Evaluation of Optimal Combination of Planning Parameters (Field Width, Pitch, and Modulation Factor) in Helical Tomotherapy for Bilateral Breast Cancer

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Abstract

Aim: The aim of the study was to find the most balanced plan with an optimal combination of planning parameters in helical tomotherapy (HT) for bilateral breast irradiation by evaluating dosimetric indices and time factors. In particular, we investigated the best combination of field width (FW), pitch, and modulation factor (MF). **Materials and Methods:** A total of 90 plans (18 plans for each patient) was created in this study, with different combination of planning parameters (FW: 2.5 cm [F1] and 5 cm [F2]; pitch: 0.215 [P1], 0.287 [P2], and 0.43 [P3]; and MF: 2.0 [M1], 2.5 [M2], and 3.0 [M3]). Plans were analyzed using several dosimetric indices: homogeneity index, conformity index, dose near minimum $D_{98\%}$, dose near maximum $D_{2\%}$, and the coverage by $D_{95\%}$ of the target. Organ at risk (OAR) doses were evaluated by mean dose, V_{5Gy} and V_{25Gy} for the heart and mean dose V_{5Gy} and V_{20Gy} for both the lungs. Treatment time was also reported for all plans. **Results:** Reducing FW from 5 cm to 2.5 cm increased the treatment time by 40%–50% and improved homogeneity of the target. Tightening the pitch value from 0.43 to 0.215 improved target as well as OAR doses without increasing the treatment time. Increasing MF from 2 to 3 improved all the dosimetric indices and also increased treatment time. **Conclusions:** On the basis of our analysis, a plan with FW 5 cm, pitch 0.215, and MF 2.5 can be considered as an optimal combination of planning parameters for bilateral breast irradiation in HT technique.

Keywords: Bilateral breast cancer, helical tomotherapy, planning parameters

INTRODUCTION

Breast cancer is the most common malignancy among the women in the world, but synchronous bilateral breast cancer (BBC) is uncommon with an incidence of 2.1%.[1] Treatment planning and dose delivery of BBC is a time consuming, challenging task because of the large target volume and nearby critical structures. It is difficult to give a homogeneous distribution with traditional tangential fields, as it required a significant amount of beam overlap or alternatively underdosing of the target needs to be accepted. Helical tomotherapy (HT) is capable to deliver well tolerated homogeneous dose to BBC without field overlapping.[2,3]

HT is an intensity modulated radiotherapy technique using a rotating linear accelerator mounted on a continuously moving slip ring gantry in synchrony with the couch motion. It delivers a uniform dose, slice by slice using 6 MV photon beam with 64 binary leaf collimators. In our Tomotherapy H

machine (Accuray Ltd), the fan beam has an extension of 40 cm in lateral (x) direction at isocenter and in the superior–inferior (y) direction, the beam is collimated to three distinct field widths (FWs) (1.0, 2.5, and 5.0 cm at isocenter) by an adjustable jaw with fixed or dynamic jaw mode.[4]

During the initial treatment planning stage, because of the many combinations of planning parameters, the HT treatment planning system (TPS) takes time based on trials. HT TPS requires unique planning parameters (FW, pitch, and modulation factor [MF]) to be set prior to optimization, which influence plan quality as well as treatment time. FW and pitch

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Access this article online

Quick Response Code:

Website:
www.jmp.org.in

DOI:
10.4103/jmp.JMP_31_20

cannot be changed during optimization, but the MF can be modified during optimization.

FW represents the longitudinal extent of the treatment field at machine isocenter. We used FW of 2.5 cm and 5 cm with dynamic jaw mode for this study. Pitch represents the couch travel distance for a complete gantry rotation relative to the axial beam width at the axis of rotation. While selecting the pitch value, we need to consider the FW being used, dose/fraction, axial offset of the target, and amount of blocking. As per Kissick representation,[5] ripple effect has sharp minima near 0.86/n, where n is an integer. Hence, we used a pitch value of 0.43 ($n = 2$), 0.287 ($n = 3$), and 0.215 ($n = 4$) for this study. MF is the ratio of longest leaf open time and average leaf opening time of all nonzero leaf. MF 1 represented a uniform leaf open time of all leaf, which meant fields were not modulated. We selected 2.0, 2.5, and 3.0 for this study and did not modify the MF during optimization.

The aim of the study was to evaluate the influence of planning parameters and to find the optimal combination of planning parameters in HT for bilateral breast irradiation, as there are limited publications available in bilateral breast planning, especially in tomotherapy, and also, it was difficult for us to select the best planning parameters in the initial planning stage. To the best of our knowledge, this is the first article evaluating HT planning parameters for bilateral breast irradiation.

MATERIALS AND METHODS

Patient characteristics and treatment planning

Five bilateral breast patients previously treated in HT were selected for this study. Noncontrast computer tomography (CT) scan in a supine position with 2.5-mm slice thickness acquired from GE Discovery positron-emission tomography CT Elite 690 was used for this study. As per the Radiation Therapy Oncology Group guidelines, the clinical target volume (CTV) excluding supraclavicular nodes, organs such as heart, right and left lung, spinal cord were delineated and the planning treatment volume (PTV) was created by expanding CTV by 5 mm in Eclipse TPS and transferred to voxel less optimization (VoLO) TPS version 5.1.4 for HT planning.

A total of 90 plans (18 plans for each patient) were created in this study, with different combination of planning parameters (FW: 2.5 cm [F1] and 5 cm [F2]; pitch: 0.215 [P1], 0.287 [P2], and 0.43 [P3]; and MF: 2.0 [M1], 2.5 [M2], and 3.0 [M3]). With smallest FW (1 cm), we can get a sophisticated plan with unacceptable high treatment time (~20 mins), so we have not used 1 cm FW for this study.

For every patient, the initial plan was created with FW 5 cm, pitch 0.287, and MF 2.5 and the PTV was prescribed to dose of 50 Gy in 25 fractions. Using helping structure [Figure 1], we have blocked the beams from posterior direction to reduce the low-dose spillage in organ at risks (OARs). We optimized the plan to achieve 50 Gy to 95% of the PTV, keeping the volume receiving more than107% of prescription dose to less than
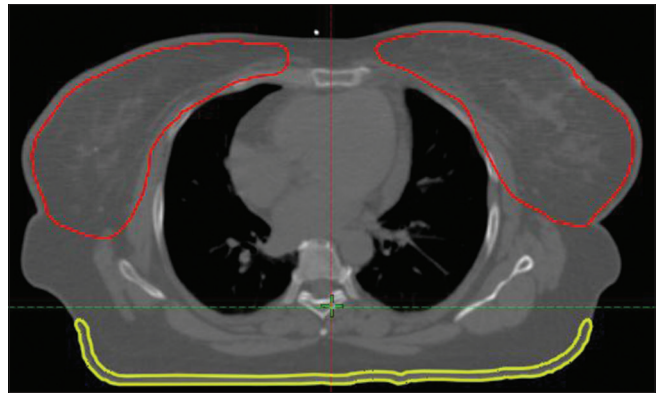

Figure 1: Helping structure (yellow) used to block the beams from posterior direction

2% volume. We used VoLO with convolution superposition algorithm, and the final dose was calculated with fine grid size 0.205 cm × 0.205 cm. After achieving acceptable OAR results, the plan was copied with its optimization constraints and 17 more plans were created by changing only its plan parameters. The plans were allowed for 200 iterations without interaction to maintain the same constraints.

Plan evaluation indices

Plans were evaluated by dose–volume histogram (DVH) analysis. Plan quality was quantified using the homogeneity index (HI), conformity index (CI), dose near minimum $D_{98\%}$, dose near maximum $D_{2\%}$, and the coverage by $D_{95\%}$ of the target.

Homogeneity of the plan was measured by HI: $(D_{2\%} - D_{98\%}/D_{50\%}) \times 100$,[6] a ratio evaluating the dose homogeneity of the target where $D_{2\%}$, $D_{98\%}$, and $D_{50\%}$ are the highest dose received by 2%, 98%, and 50% volume of the target, respectively. Therefore, lower HI indicates a more homogeneous dose distribution across the PTV.

CI was measured by $V_{95\%}$/target volume (PTV),[7] a ratio evaluating the coverage of the prescribed dose in treatment plans, where $V_{95\%}$ was the volume of body receiving 95% of the prescribed dose and target volume PTV was the volume of PTV. CI of one indicates the good dose conformity.

OAR doses were evaluated by mean dose $V_{5\ Gy}$ and $V_{25\ Gy}$ for the heart and mean dose $V_{5\ Gy}$ and $V_{20\ Gy}$ for both the lungs. Treatment time was also reported for all plans.

Data were statistically analyzed using ANOVA repeated-measures analysis variance test and the difference were considered significant if p value < 0.05.

RESULTS

Field width

The dosimetric values of PTV and OARs were assessed from the patient's average DVH data. Figure 2 represents the FW comparison of target indices, which was analyzed in all three pitch conditions. Both the plans (F1 and F2) showed good coverage as the $D_{98\%}$ and $D_{95\%}$ were similar. When compared

with F2 plans, F1 plans improved the dose homogeneity of the target as the average $D_{2\%}$ was reduced.

The CI of F1 was 0.999 ± 0.001 in all three pitch conditions and it was 0.997 ± 0.003, 0.998 ± 0.001, and 0.998 ± 0.002 for F2 in pitch condition P1, P2, and P3, respectively ($p = 0.1$). The HI was significantly reduced ($p < 0.05$) in F1 than F2 in pitch condition P3, and it was 0.04 ± 0.009, 0.04 ± 0.008, and 0.05 ± 0.01 for F1 and 0.05 ± 0.01, 0.06 ± 0.01, and 0.08 ± 0.02 for F2 in pitch condition P1, P2, and P3, respectively.

OAR doses such as mean dose, $V_{5\ Gy}$ and $V_{25\ Gy}$ for the heart and mean dose, $V_{5\ Gy}$ and $V_{20\ Gy}$ for the right and left lungs were also compared between F1 and F2 in three different pitch conditions (P1, P2, and P3). Figures 3-5 represent the results. OAR doses were slightly better for F1 than F2 for all three pitch conditions ($p > 0.1$).

Pitch

Table 1 represents the statistical results of dosimetric indices and time factors due to pitch modification for both FWs (F1 and F2). As shown in the table, tightening the pitch value reduces the dose near minimum as well as dose near maximum and improved homogeneity of the target. While tightening the pitch value from P3 to P1, $V_{105\%}$ of the PTV reduced from 3.4% to 0.17% for the FW F1 and from 23.5% to 1.5% for the FW F2, respectively. In addition, there is no significant reduction in CI. Figure 6 represents the isodose distribution of the target

for one representative patient with different pitch values (P3, P2, and P1), without changing FW (F2) and MF (MF2).

As shown in Table 2, tightening the pitch value slightly improved OAR doses, especially the low dose, without increasing the treatment time [Figure 7].

Modulation factor

Table 3 represents the statistical results of dosimetric indices due to MF modification for both FWs (F1 and F2). As shown in the table, increasing MF slightly improved coverage, conformity as well as homogeneity of the target and the results were almost similar for M2 and M3. While increasing the MF (M1, M2, and M3), $V_{105\%}$ of the target reduced as 2.03%, 0.9%, and 0.8% for FW1 and it was 13.8%, 7.8%, and 7.3% for FW2, respectively.

As represented in Table 4, OAR doses were comparatively lesser for M2 and M3 than M1. As per the dosimetric comparison of target as well as OAR, M2 and M3 show similar results and comparatively better results than M1. Treatment time increased by almost 15%, while increasing MF for both the FW [Figure 7].

DISCUSSION

Although breast cancer is one of the common malignancies in women, synchronous BBC is uncommon and also challenging in RT planning as well as treatment.[8] In RT planning, PTV should get enough coverage without a cold spot to avoid recurrence; at the same time, hot spot s should be avoided in
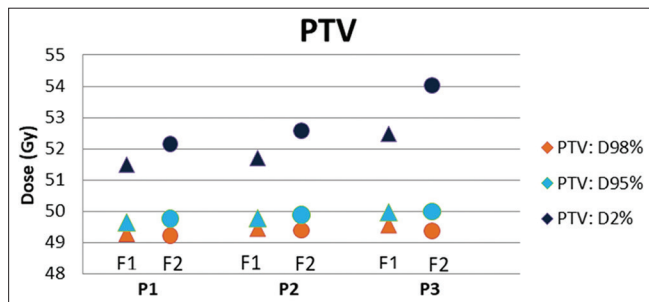

Figure 2: Dosimetric comparison of plans with field width 2.5cm (F1) and 5cm (F2) for target indices $D_{2\%}$, $D_{95\%}$, and $D_{98\%}$ in three different pitch condition (P1, P2, and P3)

Figure 3: Organ at risk (heart, right lung, and left lung), mean dose comparison of F1 and F2 in three different pitch (P1, P2, and P3) condition
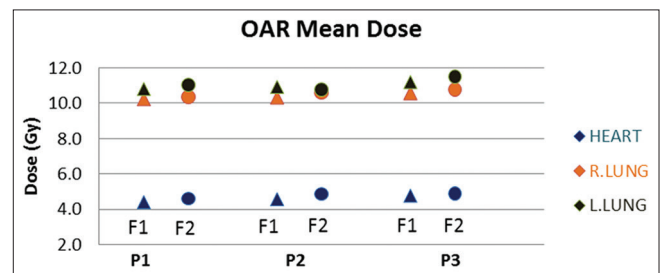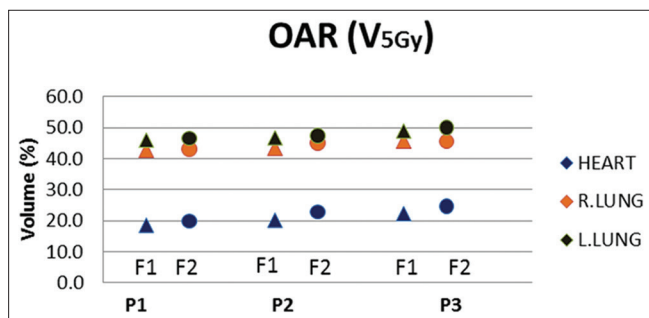

Figure 4: Organ at risk (heart, right lung, and left lung) volume receiving 5 Gy comparison of F1 and F2 in three different pitch (P1, P2, and P3) condition
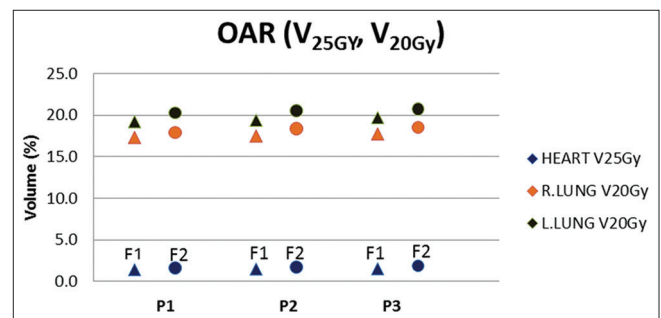

Figure 5: Volume receiving 25 Gy in heart, and volume receiving 20 Gy in right and left lung comparison of F1 and F2 in three different pitch (P1, P2, and P3) condition

Table 1: Statistical results of dosimetric indices of planning treatment volume for pitch P1, P2, and P3

	F1				F2			
	P1	P2	P3	p value	P1	P2	P3	p value
$D_{98\%}$ (Gy)	49.28±0.18	49.44±0.16	49.55±0.14	<0.05	49.21±0.20	49.38±0.18	49.37±0.21	<0.05
$D_{95\%}$ (Gy)	49.64±0.18	49.78±0.12	49.96±0.07	<0.05	49.76±0.16	49.89±0.16	49.99±0.07	<0.05
$D_{2\%}$ (Gy)	51.49±0.40	51.70±0.35	52.47±0.46	<0.05	52.15±0.45	52.58±0.45	54.02±0.78	<0.05
$V_{105\%}$ (%)	0.17±0.27	0.22±0.34	3.44±4.2	<0.05	1.58±2.0	3.93±5.1	23.58±13.9	<0.05
CI	0.9989	0.9990	0.9992	0.76	0.9976	0.9983	0.9978	0.9
HI	0.0438	0.0447	0.0573	<0.05	0.0577	0.0626	0.0898	<0.05

*Average value±SD. SD: Standard deviation, CI: Conformity index, HI: Homogeneity index

Table 2: Statistical results of dosimetric indices of organ at risk for pitch P1, P2, and P3

	F1				F2			
	P1	P2	P3	p value	P1	P2	P3	p value
Heart								
Mean (Gy)	4.42±0.9	4.58±0.9	4.78±0.9	0.57	4.61±1.0	4.86±1.0	4.90±1.4	0.73
V_{5Gy} (%)	18.55±5.6	20.19±5.1	22.26±5.2	0.22	19.91±6.7	22.8±6.8	24.65±6.6	0.18
V_{25Gy} (%)	1.42±1.2	1.49±1.2	1.53±1.3	0.93	1.63±1.4	1.75±1.5	1.87±1.5	0.84
R Lung								
Mean (Gy)	10.23±1.8	10.33±1.8	10.58±1.8	0.76	10.36±1.9	10.59±1.9	10.79±1.9	0.58
V_{5Gy} (%)	42.72±5.0	43.40±6.0	45.67±5.4	0.37	43.13±5.5	45.05±5.9	45.62±5.7	0.47
V_{20Gy} (%)	17.32±4.4	17.50±4.5	17.75±4.5	0.92	17.94±4.7	18.37±4.6	18.55±4.8	0.83
L. Lung								
Mean (Gy)	10.81±1.6	10.93±1.6	11.20±1.5	0.43	11.04±1.7	10.78±2.4	11.52±1.6	0.38
V_{5Gy} (%)	45.99±3.9	46.74±5.0	48.88±3.8	0.27	46.56±4.1	47.39±4.3	50.01±4.1	0.13
V_{20Gy} (%)	19.22±3.8	19.40±3.9	19.72±3.8	0.75	20.26±4.5	20.51±4.4	20.74±4.5	0.89

*Average value±SD. SD: Standard deviation

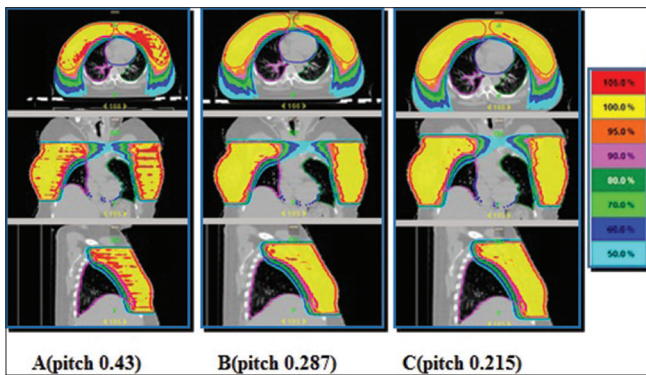A(pitch 0.43)   B(pitch 0.287)   C(pitch 0.215)

Figure 6: Axial, coronal, and sagittal dimensional isodose distribution of a patient representing the effect of pitch P3 (0.43), P2 (0.287), and P1 (0.215), respectively, when field width and modulation factor were fixed at 5cm and 2.5. The distribution was shown in the same slice from 105% dose to 50% dose

Figure 7: Average treatment time comparison of fieldwidth, pitch, and modulation factor

the junction area to spare the tissue. This article describes the process of planning synchronous BBC with HT technique in which we can avoid field overlapping problems existing with the tangential field arrangements. This technique increases the dose coverage and improves homogeneity of the target and also it is easy to deliver. Although it gives a homogeneous distribution, low dose volume to the OARs should be considered as it uses multiple beams.
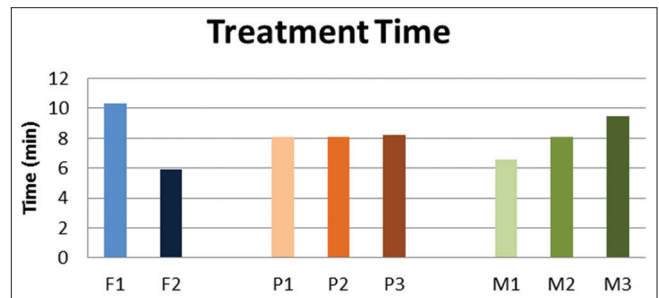
Previously published studies have reported HT as a better modality for BBC irradiation. In a series of 10 patients with BBC, Wadasadawala *et al.* assessed the dosimetric feasibility and the pros and cons of various RT techniques such as Field in Field (FIF), helical and direct tomotherapy (both three-dimensional conformal radiotherapy mode and IMRT mode) in comparison with the conventional tangential technique. They used 2.5-cm FW, 0.3 pitch, and 3.0 MF and concluded HT showed better homogeneous and conformal distribution and lesser mean dose to the OARs by specifically lowering the higher dose volumes.[9] These findings were supported by the study of Valentina Lancellotta, who compared HT plans with plan parameters such as FW: 5 cm, pitch: 0.287,

Table 3: Statistical results of dosimetric indices of planning treatment volume for modulation factor: M1, M2, and M3

	F1				F2			
	M1	M2	M3	p value	M1	M2	M3	p value
$D_{98\%}$ (Gy)	49.34±0.2	49.47±0.17	49.45±0.17	0.12	49.18±0.24	49.38±0.15	49.4±0.13	0.02
$D_{95\%}$ (Gy)	49.86±0.16	49.77±0.18	49.75±0.19	0.27	49.96±0.14	49.87±0.14	49.80±0.17	0.02
$D_{2\%}$ (Gy)	52.06±0.62	51.82±0.58	51.79±0.54	0.26	53.24±1.1	52.79±0.92	52.72±0.89	0.31
$V_{105\%}$ (%)	2.03±3.9	0.98±2.2	0.82±2.0	0.28	13.82±16	7.88±11	7.39±10	0.38
CI	0.990	1.000	1.000	<0.05	0.996	0.998	0.999	<0.05
HI	0.054	0.046	0.046	0.11	0.079	0.067	0.065	0.17

*Average value±SD. SD: Standard deviation, CI: Conformity index, HI: Homogeneity index

Table 4: Statistical results of dosimetric indices of organ at risk for modulation factor: M1, M2, and M3

	F1				F2			
	M1	M2	M3	p value	M1	M2	M3	p value
Heart								
Mean (Gy)	5.35±0.95	4.77±1.0	4.55±1.0	0.10	5.39±1.0	4.48±1.3	4.51±1.0	0.1
V_{5Gy} (%)	24.97±5.1	20.87±5.2	19.70±5.8	<0.05	26.86±6.2	20.75±6.0	19.75±6.4	<0.05
V_{25Gy} (%)	2.48±1.7	1.95±1.6	1.61±1.3	0.22	2.11±1.6	1.66±1.4	1.48±1.3	0.39
R.Lung								
Mean (Gy)	11.22±1.8	10.73±1.9	10.49±1.9	0.25	11.04±1.6	10.44±1.9	10.27±2	0.05
V_{5Gy} (%)	48.46±6.5	45.97±7.0	44.69±7.3	0.27	47.57±4.4	43.91±5.8	42.32±5.8	0.05
V_{20Gy} (%)	19.44±4.3	18.2±4.3	17.6±4.3	0.23	19.33±4.2	17.99±4.7	17.54±4.9	0.37
L.Lung								
Mean (Gy)	10.60±1.9	10.19±2.0	10.02±2.1	0.41	11.14±2.3	11.16±1.8	11.04±1.7	0.54
V_{5Gy} (%)	47.72±5.1	45.43±4.5	44.73±4.3	0.19	50.08±4.5	47.36±3.9	46.52±3.9	0.11
V_{20Gy} (%)	17.88±0.9	16.81±1.0	16.30±1.2	0.39	21.36±4.0	20.22±4.6	19.93±4.6	0.37

Average value±SD. SD: Standard deviation

and MF: 3 with TomoDirect[3] for bilateral synchronous Grade 1 and Stage 1 breast cancer and concluded HT was more suitable than direct tomotherapy. Studies reported the influence of planning parameters in helical planning for sites such as the prostate, head and neck, and breast, but the results depended on the dose/fraction, axial offset, and the beam blocking, etc.[10-15]

To find the most balanced plan that resulted in good coverage and OAR sparing with less treatment time, we evaluated 90 plans with different combinations of plan parameters, (FW: 2.5 cm [F1] and 5 cm [F2]; pitch: 0.215 [P1], 0.287 [P2], and 0.43 [P3]; and MF: 2.0 [M1], 2.5 [M2], and 3.0 [M3]). The FW is the main parameter that has a greater impact on treatment time as well as plan quality. When FW changed from 5 cm to 2.5 cm, treatment time increased by 40%–50% [Figure 7] which was in agreement with the planning parameter comparison study of the prostate.[10] The doses to PTV as well as OARs were not significantly different for FW 5 cm plans from 2.5 cm FW plans except $D_{2\%}$ of PTV. As per our analysis, 5 cm was the best FW for bilateral breast irradiation.

Tightening the pitch value significantly improved the homogeneity of the target without affecting the treatment time. When the pitch value increased from 0.215 to 0.43, the mean difference in treatment time was <30 s [Figure 7], as the gantry period increased. So the effect of pitch in treatment time was very minimal and it was in agreement with the breast planning

parameter comparison results.[12] Among the compared target as well as OAR doses (mean $V_{5\ Gy}$ and $V_{25\ Gy}$ for the heart and mean $V_{5\ Gy}$ and $V_{20\ Gy}$ for both the lungs) plans, pitch value of 0.43 did not offer any dosimetric advantage. An optimal pitch should be 0.215 or 0.286, while analyzing $V_{105\%}$ of the target and $V_{5\ Gy}$ of lungs and heart doses pitch value of 0.215 showed better results.

In general, high MF facilitated steeper dose gradients and it resulted in longer treatment time as well. Geert De Kerf suggested MF >2 in his evaluation study using Pareto optimal fronts.[13] In this study, as expected, increasing MF improved all the dosimetric indices of PTV as well as OARs and also increased treatment time. MF 1 (2) did not offer any dosimetric advantage. MF, M2 and M3 showed similar dosimetric results for OAR as well as the target. On the basis of treatment time comparison, M2 will be the optimal choice as it reduced treatment time by 15% lesser than M3 [Figure 7] without affecting the dosimetric results.

CONCLUSIONS

The finest treatment plan with longer treatment time can be achieved by small FW, tighter pitch, and large MF. It results in two adverse outcomes: patient discomfort (to lie down static during irradiation) and inherent organ movement due to breathing. Considering all these and on the basis of our

analysis, a plan with FW: 5 cm, pitch: 0.215, and MF: 2.5 can be considered as an optimal combination of planning parameters for bilateral breast irradiation in the HT technique.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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