Dosimetric comparison for volumetric modulated arc therapy and intensity-modulated radiotherapy on the left-sided chest wall and internal mammary nodes irradiation in treating post-mastectomy breast cancer

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Background. The aim of the study was to evaluate the dosimetric benefit of applying volumetric modulated arc therapy (VMAT) on the post-mastectomy left-sided breast cancer patients, with the involvement of internal mammary nodes (IMN).

Patients and methods. The prescription dose was 50 Gy delivered in 25 fractions, and the clinical target volume included the left chest wall (CW) and IMN. VMAT plans were created and compared with intensity-modulated radiotherapy (IMRT) plans on Pinnacle treatment planning system. Comparative endpoints were dose homogeneity within planning target volume (PTV), target dose coverage, doses to the critical structures including heart, lungs and the contralateral breast, number of monitor units and treatment delivery time.

Results. VMAT and IMRT plans showed similar PTV dose homogeneity, but, VMAT provided a better dose coverage for IMN than IMRT (p = 0.017). The mean dose (Gy), V30 (%) and V10 (%) for the heart were 13.5 ± 5.0 Gy, 9.9% ± 5.9% and 50.2% ± 29.0% by VMAT, and 14.0 ± 5.4 Gy, 10.6% ± 5.8% and 55.7% ± 29.6% by IMRT, respectively. The left lung mean dose (Gy), V20 (%), V10 (%) and the right lung V5 (%) were significantly reduced from 14.1 ± 2.3 Gy, 24.2% ± 5.9%, 42.4% ± 11.9% and 41.2% ± 12.3% with IMRT to 12.8 ± 1.9 Gy, 21.0% ± 3.8%, 37.1% ± 8.4% and 32.1% ± 18.2% with VMAT, respectively. The mean dose to the contralateral breast was 1.7 ± 1.2 Gy with VMAT and 2.3 ± 1.6 Gy with IMRT. Finally, VMAT reduced the number of monitor units by 24% and the treatment time by 53%, as compared to IMRT.

Conclusions. Compared to 5-beam step-and-shot IMRT, VMAT achieves similar or superior target coverage and a better normal tissue sparing, with fewer monitor units and shorter delivery time.

Key words: breast cancer; radiotherapy; VMAT; IMRT

Introduction

Among the most commonly diagnosed cancers, breast cancer alone accounts for 29% of all new cancers among women in 2014. Most early-stage patients can be treated with breast conserving surgery, adjuvant radiotherapy or systemic treatment combined with neoadjuvant chemotherapy. However, patients with the advanced conditions usually receive mastectomy and postoperative ra-
diotherapy. It has been shown that adjuvant post mastectomy radiotherapy (PMRT) is efficient in reducing locoregional recurrence rate, and improving 10-year overall survival rate in patients with lymph node-positive breast cancer.\(^3,4\)  

However, there is a dosimetric challenge to deliver an uniform target dose to the patient with three-dimensional conformal radiotherapy (3D-CRT) if internal mammary node (IMN) is involved, especially in the patients with left-sided breast cancer.\(^9,10\) In order to achieve better cosmetic results and decrease the toxicity in normal tissues, the intensity modulated radiation therapy (IMRT) has been widely implemented in the clinic to improve the target dose homogeneity and conformity for breast cancer treatment as well as spare the irradiation doses of normal tissues.\(^11\)  

Compared to the 3D-CRT, Van der Laan et al. reported that the IMRT technique improved the chest wall (CW) and IMN dose coverage and reduced the cardiac dose. Previously, we conducted a similar study in 30 patients with left-sided post-mastectomy breast cancer, and the results showed that the conformity index of IMRT was better than that of 3D-CRT and IMRT increased the low-dose volume of normal tissue.\(^14,15\)  

Volumetric modulated arc therapy (VMAT), a novel technique that delivers the radiation dose to the target in a single or multiple gantry rotations, has been used in the treatment of many cancers sites, such as prostate, head and neck, and Hodgkin lymphoma.\(^16\) Some dosimetric studies compared VMAT with other techniques in treating breast cancer patients.\(^21\)  

In the present dosimetric study, one step-and-shoot IMRT and one VMAT treatment plan were created for each patient within the Pinnacle treatment planning system with the same dose optimisation.  

## Target definitions

The clinical target volume (CTV) of CW (CTV\(_{CW}\)) and IMN (CTV\(_{IMN}\)) was delineated according to the Radiation Therapy Oncology Group (RTOG) breast cancer consensus definitions. The CTV\(_{IMN}\) was contoured from the superior aspect of the medial first rib to the forth one by encompassing the internal mammary/thoracic vessels. A margin of 10 mm was added to CTV\(_{CW}\) and CTV\(_{IMN}\) to define the planning target volume of CW (PTV\(_{CW}\)) and IMN (PTV\(_{IMN}\)). Total PTV (PTV\(_{total}\)) consisted of PTV\(_{CW}\) and PTV\(_{IMN}\). All the PTV\(_{CW}\) PTV\(_{IMN}\) and PTV\(_{total}\) were limited to the skin surface. The organs at risk were also outlined: the heart contoured from the first CT slice below the pulmonary artery to the apex inferiorly; the entire ipsilateral and contralateral lung contoured; and the contralateral breast outlined based on the visible breast parenchyma.

## Treatments

The treatments were planned for delivery on an Elekta Synergy linear accelerator (Elekta Oncology System, Crawley, UK) with 1-cm width multileaf collimator (MLC). A 5 mm tissue-equivalent bolus was placed on the patient’s skin with the coverage of PTV and surgical scar to increase the skin dose. The dose was calculated using the collapse cone superposition convolution algorithm with inhomogeneity correction.

In the present dosimetric study, one step-and-shoot IMRT and one VMAT treatment plan were created for each patient within the Pinnacle treatment planning system with the same dose optimi-
zation objectives. The isocenter was placed at the center of the PTV. The prescription dose was 50 Gy in 25 fractions. The plan quality for both treatment techniques was evaluated against the following criteria: at least 95% of the PTV volume receiving 50 Gy, 95% of the prescription dose ($V_{95\%}$) covering at least 99% of the PTV volume; the hot spot defined as PTV receiving more than 110% of prescription dose as little as possible; less than 20% of the left lung to 20 Gy ($V_{20}$); less than 10% of the heart to 30 Gy ($V_{30}$); a minimized dose to the contralateral lung and breast since some of the beams could penetrate the patient’s right lung and right breast.

A step-and-shoot IMRT plan with 5 beams (300, 0, 40, 80 and 110 degree) was created for each patient. The optimization was performed using the direct machine parameter optimization (DMPO) technique with preset parameters of minimum 3 monitor units, minimum 3 cm² segment area and maximum 50 segments. Before the final dose calculation, the MLC leaves were manually pushed outside of the patient’s skin by 1 cm if they blocked only the air part in the beam’s eye view.

The SmartArc in Pinnacle was used for the VMAT planning. One or two 200 degree partial arcs (gantry rotated from 310 to 150 degrees) and 15 degree collimator rotation were utilized to generate VMAT plans. A 4-degree resolution was used for the final dose calculation. For the purpose of fair plan comparison, several step-and-shoot IMRT and SmartArc VMAT plans were created for the initial 3 patients and the best IMRT and VMAT plans were selected for dose volume histogram (DVH) data analysis. Then, the optimization parameters for the best plans were used for the following patients and all the required DVH data were obtained.

The DVHs of the PTV total, PTV IMN, lungs, heart and contralateral breast were derived from the IMRT and VMAT plans. For the targets were calculated the $D_{98}$ (the minimum dose received by 98% of the target volume), $D_2$ mean dose, dose homogeneity index (HI), $V_{90\%}$ (percentage of the PTV receiving at least 90% of the prescription dose) and $V_{85\%}$. $D_{98}$ and $D_2$ were used to evaluate the minimal and maximal dose to the target, respectively. The homogeneity index was calculated as follows:

$$HI = \frac{(D_2 - D_{88})}{D_p} \times 100\%$$

where the $D_p$ is the prescription dose, and lower HI means better homogeneity. Additionally, the $V_{10\%}$ and $V_{5\%}$ for the PTV IMN were also recorded. For the critical structures, the mean dose, $D_{9\%}$, $V_9$ and $V_{10}$ of the heart, and $V_{20\%}$, $V_9$, $V_{10}$ and mean dose.
of the ipsilateral lung, $V_x$ and mean dose of the contralateral lung and mean dose of the contralateral breast were calculated. Number of monitor units and treatment delivery time were also calculated. Dry runs were performed for all the plans.

Statistical analysis

The results were represented as mean ± standard deviation (SD). Statistical analysis was performed using SPSS 17.0 software (Chicago, IL, USA). The two-sided paired $t$ test was used when the datasets were normally distributed. Otherwise, datasets were compared by Wilcoxon Cox test. The $p$ value less than 0.05 was considered statistically significant.

Results

Target coverage

The mean volume of $PTV_{\text{total}}$ was 212 cm$^3$ (90 to 425 cm$^3$). A dose distribution is shown in Figure 1 and the corresponding DVHs in Figure 2 for a typical patient. The differences in the $PTV_{\text{total}}$ coverage and dose homogeneity between two techniques were of no statistical significance, $V_{95\%}$ being 99.1% ± 1.1% with VMAT and 98.9% ± 1.1% with IMRT ($p = 0.363$); the similar maximum dose of $PTV_{\text{total}}$ defined as one in 2% of the target volume, i.e. $D_{2}$, 55.6 ± 2.2 Gy with IMRT and 55.4 ± 1.7 Gy with VMAT, respectively; and the dose homogeneity index being 0.15 with both VMAT and IMRT (Table 1).

As for the dosimetric comparison data for the smaller $PTV_{\text{IMN}}$, the VMAT plans provided a better IMN coverage than the IMRT ones, the mean values of $V_{95\%}$ were 99.2% ± 1.8% and 98.1% ± 2.9% with VMAT and IMRT, respectively ($p = 0.017$). Although there was no significant difference in $PTV_{\text{IMN}}$ mean doses, the VMAT plans seemed to develop more homogeneous dose distribution in the IMN. The minimal dose to $PTV_{\text{IMN}}$ (D$_{98}$) with VMAT was higher than that with IMRT (45.3 ± 6.9 Gy for VMAT vs. 41.7 ± 5.4 Gy for IMRT) ($p = 0.016$). The mean $HI$ was found to be 0.13 ± 0.06 with VMAT and 0.15 ± 0.06 with IMRT ($p = 0.048$). Both techniques presented comparable hot spots as the $p$ values for $V_{110\%}$ and $V_{115\%}$ were 0.421 and 0.334, respectively (Table 1).

Normal tissue sparing

In terms of the doses to the normal tissues for the two treatment techniques, VMAT slightly reduced the mean dose to the heart, 13.5 ± 5.5 Gy for VMAT vs. 14.0 ± 5.3 Gy for IMRT ($p = 0.792$). Meanwhile, it did not show any significant differences in heart $V_{30}$ and $V_{5}$, as well as in $V_{10}$ compared with IMRT (50.2% ± 29.0% with VMAT vs. 55.7% ± 29.6% with IMRT, $p = 0.611$) (Table 2).

It was also found that the VMAT plans achieved lower mean dose to the left lung than the IMRT ones, i.e., 12.8 ± 1.9 Gy vs. 14.0 ± 2.3 Gy for IMRT ($p = 0.001$). Moreover, the values of left lung $V_{30}$, $V_{10}$ and $V_{5}$ were 21.0% ± 3.8%, 37.1% ± 8.4%, 61.1% ± 18.0% for VMAT, and 24.2% ± 5.9%, 42.4% ± 11.9%, 66.0% ± 15.5% for IMRT. There was no significant difference in the mean dose of right lung, but VMAT plans achieved lower $V_{5}$ to the right lung, as compared to IMRT (32.1% ± 18.2% with VMAT vs. 41.2% ± 12.3% with IMRT, $p = 0.034$). The mean dose to the contralateral breast was 1.7 ± 1.2 Gy and 2.3 ± 1.6 Gy, respectively ($p = 0.001$) (Table 2).

Monitor units and treatment delivery time

The dose rate for IMRT was 512 MU/min, and the maximum dose rate for VMAT was 512 MU/min.
The mean number of MU for VMAT plans was 462 (range, 380 to 590 MU) compared to 604 (range, 488 to 850 MU) for IMRT. The mean treatment time for one arc was 2.0 minutes, and the mean treatment time to deliver two arcs was 4.20 minutes (range, 4.1 to 4.3 minutes) compared to 9.0 minutes (range, 8.7 to 11.2 minutes) for IMRT.

**Discussion**

IMRT and VMAT can shape the dose to the concave target in the CW and IMN in breast cancer radiotherapy. In the current study, we reported a dosimetric comparison between the two techniques on 15 cases of left-sided breast cancer. The step-and-shoot IMRT plans using DMPO technique and the VMAT plans using the SmartArc were used in the Pinnacle treatment planning system. In our study, CT images were acquired base on a CT scanner with a slice thickness of 5 mm. Though the widths of slices are usually 2-3 mm, CT scan could also be performed using 5 mm slice thickness to evaluate the dose distribution of IMRT.

**Target coverage**

It has a benefit in maximizing efficacy and improving local control to ensuring homogeneous dose coverage of PTV by avoiding areas of under dose (‘cold spots’, PTV receiving less than 90% of prescription dose), and at the same time eliminating areas of relative overdose (‘hot spots’), minimizing normal long-term tissue toxicity (skin changes and fibrosis) which negatively affect cosmesis. In our study, the IMRT and VMAT plans showed similar PTV total coverages and both avoided the hot spots successfully. However, the VMAT had a better dose homogeneity in the PTV by reducing the “cold spot”, which might decrease the local recurrence in the IMN area.

The radiotherapy target volume includes the CW, supraclavicular fossa and IMN with or without the axilla. Though the inclusion of the supraclavicular region in the post-mastectomy

<table>
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<tr>
<th>Structure</th>
<th>Parameters</th>
<th>IMRT</th>
<th>VMAT</th>
<th>VMAT/IMRT</th>
<th>p value</th>
</tr>
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<tr>
<td>Heart</td>
<td>Mean dose</td>
<td>14.0 ± 5.3</td>
<td>13.5 ± 5.0</td>
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<td>V&lt;sub&gt;30&lt;/sub&gt; (%)</td>
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<td>9.9 ± 5.9</td>
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<td>55.7 ± 29.6</td>
<td>50.2 ± 29.0</td>
<td>0.89 ± 0.12</td>
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<td></td>
<td>V&lt;sub&gt;5&lt;/sub&gt; (%)</td>
<td>77.0 ± 21.1</td>
<td>78.0 ± 20.1</td>
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<td>Left Lung</td>
<td>Mean dose</td>
<td>14.1 ± 2.3</td>
<td>12.8 ± 1.9</td>
<td>0.91 ± 0.05</td>
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<tr>
<td></td>
<td>V&lt;sub&gt;30&lt;/sub&gt; (%)</td>
<td>24.2 ± 5.9</td>
<td>21.0 ± 3.8</td>
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<td>V&lt;sub&gt;50&lt;/sub&gt; (%)</td>
<td>42.4 ± 11.9</td>
<td>37.1 ± 8.4</td>
<td>0.89 ± 0.09</td>
<td>0.001</td>
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<td>V&lt;sub&gt;5&lt;/sub&gt; (%)</td>
<td>66.0 ± 15.5</td>
<td>61.1 ± 18.0</td>
<td>0.92 ± 0.07</td>
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<tr>
<td>Right Lung</td>
<td>Mean dose</td>
<td>4.67 ± 0.93</td>
<td>4.49 ± 1.06</td>
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<td>0.409</td>
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<td>V&lt;sub&gt;5&lt;/sub&gt; (%)</td>
<td>41.2 ± 12.3</td>
<td>32.1 ± 18.2</td>
<td>0.71 ± 0.31</td>
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<tr>
<td>Right Breast</td>
<td>Mean dose</td>
<td>2.3 ± 1.6</td>
<td>1.7 ± 1.2</td>
<td>0.70 ± 0.04</td>
<td>0.002</td>
</tr>
</tbody>
</table>

IMRT = intensity-modulated radiotherapy; SD = standard deviation; V<sub>30</sub> = the percentage of the lung volume which receives radiation doses of 30 Gy; VMAT = volumetric modulated arc therapy

**Table 2.** Comparison parameters of normal tissue with VMAT or IMRT (mean ± SD)
Partial breast irradiation patients.35 In this study, better dose conformity than 3D-CRT technique for er doses to the ipsilateral breast and lung and offer Moreover, VMAT has been revealed to deliver low-.

Rudat was significantly lower than 3D-CRT levels for pa-
cer. It has been reported that the heart V30 of IMRT
patients, especially those with left-sided breast can-
Therefore, it is critical to limit the heart dose in pa-
plan had a significant reduction in the V20, V 10,
rameter in our centre. We found that the VMAT
V5 or the mean dose in the left lung than IMRT. These re-
sults strongly suggested that the VMAT technique
also reported that the complication rate could be
expected to be 20% if more than 50% of the lung
volume received 10 Gy.29 We selected V20 < 20%
as a criterion since it is also an optimization pa-
parameter in our centre. We found that the VMAT
right lung sparing compared with IMRT. These re-
results strongly suggested that the VMAT technique
achieve better sparing of the lung. It has been reported that the V30 and mean dose to the lung are good predictors for radiation induced lung toxicity.26 Also, an analysis of non-small-cell lung cancer has shown that the V5 is a significant cut off point for the subsequent development of pneumonitis.27 When it comes to the breast cancer, it was found that clinically significant pneumoni-
tis was rare if the V20 of ipsilateral lung was less
30% for breast cancer patients.28 It has been
also reported that the complication rate could be
expected to be 20% if more than 50% of the lung
volume received 10 Gy.29 We selected V20 < 20%
as a criterion since it is also an optimization pa-
parameter in our centre. We found that the VMAT
V20, V10, V5 or the mean dose in the left lung than IMRT.
Also, the VMAT showed the superior or similar
right lung sparing compared with IMRT. These re-
results strongly suggested that the VMAT technique
achieve better sparing of the lung.

It has been reported that the use of 3D-CRT and
IMRT techniques in the treatment of breast cancer
could reduce the cardiac dose and cardiac mortal-
However, the potential cardiac toxicity was increased dramatically owing to the widespread
use of anthracyclines, taxanes and trastuzumab.32,33
Therefore, it is critical to limit the heart dose in pa-
ients, especially those with left-sided breast can-
cancer. It has been reported that the heart V30 of IMRT
was significantly lower than 3D-CRT levels for pa-
ents underwent left-sided mastectomy.14 Rudat et al.
have found that IMRT significantly reduced the ipsilateral lung dose and heart dose in 20 sub-
sequent post mastectomy breast cancer patients.44
Moreover, VMAT has been revealed to deliver lower
doses to the ipsilateral breast and lung and offer
better dose conformity than 3D-CRT technique for
partial breast irradiation patients.35 In this study,
the dose to the heart for IMRT and VMAT was similar.
The dose to the contralateral breast is another
critical factor to consider, especially in younger
women who received RT. Previous studies showed
that there was an elevated long-term risk of de-
veloping the secondary contralateral breast can-
cer, and the mean dose to the contralateral breast
was 3.2 Gy with RapidArc.23,36 In our study, a
slightly lower mean dose of 1.7 Gy was observed
with VMAT, which may be the results of differ-
ent dose calculation algorithms or inhomogeneity
correction in the two treatment planning systems. We also found that the average mean dose to the
contralateral breast was 2.3 Gy in the IMRT, sug-

gesting that VMAT might have dosimetric effect in
reducing the risk of contralateral breast cancer oc-
currence.

Organ motion
It is well known that the respiration-induced target
motion can lead to variation between the planned
and delivered dose. A 10 mm margin was applied
in the study for expanding the CTV to PTV. We
then evaluated the intra-fraction motion of the
chest wall using the fluoroscopic imaging on the
simulator and found that the maximum displace-
ment was around 3 mm. It’s been reported that the
respiratory movements of the breast during normal
breathing were negligible, and at 80% of the tidal
capacity the mean displacement of the breast and
chest wall from the exhale was less than 1 mm in
the anterior and superior directions.37,38 The 5 mm
margin may extend the PTV to the outside of skin.
With limited segments of the step-and-shot IMRT
plans (maximum 50 segments), the MLC leaves
can be pushed outwards from the patient’s skin by 1
or 2 cm if only the air part in BEV was blocked.
However, such manual adjustment is unfeasible
in the VMAT plans. Therefore, the solutions with
improved target coverage for possible changes in
size and position of target and rest tissues caused
by respiration or oedema are to use the third-party
software to move the block-air MLC away from the
skin, or manually add 10-mm tissue around the
skin for optimization but removing it in the final
dose calculation.39 Another clinical advantage of
VMAT is that it generally takes fewer MUs to de-

deliver a VMAT treatment than IMRT for the same
plan quality. Our results showed that the MUs for
the fifteen chest walls examined by VMAT plans
were about 2/3 to 3/4 of those by IMRT plans.
Obviously, fewer MUs are always favourable as to

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shorten the treatment delivery time and reduce the whole body dose.

Conclusions
Overall, our results showed that VMAT achieved similar or superior target coverage, better normal tissue sparing, fewer monitor units and shortened delivery time, as compared with 5-beam step-and-shot IMRT.

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