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Dosimetric comparison of hybrid volumetric-modulated arc therapy, volumetric-modulated arc therapy, and intensity-modulated radiation therapy for left-sided early breast cancer

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ABSTRACT

To compare the dosimetric performance of 3 different treatment techniques: hybrid volumetric-modulated arc therapy (hybrid-VMAT), pure-VMAT, and fixed-field intensity-modulated radiation therapy (F-IMRT) for whole-breast irradiation of left-sided early breast cancer. The hybrid-VMAT treatment technique and 2 other treatment techniques—pure-VMAT and F-IMRT—were compared retrospectively in 10 patients with left-sided early breast cancer. The treatment plans of these patients were replanned using the same contours based on the original computed tomography (CT) data sets. Dosimetric parameters were calculated to evaluate plan quality. Total monitor units (MUs) and delivery time were also recorded and evaluated. The hybrid-VMAT plan generated the best results in dose coverage of the target and the dose uniformity inside the target ($p < 0.0001$ for conformal index [CI]; $p = 0.0002$ for homogeneity index [HI] of planning target volume $[PTV]_{50.4\ Gy}$ and $p < 0.0001$ for HI of $PTV_{62\ Gy}$). Volumes of ipsilateral lung irradiated to doses of 20 Gy ($V_{20\ Gy}$) and 5 Gy ($V_{5\ Gy}$) by the hybrid-VMAT plan were significantly less than those of the F-IMRT and the pure-VMAT plans. The volume of ipsilateral lung irradiated to a dose of 5 Gy was significantly less using the hybrid-VMAT plan than that using the F-IMRT or the pure-VMAT plan. The total mean MUs for the hybrid-VMAT plan were significantly less than those for the F-IMRT or the pure-VMAT plan. The mean machine delivery time was 3.23 ± 0.29 minutes for the hybrid-VMAT plans, which is longer than that for the pure-VMAT plans but shorter than that for the F-IMRT plans. The hybrid-VMAT plan is feasible for whole-breast irradiation of left-sided early breast cancer.

Background

Breast-conserving therapy has been proven to achieve survival equivalent to that with mastectomy in the treatment of patients with early breast cancer in previous randomized clinical trials.[1-3] Adjuvant whole-breast irradiation is an essential part of breast-conserving therapy. The standard adjuvant whole-breast radiotherapy comprises 5 to 6 weeks of whole-breast irradiation with total doses of 50 to 50.4 Gy with or without the addition of tumor bed boost. The common radiation technique for whole-breast irradiation in most centers worldwide is standard wedge opposite tangential beams. The dose distribution inhomogeneity to the target and higher doses to the organs at risk (OAR) such as the heart, ipsilateral lung, and contralateral breast are the major limitations of this technique.[4] Over the past 40 years, an advanced radiation therapy technique has been developed to reduce the "hot spot" and to improve the dose distribution to the target. In addition, efforts have been made to reduce the normal tissue injury, especially in the lungs and the heart, by more conformal dose distribution to the target. The development of intensity-modulated radiotherapy is capable of diverting doses to a concave tumor with better conformity and improved dose homogeneity that is impossible for 3-dimensional conformal radiotherapy.[5] Intensity-modulated radiation therapy (IMRT) reduces the volume of OAR such as the heart and the ipsilateral lung receiving high doses of radiation while improving the conformity and homogeneity of the tumor doses. To deliver an IMRT plan for whole-breast

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irradiation, 4 to 7 coplanar beams are usually required with a treatment time of 10 to 15 minutes. The extended delivery time is owing in part to the patient setup time and the use of multiple fields. The development of novel techniques that reduce normal tissue injury without compromising the radiation doses to the tumor in a short delivery time is now the subject of much interest in radiation therapy research. Volumetric-modulated arc therapy (VMAT) has the potential of lowering the radiation doses to the OAR while improving the conformity and homogeneity to the tumor with fewer monitor units (MUs) and a shorter delivery time.

In breast cancer, VMAT has been studied in investigations comparing the partial breast irradiation treatment with 3-dimensional conformal radiation therapy as well as in a comparison with conventional IMRT to the bilateral breast cancer after breast-conserving surgery.[6] Fewer MUs and shorter treatment times were found to be the main benefits in these studies. Other studies of VMAT in breast cancer also showed better dose conformity, though this was not significant in lowering doses to the ipsilateral lung or the contralateral breast.[6] This study was designed to investigate whether a hybrid of VMAT and intensity-modulated tangential beams (hybrid-VMAT), when compared with fixed-field IMRT (F-IMRT) or 2 coplanar arcs VMAT (pure-VMAT), can provide an optimal treatment for plan dosimetry, better plan quality, and delivery efficiency for whole-breast irradiation of left-sided early breast cancer.

Materials and Methods

Patient selection and structure delineation

A total of 10 patients with left-sided breast cancer who underwent breast-conserving surgery were selected in this retrospective study under an institutional review board–approved protocol. These patients were previously treated with conventional IMRT to the left breast after breast-conserving surgery. Treatment to the same contours based on the original computed tomography (CT) data sets was replanned using the hybrid-IMRT, the pure-VMAT, and the F-IMRT techniques.

All patients were immobilized in the supine position on a customized vacuum bag with both the arms elevated above the head. A CT scan with a slice thickness of 5 mm was acquired from each patient with coverage from the mandible to 4 to 6 cm below the inframammary fold to cover the entire lung volume. The clinical target volume (CTV) for the whole left breast included the supraclavicular head as the superior margin, 2 cm below the inframammary fold as the inferior margin, anterior axillary line as the lateral margin, and midsternal line as the inner margin. The CTV for the tumor bed was defined as the lumpectomy cavity (seroma) found on the CT scan image or the fibrous tissue under the surgical scar if no seroma could be found on the CT scan image. The normal tissue and OAR including healthy tissue, the lungs, the heart, the spinal cord, and the contralateral breast were contoured for dose calculation. The planning target volume (PTV) was expanded by 5 mm from CTV but was restricted to the tissue within 3 mm from the skin.

Treatment planning technique planning

In this retrospective study, we prescribed a radiation dose of 50.4 Gy administered daily at a dose of 1.8 Gy per fraction to cover the PTV ($PTV_{50.4\ Gy}$) and a 2.2 Gy per fraction simultaneous integrate boost dose up to 62 Gy to cover the tumor bed ($PTV_{62\ Gy}$). All the treatment plans were generated using an Eclipse treatment planning system (Varian Medical System version 10). The dose constraints and treatment center were the same for all these 3 plans. The treatment plans were planned to deliver with 6-MV photon beams using the Varian iX linear accelerator that is mounted with a 120-leaf of Millennium multileaf collimator (MLC) (maximum leaf speed of 2.5 cm/s). Inversed treatment planning was performed using Eclipse dose-volume optimization and progressive resolution optimizer. For dose calculation, the novel algorithm Acuros XB[7] was used with the heterogeneity correction to achieve a practical dose distribution. In this study, we set the angle of the collimator to 0°, because this parameter often changed with the shape of the target. However, the planned performance was note changed by the different collimator angle.

During the whole-breast radiotherapy, the skin flash tool is important in IMRT planning to avoid targets close to the skin not being irradiated. In the VMAT plan, the pseudo–body contour was drawn to obtain an expanded electron fluence map, if skin flash was necessary. During dosimetric comparison, this process was not performed because it does not change the planning performance.

For F-IMRT planning, 7 fixed angles (120°, 90°, 60°, 30°, 0°, 330°, and 300°) of coplanar fields were selected. The F-IMRT plans were optimized to cover 95% of the PTV by 95% of the prescribed dose, while minimizing the doses to the OAR as much as possible. The dose constraints were less than 3% of the heart to 30 Gy ($V_{30\ Gy}$), less than 20% of the ipsilateral lung to 20 Gy ($V_{20\ Gy}$), less than 15% of contralateral lung to 5 Gy ($V_{5\ Gy}$), less than 2% of right breast to 9 Gy ($V_{9\ Gy}$), and 0% to spinal cord to 28 Gy ($V_{28\ Gy}$). The final dose calculation with a 0.25 cm grid resolution was performed with an Acuros XB algorithm. The F-IMRT treatment plans were delivered through a sliding window MLC with 6-MV photons from a Varian iX linear accelerator. The treatment delivery time (excluding setup time), beam-on time, and number of MUs were recorded.

For pure-VMAT planning, 2 coplanar arc arrangements were selected.[8] The gantry angle was designed so that it ran counterclockwise from 120° to 300° and clockwise from 300° to 120°, while the dose rate varied between 0 MU/min and 600 MU/min. The range of the arc was selected to avoid angles directed toward the heart, lung, and contralateral breast. The collimator angle of the 2 arcs was set to 0°. There was a 2-cm field overlap between the fields of the 2 arcs to cover this wide target volume.[8] To cope with the limitation of the MLC motion, the field size should not be greater than 15 cm. The dose constraints for the VMAT plans were the same as those for the F-IMRT plans. Throughout the treatment plan system optimization, the continuous gantry motion is modeled as a number of control points, which included the treatment parameters such as MLC aperture shaping, the speed of gantry, and the dose rate. Between the 2 control points, the change of the parameters and MLC positions was linear. The treatment delivery time, beam-on time, and number of MUs were recorded.

For the hybrid-VMAT treatment plan, 2 tangential IMRT fields plus 2 coplanar conformal arcs were integrated into a single treatment plan. The fraction size and fraction numbers for the IMRT plan and the VMAT plan were identical, but the actual dose weighting for the IMRT plan was 75% of the prescribed dose and was used as the base plan of this hybrid plan. To reduce the delivery time, 1 fraction of the radiation delivery started from the delivery of 1 tangential beam of IMRT at 120° followed by a counterclockwise arc running from 120° to 300°. Then the second tangential IMRT delivered the radiation doses at 300° followed by another clockwise arc running from 300° to 120°. As the priority of target constraints was slightly sacrificed in the tangential IMRT plan, the VMAT plan would compensate for those areas from which tangential IMRT planning may not be capable of covering. The VMAT plan was designed to compensate for the dose nonuniformity in the target of the IMRT plan. Again, the treatment delivery time, beam-on time, and number of MUs were recorded.

Plan comparisons

The same organ constraints were applied for all the 3 treatment plans. Dose-volume histograms were generated for the PTVs and all OAR for dose analysis. The homogeneity index (HI) was measured by $D_{5\%}$–$D_{95\%}$. The lower this value, the better is the dose homogeneity. The conformal index (CI) is calculated by

$$CI = \frac{V_{PTV,ref}}{V_{PTV}} \times \frac{V_{PTV,ref}}{V_{ref}} \quad (1)$$

where $V_{PTV,ref}$ refers to a volume of 95% of the prescribed dose to cover PTV, V_{PTV} refers to the volume of the contoured PTV, and V_{ref} refers to the volume of 95% of the prescribed dose to cover the body. The following parameters were recorded for

Table 1
Plan comparison of PTV doses, CI, and HI for the F-IMRT, the pure-VMAT, and the hybrid-VMAT plans.

PTV	F-IMRT (mean ± SD)	Pure-VMAT (mean ± SD)	Hybrid-VMAT (mean ± SD)	*p* Value
Volume, c.c.	625.2 ± 170.8	625.2 ± 170.8	625.2 ± 170.8	
$D_{99\%}$, Gy	45.93 ± 0.83	45.96 ± 1.33	46.35 ± 1.07	$p = 0.0179$
$D_{1\%}$, Gy	60.88 ± 2.83	62.11 ± 3.03	59.08 ± 2.79	$p = 0.0063$
D_{mean}, Gy	52.64 ± 1.13	54.11 ± 1.11	51.57 ± 1.04	$p < 0.0001$
HI for $PTV_{50.4\ Gy}$	9.55 ± 1.78	10.52 ± 1.22	7.56 ± 1.44	$p = 0.0002$
HI for $PTV_{62\ Gy}$	6.21 ± 1.07	7.57 ± 1.11	4.50 ± 0.62	$p < 0.0001$
CI	0.786 ± 0.035	0.840 ± 0.024	0.841 ± 0.028	$p < 0.0001$

SD = standard deviation.