Quantification of Cold Spots Caused by Geometrical Uncertainty in Field-in-field Techniques for Whole Breast Radiotherapy

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Objective: To quantify the cold spot under geometrical uncertainties in field-in-field techniques for whole breast radiotherapy.

Methods: Ten consecutive patients from both the left- and right-sided treatment site groups who received whole breast radiotherapy with the field-in-field technique were included. Virtual plans were made with moving isocenters to the posterior direction having two amplitudes (5 and 10 mm) and prescribing the same monitor unit as the original plan (FIF_5 and FIF_10). The planning target volume for evaluation was defined by subtracting the areas within 5 mm from the skin and within 5 mm from the lung from the whole breast. The differences in V90, V95 and D98 of planning target volume for evaluation were measured between the original and virtual plans. As a reference, the same measurements were taken for the wedge techniques (Wedge_5 and Wedge_10).

Results: The differences in V95 were –0.2% on FIF_5, –1.7% on FIF_10, –0.5% on Wedge_5 and –1.5% on Wedge_10. The differences in V90 were –0.02% on FIF_5, –0.3% on FIF_10, –0.05% on Wedge_5 and –0.1% on Wedge_10. The differences in D98 were 0 Gy on FIF_5, –0.1 Gy on FIF_10, –0.2 Gy on Wedge_5 and –0.4 Gy on Wedge_10. The differences in D98 between the original plans and virtual scenarios for field-in-field techniques were significantly smaller than those for wedge techniques, but there were no statically significant differences in V90 and V95.

Conclusions: The quantity of the cold spots caused by the geometrical uncertainties in field-in-field techniques was similar to that for the wedge techniques and was acceptable.

Key words: breast cancer – radiotherapy – whole breast radiotherapy – field-in-field technique – geometrical uncertainty

INTRODUCTION

Whole breast radiotherapy has been widely used after breast-conserving surgery to prevent local recurrence in patients with early breast cancer. A tangential parallel-opposed technique is used for whole breast radiotherapy. Achieving acceptable dose homogeneity across the whole breast volume is difficult because of the continuous change in breast shape across multiple planes and the effect of the lung tissues that are included in the irradiated volume (1, 2).

Several groups have reported that the field-in-field (FIF) technique can reduce dose inhomogeneity in whole breast radiotherapy (3–7). FIF is a forward planning intensity modulating technique. Fields are created using multileaf collimator (MLC) leaves such that the leaves are strategically placed in areas where the dose to the breast is considerably higher than the prescription dose, otherwise known as hot spots (7). However, geometrical uncertainties arising from set-up errors and respiratory motion are not considered in this
strategy. If the MLC leaves are tilted to the posterior direction because of the geometrical uncertainties, cold spots where the dose to the breast is considerably lower than the prescription dose may arise.

We evaluated the quantities of cold spots caused by geometrical uncertainties in FIF techniques for whole breast radiotherapy compared with wedge plans.

PATIENTS AND METHODS

Ten consecutive patients from both the left- and right-sided treatment site groups who received whole breast radiotherapy with the FIF technique at St Luke’s International Hospital were included in this study. Computed tomographic scans were performed with a LightSpeed RT16 (GE Healthcare) helical scanner and 5 mm slice thickness without breath holding. All patients were treated with 4 MV X-ray. All patients were treated with four fields, two of which were reduction fields to eliminate hot spots where the doses are higher than 107–110% of the prescription dose (Fig. 1). The treatment machine was CLINAC21EX (Varian) which has 1 cm thick MLCs. The treatment planning system (TPS) was Pinnacle ver. 8.0 m (Phillips).

We have in-house regulations to ensure the accuracy of the TPS when we use FIF techniques: do not put MLC leaves within 1 cm from the reference point, the minimum monitor unit (MU) in each field is 5, do not make any part of the field narrower than 2 cm, and the proportion of field blocked by MLC leaves must be <50%.

Virtual plans were made on the TPS by moving isocenters to the posterior direction with two amplitudes (5 and 10 mm) and prescribing the same MU as in the original plan (FIF_5 and FIF_10) (Fig. 1). The planning target volume for evaluation (PTV_EV) was defined by subtracting the areas within 5 mm from the skin and within 5 mm from the lung from the whole breast (Fig. 2). The differences in the percentages of the volume of the PTV_EV which receive more than 90 and 95% of the prescribed dose (V90 and V95) and the doses received by 98% of the PTV_EV (D98) were compared between the original and virtual plans. As a reference,
virtual plans using a physical wedge with a 15° angle were made and the same measurements were taken on the same 20 patients (Wedge_5 and Wedge_10).

The calculation algorithm was CC Convolution. The grid size of the calculation matrix was 2 mm.

We used GraphPad Prism version 5 (GraphPad Software Inc.) for statistical analysis. The paired t-test was used to compare the results for FIF and wedge techniques. Differences were deemed significant when two-tailed P values were <0.05.

RESULTS

The mean total MU was 236 (range: 227–250) per 2 Gy. The mean percentage of MU of the reduction fields was 5.5% (4.3–7.5). The mean V90, V95 and D98 of the PTV_EV on FIF techniques were 99.2% (94.9–100), 92.4% (72.2–99.5) and 46.4 Gy (44.1–48.3), respectively, whereas the mean V90, V95 and D98 on wedge plans were 99.8% (97.9–100), 96.5% (82.8–100) and 47.4 Gy (45.0–49.0), respectively (Tables 1 and 2). The differences in D98 between the original plans and virtual scenarios for FIF techniques were significantly smaller than those for wedge techniques (Table 3). No statistically significant differences were observed in the differences in V90 and V95 between plans for FIF techniques and those for wedge techniques (Table 3).

DISCUSSION

To the best of our knowledge, this is the first report to focus on the dosimetric impact of geometrical uncertainties in FIF techniques for whole breast radiotherapy. Several groups have reported that geometrical uncertainties have a considerable impact on intensity-modulated radiation therapy (IMRT) dose distributions (8–11). Although the FIF technique is a kind of
IMRT, our results showed that the quantity of the cold spots caused by geometrical uncertainties in FIF techniques for whole breast radiotherapy was similar to that in wedge plans. This might be partly because the proportion of the reduction fields was quite low. Most patients do not need a high MU for reduction fields, but caution might be needed when the proportion of the reduction fields is a little larger. Several groups have reported that the FIF technique can reduce dose inhomogeneity in whole breast radiotherapy compared with that using physical wedge techniques (3–7).

### Table 2. V95, V90 and D98 of the PTV_EV on wedge plans for each patient

<table>
<thead>
<tr>
<th>Patient #</th>
<th>Monitor unit</th>
<th>V95 (%)</th>
<th>V90 (%)</th>
<th>D98 (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>W_0</td>
<td>W_5</td>
<td>W_10</td>
</tr>
<tr>
<td>R-1</td>
<td>322</td>
<td>96.1</td>
<td>96.4</td>
<td>96.1</td>
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<tr>
<td>R-2</td>
<td>316</td>
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<td>96.7</td>
<td>95.2</td>
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<td>R-3</td>
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<td>100.0</td>
<td>99.9</td>
<td>99.8</td>
</tr>
<tr>
<td>R-4</td>
<td>323</td>
<td>99.9</td>
<td>99.9</td>
<td>99.9</td>
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<tr>
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<td>99.4</td>
<td>98.8</td>
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<tr>
<td>R-6</td>
<td>310</td>
<td>88.1</td>
<td>85.8</td>
<td>82.6</td>
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<tr>
<td>R-7</td>
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<td>99.7</td>
<td>99.7</td>
<td>99.6</td>
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<tr>
<td>R-8</td>
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<td>96.2</td>
<td>95.7</td>
<td>95.0</td>
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<td>94.8</td>
<td>94.0</td>
<td>92.5</td>
</tr>
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<td>R-10</td>
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<td>98.4</td>
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<td>L-1</td>
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<td>93.2</td>
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<td>L-10</td>
<td>314</td>
<td>97.4</td>
<td>97.2</td>
<td>96.6</td>
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<td>Average</td>
<td>320</td>
<td>96.5</td>
<td>96.0</td>
<td>95.0</td>
</tr>
</tbody>
</table>

V95 (90) is the percentage of the PTV_EV that receives more than 95% (90%) of the prescribed dose; D98 is the dose received by 98% of the PTV_EV; Wedge_0, Wedge_5 and Wedge_10 are the virtual plans for a physical wedge, moving isocenters to the posterior direction by 0, 5 and 10 mm, respectively; numbers are shown in italics when the values are smaller than those on Wedge_0.

### Table 3. The mean differences (range) of V95, V90 and D98 between original plans and virtual scenarios

<table>
<thead>
<tr>
<th></th>
<th>V95 (%)</th>
<th>V90 (%)</th>
<th>D98 (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIF_5</td>
<td>0.2% (-2.1 to 2.8)</td>
<td>-0.02% (-0.1 to 0)</td>
<td>0 Gy (-0.1 to +0.3)</td>
</tr>
<tr>
<td>Wedge_5</td>
<td>-0.5% (-2.3 to -0.4)</td>
<td>-0.05% (-0.5 to -0.1)</td>
<td>-0.2 Gy (-0.3 to 0.2)</td>
</tr>
<tr>
<td>P</td>
<td>0.28</td>
<td>0.3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>FIF_10</td>
<td>-1.7% (-5.7 to -2.1)</td>
<td>-0.3% (-3.1 to -0.6)</td>
<td>-0.1 Gy (-0.9 to 0.2)</td>
</tr>
<tr>
<td>Wedge_10</td>
<td>-1.5% (-5.5 to -0.3)</td>
<td>-0.1% (-1.2 to -0.1)</td>
<td>-0.4 Gy (-0.6 to 0.2)</td>
</tr>
<tr>
<td>P</td>
<td>0.76</td>
<td>0.38</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

V95 (90) is the percentage of the volume of the PTV_EV which receives more than 95% (90%) of the prescribed dose; D98 is the dose that 98% of the PTV_EV receives; FIF_5 (FIF_10) is the virtual plan for FIF techniques with moving isocenters to the posterior direction with 5 (10 mm); Wedge_5 (Wedge_10) is the virtual plan for a physical wedge, moving isocenters to the posterior direction by 5 (10 mm). The bold values indicate statistically significant differences.
An additional benefit of using the FIF technique is that FIF techniques can reduce MU and dose in the contralateral breast. Lee et al. (3) have reported that the volumes in the contralateral breast that receive more than 2 Gy with a prescription dose of 50.4 Gy were 0.3% for FIF techniques, but 2.0% for physical wedge techniques \( (P < 0.01) \). By using the FIF techniques, the incidence of radiation-induced contralateral breast cancer might be reduced.

The possible disadvantage of using the FIF techniques is that FIF techniques may increase the uncertainties of dose calculation on the TPS. If we use fields that are too small or too irregular as the reduction fields, the TPS may not calculate the MU and the dose distributions accurately. Furthermore, if we prescribe MU that is too small, the output from the linear accelerator may become unstable. In such cases, dosimetric verification should be done for each plan. For this reason, we regulate the in-house protocol as described in the Patients and Methods section to ensure the accuracy of the TPS when we use FIF techniques in order to eliminate the necessity of dosimetric verification for individual plans.

A limitation of this study is that it evaluated a small series of patients and does not have sufficient statistical power to recognize potential differences in V90 and V95 between plans for FIF techniques and those for wedge techniques. Nevertheless, the outcomes of this study offer some guidance to clinicians in an area where data are lacking and show that the quantity of cold spots caused by geometrical uncertainties in FIF techniques is similar to that using wedge techniques.

In conclusion, the quantity of cold spots caused by geometrical uncertainties in FIF techniques for whole breast radiotherapy was similar to that on for the wedge techniques and was acceptable.

**Conflict of interest statement**

None declared.

**References**