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Dosimetric aspects of breast radiotherapy with three-dimensional and intensity-modulated radiotherapy helical tomotherapy planning modules

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ABSTRACT

In this work, we investigated the dosimetric differences between the intensity-modulated radiotherapy (IMRT) plans and the three-dimensional (3D) helical plans based on the TomoTherapy system. A total of 15 patients with supine setup were randomly selected from the data base. For patients with lumpectomy planning target volume (PTV), regional lymph nodes were also included as part of the target. For dose sparing, the significant differences between the helical IMRT and helical 3D were only found in the heart and contralateral breast. For the dose to the heart, helical IMRT reduced the maximum point dose by 6.98 Gy compared to the helical 3D plan ($p = 0.01$). For contralateral breast, the helical IMRT plans significantly reduced the maximum point dose by 5.6 Gy compared to the helical 3D plan. However, compared to the helical 3D plan, the helical IMRT plan increased the volume for lower dose (13.08% increase in $V_{5\ Gy}$, $p = 0.01$). In general, there are no significant differences in dose sparing between helical IMRT and helical 3D plans.

Introduction

Breast cancer is the most common type of cancer. It is the main cause of cancer-related deaths among women worldwide.[1] Radiotherapy is frequently given as an adjuvant therapy both in early and locally advanced breast cancer. Use of a set of parallel opposing tangent beam or nearly tangent oblique beams, named medial and lateral tangents remains the most commonly employed method for treatment of the intact breast or postmastectomy chest wall.[2] The beams are angled to include the breast or chest wall tissue while their posterior field borders are matched to eliminate the divergence of beams toward the lung. For higher stage breast cancers, nodal chains in the supraclavicular (SC) and axillary areas need to be treated along with the breast tissue. The nodal areas are best treated with a combination of slight anterior oblique[3-13] degrees) and posterior-anterior (PA) beams. PA beam is added to boost the posterior axillary nodes that may have received less dose than rest of SC field. For treatment of SC and PA fields, beams are split at the inferior field edge. The divergences of tangents are matched in this plane by a combination of collimator and couch rotations that are determined by the tangent angles and superior tangent border.[2,3,14,15] In cases involving internal mammary nodes, the node chain is treated with 12 or 15 MeV electron energies as internal mammary chain lies at a depth of 3 cm.[14,15]

In recent years, several intensity-modulated radiotherapy (IMRT) has been reported for the breast cancer treatment.[2,3] TomoTherapy (Accuray, Inc., Madison, WI) is one of the emerging IMRT technologies that delivers dose while gantry continuously rotates around the patient and the patient is translated through the beam delivery plane during treatment. Compared to conventional treatment, better sparing of organs at risk (OARs) (*e.g.,* lungs, heart, and contralateral breast) is achieved with TomoTherapy.[4,5] TomoTherapy has proven to be feasible alternate for treating postlumpectomy or postmastectomy cases that were conventionally treated with electrons, photons, or combination of both.[7,9-13,16,17] Overall, TomoTherapy is capable of delivering higher mean dose to target with improved dose sparing to OARs. TomoTherapy treatment planning station (TPS) has 3 options for planning and delivery; IMRT helical, three-dimensional (3D) helical, and Tomo Direct. The 3D helical and Tomo Direct are relatively new approaches.[17,18] In IMRT mode, the targets and OARs

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Table 1
Summary of patients' information

Patient	Target location	Chemo	Stage	Histology
1	Right	NO	0	DCIS
2	Left	YES	IA	Invasive ductal
3	Left	YES	I	Invasive ductal
4	Left	NO	I	Invasive ductal
5	Left	YES	IIA	Invasive ductal
6	Left	NO	I	Invasive ductal
7	Left	YES	I	Invasive ductal
8	Left	YES	IIIA	Invasive ductal
9	Right	NO	IA	Invasive ductal
10	Right	NO	IA	Invasive ductal
11	Right	YES	IIA	Invasive ductal
12	Left	YES	I	Invasive ductal
13	Right	YES	I	Invasive ductal
14	Left	NO	0	DCIS
15	Left	YES	I	Invasive ductal

DCIS = ductal carcinoma *in situ*.

can be optimized. The 3D helical mode is based on forward-planning and optimization is not possible. IMRT and 3D helical planning consists of combination of fast binary MLC with continuous gantry and couch motion. Tomo Direct planning is the combination of fast binary MLC with discrete gantry rotation and continuous couch motion.[19] University of Wisconsin (UW) Riverview Cancer Center is a TomoTherapy-based single treatment modality institute. The version of the TPS we use, allows us to perform IMRT and 3D helical planning and treatment delivery. We present a dosimetric analysis of the retrospective clinical results from IMRT helical and 3D helical planning for breast. This study investigates the dosimetric differences in target coverage and dose sparing to OARs between the helical IMRT and 3D helical technique for patients with breast cancer.

Methods and Materials

A total of 15 patients with breast cancer were randomly selected for this retrospective study. Patients' ages range from 38 to 74 years. Table 1 shows the details about patients selected for this study. All patients were simulated on GE CT scanner in a supine position with both arms overhead in a VacLoc (Med-Tec, Orange City, IA) to immobilize the patient, and computed tomography (CT) images were reconstructed with an axial slice thickness of 2.5 mm. The kV CT images were exported to Pinnacle TPS (version 9.2, Phillips Medical System, Fitchburg, WI). Physician contoured the target and OARs on the Pinnacle TPS. The OARs included bilateral lungs, esophagus, superior vessels, cord, trachea, heart, and contralateral breast. Average volume of breast planning target volume (PTV) and lumpectomy PTV varied in the range from 56 to 135 cc. The PTV included all the radiographically visible breast tissues plus 3-mm uniform margin except the superior borders of PTV to the skin to take into account setup uncertainty. The lumpectomy bed was contoured with 2- to 5-mm clinical margin. Once the contouring was done, the kV CT and all contours were exported to TomoTherapy TPS for planning.

All plans were generated on TomoTherapy TPS (TomoTherapy Inc., Madison, WI). Plans for each patient were optimized in 2 different ways—standard helical IMRT and 3D helical. For all patients, the breast PTV was prescribed to 50.4 Gy with 1.8 Gy per fraction. The lumpectomy cavity was prescribed to a total dose of 59.36 Gy with 2.12 Gy per fraction. The prescribed dose of the lumpectomy cavity was normalized to the 95% of its volume. All patients were treated with simultaneous integrated boost). Aim of each planning technique was to achieve homogeneous dose distribution throughout target volume and minimum dose to OAR. To limit the dose to OARs in IMRT planning technique, a blocking structure was contoured to prevent the beamlets from entering and exiting through this structure. Additionally, 2- and 4-cm rings around PTV were used to provide conformal dose to the target and reduced the dose in the peripheral region of the PTV (Figs. 1 and 2). The 3D helical plans were generated using the same block structure as was used in IMRT plans. All plans were generated using a 5-cm field width along the longitudinal direction. Modulation factor used for the helical IMRT 3D plan was 2.2 with 0.215 pitch. Dose-volume histograms (DVH) were studied for all plans.

Target dose homogeneity index (HI) is defined as:

$$HI = [(D_{2\%} - D_{98\%})/Dp] * 100\%$$

where $D_{2\%}$ and $D_{98\%}$ refer to dose received by 2% and 95% volumes of PTV, respectively.[20] Dp represents the prescribed dose. HI was used for plan comparison in addition to DVH. Other dosimetric parameters are the percentage of the PTV receiving 107% ($V_{107\%}$), and 95% ($V_{95\%}$) of the prescription dose. Dosimetric indexes for different OARs are mean dose, percentage volume receiving dose of 5 ($V_{5\ Gy}$), 20 ($V_{20\ Gy}$), 30 ($V_{30\ Gy}$), and 40 ($V_{40\ Gy}$). The two-sided Wilcoxon rank-sum test was used to evaluate the statistical differences between the helical IMRT and helical 3D plans (statistical significance, $p < 0.05$). Delivery quality assurance was performed for all patients' plans. Gamma index[21] was used to analyze the quality of the beam delivery. The thresholds for position and dose deviations were set to be 3 mm and 3% (3 mm/3%), respectively. More than 95% of the gamma index passing rates were obtained for all cases.

Results and Discussion

The dosimetric analysis of maximum dose, mean dose, and DVH values for targets and OARs are shown in Tables 2 and 3, respectively. The inhomogeneity indexes analysis for targets are also provided in Table 2. All results are expressed as the mean 1 SD. Isodose distribution and DVHs for one randomly selected case are represented in the Figs. 1 and 2. Target coverage, for whole-breast PTV, the helical IMRT and helical 3D showed significant differences ($p < 0.05$) in D_{max}, D_{mean}, $V_{107\%}$, $D_{2\%}$, $D_{98\%}$, and HI. Among the 2 techniques, the helical 3D generated the highest maximum (D_{max}) and mean doses (D_{mean}) to the target. According to Table 2, the helical 3D created much higher hot spot volume ($V_{107\%}$) in the target compared to helical IMRT for both whole breast and lumpectomy cases. Among the 2 techniques, the helical IMRT provided rapid dose fall-off. Compared to helical IMRT, the helical 3D provided highest dose to cover 98% of the target ($D_{98\%}$).

It can be observed from Figs. 1 and 2 that even if the contralateral breast receives less dose in 3D helical planning, the high dose isodose lines are spread outside the target volume. Overall, the helical IMRT showed the best HI. The significant differences in D_{max}, D_{mean}, and HI are demonstrated in Table 2 for target. For lumpectomy PTV, the helical IMRT shows significant differences in D_{max}, D_{mean}, D_{min}, $V_{107\%}$, $D_{2\%}$, and HI. Helical 3D created noticeably higher maximum dose and hot spot (D_{max} and $V_{107\%}$) compared to helical IMRT. For the mean target dose (D_{mean}), the helical IMRT provided lower mean dose. Among the 2 techniques, the helical IMRT showed the fastest dose fall-off ($D_{2\%}$). Overall, the helical IMRT provided best target HI to lumpectomy PTV.

For dose sparing, the significant differences between the helical IMRT and helical 3D are only found in the heart and contralateral breast. According to Table 3, for helical IMRT, averaged among all cases, the maximum dose to heart is 20.91 Gy. For helical 3D plans, this value reaches 27.89 Gy. Compared to helical 3D plan, the helical IMRT reduced the averaged maximum point dose by 6.98 Gy to the heart. The statistical calculation indicates that the helical IMRT provides significant dose reduction ($p = 0.01$) to the heart compared to the helical 3D plans. For contralateral breast, the helical IMRT plans significantly ($p = 0.03$) reduced the averaged maximum point dose by 5.6 Gy compared to the helical 3D plans. However, compared to the helical 3D plan, the helical IMRT plan increased the volume for lower dose (13.08% increase in $V_{5\ Gy}$, $p = 0.01$). In general, there are no significant differences in dose sparing between helical IMRT and helical 3D plans.

One interesting phenomenon is that the helical 3D plans could provide lower dose to the OARs compared to the IMRT helical technique. According to Table 3, the helical 3D plan provided much lower volume for low dose level (D_{mean}, $V_{5\ Gy}$ (%), and $V_{5\ Gy}$ (cc)) compared to the IMRT helical technique for contralateral breast. This is because of the multiple beam angles of the helical IMRT technique compared to the 3D helical technique.