Optimization of Treatment Planning Parameters used in Tomotherapy for Breast Cancer Patients


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Abstract

Aim: To study the effect of various planning parameters viz field width (FW) and pitch factor (PF) and their influence on the quality of plan and the treatment time for adjuvant breast radiotherapy.

Material and method: Nine plans for each of the ten breast cancer patients were created taking various combinations of field width (FW) and pitch keeping the modulation factor (MF) constant as 3. The reference plan selected for the study is field width of 1, pitch 0.215. Other plans were created keeping the same constraints and penalty as the reference plan and 1000 iterations. Target coverage was evaluated in terms of conformity index (CN) and homogeneity index (HI) while the sparing of organs at risk (OARs) were evaluated in terms of mean, maximum and relevant dose volumes. Low dose spillage in normal tissues was also evaluated. The plans were compared with the reference plan using the Wilcoxon Signed Ranks Test. Concept of plan quality index is also used to evaluate the plans qualitatively.

Results: The mean treatment delivery time for 5, 2.5 and 1.0cm FW plans were 5.04 ± 0.4, 8.51 ± 0.87 and 20.67 ± 2.02 minutes respectively. There was no significant variation in doses for OARs and COIN as well as HI of targets for 1cm and 2.5cm plans except for 5cm plans. But the low dose spillage increased by 9-14% and 23-43% for 2.5 and 5cm respectively.

Conclusion: With larger FW and higher pitch, more spillage was observed. On the basis of our analysis, 2.5_0.215 plan with MF=3, can be considered as the optimum plan for unilateral breast treatment using Tomotherapy.

Keywords: Breast; Tomotherapy; Field width; Pitch

Introduction

Helical Tomotherapy (HT) is a modern radiation therapy technology that can deliver highly conformal dose distributions to complex target volumes while reducing the dose to critical normal tissues. Optimization is guided using several parameters unique to helical Tomotherapy system [1]. The parameters are the field width (FW), pitch, and modulation factor (MF) and they can affect dose conformity and treatment times for tomotherapy [2]. For best dose conformity, small FW and pitch and high MF should be employed, at the expense, of longer treatment times. In clinical practice, the selection of FW, pitch and MF is unique to the clinical site being treated and represents a compromise between excessively long treatment times (with highly conformal delivery) and shorter treatment times (with some loss of conformity and/or dose homogeneity) [3]. Adjuvant radiotherapy (RT) forms an integral part of local regional management of breast cancer. The standard technique of whole breast irradiation involving two tangential beams is appropriate for large majority of patients. 3D-CRT and field-in-field IMRT (FIF-IMRT) are some patient specific variation in the established tangential techniques which have been introduced following the increasing use of computerized tomography (CT) based treatment planning. FIF-IMRT plans gives better homogeneity as compared with 3D-CRT, thereby reducing acute skin and soft tissue toxicities and gives better cosmesis of the treated breast in the long term [4]. However, doses to heart and lungs are not significantly improved when compared to 3D-CRT. Tomotherapy delivers a kind of multifield IMRT. Many authors had studied and compared the tomotherapy breast planning with the conventional 3DCRT and IMRT. Advantages include better conformity of the dose with lowering of dosages to underlying organs at risk, for example ipsilateral lung and heart. There is improved coverage of the planning target volume, including regional nodes, without field junction problems [5]. Increase in low dose spillage is also reported by many authors [5,6]. The purpose of this study is to find the optimum plan with the lowest achievable dose to OARs and to minimize the low-dose spill in case of adjuvant radiation for unilateral breast cancer.

Material and Methods

Patient selection and planning CT

Ten breast cancer patients (five rights and five left sided) who had undergone standard (bi-tangential) adjuvant radiotherapy after breast conserving surgery were selected for this planning study. All patients were immobilized in supine position on inclined breast board with both arms above head. Planning CT scan of 5 mm slice thickness without contrast was acquired on Somatom Emotion, SiemensTM, Germany. Images were acquired from the angle of mandible to upper abdomen, with radio-opaque wires marking the clinically palpable ipsilateral breast borders.

Treatment volumes and organs at risk

The clinical target volume (CTV) was the whole ipsilateral breast delimited within the radio-opaque wires. The planning target volume

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whole breast (PTVw,b) was generated by adding a 5 mm margin around CTV to allow for respiratory motion and setup errors but confined 5 mm within the body contour. Similarly, boost volume was delineated taking into consideration the tumor bed clips, visualized seroma and any postoperative changes. CTV of 1 cm was added to the tumor bed. PTV boost (PTVb) was created by adding a 5 mm margin around the CTV boost. Organs at risk (OARs) contoured were lungs, heart, and contra-lateral breast. Contouring was done on Oncentra Master PlanTM (version 4.2). Regional nodes were not contoured in any of the patients. CT scan along with the structure set was transferred to the Tomotherapy planning systemTM (TomoPlan version 4.2.1), Accuray.

### Dose goals

The prescribed dose for PTVw and PTVb was 61 Gy and 50 Gy respectively in 25 fractions. HT planning was done to achieve 95% of PTV receive 95% of the prescribed dose. The treatment volume receiving more than 107% of the prescribed dose should be less than 1%. The primary aim of this study was to study the effect of planning parameters on dose distribution, OAR sparing and low dose spill. The constraints are summarized in Table 1.

### Tomotherapy planning

Tomotherapy plans were created with Tomotherapy planning system (version 4.2.1). The calculation grid size used for the dose calculation was (0.39 × 0.39 × 0.50)cm³. Contra-lateral lung and breast and the dummy structures drawn at the posterior part of ipsi-lateral lung were directionally blocked to avoid beam entry to these structures. For each patient, nine plans were created taking various combinations of field width and pitch keeping the MF constant. So, the total number of plans created for the study was 90. The pitch were selected as 0.215, 0.287 and 0.43 which was derived from the optimum pitch value defined as 0.86/n where n is an integer [2]. Westerly et al had also recommended to choose a pitch value so that the gantry period is greater than the minimum value of 15 second and thereby to lessen the impact of MLC latency inaccuracies [7]. The MF was set to 3 for all the plans. The 1 cm FW and the pitch of 0.215 are selected as reference plan on the assumption that it can produced the best dose distribution. Other plans were generated keeping the same constraints and penalty as the reference plan and the number of iteration was kept fixed at 1000.

### Plan analysis and comparison

All the plans were dosimetrically and statistically analysed and compared to the reference plan on the basis of Target coverage, dose to OARs, treatment time and low dose spillage. Target coverage was evaluated in terms of conformity index (CN) and homogeneity index (HI) while the sparing of organs at risk (OARs) were evaluated in terms of mean, maximum and relevant dose volumes.

#### Conformity index (CN)

Dose conformity was characterized by the CN as proposed by Van’t Riet et al. [8], which accounts for dose coverage and dose spillage for a given prescription dose. The CN is defined by the formula:

\[
CN = \frac{C_1}{C_2}
\]

Where \(C_1 = \frac{PTV_{ref}}{PTV}\) and \(C_2 = \frac{PTV_{ref}}{V_{ref}}\)

PTV_{ref} means PTV covered by the reference dose (95%) and V_{ref} means the total volume covered by the reference isodose (95%). The CN ranges between 0 and 1, where 1 is the ideal value.

#### Homogeneity index (HI)

Homogeneity Index was defined as

\[
HI = \frac{(D_{2} - D_{98})}{D_{2}}
\]

Where \(D_2\) and \(D_{98}\) represent the doses to 2% and 98% of the PTV, respectively [9]. Smaller values of HI correspond to more homogeneous irradiation of the target volume.

### Low dose spillage

For quantification of low dose spillage, the volumes of low doses \(V_5\), \(V_{10}\), \(V_{20}\) (5 Gy, 10 Gy and 20 Gy) in the normal tissue outside the target volume were considered. Low dose to normal tissue (Body-PTV) was evaluated from dose volume histogram (DVH). Percentage difference of these volumes from different plans with respect to the reference plan were evaluated and presented in the Table 2. The increase in the low dose spillage is assessed by giving rank (1-8) among the 8 plans; the lowest % spillage is given rank 1 and the highest spillage as rank 8 (Figures 1 and 2).

#### Plan evaluation

To compare the plans qualitatively with respect to the reference plan, a parameter called plan quality index (PQI) was generated for target volumes (PTVw,b and PTVb) and organs at risk (OAR) [7]. The plan quality index (PQI) is calculated by equation 3:

\[
PQI = \frac{P(V)}{P_{ref}(V)}
\]

Where \(P_{ref}(V)\) is mean value of the parameter for 10 patients for in a specific organ for reference plan and \(P(V)\) is mean value of parameter in a specific organ for the analysed plan. When the value of PQI increases, it shows that the plan quality decreases as compared to the reference plan. For all the remaining 8 plans, the PQIs for each parameter are calculated and rankings (1 to 8) are given as per the value of PQI, the smallest value of PQI is taken as rank 1 while the highest value is taken as rank 8. The plan quality is assessed by the sum of PQIs, the plan with smallest value of the sum is taken as the best plan.

<table>
<thead>
<tr>
<th>Dose level</th>
<th>Constraint</th>
<th>Achievable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ipsilaterallung</td>
<td>≤ 10 Gy</td>
<td>Yes</td>
</tr>
<tr>
<td>(V_{5%})</td>
<td>&lt;10%</td>
<td>Yes except 5_0.43</td>
</tr>
<tr>
<td>Contra-lateral lung</td>
<td>&lt;2 Gy</td>
<td>Yes except 5_0.43</td>
</tr>
<tr>
<td>(V_{5%}) (Left side)</td>
<td>&lt;5%</td>
<td>Yes except 5_0.43 and 5_0.287</td>
</tr>
<tr>
<td>(V_{5%}) (Right side)</td>
<td>&lt;2%</td>
<td>Yes</td>
</tr>
<tr>
<td>Heart</td>
<td>&lt;30 Gy</td>
<td>Yes</td>
</tr>
<tr>
<td>(V_{5%})</td>
<td>≤ 10%</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1: Dose constraints achieved for SIB RT with prescription of 50 Gy/25f to PTV breast and 61 Gy/25f to PTV boost.

<table>
<thead>
<tr>
<th>SPILLAGE (%)</th>
<th>1 cm</th>
<th>2.5 cm</th>
<th>5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_5)</td>
<td>0</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>(V_{10})</td>
<td>0</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>(V_{20})</td>
<td>0</td>
<td>8</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 2: Percentage of low dose spill with reference to the volumes of plan 1_0.215.
Results

Treatment time

The mean treatment delivery time for the 5, 2.5 and 1.0 in the range of 5, 8.5 and 20 minutes, it is given in details at (Table 3).

Quality of plans

The target coverage of the PTV boost and PTV breast were evaluated by comparing the CN and HI of the 8 plans with the reference plans using the Wilcoxon rank test. It was observed that CN of PTVb was not significantly different from the reference plan for the 3 plans 1_0.287, 1_0.43 and 2.5_0.215, but the remaining 5 plans (2.5_0.287, 2.5_0.43, 5_0.215, 5_0.287 and 5_0.43) were significantly worse. The CN of PTVbw is not significantly different up to 2.5_0.287 but all the remaining plans showed significantly worse values.

But HI_PTVb shows no significant different for all the plans and HI_PTVbw shows significant difference for all the 2.5 and 5cm plans except 1cm plans.

Figure 1: Comparison of OAR DVH for different field width; 1 cm (dotted), 2.5 cm (dash) and 5 cm (line).

Figure 2: Comparison of PTV DVH for different field width; 1 cm (green), 2.5 cm (brown) and 5 cm (black).
Ipsilateral lung

For value of D_{mean}, there was no significant difference in all the 2.5 plans but it was worse for all 5cm plans. There is significant variation in V_{20} value for all the plans except for the plan 2.5_0.215 (Table 4).

Contra-lateral lung

The mean dose was significantly higher for all 5cm plans though it was not significant for all the 2.5 plans. However, all values were less than 2.5 Gy and met the dose constraint. Similarly, D_{max} was significantly increased for all the 5cm plans.

Heart

There was no significant variation in dose constraints for most of the plans with respect to the reference plan.

The value of D_{mean} and D_{max} was not significantly higher for plans upto 5cm_0.215 but was significantly higher for 5cm_0.287 and 5cm_0.43 plans. Similarly, for left sided tumor, the value of V_{13} was not significantly changed from the reference plan for all the plans with 2.5 and 5cm.

Contra-lateral breast

<table>
<thead>
<tr>
<th>Field Width</th>
<th>FW=1 cm</th>
<th>FW=2.5 cm</th>
<th>FW=5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>OAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ipsilateral Lung</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V_{20} (%)</td>
<td>8.67 ± 1.36</td>
<td>8.76 ± 1.30</td>
<td>8.59 ± 1.40</td>
</tr>
<tr>
<td>D_{mean} (Gy)</td>
<td>8.89 ± 1.51</td>
<td>8.78 ± 1.41</td>
<td>8.82 ± 1.45</td>
</tr>
<tr>
<td>D_{max} (Gy)</td>
<td>51.9 ± 4.51</td>
<td>52.2 ± 4.51</td>
<td>52.2 ± 4.51</td>
</tr>
<tr>
<td>Contralateral Lung</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D_{mean} (Gy)</td>
<td>1.76 ± 0.47</td>
<td>1.82 ± 0.52</td>
<td>1.81 ± 0.52</td>
</tr>
<tr>
<td>D_{max} (Gy)</td>
<td>8.51 ± 2.82</td>
<td>8.71 ± 2.78</td>
<td>8.83 ± 2.77</td>
</tr>
<tr>
<td>V_{5} (PTV Right side) (%)</td>
<td>1.07 ± 2.20</td>
<td>1.24 ± 2.08</td>
<td>1.24 ± 2.00</td>
</tr>
<tr>
<td>V_{5} (PTV Left side) (%)</td>
<td>2.64 ± 1.87</td>
<td>3.26 ± 2.96</td>
<td>3.75 ± 3.92</td>
</tr>
<tr>
<td>Heart (PTV Right side)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D_{max} (Gy)</td>
<td>1.81 ± 0.68</td>
<td>1.77 ± 0.58</td>
<td>1.76 ± 0.58</td>
</tr>
<tr>
<td>V_{13} (%)</td>
<td>5.3 ± 2.35</td>
<td>5.41 ± 1.21</td>
<td>5.5 ± 2.62</td>
</tr>
<tr>
<td>D_{max} (Gy)</td>
<td>27.08 ± 3.72</td>
<td>27.51 ± 3.50</td>
<td>26.93 ± 3.11</td>
</tr>
<tr>
<td>Contralateral breast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D_{mean} (Gy)</td>
<td>1.52 ± 0.40</td>
<td>1.55 ± 0.45</td>
<td>1.55 ± 0.47</td>
</tr>
<tr>
<td>D_{max} (Gy)</td>
<td>8.49 ± 1.12</td>
<td>8.53 ± 1.12</td>
<td>8.56 ± 1.13</td>
</tr>
<tr>
<td>V_{5} (Left side) (%)</td>
<td>2.14 ± 0.97</td>
<td>2.54 ± 0.98</td>
<td>2.53 ± 1.04</td>
</tr>
<tr>
<td>V_{5} (Right side) (%)</td>
<td>0.76 ± 0.49</td>
<td>0.78 ± 0.43</td>
<td>0.75 ± 0.54</td>
</tr>
</tbody>
</table>

Table 3: Treatment time.

Table 4: Average dose volume parameters for all the OARs in different plans.
pitch values showed no significant difference in the treatment time. When the pitch is increased from 0.215-0.43, mean reduction in treatment time is 0.23 min as the gantry rotation period increases. So, the effect of pitch on treatment time is very minimal and the field width is the main parameter that has the greatest impact on it. It is in agreement to the planning study done by other authors [10,11]. The average treatment time reduces by four times when FW is increased from 1.0cm to 5.0cm (Table 3). A long treatment time of 20 minutes disqualifies the plans with 1cm FW from clinical practice. The shorter treatment time given by 5cm FW would have been ideal but certain dosimetric disadvantages arise with respect to the conformity and low dose spillage. As per our analysis in terms of rank, plan 2.5_0.215 is the best deliverable plan.

An optimum modulation factor that should be arbitrarily chosen for starting planning would range between 3-3.5 [10]. In general, a greater modulation factor facilitates greater dose gradients; however, the benefit of increasing the modulation factor quickly diminishes once it increases beyond this range. Fiorino et al also used a modulation factor of 3-3.5 in complex planning of simultaneous integrated boost for radically treated patients of prostate with nodes while he had used a modulation factor of 2-2.5 in simple planning of prostate alone without nodes [12]. Higher modulation factors lead to longer treatment times [9]. Ryczkowski A et al had found out that the optimal range of MF for head and neck was determined as 3.0>MF>1.8 [13]. Very high values of MF can lead to hot spots in healthy tissues and modification structures or dummy structures should be drawn outside the OARs to avoid unwanted high doses outside the PTV. Though the modulation factor was arbitrarily set to 3 for all the plans in our study, the average
modulation factors achieved were less than 2 (average value 1.717 with SD=0.20). Several authors have already reported similar to us that the final MF value is less than the value calculated after each loop of optimization.

Yi Rong et al [14] had reported that the thread effects are distinct without sufficient iterations of optimization. Though higher number of iterations might improve plan quality, it is at the cost of increased planning and delivery time. Adrian Nalichowski et al had optimized the plans with a fixed number of iterations in their planning study [15]. So keeping 1000 iteration fixed for all plans we assume that the set constraints will give same quality of plan.

The doses to the OARs were not significantly different for 2.5cm FW plans from the 1cm FW plans except V_5 values. However, the absolute difference in V_5 was very less and the respective OAR constraints were very well satisfied (Table 6). An optimal pitch appears to be 0.215 or 0.287. A pitch value of 0.43 does not offer any dosimetric advantage.

<table>
<thead>
<tr>
<th>Field width</th>
<th>1 cm</th>
<th>2.5 cm</th>
<th>5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>OARs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D_{MEAN}</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>D_{MAX}</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>V_{5}</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 6: Difference of OARs’ dose and volume with respect to the reference plan.

Figure 4: 25 Gy (pink) and 5 Gy (cyan) Dose spillage for different plans in the coronal slice.
patients with left sided tumor in comparison with the patients of right sided tumor. This could be due to the fact that isodose horns are created in an attempt to reduce the heart dose in left sided tumor, and thereby giving higher dose spill into the contra-lateral breast and contra-lateral lungs.

The use of a 5cm field width instead of a 2.5cm field width for Tomotherapy would reduce treatment time with 30–50%, but that might cause worse dosimetry and wider dose spread in the patient superior and inferior to the target [16]. In our study also, 23-47% spillage of low doses in 5cm FW plans was seen as compared to 9-14% for 2.5cm FW plans. Our finding is matching with Sko´rska M et al [10] who has also reported the dose fall off in the longitudinal direction because of dose deposition in tissues several centimetres below and above the PTV (Figure 4 and 5).

Conclusion

We have performed dosimetric comparisons among the treatment plans as a function of pitch and FW. By applying small FW, tighter pitch and large MF values, it is possible to get a sophisticated treatment plan with a very long treatment time. However, this results in two adverse outcomes: patient discomfort (to lie down static during irradiation) and inherent organ movement due to breathing. Moreover the daily number of patients for treatment or machine throughput will also be reduced. From the above study, it is shown that changing pitch does not help in reduction of treatment time but the plan quality is slightly compromised. On the basis of our analysis, 2.5_0.215 plan with MF=3, can be considered as the optimum plan for unilateral breast treatment using Tomotherapy.

References