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Original Article

Dosimetric analysis of intensity-modulated radiotherapy and three-dimensional conformal radiotherapy for chest wall irradiation in breast cancer patients

Mehlam Kausar, Om Prakash Gurjar, Priyusha Bagdare, Krishna Lal Gupta, Virendra Bhandari, Ayush Naik, Pulkit Nag, Jeetendra Kancherla

Roentgen-SAIMS Radiation Oncology Centre, Sri Aurobindo Institute of Medical Sciences, Indore, Madhya Pradesh, India

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Abstract

Background: For chest wall irradiation in breast cancer patients, three-dimensional conformal radiotherapy (3DCRT) and intensity-modulated radiotherapy (IMRT) have made tremendous changes in treatment delivery.

Purpose: The purpose of this study is to compare the dosimetric parameters in IMRT and 3DCRT plans.

Materials and methods: IMRT and 3DCRT plans were generated for 25 randomly selected postmastectomy breast cancer patients. The prescribed dose (PD) was 50 Gray (Gy) in 25 fractions (#) at the rate of 2 Gy/# with 5#/week. Dose volume histogram was evaluated for planning target volume (PTV) coverage and dose to organs at risk (OARs). All the dosimetric parameters were compared using unpaired student's *t*-test.

Results: PTV coverage was significantly better in IMRT, although the 90% of PTV was well covered by 90% of PD in all plans by both the techniques. Homogeneity index and conformity index were better in IMRT. $V_{5\,Gy}$ and D_{mean} of contralateral lung, contralateral breast and heart (right side chest wall cases) were found to be lesser in 3DCRT compared with that in IMRT. However, there was no significant difference in $V_{20\,Gy}$ of ipsilateral lung and $V_{25\,Gy}$ of heart (left side chest wall cases) in all the plans by both the techniques.

Conclusion: Adequate target coverage was achieved by both the techniques, however, dose to OARs were lesser in 3DCRT plans as compared with that in IMRT plans. Thus, it can be concluded that 3DCRT is as efficient as IMRT for the chest wall irradiation.

Keywords: chest wall irradiation; dosimetric parameters; intensity-modulated radiotherapy ipsilateral lung; three-dimensional conformal radiotherapy

Correspondence to: Dr Om Prakash Gurjar, Roentgen-SAIMS Radiation Oncology Centre, Sri Aurobindo Institute of Medical Sciences, Indore, Madhya Pradesh 453111, India. Tel: 91 731 423 1728. E-mail: ominbarc@gmail.com

INTRODUCTION

Breast cancer is one of the most common female cancer in the world, with an estimated 1·67 million cases diagnosed in 2012. With an estimated 1,44,000 new cases being diagnosed in India,[1] it is now the most common female cancer in urban India. As like other cancers, breast cancer is also reported at a late stage in India with most of the patient requiring modified radical mastectomy. Around 80% of breast cancer patients require radiotherapy either as adjuvant or palliative setting.

The most adopted treatment in breast cancer patients consists of breast-conserving surgery (BCS) or mastectomy followed by adjuvant radiation. Adjuvant radiation improves local control and overall survival.[2] Radiotherapy delivery techniques differ in different institutions for breast cancer treatment, but dose delivery to chest wall following mastectomy or breast following BCS remains a complex issue. In the conventional breast irradiation technique, the field arrangement consists of two parallel opposing tangential fields.[3] Wedges or compensators are commonly used to compensate for the rapid changes in the external contours and to improve the dose uniformity around breast or chest wall. With the development of three-dimensional conformal radiotherapy (3DCRT) technique, that is, using computerised tomography- (CT) based treatment planning system (TPS) and multileaf collimator (MLC) better radiotherapy plans with better conformity and decreased dose to normal organs can be achieved.[4,5] Intensity-modulated radiotherapy (IMRT) has proved its importance in various sites, particularly where there are constraints in dose delivery in general, and restricting minimum dose to critical structure in particular. Several single institutional studies and randomised trials have shown IMRT improves dose homogeneity and decreased dose to skin and contralateral breast when compared with conventional technique with wedges.[6]

The main aim of any radiotherapy technique is to increase tumour control probability and to decrease normal tissue complication rate. The choice of radiotherapy technique for treatment is made on the basis of these two properties.

In the present study, we attempt to compare the dosimetric aspect of IMRT and 3DCRT for chest wall irradiation in breast cancer patients.

MATERIALS AND METHODS

In total, 25 patients (13 left sided and 12 right sided) were randomly chosen for this retrospective study. They were already treated with IMRT plans, and 3DCRT plans were generated for study purpose. The radiation was started at least 3 weeks after commencement of surgery or chemotherapy. A dose of 50 Gray in 25 fractions (50 Gy/25#) at the rate of 2 Gy/# was prescribed for all the patients. The same CT datasets along with target volume and organs at risk (OARs) were used for 3DCRT planning.

All the patients were immobilised by using breast board and thermoplastic sheet (Orfit Industries, Wijnegem, Belgium). Siemens Somatom AS scanner (Siemens Medical Systems, Erlangen, Bavaria, Germany) was utilised for CT simulation and CT images with 3 mm slice thickness were obtained for all the patients. The CT images were transferred on the TPS Eclipse version 8·9 (Varian Medical Systems, Palo Alto, CA, USA) for radiotherapy planning. The clinical target volume (CTV), planning target volume (PTV) and OARs were delineated as per Radiation Therapy Oncology Group (RTOG) breast cancer atlas. Radioopaque wires were placed at the time of CT simulation to identify the chest wall. Bony landmarks were used for supraclavicular fossa (SCF). PTV included chest wall muscle, pectoralis, ribs and the draining areas, that is, SCF (depending upon the histopathology report and stage of the patient) and all three levels of axilla. OARs were delineated based on clinical and radiological data. OARs included right lung, left lung, heart, spinal cord, contralateral breast and left anterior descending artery (LAD). To limit the interobserver variation, the target delineation in all the plans was performed by same physician.

All the IMRT plans were done by 6 MV energy with five to seven coplanar (CP) fields with couch angle 0° and no parallel opposed fields were chosen. The isocentre was placed at the geometrical centre of the PTV. The range of gantry angles chosen were 80–196° (counter clockwise) for right chest wall cases and 280–165° (clockwise) for left chest wall cases. No field was placed at gantry angles 90 and 270° in any plan.

Dose constraints as per the RTOG chest wall guidelines[7] (as shown in Table 1) and adequate weights were given for OARs and target volumes. Varian leaf motion calculator version 8·9·08 was used to calculate the leaf motion for dynamic dose delivery. Dose volume optimiser was used for plan optimisation. Anisotropic analytical algorithm (AAA) was used to calculate doses with grid size of 0·25 cc.

After approval, all the plans were exported to medical electron linear accelerator (Clinac) 'Clinac DMX' (Varian Medical Systems, Palo Alto, CA, USA) having 6 and 15 MV photon energies and 6, 9, 12 and 15 MeV electron energies. The Clinac is equipped with Millennium 80 MLC system, which has 40 pairs of leaves and each leaf with width of 1 cm projected at isocentre. The MLC leaf ends are rounded. Tongue-and-groove arrangement of the leaves makes the interleaf leakage minimal. The standard MLC leaf speed is 2·5 cm/s in dynamic/moving window treatment mode.

For the retrospective study purpose, all the 3DCRT plans were done by using 6, 15 MV or combination of both photon energies. Two to five CP fields with couch angle 0° were used and two kinds of plans were prepared as per requirement of individual case as follows:

1. Only chest wall irradiation: in the cases where only chest wall had to be treated were planned with only two tangential fields (couch 0°, gantry angles 310°/50°–325°/35° and 130°/230°–145°/215°). Although, in some of the cases, one or two field-in-field (FIF) were also used to cover the cold spot. The isocentre was placed longitudinally at the geometrical centre of PTV. Lateral and vertical coordinates for isocentre were decided in such a way that it should live at equal depth from entry points of both the fields, and after fitting the MLCs to PTV, both the major fields should look like half beams, which is important for low dose to lung.
2. Chest wall plus SCF irradiation: two tangential fields as mentioned above for the chest wall and one anterior field for SCF were used. In many of the cases one or two FIF were also used, these fields were mainly required to cover the cold spot in the depth at the level of axilla. The isocentre of plan was placed at the junction of PTV for chest wall and PTV for SCF. Collimator Y2 in both the tangential fields and Y1 in anterior field was fully closed. The lateral and vertical coordinates for isocentre were decided similarly as mentioned above in 'only chest wall irradiation'. Hence, both the tangential fields were like a quadrant and the anterior field was half beam.

Table 1. Dose constraints for intensity-modulated radiotherapy[7]

Target and organs at risk	Constraints
PTV	$D_{90} > 90\%$
Ipsilateral lung	$V_{20\,Gy} < 35\%$
Heart	$V_{25\,Gy} < 20\%$
	$V_{5\,Gy} < 40\%$ (<50% for left-sided tumours)
Spine	$1\% < 45$ Gy
Contralateral breast	$V_{5\,Gy} < 15\%$

D_{90} = dose to 90% planning target volume (PTV); $V_{x\,Gy}$ = volume receiving x Gray (Gy).

In both the kind of 3DCRT plans as mentioned above doses were calculated by using AAA with 0·25 cc grid size. Weight of particular fields including FIF was decreased/increased by changing monitoring units (MU) wherever required to manage hot/cold spot and dose homogeneity.

Dosimetric parameters of all the plans generated by both the techniques were compared objectively using the dose volume histograms (DVH).

PTV coverage was compared on the basis of D_{90} (dose to 90% PTV), D_{mean} (mean dose) and D_{max} (maximum dose).

Dose to OARs such as ipsilateral lung, values of $V_{20\,Gy}$ (volume receiving 20 Gy) and D_{mean} (mean dose); contralateral lung, values of V_5 (volume receiving 5 Gy) and D_{mean}; heart, values of $V_{5\,Gy}$, $V_{40\,Gy}$, $V_{25\,Gy}$ and D_{mean}; contralateral breast, values of $V_{5\,Gy}$ and D_{mean} and for LAD value of D_{max} were compared for both the techniques.

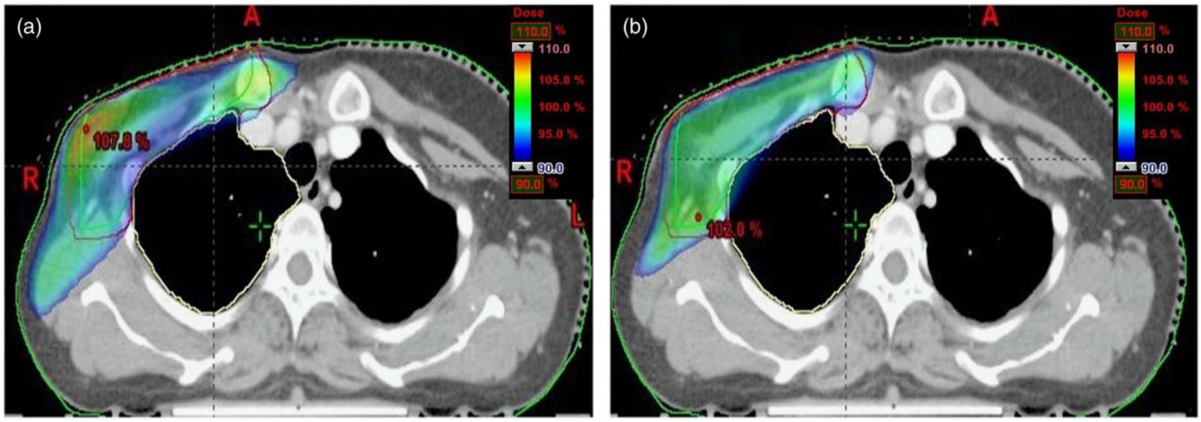

Figure 1. 90% dose distribution to planning target volume in (a) three-dimensional conformal radiotherapy and (b) intensity-modulated radiotherapy plan.

Moreover, the homogeneity index (HI) and conformity index (CI) at 90% of prescribed dose (PD) were compared for both the techniques. HI and CI were calculated by using following formulae[8]:

HI = D_5/D_{90}, where D_5 is the PTV receiving 5% and D_{90} the PTV receiving 90% of PD.

The ideal HI and CI value is one. More the deviation from the value of 1 the less is homogeneity and conformity of the plans.

CI = total volume receiving 90% of PD/PTV.

The statistical significant difference between each set of dosimetric parameters was known by calculating *p*-value using student's *t*-test. A value of $<0{\cdot}05$ was considered significant.

RESULTS

All the plans in both the techniques achieved acceptable dose coverage to the PTV with 90% volume receiving >90% of PD. Figures 1a and 1b show the 90% dose coverage to PTV in the 3DCRT and IMRT plans, respectively, in one of the case. Maximum dose (D_{max}) was in the range of 104·6–110% (mean 108·58%) of PD for 3DCRT and 104·1–109·8% (mean 108·17%) of PD for IMRT plans. There was no statistical significant difference between the D_{max} in the plans by both the techniques. The CI and HI

Table 2. *Mean planning target volume (PTV) coverage, homogeneity index and conformity index of 25 intensity-modulated radiotherapy and three-dimensional conformal radiotherapy plans*

Dosimetric parameters	IMRT	3DCRT	*p*-values
D_{90} (% of PD)	$94{\cdot}8 \pm 2{\cdot}5$	$92 \pm 1{\cdot}4$	<0·001
D_{max} (% of PD)	$108{\cdot}17 \pm 1{\cdot}48$	$108{\cdot}58 \pm 1{\cdot}41$	0·4262
D_{mean} (Gy)	$49{\cdot}7 \pm 0{\cdot}70$	$48{\cdot}83 \pm 0{\cdot}86$	<0·001
HI	1·08	1·1	<0·001
CI	1·40	1·83	<0·001

D_{90} (% of PD) = % of prescribed dose (PD) to 90% of PTV; D_{max} (% of PD) = maximum dose in % of PD; D_{mean} (Gy) = mean dose [in Gray (Gy)] to PTV.

were better in IMRT plans as compared with 3DCRT plans and the difference was statistically significant. The results of target coverage, HI and CI of IMRT and 3DCRT plans are given in Table 2.

For IMRT technique, average $V_{20\,Gy}$ of ipsilateral lung and average $V_{25\,Gy}$ for heart (in left-sided patients) showed decreased values for IMRT as compared with 3DCRT; however, there was no significant difference. The average value of D_{mean} for ipsilateral lung and heart was greater for IMRT compared with 3DCRT. The low dose volumes $V_{5\,Gy}$, that is, for heart (in right-sided patients) and contralateral lung were significantly higher for IMRT technique. Volume of contralateral breast receiving 5 Gy and D_{mean} were significantly higher for IMRT technique. Table 3 shows the average dosimetric parameters for various OARs.

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Table 3. Doses to organs at risk (OARs)

OARs	IMRT	3DCRT	*p*-values
Ipsilateral lung			
$V_{20\,Gy}$	33·67 ± 11·6	36·6 ± 9·15	0·32
D_{mean}	18·9 ± 3·7	17·93 ± 4·25	0·39
Contralateral lung			
$V_{5\,Gy}$	33·67 ± 23·5	1·7 ± 6·5	<0·0001
D_{mean}	4·6 ± 1·5	0·83 ± 0·3	<0·0001
Heart			
$V_{25\,Gy}$ (for left-sided patients)	28·23 ± 8·43	21·9 ± 9·7	0·093
$V_{5\,Gy}$ (for right-sided patients)	77·8 ± 28·3	5·68 ± 5·04	<0·0001
D_{mean}	19·47 ± 4·14	12·5 ± 4·27	0·0003
Contralateral breast			
$V_{5\,Gy}$	38·7 ± 29·37	7·7 ± 4·5	<0·0001
D_{mean}	7·44 ± 4·85	2·7 ± 1·5	<0·0001
LAD			
D_{max}			
Left side	27·0 ± 9·8	31·0 ± 16·54	0·452
Right side	12·7 ± 5·93	2·25 ± 1·33	<0·0001

$V_{x\,Gy}$ = percentage of volume receiving x Gy; D_{mean} = mean dose in 6 Gy; D_{max} = maximum dose in Gray (Gy).Abbreviations: IMRT, intensity-modulated radiotherapy; 3DCRT, three-dimensional conformal radiotherapy; LAD, left anterior descending artery.

DISCUSSION

Both the techniques namely IMRT and 3DCRT shown similar results regarding PTV coverage, that is, 90% of PTV was covered with ≥90% of PD with acceptable hotspot, although when dosimetric parameters were analysed, it was found that IMRT plans had better target coverage, HI and CI as shown in Table 2.

Better coverage and HI in the case of IMRT plans was mainly because of the multiple beam angles and hence in most of the beams, adequate build up thickness before the PTV was present, which made sufficient dose even at the edges of the PTV, although the multiple beams from different gantry angles increased the doses to the OARs. Although, in the case of 3DCRT, mainly two tangential fields with one or two FIF (in most of plans) for the chest wall and one field for SCF were used, which resulted in the decreased dose spillage in 3DCRT plans as compared with that in IMRT plans. Figures 2a and 2b show the 10% dose spillage in the 3DCRT and IMRT plans, respectively, in one of the case.

As in the tangential fields, the beams were incident directly on the chest wall in the major area, whereas the CTV as well as PTV live up to the skin contour, hence the required build up thickness does not present before the PTV, which is the major reason for low dose coverage presentation on the TPS. Although, Panettieri et al.[9] shown in their study that AAA underestimates the dose in build up region in the plans with tangential fields in the case of breast cancer. The reason for the underestimation of the dose by AAA in the build up region is inefficacy of this algorithm to calculate the tertiary and higher level of scattering.

3DCRT plans were superior than IMRT plans in aspect of doses to OARs, especially mean doses to heart, contralateral lung and contralateral breast with no significant differences for ipsilateral lung as shown in Table 3. Figures 3a and 3b show the DVH of the 3DCRT and IMRT plans, respectively, in one of the case. In a similar study done by Rudat et al.,[10] they showed that IMRT plans with tangential beams decreases dose to ipsilateral lung and heart compared with 3DCRT plans. This result was mainly because the IMRT plans were forward planned rather than inverse. Al Rahbi et al.[11] compared between inverse plan (IP)-IMRT, FIF-IMRT and 3DCRT techniques for chest wall/intact breast irradiation and shown that 3DCRT and FIF-IMRT had significant sparing of OARs as compared with IP-IMRT. Li et al.[12] in a similar study concluded that IMRT results in better

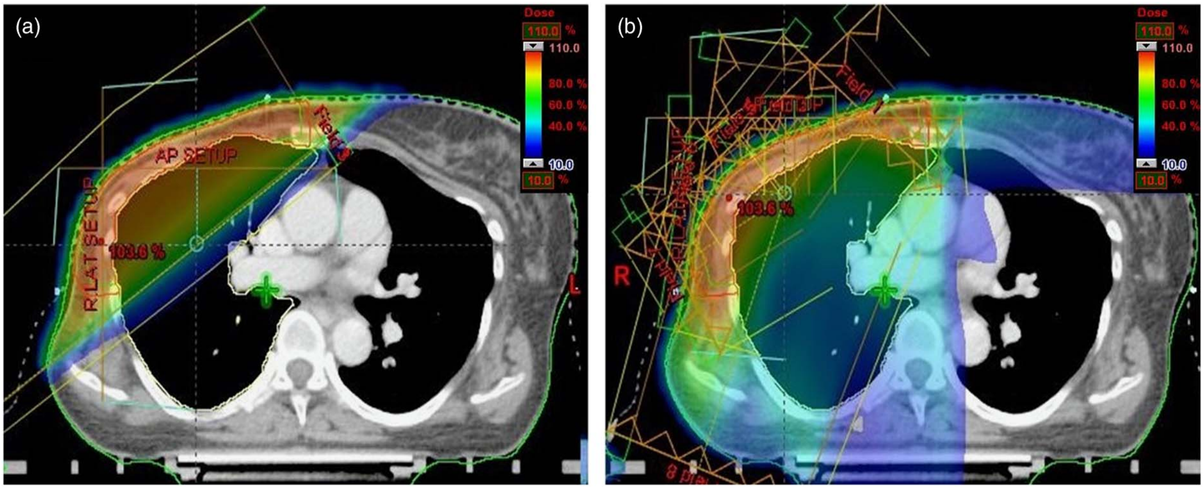

Figure 2. 10% dose spillage on computerised tomography image in (a) three-dimensional conformal radiotherapy and (b) intensity-modulated radiotherapy plan.

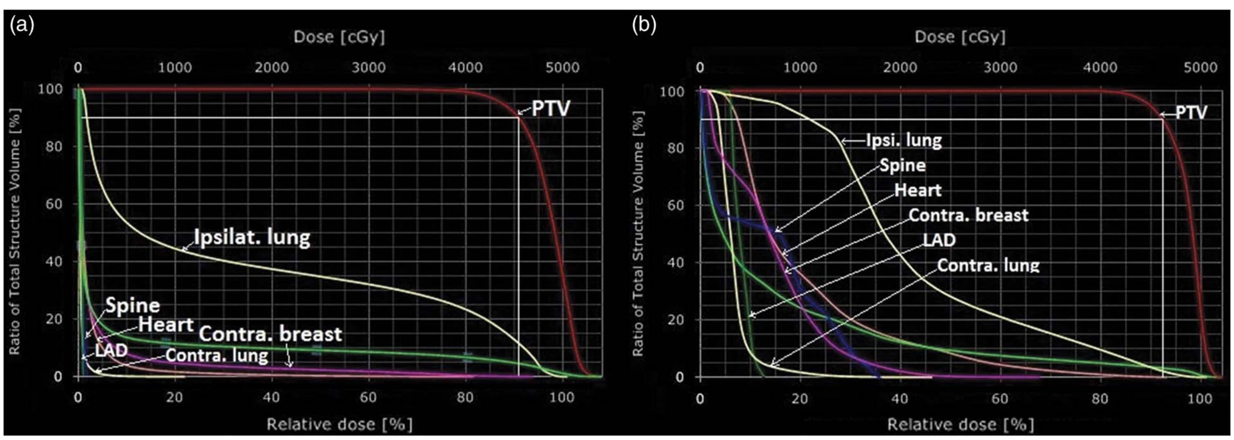

Figure 3. Dose volume histogram of one of (a) three-dimensional conformal radiotherapy and (b) intensity-modulated radiotherapy plan. Abbreviations: PTV, planning target volume; LAD, left anterior descending artery.

target coverage, however, whether they are better in normal tissue sparing is unclear. Yang et al.[13] showed that V30 of ipsilateral lung and mean dose of heart were lower in IMRT compared with conventional technique. However, V5 and V10 of ipsilateral lung and V5 of heart was higher for IMRT than for conventional technique. Ayata et al.[14] in its study for left sided breast cancer patients after lumpectomy concluded that IMRT improves target coverage, but OARs receiving low doses is increased. The results of these studies are in regard to our study, which shows decreased dose to OARs in 3DCRT.

George et al.[15] concluded in their study regarding intrafraction motion during breast IMRT planning and dose delivery, that intra-fraction motion degraded IMRT plans and a larger margins would be required for its compensation. Intrafraction motion was not taken into account for IMRT plans in our study, thus there may be increased chances of target miss during IMRT delivery, though for 3DCRT plans increased margins were taken as compared with IMRT plans, which may account for fewer target miss. Moreover, in the case of IMRT, the dose distribution varies point to point which is due to the non-uniform dose delivery by planned MLC motion pattern, which counts the depth at each and every point, and this planning is done on stationary chest CT images. As the chest wall moves from 1·5 to 2 cm due to respiration,[15] hence it is rational conclusion that there is possibility of wrong dose fluence delivery. Although mainly homogeneous beam intensity is delivered by 3DCRT fields, that is, uniform intensity remains in the open field with stationary MLCs, and so if target moves by any instant but remains within the field then there is minimal chances of under dosing.

3DCRT requires less MU as compared with IMRT technique to deliver a given dose. In our study, the mean MU was 391 and 1,187 in 3DCRT and IMRT plans, respectively. Increased MU results in excess treatment time and normal tissue integral dose, which also results in increased cost of the treatment. Recently, there have been reports on the dose to contralateral breast during breast/chest wall irradiation,[16] as increased dose may lead to increased chances of second malignancy in contralateral breast. Our study showed that dose to contralateral breast was significantly lower in 3DCRT as compared with that in IMRT.

CONCLUSIONS

In this study, it has been observed that adequate target coverage and acceptable hotspot was achieved by both the techniques. The doses to certain OARs were lesser in 3DCRT plans as compared with that in IMRT plans that includes contralateral breast, contralateral lung, LAD (in right-sided patients) and heart (in right-sided patients). However, there was no significant difference to doses received by ipsilateral lung and heart (in left-sided patients) in 3DCRT and IMRT plans, respectively. Thus, it can be concluded that 3DCRT is as efficient as IMRT technique for the chest wall irradiation in postmastectomy breast cancer patients.

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Conflicts of Interest

No conflicts of interest.

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