Original Article

Determination and comparison of dosimetric parameters of three-dimensional conformal radiotherapy, field in field, and intensity-modulated radiotherapy techniques in radiotherapy of breast conserving patients

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ABSTRACT

Purpose: Three radiation therapy techniques for breast are common, namely three-dimensional conformal radiotherapy (3D-CRT), Field-in-Field (FIF), and Intensıty-Modulated Radıotherapy (IMRT). The purpose of this study was to determine and compare dosimetric parameters of three different treatment planning planning types; 3D-CRT, FIF, and IMRT in target and normal tissues after breast-conserving surgery.

Methods: One hundred patients with left or right breast cancer cooperated in this study. They were divided into three categories (small, medium, and large size) based on breast volume. Three treatment planning techniques were carried out by planner for each patient in Prowess® 5.2 Treatment Planning System. The dosimetric parameters were obtained from dose-volume histograms using the CERR software (MATLAB Company, Washington, USA), which runs as an add-on in MATLAB software.

Results: 3D-CRT technique with the highest value of D_{max} creates more hot spots than the other techniques in the tumor region ($P = 0.013$). IMRT and FIF showed the best uniformity compared to 3D-CRT in all groups with respect to the values of the parameters D_{98} and D_2. IMRT provided the best coverage in the tumor compared to other methods ($P < 0.001$). 3D-CRT technique yielded a high volume receiving ≥107% of the prescription dose ($P < 0.001$). Among the three methods, the FIF method results in a lower dose to the lung for treatment based on the V_5 and V_{20} parameters ($P < 0.001$). Homogeneity index for IMRT was better than FIF, as well as, conformity index (CI) for IMRT and FIF was better than 3D-CRT.

Conclusion: IMRT and FIF plans offered excellent target coverage and uniformity, whereas FIF had better protection of healthy tissues. Thus FIF method is an efficient method to improve the quality of treatment for breast cancer patients.

KEY WORDS: Breast neoplasms, field-in-field, intensity-modulated radiotherapy, three-dimensional conformal radiotherapy

INTRODUCTION

Breast cancer is the most common cancer in women.[1] It can be treated by using a multimodality approach of surgery, chemotherapy, radiotherapy, hormone therapy, and targeted therapy. Adjuvant radiotherapy following surgery is usually recommended for the treatment of breast cancer in patients.[1] Radiotherapy has an important role in the prevention of local and regional recurrences after breast-conserving surgery. In radiotherapy, the goal is to deliver the dose to the tumoral tissue as well as sparing normal tissues.[2] To achieve the goal, various radiotherapy techniques developed dose distributions in the target and decreasing doses in healthy tissues.

Some studies[3-6] aimed at finding the best therapeutic method to assess dosimetric parameters

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among current methods, including three-dimensional conformal radiotherapy (3D-CRT), Field-in-Field (FIF), and Intensıty-Modulated Radıotherapy (IMRT).

3D-CRT technique was used as the standard care of irradiation of breast until 2000. It was frequently performed using two opposing tangential fields which allow acceptable coverage of the breast tissue while minimizing the dose to the adjacent critical structures (i.e., ipsilateral lung, contralateral lung, contralateral breast, and heart). FIF technique is designed by creating sub fields in the tangential fields using multileaf collimator (MLCs), while not using the physical wedge. In this method, hot spots and cold spots are reduced.[7] In FIF technique, segment is designed and the dose distribution is obtained, but in IMRT technique, dose is presented and segment is obtained. IMRT uses special beam modifiers to vary or modulate the intensity of the radiation over the field of delivery.

Literature show much controversy on the use of these techniques;[8,9] each technique has its own advantages and disadvantages. In 3D-CRT method, the main advantage is simplicity of planning and treatment process and the main disadvantage is nonuniform dose distribution.[9] For FIF, uniform dose distribution and spare of normal tissues are important advantages, while requiring high skill and long time in planning are disadvantages.[10] In IMRT method, the advantages include high coverage in breast and improvement conformity index (CI), and the disadvantages include the need for quality control and long time for planning and treatment.[11]

There are several studies[8,12] which have shown the superiority of IMRT method compared to the other two methods. On the other hand, there are several investigations[13,14] reported that FIF is as an effective method. In Iran, 3D-CRT technique is common for breast radiotherapy and FIF and IMRT have not been sufficiently developed. Therefore, due to the increasing rate of breast cancer patients, finding the effective radiotherapy technique is an important issue.

The aim of this study was to determine and compare the dosimetric parameters in 3D-CRT, FIF, and IMRT techniques in breast-conserving patients.

METHODS

Patients

This study was approved by the Institutional Review Board (98-6389). Computed tomography (CT, 2 slice, Siemens, Munich, Germany) scan images of 100 patients with breast cancer were used. The patients referred to the XXX, during 2015 to 2018. Furthermore, all patients in our center signed the consent form regarding the use of their CT data for research agenda. At the time of CT scan, the patients were placed in the supine position on the breast board, while the ipsilateral arm was placed above their heads. To position the patient reproducibly, the angulation of the breast board and X and Y-coordinate was noted using breast board coordinate scale. It is notable that, the breast board and marker positioning in the chest wall along with the tattoo markers used for patient reproducibility at the time of simulation and treatment. The CT images were obtained with a slice thickness of 5 mm using Siemens 2 Slice CT Scanner. The CT data in Digital Imaging and Communication in Medicine format were transferred to the Treatment Planning System (TPS) for both contouring and planning.

Target volume and delineation of organs at risk

The target volumes and critical structures were delineated on the CT data by a radiation oncologist using Prowess® Panther Version 5.2 (Prowess® Inc, Prowess Panther, California, USA) TPS. TPS was commissioned using CIRS phantom and validated by Atomic Energy Organization of Iran which is the principal authority for any radiation-related affairs. The whole breast tissue was outlined as the planning target volume (PTV). The ipsilateral lung, heart, contralateral lung, and contralateral breast were also contoured as organs at risk (OARs).

Treatment planning

All patient treatment plans were designed to dose 50 Gy to the PTV in 25 fractions with a 6-MV photon beam from Siemens ONCOR® treatment machine. The PTV of each patient was planned by planner, the CTV to PTV margins in different directions, were 9, 11, and 8 mm in lateral, anterior-posterior, and superior-inferior directions, respectively. These margins were choose regarding the patients setup errors and patients intra-fraction motions obtained from the Van Herk *et al*. method.[15] In 3D-CRT plans, two opposite tangential beams were constructed to conform to whole breast PTV. A margin of 2 cm between the (OPTIFOCUS) MLC and PTV was set in anterior (air side) direction and 5 mm margin in the lung side direction as well. Physical wedge filters were used, and the angles or degrees were chosen according to PTV coverage and breast size [Figure 1]. Fields were set up to minimize the dose to ipsilateral lung, heart, contralateral breast, and contralateral lung and maximize the target coverage, using Beam Eye View (BEV). Critical organs were shielded using MLC without compromising with the PTV coverage. Beam weights were adjusted until the optimum coverage and acceptable hot spots were achieved. In addition PTV was set to receive 95% of the prescribed dose. In the FIF technique [Figure 2], each two tangential beams were divided into two different segments. One segment was designed to whole breast regions without filters (with 6 MV photons). A second segment (usually with photons of 18 MV energy to increase the dose to the deepest part of the breast while sparing the most superficial part) for the deepest area of under dosage to compensate tissue deficiency in thick breast. The MLCs were manipulated to shield the areas of the breast receiving any dose on the BEV (mainly at 105%–107% of the prescription dose). By the MLCs movement, hot and cold points were reduced in the subfields. For IMRT

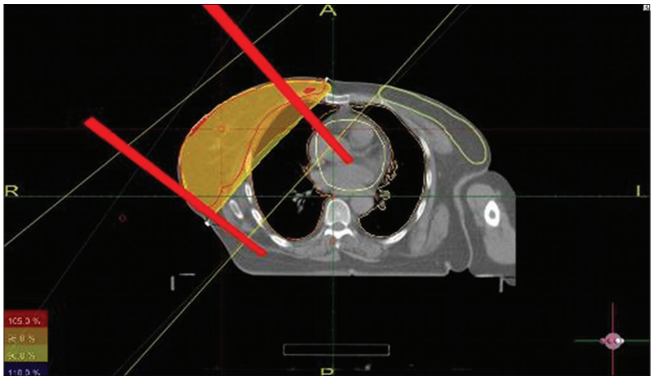

Figure1: An example of three dimensional conformal radiotherapy fields (medial and lateral) used in current study. The planning target volume in red, the heart in yellow, the contralateral breast in green and the lungs in orange

technique [Figure 3], both tangential fields were copied in the new plan and nine segments per field were considered. Dose was prescribed to the PTV, and dose constraints were set to the TPS. Normal tissues constraints include: For ipsilateral lung, no more than 40% of the volume can receive the 30.0% of the prescribed dose ($V_{30\%}$ <40%), and 20.0% of the volume can receive the maximum dose of 40.0% of prescribed dose ($V_{40\%}$ <20%). For heart, no more than 30% of the volume can receive the 40.0% of the prescribed dose ($V_{40\%}$ <30%), and the mean dose must be lower than 20 Gy (or 50% of the prescribed dose). For contralateral lung, no more than 20% of the volume can receive the 10.0% of the prescribed dose ($V_{10\%}$ <20%).[16]

The dose calculation was done by using Collapsed Cone Convolution Superposition (CCCS) algorithm.

Dosimetric comparisons

DVHs were drawn up for each technique and dosimetric parameters (D_x and V_x) were evaluated, using the CERR software, which runs as an add-on in MATLAB®:2016b software. D_x (cGy) is the minimum dose that delivered to the x% of the organ/structure volume and V_x (%) is the percentage volume of the organ/structure which received at least x% of the prescribed dose. We compared D_{98}(cGy), D_2(cGy), D_{50}(cGy), V_{95}(%), and V_{107}(%) parameters for comparing PTV dose distribution among different radiotherapy techniques. Further parameters including V_5(%) (for ipsilateral lung, contralateral lung, and contralateral breast), V_{10}(%) (for contralateral breast), V_{20}(%) (for ipsilateral lung, contralateral lung, and heart), V_{25}(%) (for heart), and V_{30}(%) (for heart) were used for comparing the doses received by OARs.

Dmax (cGy) and Dmin (cGy) as the maximum and minimum point doses received by the PTV were used for comparing the PTV dose; furthermore, homogeneity index (HI) and CI as explained by the (international commission of radiation units and measurements) report,[17] were obtained and used for comparing the homogeneity and conformity of the dose distributions among different radiotherapy techniques.

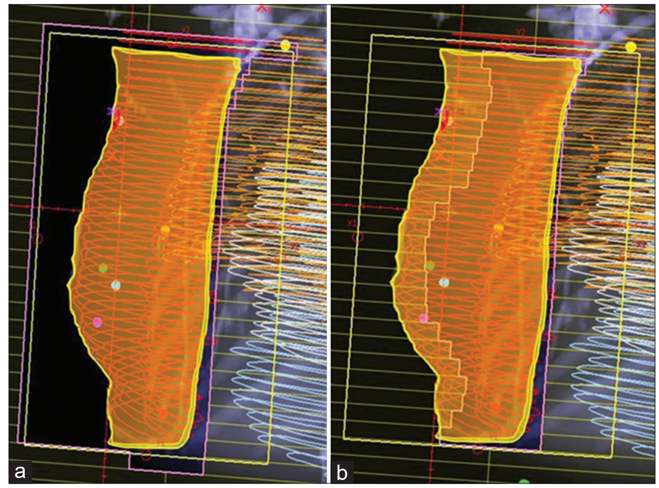

Figure 2: (a) An example of the main field without multileaf collimator blocking and (b) sub-field in the Field-in-Field technique

Statistical analysis

In this study, 100 female patients with a mean age of 43.2 ± 12.1 years were included. The patients were categorized into three groups according to the volume of the breast tissue: (a) 25 patients in the small breast volume group (<1170cc), (b) 50 patients in the medium breast volume group (1170cc≤ and ≥1721cc), and (c) 25 others in the large breast volume group (>1721cc). Mean and standard deviation for each parameter were reported, and the comparisons were performed using the one-way analysis of variance (ANOVA) for all patients with and without considering breast volume in the three methods. In addition, intergroup comparisons of extracted parameters with and without breast volume were performed using *post hoc* test. The Statistical Package for the Social Sciences (SPSS) software version 22.0 (IBM Company, New YORK, USA) was used for the statistical analyses. For statistical analysis, *P* value less than 0.05 was considered to be statistically significant.

RESULTS

D_{max}, D_{min}, D_{98}, D_2, V_{95}, and V_{107} along with the HI and CI values for PTV are presented for comparison of three techniques in Table 1. In *post hoc* test, significant differences for D_{max} were found (P = 0.013); further One-Way ANOVA indicated that there were no significant differences between IMRT and FIF (P = 0.373), and FIF and 3D-CRT (P = 0.299), while a significant difference was observed between IMRT and 3D-CRT (P = 0.013) [Table 2]. For D_{min}, the differences among the 3 techniques were statistically significant (P = 0.011) [Table 1], as well as, one-way ANOVA showed that there were significant differences between IMRT and FIF (P = 0.032), and IMRT and 3D-CRT (P = 0.033) [Table 2]. For D_{98}, the difference among the 3 techniques was statistically significant (P < 0.001), and in one-way ANOVA between two techniques (IMRT and FIF) this amount is a similar [Table 2]. Statistically significant differences for parameters including V_{95}, and V_{107} (P < 0.001) were recorded [Table 1], then one-way ANOVA showed

Table 1: Results of comparison of dosimetric parameters for target tissue and organ at risk among three dimensional conformal radiotherapy, field-in-field and intensity modulated radiotherapy regardless of breast size *(post hoc)*

Structures	Parameters	3D-CRT	FIF	IMRT	*P*
PTV	D_{max} (cGy)	5462.6±525.5	5377.1±118.9	5300.0±406.4**	0.013*
	D_{min} (cGy)	0.5±0.0	0.4±0.0	97.1±427.0	0.011*
	D_{98} (cGy)	1770.2±1053.8	3097.7±630.3	3813.1±412.4	<0.001*
	D_2 (cGy)	5140.8±286.3	5145.5±88.9	5165.5±78.4	0.369
	D_{50} (cGy)	4115.4±518.1	4524.1±483.2	4822.6±377.5	0.402
	V_{95} (%)	88.1±12.4	93.9±10.3	99.0±9.1	0.028*
	V_{107} (%)	2.0±5.2	0.0±0.2	0.0±0.2	<0.001*
	HI	0.82±0.16	0.46±0.08	0.28±0.04	<0.001*
	CI	0.46±0.05	0.59±0.06	0.72±0.06	0.044*
Ipsilateral lung	V_5 (%)	41.7±9.6	31.8±8.2	45.3±7.7	<0.001*
	V_{20} (%)	25.4±8.3	20.0±6.4	28.2±6.5	<0.001*
Contralateral lung	V_5 (%)	4.9±12.6	2.0±4.1	2.2±4.6	0.022*
	V_{20} (%)	3.3±10.6	1.3±2.9	1.9±4.0	0.112
Heart	V_{25} (%)	7.0±8.6	6.7±9.8	7.9±9.6	0.652
	V_{30} (%)	6.3±8.1	6.3±9.4	6.6±8.5	0.973
Contralateral breast	V_2 (%)	1.1±2.4	0.9±2.6	1.1±1.9	0.717
	V_5 (%)	0.3±1.2	0.3±1.6	0.5±0.9	0.634
	V_{10} (%)	0.1±0.5	0.1±1.2	0.3±0.6	0.248

**P*<0.05, statistically significant, **Mean±SD. 3D-CRT=Three dimensional conformal radiotherapy, FIF=Field-in-field, IMRT=Intensıty modulated radiotherapy, PTV=Planning target volume, SD=Standard deviation, HI=Homogeneity index, CI=Conformity index

Table 2: Results of bivariate of dosimetric parameters for target tissue and organ at risk among three dimensional conformal radiotherapy, field-in-field and intensity modulated radiotherapy regardless of breast size (one-way ANOVA)

Structures	Parameters	3D-CRT	FIF	IMRT	*P*		
					3D-CRT versus FIF	3D-CRT versus IMRT	FIF versus IMRT
PTV	D_{max} (cGy)	5462.6±525.5	5377.1±118.9	5300.0±406.4**	0.299	0.013*	0.373
	D_{min} (cGy)	0.5±0.0	0.4±0.0	97.1±427.0	1.000	0.033*	0.032*
	D_{98} (cGy)	1770.2±1053.8	3097.7±630.3	3813.1±412.4	<0.001*	<0.001*	<0.001*
	D_2 (cGy)	5140.8±286.3	5145.5±88.9	5165.5±78.4	1.000	0.473	0.473
	D_{50} (cGy)	4115.4±518.1	4524.1±483.2	4822.6±377.5	0.324	0.084	0.447
	V_{95} (%)	88.1±12.4	93.9±10.3	99.0±9.1	<0.001*	<0.001*	0.044*
	V_{107} (%)	2.0±5.2	0.0±0.2	0.0±0.2	<0.001*	<0.001*	1.000
	HI	0.82±0.16	0.46±0.08	0.28±0.04	<0.001*	<0.001*	<0.001*
	CI	0.46±0.05	0.59±0.06	0.72±0.06	0.038*	<0.011*	0.067
Ipsilateral lung	V_5 (%)	41.7±9.6	31.8±8.2	45.3±7.7	<0.001*	0.011*	<0.001*
	V_{20} (%)	25.4±8.3	20.0±6.4	28.2±6.5	<0.001*	0.026*	<0.001*
Contralateral lung	V_5 (%)	4.9±12.6	2.0±4.1	2.2±4.6	0.048*	0.069	0.988
	V_{20} (%)	3.3±10.6	1.3±2.9	1.9±4.0	0.126	0.351	0.839
Heart	V_{25} (%)	7.0±8.6	6.7±9.8	7.9±9.6	0.968	0.813	0.668
	V_{30} (%)	6.3±8.1	6.3±9.4	6.6±8.5	0.999	0.977	0.984
Contralateral breast	V_2 (%)	1.1±2.4	0.9±2.6	1.1±1.9	0.830	0.987	0.741
	V_5 (%)	0.3±1.2	0.3±1.6	0.5±0.9	1.000	0.705	0.715
	V_{10} (%)	0.1±0.5	0.1±1.2	0.3±0.6	0.792	0.252	0.619

**P*<0.05, statistically significant, **Mean±SD. 3D-CRT=Three dimensional conformal radiotherapy, FIF=Field-in-field, IMRT=Intensıty modulated radiotherapy, PTV=Planning target volume, SD=Standard deviation, HI=Homogeneity index, CI=Conformity index

that there was a similar significant difference between all techniques for V_{95} ($P < 0.044$) [Table 2]. For V_{107}, there were no differences between IMRT and FIF, however, 3D-CRT technique had significantly higher values compared to other techniques ($P < 0.001$). The HI values were significantly lower in IMRT technique ($P < 0.001$), and CI values were higher in IMRT technique without significant differences between IMRT and FIF technique ($P = 0.067$).

Also, the parameters of V_5 and V_{20} of the lung ($P < 0.001$), and V_5 of contralateral lung ($P = 0.022$) in intergroup test showed significant differences [Table 1]. For ipsilateral V_5 and V_{30}, FIF spared more than other techniques [Table 2]. V_{20} value in contralateral lung was lower in FIF plan compared to 3D-CRT method ($P = 0.048$). As shown in Table 3, a significant difference was noted for dosimetric parameters including HI, D_{max}, D_{98}, V_{95} and V_{107} in small-size group. In medium-size HI, D_{98}, V_{95}, and V_{107} yielded significant differences and listed in Table 4. Furthermore, significant differences existed for HI, D_{max}, D_{98}, V_{95}, and V_{107} in large-size group [Table 5]. In general, it can be considered two techniques IMRT and FIF showed better coverage and uniformity than 3D-CRT technique, while the comparison between IMRT and FIF showed a better improvement for IMRT in V_{95} ($P = 0.001$) and D_{98} ($P = 0.011$) [Tables 6-8]. V_5 of ipsilateral lung in any 3 groups ($P < 0.001$), V_{20} of ipsilateral lung in small and

Table 3: Results of comparison of dosimetric parameters for target tissue and organ at risk among three dimensional conformal radiotherapy, field-in-field and intensity modulated radiotherapy according to small breast size (*post hoc*)

Structures	Parameters	3D-CRT	FIF	IMRT	*P*
PTV	D_{max} (cGy)	5460.5±31.6	5374.8±24.5	5313.3±15.6**	<0.001*
	D_{min} (cGy)	0.5±0.0	0.5±0.0	91.5±91.0	0.373
	D_{98} (cGy)	1543.3±207.9	2997.4±108.2	3736.7±82.4	<0.001*
	D_2 (cGy)	5126.3±52.1	5151.1±18.8	5170.7±15.2	0.641
	D_{50} (cGy)	3932.3±485.7	4456.4±402.9	4771.3±375.0	0.106
	V_{95} (%)	89.2±9.7	95.2±10.8	99.6±10.8	<0.001*
	V_{107} (%)	1.2±0.4	0.0±0.0	0.1±0.0	<0.001*
	HI	0.91±0.11	0.48±0.06	0.30±0.03	0.011*
	CI	0.47±0.05	0.61±0.05	0.73±0.06	0.029*
Ipsilateral lung	V_5 (%)	45.6±1.4	31.8±1.3	44.8±1.2	<0.001*
	V_{20} (%)	28.1±1.1	18.6±1.1	29.3±1.0	<0.001*
Contralateral lung	V_5 (%)	9.1±4.7	1.5±0.7	1.7±0.7	0.104
	V_{20} (%)	5.7±4.1	1.0±0.5	1.6±0.6	0.336
Heart	V_{25} (%)	6.8±1.7	6.1±1.7	7.8±1.9	0.809
	V_{30} (%)	5.8±1.6	5.9±1.6	6.4±1.6	0.960
Contralateral breast	V_2 (%)	1.6±0.7	1.4±0.6	0.6±0.3	0.464
	V_5 (%)	0.6±0.4	0.5±0.4	0.2±0.1	0.757
	V_{10} (%)	0.2±0.2	0.2±0.2	0.1±0.1	0.949

**P*<0.05, statistically significant, **Mean±SD. 3D-CRT=Three dimensional conformal radiotherapy, FIF=Field-in-field, IMRT=Intensıty modulated radiotherapy, PTV=Planning target volume, SD=Standard deviation, HI=Homogeneity index, CI=Conformity index

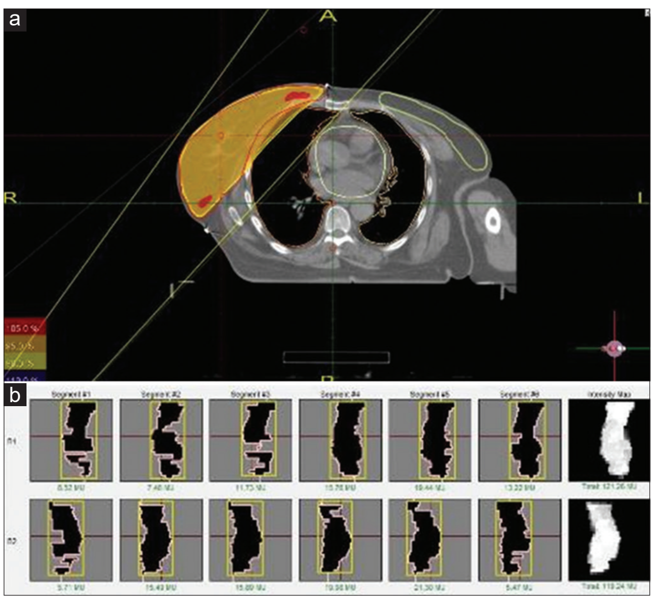

Figure 3: (a) An example of intensity modulated radiotherapy fields in current study and (b) An example of obtained intensity modulated radiotherapy fluence map

medium-size group ($P < 0.001$) and V_5 and V_{10} of contralateral breast in medium-size group ($P < 0.001$) all yielded significant differences in *post hoc* test [Tables 3-5]. In one-way ANOVA and bivariate FIF improved sparing in ipsilateral lung in any group, while 3D-CRT compared to IMRT significantly reduced ipsilateral lung dose. For V_5 and V_{10} of contralateral breast significant differences were found between 3D-CRT and IMRT ($P < 0.005$), and FIF and IMRT ($P \leq 0.001$) in medium-size group, and IMRT showed higher dose in contralateral breast compared to the other techniques [Table 7]. In overall sample, no statistically significant difference in heart and contralateral lung sparing was recorded among the 3 techniques [Tables 3-5].

DISCUSSION

A dosimetric analysis including 100 patients was performed with the aim to find the most effective method to treat breast cancer in postoperative treatment of breast carcinoma. IMRT and FIF techniques can improve the quality of treatment by providing a uniform dose distribution and better coverage of target tissue and protection of healthy organs.

The results of the comparison of dosimetric parameters of target tissues and OAR in two groups with and without breast tissue volume were evaluated. Regardless of breast size study, with the exception of D_2 and D_{50} parameters, the values of other parameters including HI, CI, D_{max}, D_{min}, D_{98}, V_{95}, and V_{107} in the target tissue varied statistically among the three methods. This means changing the treatment techniques, significantly changes the dose distribution in the target tissue. Tables 1 and 2 indicate the 3D-CRT method showed the greatest value of D_{max} among the three methods. Therefore, the 3D-CRT method leads to the creation of hot spots in the target tissue. Due to the larger values of D_{98} and lower values of HI in the IMRT and FIF methods and the position of these two points in the DVH diagram, it can be concluded that the tumor coverage in these two methods was improved compared to the 3D-CRT method.

In addition, the results showed better homogeneity (lower HI values) for IMRT and FIF methods, indicating better uniformity of these two methods compared to 3D-CRT method. However, the IMRT had statistically best homogeneity. On the other hand, conformity (CI values) were more similar in different techniques, however, the CI values were statistically better (having higher values) in FIF and IMRT methods compared to 3D-CRT method for patients having small and medium breasts. The comparison of V_x values in the target tissue, regardless of breast size, it was suggested that the

Table 4: Results of comparison of dosimetric parameters for target tissue and organ at risk among three dimensional conformal radiotherapy, field-in-field and Intensıty modulated radiotherapy according to medium breast size (*post hoc*)

Structures	Parameters	3D-CRT	FIF	IMRT	*P*
PTV	D_{max} (cGy)	5415.2±92.9	5385.2±16.4	5275.9±72.5**	0.323
	D_{min} (cGy)	0.5±0.0	0.5±0.0	71.4±50.0	0.139
	D_{98} (cGy)	1892.1±145.5	3140.3±84.5	3829.2±53.1	<0.001*
	D_2 (cGy)	5141.3±39.4	5142.0±11.8	5170.7±10.2	0.627
	D_{50} (cGy)	4224.3±417.7	4564.5±456.3	4855.7±377.8	0.128
	V_{95} (%)	88.3±9.9	93.5±8.7	99.1±8.1	<0.001*
	V_{107} (%)	1.4±0.3	0.0±0.0	0.0±0.0	<0.001*
	HI	0.77±0.08	0.44±0.05	0.28±0.03	0.010
	CI	0.45±0.05	0.60±0.05	0.71±0.05	0.071
Ipsilateral lung	V_5 (%)	40.4±1.3	32.1±1.0	45.8±1.2	<0.001*
	V_{20} (%)	24.3±1.0	20.6±0.8	28.6±0.9	<0.001*
Contralateral lung	V_5 (%)	3.8±0.8	2.3±0.6	2.5±0.6	0.300
	V_{20} (%)	2.5±0.5	1.6±0.4	2.1±0.5	0.432
Heart	V_{25} (%)	6.2±1.0	5.7±1.1	7.9±1.3	0.392
	V_{30} (%)	5.7±0.9	5.4±1.0	6.7±1.2	0.674
Contralateral breast	V_2 (%)	0.8±0.2	0.4±0.1	1.2±0.2	0.680
	V_5 (%)	0.1±0.0	0.0±0.0	0.5±0.1	<0.001*
	V_{10} (%)	0.0±0.2	0.0±0.0	0.3±0.0	<0.001*

**P*<0.05, statistically significant, **Mean±SD. 3D-CRT=Three dimensional conformal radiotherapy, FIF=Field-in-field, IMRT=Intensıty modulated radiotherapy, PTV=Planning target volume, SD=Standard deviation, HI=Homogeneity index, CI=Conformity index

Table 5: Results of comparison of dosimetric parameters for target tissue and organ at risk among three dimensional conformal radiotherapy, field-in-field and intensity modulated radiotherapy according to large breast size (*post hoc*)

Structures	Parameters	3D-CRT	FIF	IMRT	*P*
PTV	D_{max} (cGy)	5589.0±40.5	5359.5±24.3	5347.8±16.3**	<0.001*
	D_{min} (cGy)	20.8±20.3	18.6±18.1	170.7±117.8	0.219
	D_{98} (cGy)	1710.3±224.8	3100.6±163.9	3858.2±103.6	<0.001*
	D_2 (cGy)	5156.2±68.6	5148.0±19.9	5146.0±19.4	0.374
	D_{50} (cGy)	4147.4±413.1	4622.5±387.7	4887.1±377.6	0.255
	V_{95} (%)	87.1±8.6	94.6±9.0	98.6±8.2	<0.001*
	V_{107} (%)	4.2±2.2	0.0±0.0	0.0±0.0	0.041*
	HI	0.84±0.07	0.44±0.05	0.26±0.04	0.007
	CI	0.47±0.06	0.58±0.08	0.74±0.06	0.208
Ipsilateral lung	V_5 (%)	40.4±1.3	32.1±1.0	45.8±1.2	<0.001*
	V_{20} (%)	24.3±1.0	20.6±0.8	28.6±0.9	0.680
Contralateral lung	V_5 (%)	3.8±0.8	2.3±0.6	2.5±0.6	0.690
	V_{20} (%)	2.5±0.5	1.6±0.4	2.1±0.5	0.549
Heart	V_{25} (%)	6.2±1.0	5.7±1.1	7.9±1.3	0.843
	V_{30} (%)	5.7±0.9	5.4±1.0	6.7±1.2	0.661
Contralateral breast	V_2 (%)	0.8±0.2	0.4±0.1	1.2±0.2	0.882
	V_5 (%)	0.1±0.0	0.0±0.0	0.5±0.1	0.800
	V_{10} (%)	0.0±0.2	0.0±0.0	0.3±0.0	0.597

**P*<0.05, statistically significant, **Mean±SD. 3D-CRT=Three dimensional conformal radiotherapy, FIF=Field-in-field, IMRT=Intensıty modulated radiotherapy, PTV=Planning target volume, SD=Standard deviation, HI=Homogeneity index, CI=Conformity index

IMRT method leads to better tumor coverage and the FIF method leads to less hot spots. Therefore, it is not possible to recommend FIF or IMRT in terms of tumor coverage. Dean *et al*.[18] reported that the coverage was better in IMRT plans than FIF plans for breast radiation therapy. In Kim and Choi[19] study, it was shown that FIF had better uniformity and coverage in PTV compared to 3D-CRT. The above-mentioned studies agree with the present study. Table 1 showed that only in OAR located inside the beam trajectory (for example ipsilateral lung), the dosimetric parameters have a significant difference regardless of breast volume. It should be noted that V_5 of contralateral lung also has a significant difference among the three methods, which is only comparable between the 3D-CRT and FIF methods. However, V_5 and V_{20} of ipsilateral lung in all three methods were statistically significant in bivariate. Among three methods, the FIF method results in a lower dose to the lung for treatment based on the V_5 and V_{20} parameters, which can be suggested for patients with pulmonary problems.

Regarding the heart dose parameters, we did not find any statistically significant differences between the evaluated radiotherapy techniques and for patients with different breast sizes. However, previous studies showed that IMRT and techniques with higher number of radiation fields (like FIF) resulted to better heart sparing.[20-22] In our study, all the treatment plans were reviewed and corrected by an experienced medical physicist in a way that all the OARs will have as low as possible doses, and it can the reason for the lack of differences of heart doses between different radiotherapy techniques.

Table 6: Results of bivariate of dosimetric parameters for target tissue and organ at risk between Three dimensional conformal radiotherapy and field-in-field according to breast size (one-way ANOVA)

Structures	Parameters	Small			Medium			Large		
		3D-CRT	FIF	*P*	3D-CRT	FIF	*P*	3D-CRT	FIF	*P*
PTV	D_{max} (cGy)	5460.5±31.6	5374.8±24.5**	0.055	5415.2±92.9	5385.2±16.4	0.953	5589.0±40.5	5359.5±24.3	<0.001*
	D_{min} (cGy)	0.5±0.0	0.5±0.0	1.000	0.5±0.0	0.5±0.0	1.000	20.8±20.3	18.6±18.1	1.000
	D_{98} (cGy)	1543.3±207.9	2997.4±108.2	<0.001*	1892.1±145.5	3140.3±84.5	<0.001*	1710.3±224.8	3100.6±163.9	<0.001*
	D_2 (cGy)	5126.3±52.1	5151.1±18.8	0.870	5141.3±39.4	5142.0±11.8	1.000	5156.2±68.6	5148.0±19.9	1.000
	D_{50} (cGy)	3932.3±485.7	4456.4±402.9	0.203	4224.3±417.7	4564.5±456.3	0.255	4147.4±413.1	4622.5±387.7	0.355
	V_{95} (%)	89.2±9.7	95.2±10.8	<0.001*	88.3±9.9	93.5±8.7	<0.001*	87.1±8.6	94.6±9.0	0.001*
	V_{107} (%)	1.2±0.4	0.0±0.0	0.013*	1.4±0.3	0.0±0.0	<0.001*	4.2±2.2	0.0±0.0	0.090
	HI	0.91±0.11	0.48±0.06	0.009*	0.77±0.08	0.44±0.05	0.006*	0.84±0.07	0.44±0.05	0.015*
	CI	0.47±0.05	0.61±0.05	0.018*	0.45±0.05	0.60±0.05	0.047*	0.47±0.06	0.58±0.08	0.226
Ipsilateral lung	V_5 (%)	45.6±1.4	31.8±1.3	<0.001*	40.4±1.3	32.1±1.0	<0.001*	40.4±2.1	31.2±2.3	0.008*
	V_{20} (%)	28.1±1.1	18.6±1.1	<0.001*	24.3±1.0	20.6±0.8	0.025*	25.2±2.5	20.0±1.5	0.149
Contralateral lung	V_5 (%)	9.1±4.7	1.5±0.7	0.171	3.8±0.8	2.3±0.6	0.353	3.0±1.1	1.9±0.8	0.762
	V_{20} (%)	5.7±4.1	1.0±0.5	0.397	2.5±0.5	1.6±0.4	0.434	2.5±1.0	1.1±0.5	0.551
Heart	V_{25} (%)	6.8±1.7	6.1±1.7	0.962	6.2±1.0	5.7±1.1	0.956	9.2±2.2	9.8±3.0	0.990
	V_{30} (%)	5.8±1.6	5.9±1.6	1.000	5.7±0.9	5.4±1.0	0.986	8.5±2.1	9.3±2.9	0.972
Contralateral breast	V_2 (%)	1.6±0.7	1.4±0.6	0.964	0.8±0.2	0.4±0.1	0.505	1.1±0.4	1.4±0.8	0.959
	V_5 (%)	0.6±0.4	0.5±0.4	0.968	0.1±0.0	0.0±0.0	0.821	0.5±0.2	0.9±0.6	0.824
	V_{10} (%)	0.2±0.2	0.2±0.2	0.997	0.0±0.2	0.0±0.0	0.988	0.1±0.0	0.5±0.5	0.598

**P*<0.05, statistically significant, **Mean±SD. 3D-CRT=Three dimensional conformal radiotherapy, FIF=Field-in-field, PTV=Planning target volume, SD=Standard deviation, HI=Homogeneity index, CI=Conformity index

Table 7: Results of bivariate of dosimetric parameters for target tissue and organ at risk between three dimensional conformal radiotherapy and intensity modulated radiotherapy according to breast size (one-way ANOVA)

Structures	Parameters	Small			Medium			Large		
		3D-CRT	IMRT	*P*	3D-CRT	IMRT	*P*	3D-CRT	IMRT	*P*
PTV	D_{max} (cGy)	5460.5±31.6	5313.3±15.6**	<0.001*	5415.2±92.9	5275.9±72.5	0.360	5589.0±40.5	5347.8±16.3	<0.001*
	D_{min} (cGy)	0.5±0.0	91.5±91.0	0.476	0.5±0.0	71.4±50.0	0.227	20.8±20.3	170.7±117.8	0.323
	D_{98} (cGy)	1543.3±207.9	3736.7±82.4	<0.001*	1892.1±145.5	3829.2±53.1	<0.001*	1710.3±224.8	3858.2±103.6	<0.001*
	D_2 (cGy)	5126.3±52.1	5170.7±15.2	0.642	5141.3±39.4	5170.7±10.2	0.698	5156.2±68.6	5146.0±19.4	0.477
	D_{50} (cGy)	3932.3±485.7	4771.3±375.0	0.106	4224.3±417.7	4855.7±377.8	0.161	4147.4±413.1	4887.1±377.6	0.005
	V_{95} (%)	89.2±9.7	99.6±10.8	<0.001*	88.3±9.9	99.1±8.1	<0.001*	87.1±8.6	98.6±8.2	<0.001*
	V_{107} (%)	1.2±0.4	0.1±0.0	0.017*	1.4±0.3	0.0±0.0	<0.001*	4.2±2.2	0.0±0.0	0.087
	HI	0.91±0.11	0.30±0.03	0.012*	0.77±0.08	0.28±0.03	0.041*	0.84±0.07	0.26±0.04	0.011*
	CI	0.47±0.05	0.73±0.06	0.031*	0.45±0.05	0.71±0.05	0.058	0.47±0.06	0.74±0.06	0.123
Ipsilateral lung	V_5 (%)	45.6±1.4	44.8±1.2	0.914	40.4±1.3	45.8±1.2	0.008*	40.4±2.1	44.7±1.3	0.336
	V_{20} (%)	28.1±1.1	29.3±1.0	0.738	24.3±1.0	28.6±0.9	0.007*	25.2±2.5	25.6±1.3	0.991
Contralateral lung	V_5 (%)	9.1±4.7	1.7±0.7	0.190	3.8±0.8	2.5±0.6	0.477	3.0±1.1	1.9±0.9	0.752
	V_{20} (%)	5.7±4.1	1.6±0.6	0.493	2.5±0.5	2.1±0.5	0.851	2.5±1.0	1.7±0.9	0.824
Heart	V_{25} (%)	6.8±1.7	7.8±1.9	0.933	6.2±1.0	7.9±1.3	0.601	9.2±2.2	7.8±2.0	0.917
	V_{30} (%)	5.8±1.6	6.4±1.6	0.967	5.7±0.9	6.7±1.2	0.797	8.5±2.1	6.4±1.8	0.814
Contralateral breast	V_2 (%)	1.6±0.7	0.6±0.3	0.497	0.8±0.2	1.2±0.2	0.507	1.1±0.4	1.6±0.5	0.883
	V_5 (%)	0.6±0.4	0.2±0.1	0.763	0.1±0.0	0.5±0.1	0.005*	0.5±0.2	0.5±0.2	0.995
	V_{10} (%)	0.2±0.2	0.1±0.1	0.953	0.0±0.2	0.3±0.0	0.001*	0.1±0.0	0.3±0.1	0.860

**P*<0.05, statistically significant, **Mean±SD. 3D-CRT=Three dimensional conformal radiotherapy, IMRT=Intensıty modulated radiotherapy, PTV=Planning target volume, SD=Standard deviation, HI=Homogeneity index, CI=Conformity index

Al-Rahbi *et al*.[23] reported that the doses in the OAR significantly reduced in FIF technique compared to 3D-CRT. In another study by Aras *et al*.,[24] they have reported that at low doses, IMRT delivered a higher dose to the ipsilateral lung but at higher doses, it protected the lung better compared to 3D-CRT, as well as, IMRT was also successful in sparing the heart. Compared to the present study, all patients in their study were left breast cancer and this can make a significant difference in heart sparing. Also, in their study, the Eclipse treatment planning software was used which in terms of dose and accuracy calculation algorithm is different from PROWESS® treatment planning software. It should be noted that comparing other tissues, CCCS algorithm has less accuracy in lung.[25] In the evaluation of dosimetric parameters with considering breast volume, in small breast size, a significant difference was observed for D_{max} parameter between 3D-CRT and IMRT methods.

In addition, the *P* value was borderline (0.055) in comparing FIF and 3D-CRT methods. This suggests that in terms of creating hot spots in small breasts, the IMRT method would result in a smaller volume hot spot. The evidence shows that in small, medium, and large breast groups, there are significant differences in D_{98} and D_{max} values. More accurate evaluation shows that in IMRT, tumor coverage is better than the other two methods for all groups. The reason for this superiority can

Table 8: Results of bivariate of dosimetric parameters for target tissue and organ at risk between field-in-field and intensity modulated radiotherapy according to breast size (one-way ANOVA)

Structures	Parameters	Small			Medium			Large		
		FIF	IMRT	*P*	FIF	IMRT	*P*	FIF	IMRT	*P*
PTV	D_{max} (cGy)	5374.8±24.5	5313.3±15.6**	0.231	5385.2±16.4	5275.9±72.5	0.532	5359.5±24.3	5347.8±16.3	0.960
	D_{min} (cGy)	0.5±0.0	91.5±91.0	0.476	0.5±0.0	71.4±50.0	0.227	18.6±18.1	170.7±117.8	0.313
	D_{98} (cGy)	2997.4±108.2	3736.7±82.4	0.002*	3140.3±84.5	3829.2±53.1	<0.001*	3100.6±163.9	3858.2±103.6	0.011*
	D_2 (cGy)	5151.1±18.8	5170.7±15.2	0.917	5142.0±11.8	5170.7±10.2	0.711	5148.0±19.9	5146.0±19.4	0.477
	D_{50} (cGy)	4456.4±402.9	4771.3±375.0	0.255	4564.5±456.3	4855.7±377.8	0.273	4622.5±387.7	4887.1±377.6	0.306
	V_{95} (%)	95.2±10.8	99.6±10.8	0.023*	93.5±8.7	99.1±8.1	<0.001*	94.6±9.0	98.6±8.2	0.001*
	V_{107} (%)	0.0±0.0	0.1±0.0	0.996	0.0±0.0	0.0±0.0	1.000	0.0±0.0	0.0±0.0	1.000
	HI	0.48±0.06	0.30±0.03	0.022*	0.44±0.05	0.28±0.03	0.031*	0.44±0.05	0.26±0.04	0.015*
	CI	0.61±0.05	0.73±0.06	0.106	0.60±0.05	0.71±0.05	0.085	0.58±0.08	0.74±0.06	0.216
Ipsilateral	V_5 (%)	31.8±1.3	44.8±1.2	<0.001*	32.1±1.0	45.8±1.2	<0.001*	31.2±2.3	44.7±1.3	<0.001*
lung	V_{20} (%)	18.6±1.1	29.3±1.0	<0.001*	20.6±0.8	28.6±0.9	<0.001*	20.0±1.5	25.6±1.3	0.114
Contralateral	V_5 (%)	1.5±0.7	1.7±0.7	0.998	2.3±0.6	2.5±0.6	0.974	1.9±0.8	1.9±0.9	1.000
lung	V_{20} (%)	1.0±0.5	1.6±0.6	0.985	1.6±0.4	2.1±0.5	0.768	1.1±0.5	1.7±0.9	0.894
Heart	V_{25} (%)	6.1±1.7	7.8±1.9	0.810	5.7±1.1	7.9±1.3	0.426	9.8±3.0	7.8±2.0	0.854
	V_{30} (%)	5.9±1.6	6.4±1.6	0.974	5.4±1.0	6.7±1.2	0.704	9.3±2.9	6.4±1.8	0.679
Contralateral	V_2 (%)	1.4±0.6	0.6±0.3	0.657	0.4±0.1	1.2±0.2	0.068	1.4±0.8	1.6±0.5	0.978
breast	V_5 (%)	0.5±0.4	0.2±0.1	0.891	0.0±0.0	0.5±0.1	0.001*	0.9±0.6	0.5±0.2	0.873
	V_{10} (%)	0.2±0.2	0.1±0.1	0.973	0.0±0.0	0.3±0.0	0.001*	0.5±0.5	0.3±0.1	0.896

*P<0.05, statistically significant, **Mean±SD. FIF=Field-in-field, IMRT=Intensıty modulated radiotherapy, PTV=Planning target volume, SD=Standard deviation, HI=Homogeneity index, CI=Conformity index

be the high number of beamlets (nine segments) per angle of the gantry. According to other studies, increasing dose delivery time in IMRT is one of the most controversial challenges,[26] naturally increasing the number of beamlets will make the problem more serious. Statistically significant differences for V_{95} and V_{107} in all three groups were recorded.

Evidence showed that 3D-CRT causes hotter hot spots than the other two methods, while there is no significant difference between IMRT and FIF. The present study was performed on CT images of patients undergoing breast-conservation surgery and mastectomy patients were not included in this study.

Tables 3-5 indicated that for all three groups of patients with small, medium and large breast volume, in the OAR, only the ipsilateral lung made a significant difference. The V_{20} ipsilateral lung, in the large breast group, is exception. Details show that the FIF method results in a lower V_{20} value in ipsilateral lung. El-Sayed *et al*.[27] Compared IMRT, FIF and 3D-CRT methods based on breast volume. In general, the obtained results showed that the FIF achieved the best of planning efficiency parameters for 3 groups of patients. The results of the present study show that in three treatment techniques, the values of the parameters outside the field are not different and this means that it is important to pay attention to the organs in BEV to choose the appropriate treatment technique.

CONCLUSION

It can be considered that from the perspective of covering the PTV and creating more uniformity with the ideal dosage distribution, in both studies with and without considering the volume of breast tissue, IMRT and FIF showed better results than the conventional 3D-CRT method. Sparing of healthy OAR achieved by designing a FIF treatment plan. Referring to the fact that the use of IMRT technique requires more sophisticated equipment, facilities and time, FIF method is introduced as an efficient method to improve the quality of treatment for patients with breast cancer.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Halperin EC, Wazer DE, Perez CA, Brady LW. Perez and Brady's Principles and Practice of Radiation Oncology. Philadelphia: Wolters Kluwer; 2018.
2. Nishimura Y, Komaki R. Intensity-Modulated Radiation Therapy: Clinical Evidence and Techniques. Tokyo: Springer; 2016.
3. Ma C, Zhang W, Lu J, Wu L, Wu F, Huang B, *et al.* Dosimetric comparison and evaluation of three radiotherapy techniques for use after modified radical mastectomy for locally advanced left-sided breast cancer. Sci Rep 2015;5:12274.
4. Chan TY, Tan PW, Tang JI. Intensity-modulated radiation therapy for early-stage breast cancer: Is it ready for prime time? Breast Cancer (Dove Med Press) 2017;9:177-83.
5. Liu YC, Chang HM, Lin HH, Lu CC, Lai HL. Dosimetric comparison of intensity-modulated radiotherapy, volumetric modulated arc therapy and hybrid three-dimensional conformal radiotherapy/intensity-modulated radiotherapy techniques for right breast cancer. J Clin Med 2020;9:3884.
6. Tanaka H, Ito M, Yamaguchi T, Hachiya K, Yajima T, Kitahara M, *et al.* High tangent radiation therapy with field-in-field technique for breast cancer. Breast Cancer (Auckl) 2017;11:1-5.
7. Yavas G, Yavas C, Acar H. Dosimetric comparison of whole breast radiotherapy using field in field and conformal radiotherapy techniques in early stage breast cancer. Iran J Radiat Res 2012;10:131-8.

8. Haciislamoglu E, Colak F, Canyilmaz E, Zengin AY, Yilmaz AH, Yoney A, *et al.* The choice of multi-beam IMRT for whole breast radiotherapy in early-stage right breast cancer. Springerplus 2016;5:688.
9. Lee Y, Chung W, Kim DW, Kwon O. Dosimetric comparison of four different external beams for breast irradiation. J Korean Phys Soc 2017;70:300-7.
10. Stefanovski Z, Smichkoska S, Petrova D, Lazarova E. Third Conference on Medical Physics and Biomedical Engineering. Skopje: Radiation Oncology Journal; 2013. p. 75-8.
11. Sas-Korczyńska B, Sladowska A, Rozwadowska-Bogusz B, Dyczek S, Lesiak J, Kokoszka A, *et al*. Comparison between intensity modulated radiotherapy (IMRT) and 3D tangential beams technique used in patients with early-stage breast cancer who received breast-conserving therapy. Rep Pract Oncol Radiother 2010;15:79-86.
12. Phansopkar DA, Sachdeva J, Mahajan MK, Kingsley PA, Upadhyay S, Chakravarti R. Tangential beam intensity modulated radiotherapy versus tangential beam three-dimensional conformal radiotherapy in carcinoma breast: A dosimetric comparison and clinical correlation. Korean J Clin Oncol 2015;11:120-5.
13. Morganti AG, Cilla S, de Gaetano A, Panunzi S, Digesù C, Macchia G, *et al.* Forward planned intensity modulated radiotherapy (IMRT) for whole breast postoperative radiotherapy. Is it useful? When? J Appl Clin Med Phys 2011;12:3451.
14. Lee JW, Hong S, Choi KS, Kim YL, Park BM, Chung JB, *et al.* Performance evaluation of field-in-field technique for tangential breast irradiation. Jpn J Clin Oncol 2008;38:158-63.
15. van Herk M, Remeijer P, Rasch C, Lebesque JV. The probability of correct target dosage: Dose-population histograms for deriving treatment margins in radiotherapy. Int J Radiat Oncol Biol Phys 2000;47:1121-35.
16. Emami B, Lyman J, Brown A, Coia L, Goitein M, Munzenrider JE, *et al.* Tolerance of normal tissue to therapeutic irradiation. Int J Radiat Oncol Biol Phys 1991;21:109-22.
17. ICRU Report 62. Prescribing, Recording, and Reporting Photon Beam Therapy (Supplement to ICRU Report 50). Bethesda, MD: International Commission on Radiation Units and Measurements; 1999.
18. Dean J, Hansen CJ, Westhuyzen J, Waller B, Turnbull K, Wood M, *et al.* Tangential intensity modulated radiation therapy (IMRT) to the intact breast. J Med Radiat Sci 2016;63:217-23.
19. Kim S, Choi Y. Dosimetric advantages of the field-in-field plan compared with the tangential wedged beams plan for whole-breast irradiation. Prog Med Phys 2014;25:199.
20. Landau D, Adams EJ, Webb S, Ross G. Cardiac avoidance in breast radiotherapy: A comparison of simple shielding techniques with intensity-modulated radiotherapy. Radiother Oncol 2001;60:247-55.
21. Fong A, Bromley R, Beat M, Vien D, Dineley J, Morgan G. Dosimetric comparison of intensity modulated radiotherapy techniques and standard wedged tangents for whole breast radiotherapy. J Med Imaging Radiat Oncol 2009;53:92-9.
22. Ercan T, İğdem Ş, Alço G, Zengin F, Atilla S, Dinçer M, *et al*. Dosimetric comparison of field in field intensity-modulated radiotherapy technique with conformal radiotherapy techniques in breast cancer. Jpn J Radiol 2010;28:283-9.
23. Al-Rahbi ZS, Al Mandhari Z, Ravichandran R, Al-Kindi F, Davis CA, Bhasi S, *et al.* Dosimetric comparison of intensity modulated radiotherapy isocentric field plans and field in field (FIF) forward plans in the treatment of breast cancer. J Med Phys 2013;38:22-9.
24. Aras S, İkizceli T, Aktan M. Dosimetric comparison of three-dimensional conformal radiotherapy (3D-CRT) and intensity modulated radiotherapy techniques (IMRT) with radiotherapy dose simulations for left-sided mastectomy patients. Eur J Breast Health 2019;15:85-9.
25. Sini C, Broggi S, Fiorino C, Cattaneo GM, Calandrino R. Accuracy of dose calculation algorithms for static and rotational IMRT of lung cancer: A phantom study. Phys Med 2015;31:382-90.
26. Nakamura N, Takahashi O, Kamo M, Hatanaka S, Endo H, Mizuno N, *et al.* Effects of geometrical uncertainties on whole breast radiotherapy: A comparison of four different techniques. J Breast Cancer 2014;17:157-60.
27. El-Sayed A, Mohammed M, Mahmoud ES. Comparative study between field-in-field and intensity modulated radiotherapy techniques in treatment of breast cancer. Int J Innov Sci Eng Technol 2015;2:770-7.