Volume 18, No 3 | International Journal of Radiation Research, July 2020

Dosimetric comparison of conventional and field-in-field techniques in early-stage breast cancer radiotherapy

S.M. Hosseini[1,2], M. Momennezhad[1,2,3*], SH. Naseri[1,2]

[1]*Department of Medical Physics, Faculty of Medicine, Mashhad University of medical sciences, Mashhad, Iran*
[2]*Medical physics Research Center, Faculty of Medicine, Mashhad University of medical sciences, Mashhad, Iran*
[3]*Department of Radiotherapy and Oncology, Imam Reza Hospital, Mashhad, Iran*

► ***Original article***

Corresponding authors:
Mahdi Momennezhad, Ph.D.,
E-mail:
momennezhadmahdi@gmail.com

Revised: April 2020
Accepted: April 2020

Int. J. Radiat. Res., July 2020; 18(3): 487-494

DOI: 10.18869/acadpub.ijrr.18.3.487

ABSTRACT

Background: Breast conserving surgery followed by adjuvant whole breast radiotherapy is the accepted treatment in early-stage breast cancer. Due to breast irregularities, it is difficult to achieve homogenous dose distribution with conventional techniques. Currently, it is possible to use varied breast irradiation techniques such as field-in-field (FIF) that is claimed to produce more homogenous distribution of doses within the target volumes while sparing the organs at risk, leading to a better treatment outcome. The present study aimed to compare the conventional and the FIF techniques dosimetrically. ***Materials and Methods:*** Twenty patients with early-stage breast cancer underwent computed tomography. Two different treatment plans were created for each patient: the wedge-based (conventional) plan and the FIF plan. Dosimetric parameters and monitor units were compared with paired sample t-test. ***Results:*** FIF technique obtained significantly lower dose homogeneity index, lower maximum doses and higher median doses in PTV ($P<0.05$). Similarly, the conformity index, and mean doses were higher in the FIF technique but the differences were not significant ($P>0.05$). In ipsilateral lungs, FIF significantly reduced the maximum and mean doses ($P<0.05$), and showed a tendency to reduce V20 ($P>0.05$). In patients with left -sided breast cancer, minimum and maximum doses and V40 of heart were significantly decreased in FIF plans ($P<0.05$). Doses to the contralateral lungs did not differ significantly. ***Conclusion:*** These results along with significantly less monitor units required for therapy in FIF suggest that this technique may be more advantageous during breast irradiation.

Keywords: *field-in-field, 3D conformal radiotherapy, wedge, breast irradiation, OAR dose.*

INTRODUCTION

Breast cancer is the most common malignancy in women in North America, Europe, Oceania, Latin America and the Caribbean, Africa, and most of Asia [1]. It is also one of the most frequent cancers in Iranian women [2]. External radiotherapy (RT) of the intact breast is an essential step following breast-conserving surgery (BCS) in the treatment of early-stage breast cancer. Many clinical trials comparing mastectomy with BCS followed by postoperative RT have shown similar results with these treatment procedures in women with early-stage breast cancer [3, 4].Currently, BCS followed by adjuvant whole breast RT is accepted as the standard treatment in women with early-stage breast cancer. It improves local control of the tumor as well as the post-treatment patient survival rate [5, 6].

However, the therapeutic results might be affected by the toxicity caused by irradiation.

[Downloaded from ijrr.com on 2026-11-23]

[DOI: 10.18869/acadpub.ijrr.18.3.487]

Some of the side-effects include breast pain, tiredness and fatigue, cardiotoxicity, rib fracture, and a shortened life-expectancy [7]. Therefore, it is important to deliver an accurate dose to the planning target volume (PTV). Since normal breast irregularities are exacerbated by breast tissue loss after BCS, it is difficult to achieve homogenous dose distribution in the breast tissue using conventional techniques. Dose changes of up to 15-27% of the irradiated volume have been reported in some studies [8].

With advances in RT techniques and equipment, it is possible to use alternative breast irradiation techniques and apply more homogenous dose distribution in the target volume while sparing the organs at risks (OARs), such as the lungs and the heart, resulting in a better treatment outcome. Recently, conventional hard wedges have been used to improve dose homogeneity and treatment efficiency. In wedge-based RT, although homogeneous dose distribution in the central axis of the target is achievable, occurring hot spot regions far from the axis is inevitable. These regions have been shown to receive elevated doses and are the main causes of reducing therapeutic results and the mentioned side-effects [9]. Following this, dynamic wedges were introduced. Newer breast irradiation approaches including intensity-modulated RT (IMRT), volumetric modulated arc therapy, intraoperative RT are now available. Using new computer-based treatment planning systems (TPS), dose distribution within the target as well as the doses of OARs can be easily analyzed. Highly conformal modalities in whole breast RT (WBRT) are required to achieve two fundamental goals: better dose distribution in the PTV and lower doses of the OARs [10].

The field-in-field (FIF) technique, also known as forward IMRT, uses multiple fields and subfields to achieve homogenous dose distribution in the PTV while reducing the OAR doses through shielding the critical structures in breast RT. It is claimed that this technique can provide more conformal dose coverage in the PTV and lower doses of the OARs, without any additional workload compared to three-dimensional conformal RT (3D-CRT) [11, 12].

In our department, FIF and conventional wedge-based RT are the most commonly used techniques in breast irradiation. A number of studies have previously compared these two techniques, each of which selected a number of indices as criteria for running the study. The present study was designed with 20 patients for precisely dosimetric comparison of these two important techniques in breast irradiation. Also in the present study all the important indices used in previous articles are used together to compare techniques. These criteria are some conformity indices to analyze the OAR and the PTV doses. RT machine monitor units (MUs) for these two approaches were also compared.

MATERIALS AND METHODS

Twenty patients with early-stage breast cancer (11 left-sided and 9 right-sided) were enrolled in this retrospective study. The patients' characteristics are listed in table 1. All patients had undergone breast-conserving surgery before being introduced to the radiotherapy department. Only patients with early-stage breast cancer without any lymph node involvement or distant metastasis were included in this study, i.e. patients with stage 0 (Tis, N0, M0), stage I (T1, N0, M0), and IIA (T2, N0, M0) who were confirmed through pathological tests. All patients with lymph node involvement or distant metastasis were excluded. The ability to raise the arms and to maintain this position during daily treatment was another criterion for participation in this study.

Table 1. Patients' characteristics

	Mean Value ± SD*	Range
Age (years)	48 ± 8.2	41- 60
Weight (kg)	73 ± 13.6	51- 95
BMI	28.5 ± 5	21- 38
Left Side Lesion	11 (55%)	-
Right Side Lesion	9 (45%)	-
Stage 0	4 (20%)	-
Stage I	12 (60%)	-
Stage IIA	4 (20%)	-

SD: standard deviation; BMI: body mass index. *Statistically significant

[Downloaded from ijrr.com on 2026-11-23]

[DOI: 10.18869/acadpub.ijrr.18.3.487]

All patients underwent computed tomography (CT) with a16-slice Neusoft CT simulator (Neusoft Corporation, China). In the course of CT imaging, patients were positioned in the same manner as the treatment room position during irradiation (supine position with hands up, using a breast board to maintain the position). The entire breast and thorax of each patient were scanned with a 2/5 mm slice thickness in free-breathing mode. The CT datasets were then transferred to the DOSI soft Isogray (DOSIsoft, Paris, France) treatment planning system (TPS) via digital imaging and communication in medicine connection system (DICOM).

The clinical target volumes (CTVs) and the PTVs of the tumors as well as the contours of the OARs (including the heart and lungs) were delineated by the same oncologist in line with the International Commission of Radiation Units and Measurements (ICRU; reports 50 and 62) guidelines. Skin contours were automatically delineated with TPS. All the remaining breast tissue after the surgery process was considered as the CTV. The PTVs were created with a 5 mm extension of the CTVs except the anterior part. Subsequently, wedge-based (conventional) and FIF treatment plans were designed by the same medical physicist for each patient.

In the conventional plan, two opposing fields conformal to the breast were designed to entirely cover the PTV. To reduce inhomogenous doses within the PTV, hard wedges on the medial and the lateral sides were used. Severe breast surface irregularities which can cause inhomogeneity were normally observed in the PTV. Therefore, to achieve the most uniform and homogeneous dose distribution within the target volume, wedge angles were manipulated through trial and error process. The gantry angles were determined using the Beam's-eye-view ability of TPS by placing the healthy OARs out of the irradiated field as much as possible (figure 1). A copy of the wedge-based plan was defined by removing the wedges to carry out primary computation on the FIF plan with two equally weighted, open, and tangential fields with the same gantry angle as that used in the conventional technique. Dose distribution and hot/cold spot regions were determined using TPS. Two or three subfields were then added up to improve the dose homogeneity in the PTVs while reducing the OAR doses. Finally, the main field and the linked subfields were merged into one portal (figure2).

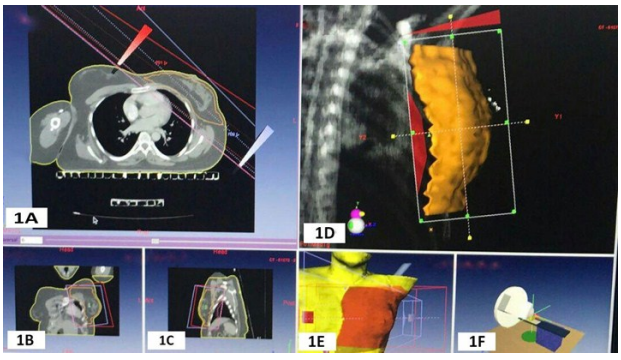


Figure 1. Image of Isogray TPS software on computer, shows conventional breast radiotherapy plan using hard wedges in 3 different CT scan sections (**1A** axial, **1B** coronal, and **1C** sagittal), Beam's eye view (BEV) of tangential field in digitally reconstructed radiography (DRR) (**1D**), treatment fields on the patient's body surface in schematic view (**1E**) and a schematic view of the patient position in the treatment room (**1F**).

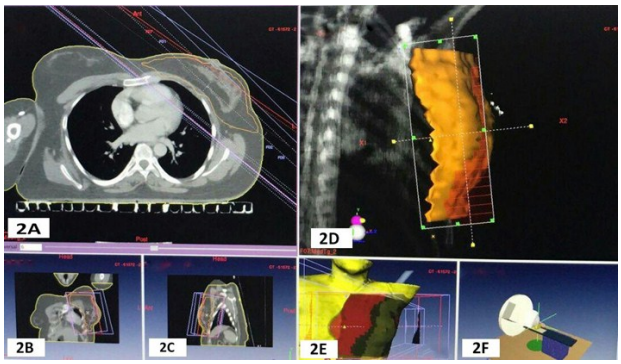


Figure 2. Image of Isogray TPS software on computer, shows Field-in-field breast radiotherapy plan using MLCs in 3 different CT scan sections (**1A** axial, **1B** coronal, and **1C** sagittal), Beam's eye view (BEV) of tangential field in digitally reconstructed radiography (DRR) (**1D**), treatment fields on the patient's body surface in schematic view (**1E**) and a schematic view of the patient position in the treatment room (**1F**).

The daily treatment dose for each patient was 2 Gy/fraction with 25 fractions overall with the aim of determining the best dose distribution while reducing the doses of the OARs in each

[Downloaded from ijrr.com on 2026-11-23]

[DOI: 10.18869/acadpub.ijrr.18.3.487]

plan. The reference point was freely shifted through the PTV. All plans were calculated with a point kernel (collapsed cone) algorithm, using the DOSIsoft Isogray TPS.

All plans were designed by the same medical physicist, after consultation with another physicist in difficult cases. The plans were checked and verified by an experienced oncologist.

Dose volume histograms (DVHs) were calculated for the PTVs, the heart, the ipsilateral lungs, and the contralateral lungs for each treatment plan in all patients (heart DVHs were considered only in left-sided breast cancer cases).

Dose homogeneity index (DHI) was employed to evaluate dose homogeneity in the PTVs. This index can be used to compare dose tolerance within the PTVs between conventional and the FIF techniques. The numerical value of DHI was calculated with the equation (1) [13]:

$$DHI = \frac{D2-D98}{Prescription\ dose} \quad (1)$$

In equation (1), D98 refers to the dose received by 98% of the PTV on the cumulative DVH, indicating that 98% of the target volume received this dose or a higher dose. Therefore, D98 is considered the ''minimum dose.'' D2 is the dose received by 2% of the PTV on the cumulative DVH, indicating that only 2% of the target volume received this dose or a higher dose. Therefore, D2 is considered the ''maximum dose.'' Lower DHI values denote more uniform dose distribution within the target volume [14].

Another index used in this study was the PTV dose improvement (PDI) or the percentage of the PTV receiving 97%-103% of the prescribed PTV dose. This index was used to evaluate improvement in the PTV dose coverage when wedges or subfields were compared to open fields without beam modifiers. Higher PDI values demonstrated better improvement in the PTV dose coverage.

Conformity index (CI) or the ratio volume confined by prescription isodose to the target volume was also analyzed [15]. Median PTV doses (D_{50}) were extracted and compared according to the ICRU recommendations (reports 50 and 62) [16]. Maximum, minimum, and mean PTV doses were also evaluated.

DVHs were determined for the ipsilateral lungs, the contralateral lungs, and the heart (in left-sided cases). Minimum (D_{min}), maximum (D_{max}), and median (D_{50}) doses for these tissues were measured and compared between the conventional and the FIF plans. The V40 of the heart (in left-sided breast irradiation) and the V20 of the ipsilateral lung were also compared.

The MUs needed for each plan were also evaluated. Planning complexity and the number of portals determined the MUs and the treatment time. This process might be challenging, especially in older patients, for whom maintaining the treatment position for a long period is intolerable.

All statistical analyses were performed using IBM SPSS software version 22. Normality of data distribution was evaluated by SPSS normality test (Kolmogorov – Smirnov test) and then, paired sample *t-test* was employed to compare the mean value of the mentioned indices. The significance level was set at $p< 0.05$.

RESULTS

Twenty patients with early-stage breast cancer (11 left-sided and 9 right-sided) were enrolled in the present study. The mean volumes and the standard deviations of the PTVs and the OARs are summarized in table 2.

Table 2. Volumes of planning target volume and organs at risk.

	Mean Volume (cm^3) ± SD	Maximum	Minimum
PTV	958.3 ± 444.3	1962.1	394.4
Ipsilateral Lung	1057.8 ± 237.4	1510	605.1
Contralateral Lung	1013.4 ± 202.4	1521.1	586.5
Heart	547.5 ± 98.6	784.5	481.6

SD: standard deviation; PTV: planning target volume.

[Downloaded from ijrr.com on 2026-11-23]

[DOI: 10.18869/acadpub.ijrr.18.3.487]

A comparison of dosimetric parameters for the PTVs between the conventional and the FIF techniques is presented in table 3. The FIF plan showed significantly lower DHI values (0.15 vs. 0.16, P=0.005), lower maximum doses (50.56 vs. 51.84 Gy, P=0.0001), greater volumes receiving 97% and 103% of the prescribed doses (P=0.0001 and 0.02, respectively), and higher median doses (46.86 vs. 46.26 Gy, P<0.0001) compared to conventional technique. The CI, the mean doses, and the volumes receiving 95% of the prescribed dose were also higher in the FIF technique, but the differences were not significant (P>0.05). PDI was equal in both groups.

Table 3. Comparison of dosimetric parameters for planning target volume.

	Wedge Plan (Mean ± SD)	FIF Plan (Mean ± SD)	p- value
DHI	0.16 ± 0.02	0.15 ± 0.03	0.005*
CI	0.94 ± 0.004	0.95 ± 0.01	0.08
PDI	0.57 ± 0.13	0.57± 0.18	0.12
Mean Dose (Gy)	46.57 ± 3.78	46.60 ± 3.88	0.4
Max Dose (Gy)	51.84 ± 4.30	50.56 ± 4.57	0.0001*
Min Dose (Gy)	26.18 ± 4.69	25.42 ± 4.28	0.04*
Median Dose (Gy)	46.26 ± 3.75	46.86 ± 3.88	< 0.0001*
D2 (Gy)	49.93 ± 4.14	49.16 ± 4.29	< 0.0001*
D98 (Gy)	42.26 ± 3.73	42.02 ± 3.75	0.03*
V95% (cm^3)	876.77 ± 363.3	878.41 ± 359.11	0.25
V97% (cm^3)	788.26 ± 319.55	825.73 ± 333.14	0.0001*
V103% (cm^3)	246.53 ± 158.96	305.40 ± 178.29	0.02*

SD: standard deviation; PDI: planning target volume dose improvement; DHI: dose homogeneity index; CI: conformity index; D2: dose received by 2% of the PTV on the cumulative dose volume histograms; D98:dose received by 98% of the PTV on the cumulative dose volume histograms. *statistically significant Vx%: volume of tissue receiving x percent of prescribed dose.

Doses received by the OARs including the ipsilateral lung, the heart (in left-sided breast irradiation), and the contralateral lung are presented in table 4. In the ipsilateral lungs, the FIF technique reduced the maximum and the mean doses significantly (P<0.05) compared with the wedge-based technique and showed a tendency to reduce the V20 and the minimum doses (P>0.05). In patients with left-sided breast cancer, the minimum and the maximum doses to the heart were significantly decreased in the FIF plan (P<0.05). Moreover, theV40 of the heart was significantly decreased in the FIF technique. FIF also led to reduction of the mean dose to the heart, but the change was not significant (P>0.05). In the contralateral lungs, the values showed no significant differences (P>0.05).

Table 4. Doses to organs at risk.

	Wedge Plan (Mean ± SD)	FIF Plan (Mean ± SD)	p- value
Ipsilateral Lung			
Min Dose (Gy)	0.11 ± 015	0.10 ± 0.12	0.06
Max Dose (Gy)	48.09 ± 4.149	46.83 ± 4.09	< 0.0001*
Mean Dose (Gy)	7.97 ± 2.62	7.57 ± 2.31	0.02*
Lung V20 (%)	14.04 ± 4.8	13.88 ± 4.6	0.2
Heart (in left sided breast irradiation)			
Min Dose (Gy)	0.45 ± 0.17	0.42 ± 0.14	0.03*
Max Dose (Gy)	46.37 ± 3.38	44.54 ± 4.16	0.0002*
Mean Dose (Gy)	6.85 ± 1.84	6.51 ± 1.69	0.12
Heart V40 (%)	6.25 ± 2.9	5.38 ± 2.9	0.03*
Contralateral Lung			
Min Dose (Gy)	0	0	-
Max Dose (Gy)	2.45 ± 1.01	2.55 ± 1.06	0.08
Mean Dose (Gy)	0.17 ± 0.08	0.16 ± 0.08	0.13

SD: standard deviation

The mean number of MUs in the wedge-based and the FIF plans were 401.6 ± 57.17 and 270.6 ± 34.17, respectively. Compared with the conventional plans, the FIF plan reduced the number of MUs significantly (P<0.0001), leading to shorter treatment times.

DISCUSSION

The gold standard treatment for early-stage breast cancer is conservative surgery followed by RT [17,18]. RT can increase the patient's survival rate by 4.8% and reduce the chances of recurrent malignancy by 19.7% over 20 years [19]. However, despite the advantages of postoperative RT in breast cancer patients, it might lead to a number of complications. These late adverse effects are related to dose inhomogeneity that can be caused by several

[Downloaded from ijrr.com on 2026-11-23]

[DOI: 10.18869/acadpub.ijrr.18.3.487]

factors such as the irregular shape and large size of the breast [9,20-22]. Various RT techniques including the wedge-based technique and the FIF technique have been developed to ensure homogenous dose distribution within the target volume and to spare healthy tissues near the tumor [23, 24]. The conventional technique, wherein two opposing tangential fields with wedge filters are applied, commonly optimizes dose distribution. This technique is reported to provide excellent local control with rare long-term complications [17,18]. However, one fundamental disadvantage of the conventional technique is that increasing the wedge angle leads to an increased scatter component from the wedge, administering nonessential doses to the patient [25-27]. Moreover, increasing the wedge angle in a tangential field RT might increase the dose in the medial and the lateral beam entries. Therefore, inducing high dose regions caused by wedge filters is inevitable [28].

Many studies have indicated that dose distribution during WBRT can be improved using the FIF technique [28-33]. In this technique, alternative subfields are added to the main field by employing a multi-leaf collimator (MLC) instead of wedge filters. The main fields and the relative subfields are subsequently merged together in one portal. In the FIF technique using MLC scatter doses administrated to the patient can be decreased compared to those in the conventional wedge-based techniques. The FIF technique reduces the number of MUs and the total treatment time. Additionally, some hotspot regions that persist in the conventional techniques and the additional time required for commissioning the wedge can be avoided [27].

In a study conducted by Yavas *et al.* (2012), 20 consecutive patients with left-sided breast cancer undergoing BCS were enrolled. Two different treatment plans (FIF and conventional) were designed for each patient and the dosimetric parameters were measured. The FIF technique provided better dose distribution in the PTV and reduced the mean doses of the OARs. The MUs required for the treatment were also significantly reduced. Thus, it was concluded that the FIF technique was more effective in whole breast irradiation [34]. Cem Onal *et al.* (2011) used dosimetric indices similar to those in the present study to compare the FIF and the wedge-based techniques in breast irradiation among 30 patients. Their results were consistent with the study performed by Yavas *et al.* (2012). Compared with the wedge beam technique, the FIF technique improved the DHI by 18% and reduced the required MUs by 22% [35].

Li-Min Sun *et al.* (2014) conducted a study and obtained contradicting results with the earlier mentioned studies. Two different FIF and wedge filter techniques were compared and three indices (homogeneity, conformity, and uniformity) along with doses of the OARs were measured. The results indicated that the wedge-based technique provides a significantly lower DHI and a significantly higher CI than the FIF technique. It was concluded that the FIF technique has no superior dosimetric advantage over the conventional technique in breast irradiation [36].

In the present study, the same indices as the ones used by Onal *et al.* (2011) and Sun *et al.* (2014) were employed. The results revealed that the FIF technique was more effective than the wedge-based technique in terms of DHI, CI, median dose (D50), maximum dose, doses of the OARs, and MUs. DHI was significantly reduced by 7.7%in the present study (0.167 and 0.154 for the conventional and FIF techniques, respectively and p=0.005). This finding was consistent with the previously mentioned studies except with the study by Sun *et al.* (2014). Lower DHI denotes lesser dose changes within the target volume. CI was higher in the FIF technique, but the difference was not statistically significant. The FIF technique also reduced the maximum dose and improved the D50, which was consistent with the previous studies.

PDI was employed to evaluate the improvement in the dose distribution in the treatment plans using physical wedges or the FIF technique compared to open field techniques without any beam modifiers. Lee *et al.* (*2008*) set dose levels corresponding to PDI indices of 97%-103% despite the fact that most of the previous studies used PDI indices between 95%-107%.The former was more rigorous and accurate, as shown in the present

[Downloaded from ijrr.com on 2026-11-23]

[DOI: 10.18869/acadpub.ijrr.18.3.487]

study. However, contrary to the findings of Lee *et al.* (*2008*), the present study observed no significant difference (similar to the results observed by Onal *et al.* (2011)).

The dose of the OARs is another criterion for choosing a better technique in RT. In agreement with the results of other studies, mean doses received by the ipsilateral lung was significantly reduced by 5% (p=0.02). The V20 of the ipsilateral lung and doses to the contralateral lung were also reduced in the FIF technique. However, the differences were not statistically significant. Moreover, compared with the conventional technique, the FIF technique significantly reduced the V40 of the heart by 14% (p=0.03). The maximum dose received by the heart (in left-sided irradiation) was also significantly decreased in the FIF technique by 4% (p=0.0002). The FIF technique declined the mean doses to the heart (in left-sided irradiation), but the difference was not statistically significant.

The MUs required for each technique were also dropped in the FIF plans by 33% (P<0.0001). Similar to the results of Yavas *et al.* (2012), Onal *et al.* (2011), and Sun *et al.* (2014) studies, the differences in the MUs between the two techniques were highly significant (P<0.0001). In fact, the MUs are reduced due to their adjustment between the subfields in the FIF technique. Treatment time can be saved due to the reduction of MUs and wedge-less treatment planning, as there was no need for the RT technicians to re-enter the treatment room after daily setup. Moreover, there was no pretreatment quality assurance procedure in the FIF technique, which was essential for IMRT. Due to these advantages, FIF is a simple, attainable, beneficial, and time-saving technique.

It is suggested that future investigations compare the FIF technique and the conventional RT in other cancers as well as in various types of TPS systems.

CONCLUSION

The FIF and the wedge-based techniques were dosimetrically and clinically assessed in the present study. Dosimetric results were clearly in favor of the FIF plan. The FIF technique using MLC achieved a more homogenous dose distribution throughout the target volume while it reduced doses to the surrounding healthy tissues. Considering these results and also the significantly less MUs required for therapy, the FIF technique seems to be more advantageous than the conventional technique during WBRT.

ACKNOWLEDGMENTS

The authors would like to thank the medical physics department of Mashhad University of Medical Sciences for supporting this project.

Conflicts of interest*: *Declared none.

REFERENCES

1. Torre LA, Siegel RL, Ward EM, Jemal A (2016) Global cancer incidence and mortality rates and trends—an update. *Cancer Epidemiology and Prevention Biomarkers,* ***25(1):*** *16-27*.
2. Rafiemanesh H, Rajaei-Behbahani N, Khani Y, Hosseini S (2016) Incidence trend and epidemiology of common cancers in the center of Iran. *Global journal of health science,* ***8(3):*** *146-55*.
3. Fisher B, Anderson S, Bryant J, Margolese RG, Deutsch M, Fisher ER, *et al.* (2002) Twenty-year follow-up of a randomized trial comparing total mastectomy, lumpectomy, and lumpectomy plus irradiation for the treatment of invasive breast cancer. *New England Journal of Medicine,* ***347(16):*** *1233-41*.
4. Wallace III HJ (2003) Twenty-year follow-up of a randomized trial comparing total mastectomy, lumpectomy and lumpectomyplus irradiation for the treament of invasive breast cancer. *Women's Oncology Review,* ***3(1):*** *81-2*.
5. Group EBCTC (1995) Effects of radiotherapy and surgery in early breast cancer—an overview of the randomized trials. *N Engl j med,* ***1995(333):*** *1444-56*.
6. Rapiti E, Fioretta G, Vlastos G, Kurtz J, Schäfer P, Sappino AP, *et al.* (2003) Breast-conserving surgery has equivalent effect as mastectomy on stage I breast cancer prognosis only when followed by radiotherapy. *Radiother Oncol,* ***69 (3):*** *277-84*.
7. Cuzick J, Stewart H, Rutqvist L, Houghton J, Edwards R, Redmond C, *et al.* (1994) Cause-specific mortality in long-term survivors of breast cancer who participated in trials of radiotherapy. *Journal of Clinical Oncology,* ***12(3):*** *447-53*.

[Downloaded from ijrr.com on 2026-11-23]

[DOI: 10.18869/acadpub.ijrr.18.3.487]

8. Buchholz TA, Gurgoze E, Bice WS, Prestige BR (1997) Dosimetric analysis of intact breast irradiation in off-axis planes. *Int J Radiat Oncol Biol Phys,* ***39(1):*** *261-7*.
9. Neal A, TorrM, Helyer S, Yarnold J (1995) Correlation of breast dose heterogeneity with breast size using 3D CT planning and dose-volume histograms. *Radiother Oncol,* ***34(3):*** *210-18*.
10. Stillie AL, Kron T, Herschtal A, Hornby C, Cramb J, Sullivan K, *et al.* (2001) Does inverse-planned intensity-modulated radiation therapy have a role in the treatmentof patients with left-sided breast cancer? *Journal of medical imaging and radiation oncology,* ***55(3):*** *311-9*.
11. Mayo CS, Urie MM, Fitzgerald TJ (2005) Hybrid IMRT plans—concurrently treating conventional and IMRT beams for improved breast irradiation and reduced planning time. *Int J Radiat Oncol Biol Phys,* ***61(3):*** *922-32*.
12. Mihai A, Rakovitch E, Sixel K, Woo T, Cardoso M, Bell C, *et al.* (2005) Inverse vs. forward breast IMRT planning. *Medical Dosimetry,* ***30(3):*** *149-54*.
13. Wu Q, Mohan R, Morris M, Lauve A, Schmidt-Ullrich R (2003) Simultaneous integrated boost intensity-modulated radiotherapy for locally advanced head-and-neck squamous cell carcinomas. I: dosimetric results. *Int J Radiat Oncol Biol Phys,* ***56(2):*** *573-85*.
14. Tu CP, Chuang, HD, Chang, NC *et al.* (2009) Clinical outcomes of the field-in-field technique for breast cancer patients with breast conservative therapy. *Ther Radiol Oncol,* ***16:*** *63-7*.
15. Dhabaan A, Elder E, Schreibmann E, Crocker I, Curran WJ, Oyesiku NM, *et al.* (2010) Dosimetric performance of the new high-definition multileaf collimator for intracranial stereotactic radiosurgery. *J Appl Clinic Med Phys,* ***11(3) :*** *.211-17*
16. Mackie TR and Gregoire V (2012) ICRU recommendations [May 13, 2013]. Available from: http://www.aapm.org/meetings/2011SS/documents/MackieUncertainty.pdf.
17. Romestaing P, Lehingue Y, Carrie C, Coquard R, Montbarbon X, Ardiet J-M, *et al.* (1997) Role of a 10-Gy boost in the conservative treatment of early breast cancer: results of a randomized clinical trial in Lyon, France. *Journal of clinical oncology,* ***15(3):*** *963-8*.
18. Bartelink H, Horiot J-C, Poortmans PM, Struikmans H, Van den Bogaert W, Fourquet A, *et al.* (2007) Impact of a higher radiation dose on local control and survival in breast-conserving therapy of early breast cancer: 10-year results of the randomized boost versus no boost EORTC 22881-10882 trial. *Journal of Clinical Oncology,* ***25(22):*** *3259-65*.
19. Group EBCTC (2000) Favourable and unfavourableeffects on long-term survival of radiotherapy for early breast cancer: an overview of therandomised trials. *The Lancet,* ***355 (9217):*** *1757-70*.
20. Fisher B, Jeong J-H, Anderson S, Bryant J, Fisher ER, Wolmark N (2002) Twenty-five-year follow-up of a randomized trial comparing radical mastectomy, total mastectomy, and total mastectomy followed by irradiation. *New England Journal of Medicine,* ***347(8):*** *567-75*.
21. Senkus-Konefka E and Jassem J (2006) Complications of breast-cancer radiotherapy. *Clinical Oncology,* ***18(3):*** *229-35*.
22. Vatanen T, Traneus E, Lahtinen T (2009) Comparison of conventional inserts and an add-on electron MLC for chest wall irradiation of left-sided breast cancer. *ActaOncologica,* ***48(3):*** *446-51*.
23. Ahunbay EE, Chen GP, Thatcher S, Jursinic PA, White J, Albano K, *et al.* (2007) Direct aperture optimization–based intensity-modulated radiotherapy for whole breast irradiation. *Int J Radiat Oncol Biol Phys,* ***67(4):*** *1248-58*.
24. Fogliata A, Clivio A, Nicolini G, VanettiE, Cozzi L (2007) A treatment planning study using non-coplanar static fields and coplanar arcs for whole breast radiotherapy of patients with concave geometry. *RadiotherOncol,* ***85(3):*** *346-54*.
25. Stasi M, Moro G, Ramella S, Bertone A, Maruca S, Ciambellotti E (1997) Factors affecting the contralateral dose for the non-treated breast in irradiation following quadrantectomy. *La Radiologiamedica,* ***93(5):*** *596-9*.
26. Prabhakar R, Julka P, Malik M, Ganesh T, Joshi R, Sridhar P, *et al.* (2007) Comparison of contralateralbreast dose for various tangential field techniques in clinical radiotherapy. *Technology in cancer research & treatment,* ***6(2):*** *135-8*.
27. Prabhakar R, Julka P, Rath G (2008) Can field-in-field technique replace wedge filter in radiotherapy treatment planning: a comparative analysis in various treatment sites. *Australasian Physical & Engineering Science in Medicine,* ***31(4):*** *317-24*.
28. Ercan T, İğdem Ş, Alço G, Zengin F, Atilla S, Dinçer M, *et al.* (2010) Dosimetric comparison of field in field intensity-modulated radiotherapy technique with conformal radiotherapy techniques in breast cancer. *Japanese journal of radiology,* ***28(4):*** *283-9*.
29. Donovan EM, Johnson U, Shentall G, Evans PM, Neal AJ, Yarnold JR (2000) Evaluation of compensation in breast radiotherapy: a planning study using multiple static fields. *Int J Radiat Oncol Biol Phys,* ***46(3):*** *671-9*.
30. Zackrisson B, Arevärn M, Karlsson M (2000) Optimized MLC-beam arrangements for tangential breast irradiation. *RadiotherOncol,* ***54(3):*** *209-12*.
31. Richmond ND, Turner RN, Dawes PJ, Lambert GD, Lawrence GP (2003) Evaluation of the dosimetric consequences of adding a single asymmetric or MLC shaped field to a tangential breast radiotherapy technique. *RadiotherOncol,* ***67(2):*** *165-70*.
32. Lee JW, Hong S, Choi KS, Kim YL, Park BM, Chung JB, *et al.* (2008) Performance evaluation of field-in-field technique for tangential breast irradiation. *Japanese journal of clinical oncology,* ***38(2):*** *158-63*.
33. Sasaoka M and Futami T (2011) Dosimetric evaluation of whole breast radiotherapy using field-in-field technique in early-stage breast cancer. *Int J Clin Oncol,* ***16(3):*** *250-6*.
34. Yavas G, Yavas C, Acar H (2012)Dosimetric comparison of whole breast radiotherapy using field in fieldand conformal radiotherapy techniques in early stage breast cancer. *Int J Radiat Res,* ***10(3):*** *131-8*.
35. Onal C, Sonmez A, Arslan G, Oymak E, Kotek A, Efe E, *et al.* (2012) Dosimetric comparison of the field-in-field technique and tangential wedged beams for breast irradiation. *Japanese Journal of Radiology,* ***30(3):*** *218-26*.
36. Sun LM, Meng FY, Yang TH, Tsao MJ (2014) Field-in-field plan does not improve the dosimetric outcome compared with the wedged beams plan for breast cancer radiotherapy. *Medical Dosimetry,* ***39(1):*** *79-82*

[Downloaded from ijrr.com on 2026-11-23]

[DOI: 10.18869/acadpub.ijrr.18.3.487]