Gy}$) and the mean volume of the heart receiving 30 Gy ($V_{30\ Gy}$) were lower for the IP-IMRT technique, both the 3D-CRT and FIF-FP-IMRT plans resulted in a lower mean volume of the lung and heart receiving low dose (5 Gy) Refer to [Tables 2 and 3]. Moreover, compared with IP-IMRT, the 3D-CRT and FIF-FP-IMRT plans resulted in a significantly smaller mean volume of the heart and lung. In addition, in the IP-IMRT, the value of the mean dose to the ipsilateral lung was higher than with the FiF-FP-IMRT and 3D-CRT [Figure 7a-b]. The FiF-IP-IMRT keeps the threshold of only 2% of heart volume receiving 30 Gy, which originates from the penumbral region of tangential fields, which is in comparison with the earlier reports[16] [Table 3].

More recently, many reports[14] have proposed a series of contralateral breast dose–volume thresholds ($V_{0.05\ Gy}$, $V_{0.6\ Gy}$, $V_{2.0\ Gy}$, and the mean dose), which could serve as the maximum dose objectives in treatment planning to limit the risk of second malignancy. In our study, compliance with these dose volume metrics was significantly better with the FiF- FP-IMRT and 3D-CRT than with the IP-IMRT.

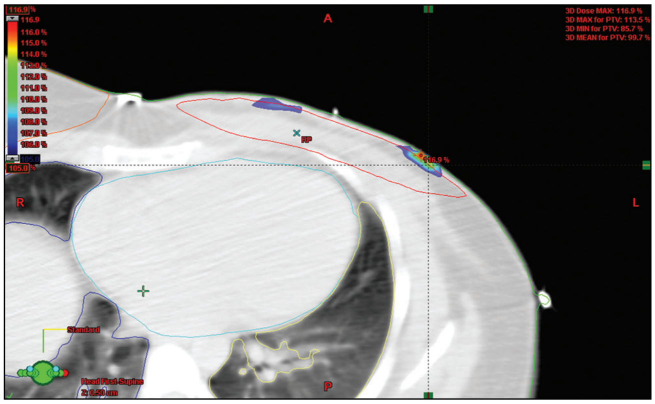


Figure 8: Islands of Hot spots with the IP-IMRT plans near the surface of the skin

The IP-IMRT plans increased the total MUs, thereby increasing the volume of normal tissues exposed to the very low dose. It is not known whether this could result in a greater probability of radiation-induced complications and secondary malignancy. The decrease in the number of monitor units leads to the reduction in leakage dose. The selected patients in this study were treated with the 3D-CRT plans, which were generated by an expert physicist, and the typical planning time was 20-30 min. For the FiF-FP-IMRT, it took about 15-20 min. In contrast, the IP-IMRT plans required about 50-60 min. This time could increase considerably for someone with lesser experience. Moreover, the treatment delivery (including patient setup) required approximately 10-15 min for both the 3D-CRT and FP-IMRT and about 15-20 min for the IP-IMRT. Hot spots in the IP-IMRT plans have some implications in cosmetic outcomes.[17] However. this is not addressed in the present work.

The afore-mentioned facts objectively bring out the fact that the IP-IMRT for breast is not justified because of increased planning time, need for more MUs, advanced planning skills, increased D_{max} value in PTV, excess dose to ipsilateral lung, contralateral breast, and islands of hot spots. Therefore, it is summarized that, compared with the 3D-CRT and IP-IMRT, the FiF-FP-IMRT[8] is a simple and efficient planning technique for breast irradiation. It provides dosimetric advantages, significantly reducing the size of the hot spot and minimally improving the coverage of the target volume. In addition, the FiF-FP-IMRT requires less planning time and is less dependent on the planner's skills.

Conclusion

FiF-FP- IMRT is a simple and efficient planning technique for breast irradiation. Compared with the 3D-CRT and IP-IMRT, the FiF-FP-IMRT is efficient in reducing the hot-spot regions within the breast volume, which could result in better cosmetic outcomes. Moreover, implementation of this technique in clinical practice is straight forward, resulting in an overall reduction of doses for OARs. The planning time is reduced and the technique is user friendly.

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