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Left-sided breast cancer irradiation using rotational and fixed-field radiotherapy

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ABSTRACT

The 3-dimensional conformal radiotherapy (3DCRT) technique is the standard for breast cancer radiotherapy. During treatment planning, not only the coverage of the planning target volume (PTV) but also the minimization of the dose to critical structures, such as the lung, heart, and contralateral breast tissue, need to be considered. Because of the complexity and variations of patient anatomy, more advanced radiotherapy techniques are sometimes desired to better meet the planning goals. In this study, we evaluated external-beam radiation treatment techniques for left breast cancer using various delivery platforms: fixed-field including TomoDirect (TD), static intensity-modulated radiotherapy (sIMRT), and rotational radiotherapy including Elekta volumetric-modulated arc therapy (VMAT) and tomotherapy helical (TH). A total of 10 patients with left-sided breast cancer who did or did not have positive lymph nodes and were previously treated with 3DCRT/sIMRT to the entire breast were selected, their treatment was planned with Monaco VMAT, TD, and TH. Dosimetric parameters including PTV coverage, organ-at-risk (OAR) sparing, dose-volume histograms, and target minimum/maximum/mean doses were evaluated. It is found that for plans providing comparable PTV coverage, the Elekta VMAT plans were generally more inhomogeneous than the TH and TD plans. For the cases with regional node involvement, the average mean doses administered to the heart were 9.2 (± 5.2) and 8.8 (± 3.0) Gy in the VMAT and TH plans compared with 11.9 (± 6.4) and 11.8 (± 9.2) Gy for the 3DCRT and TD plans, respectively, with slightly higher doses given to the contralateral lung or breast or both. On average, the total monitor units for VMAT plans are 11.6% of those TH plans. Our studies have shown that VMAT and TH plans offer certain dosimetric advantages over fixed-field IMRT plans for advanced breast cancer requiring regional nodal treatment. However, for early-stage breast cancer fixed-field radiotherapy is potentially more beneficial in terms of OAR sparing.

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Introduction

Selection of the optimal radiation-delivery technique remains a critical component for individualized breast cancer treatment, which requires adequate dose coverage as well as minimal normal tissue damage.[1] Radiation to the heart is associated with an increased risk for cardiovascular disease long after radiotherapy. Radiation-induced lung injury was found to be positively correlated with ipsilateral mean lung dose and the volume of the ipsilateral lung that was treated.[2-4] Contralateral breast irradiation is another concern. Women who received radiation to the contralateral breast appear to have elevated long-term risk of developing contralateral breast cancer.[5]

Traditionally, breast-tangent 3-dimensional conformal radiotherapy (3DCRT) technique has been used for whole-breast irradiation. However, this technique sometimes fails to meet the constraints for patients with unfavorable anatomy or who require regional nodal treatment. Fixed-beam or static intensity-modulated radiotherapy (sIMRT) shows improved dosimetric distribution compared with that shown by conventional breast tangents.[6-9] Volumetric-modulated arc therapy (VMAT) and tomotherapy helical (TH) have been shown to improve target coverage and reduce doses to normal tissues in many other sites with relatively complicated anatomy.[10,11] Recently introduced TomoDirect (TD), which uses static gantry angles combined with

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Table
Dosimetric comparison of plan metrics of the 3DCRT/sIMRT, VMAT, TD, and TH plans

Structure	Plan parameters	3DCRT/sIMRT	VMAT		TD		TH	
		Mean* (SD)	Mean* (SD)	p†	Mean* (SD)	p†	Mean* (SD)	p†
Group I								
PTV breast	Max dose	48.9 (3.6)	51.6 (2.8)	0.21	48.6 (2.1)	0.56	47.9 (1.6)	0.53
	Mean dose	46.9 (3.0)	46.0 (1.4)	0.23	44.2 (1.8)	0.01	44.5 (1.6)	0.49
	HI	1.12 (0.04)	1.12 (0.01)	0.67	1.04 (0.02)	0.007	1.06 (0.01)	0.08
Heart	Mean dose	2.9 (2.0)	4.5 (1.6)	0.15	1.4 (0.6)	0.22	5.6 (4.4)	0.28
	Max dose	40.2 (6.3)	24.0 (4.6)	0.001	32.1 (13.8)	0.22	21.8 (13.0)	0.02
	V_{20} (%)	4.2 (3.9)	0.2 (0.2)	0.08	1.3 (1.1)	0.24	1.87 (3.5)	0.24
Lt lung	Mean dose	6.8 (4.4)	5.9 (1.5)	0.69	2.9 (0.7)	0.20	5.21 (1.6)	0.32
	Max dose	46.6 (3.9)	38.7 (3.0)	0.05	44.2 (2.9)	0.18	35.8 (3.6)	0.002
	V_{20} (%)	14.2 (10.2)	3.6 (1.4)	0.11	4.8 (1.9)	0.14	3.2 (2.5)	0.07
Rt lung	Mean dose	0.2 (0.1)	1.6 (0.5)	0.004	0.2 (0.1)	0.32	2.9 (1.6)	0.02
	Max dose	5.9 (9.9)	9.6 (3.1)	0.85	4.1 (6.7)	0.17	16.0 (4.9)	0.46
Rt breast	Mean dose	0.2 (0.1)	2.4 (0.5)	0.001	0.6 (0.7)	0.27	2.4 (0.3)	0.001
	Max dose	5.6 (7.9)	9.6 (3.3)	0.20	3.6 (2.3)	0.57	8.0 (1.2)	0.50
Patient	Mean dose	2.0 (1.0)	2.1 (0.7)	0.91	2.8 (0.5)	0.006	4.0 (0.8)	0.01
	Integral dose	46.7 (23.3)	49.0 (16.3)	0.91	65.4 (11.7)	0.006	93.4 (18.7)	0.01
Group II								
PTV breast	Coverage (%)	94.6 (0.5)	94.4 (0.6)	0.57	95.1 (0.3)	0.28	95.1 (0.3)	0.36
	Mean dose	53.2 (1.1)	54.0 (0.5)	0.23	50.9 (0.1)	0.01	53.0 (1.3)	0.48
	Max dose	58.9 (1.4)	61.8 (2.4)	0.17	56.9 (1.6)	0.07	56.2 (2.7)	0.52
	HI	1.13 (0.05)	1.13 (0.02)	0.69	1.04 (0.01)	0.01	1.08 (0.04)	0.20
IMN	Mean dose	52.9 (4.1)	53.3 (0.5)	0.84	51.0 (0.4)	0.27	53.9 (1.9)	0.69
Lt lung	Mean dose	14.4 (8.2)	11.4 (1.2)	0.67	11.4 (4.6)	0.13	10.3 (2.5)	0.48
	Max dose	56.4 (6.5)	52.9 (10.0)	0.69	56.6 (2.0)	0.99	48.8 (6.9)	0.24
	V_{20} (%)	32.2 (26.7)	16.0 (6.2)	0.14	22.6 (10.4)	0.18	10.0 (6.7)	0.06
Heart	Mean dose	11.9 (6.4)	9.2 (5.2)	0.26	11.8 (9.2)	0.24	8.8 (3.0)	0.24
	Max dose	51.4 (4.4)	40.3 (9.6)	0.001	53.9 (3.9)	0.83	46.5 (7.2)	0.001
	V_{20} (%)	20.0 (11.3)	9.4 (14.8)	0.04	23.6 (20.3)	0.83	4.4 (3.4)	0.05
Rt lung	Mean dose	2.8 (4.8)	3.5 (0.4)	0.75	0.6 (0.3)	0.30	4.8 (1.3)	0.32
	Max dose	30.6 (21.2)	27.8 (11.6)	0.79	25.3 (25.3)	0.49	32.0 (12.9)	0.27
Rt breast	Mean dose	3.8 (3.4)	4.4 (0.5)	0.64	1.3 (0.8)	0.19	3.2 (0.5)	0.67
	Max dose	32.6 (22.7)	23.6 (13.3)	0.44	37.8 (17.9)	0.62	11.2 (4.8)	0.09
Patient	Mean dose	3.0 (0.72)	2.8 (0.6)	0.07	5.2 (0.9)	0.17	5.7 (0.9)	0.001
	Integral dose	71.2 (17.1)	66.5 (14.2)	0.07	123.4 (21.4)	0.17	135.3 (21.4)	0.001

Lt = left; Max = maximum; Rt = right; SD = standard deviation.

* All doses listed in this table are in Gy; the integral dose in Gy-liter.

† 3DCRT was used as baseline for t-test. $p < 0.05$ is considered as statistically significant.

simultaneous couch movement and multileaf collimator (MLC) modulation, showed some improvement in normal tissue sparing for early-stage breast cancers.[12,13]

We evaluated the advantages and disadvantages of rotational (including Elekta Monaco VMAT and tomotherapy helical) and fixed-beam (TD and tangential 3DCRT or fixed-beam sIMRT or both) radiation-delivery techniques in left-sided breast treatment in 2 commonly encountered scenarios: early stage and stages requiring regional nodal treatment. We studied 10 consecutive patients in 2 categories: 5 women treated to the whole breast in group 1 and 5 women treated comprehensively to the breast or chest wall and regional nodes in group 2. Dosimetric metrics, such as planning target volume (PTV) coverage; the organ-at-risk (OAR) sparing; dose-volume histograms (DVHs); minimum, maximum, and mean doses; and treatment-delivery parameters, including the treatment monitor units (MUs) and treatment time, are presented and discussed in the article.

Methods and Materials

A total of 10 patients with left-sided breast cancer who were treated with 3DCRT (group 1) or sIMRT (group 2) were studied. sIMRT plans were generated if normal OAR constraints (using 3DCRT) were not met for group 2 patients. For each patient, the following structures were delineated on the CT data sets: the lumpectomy cavity, lumpectomy PTV (generated using a 1.5-cm margin around the lumpectomy cavity and edited 0.5 cm from the skin surface), targeted breast or chest wall PTV (breast_PTV), left lung, heart, right breast, and lung, as well as internal mammary nodes (IMNs), supraclavicular nodes, and axillary nodes if intended. The mean breast volumes for group 1 and group 2 are 634.0 (486.0 to 893.9) cm^3 and 476.3 (268.3 to 646.6) cm^3, respectively.

For group 1, patient-specific 3D plans consisting of 2 tangential beams irradiating the whole breast were generated using the CMS XiO treatment planning system (Version 4.4, CMS Inc, St. Louis, MO). The prescription dose to the entire breast was 42.56 Gy (in 16 fractions). A plan is considered acceptable if at least 95% of the PTV receives the prescription dose and at least 90% of the breast_PTV receives the prescription dose. The volume of the ipsilateral lung receiving 20 Gy (V_{20}) should be less than 15%, and the volume of the heart receiving 50% of the prescription dose should be less than 5%. For group 2, fixed-beam sIMRT plans with prescription dose of 50 Gy in 25 fractions were developed to achieve 95% target coverage and at least 90% of PTV breast coverage.

Monaco VMAT planning

The VMAT plans were generated on CMS Monaco TPS (Version 2.03.01, CMS Inc, St. Louis, MO). Monaco employs biological models/quantities in sIMRT optimization and uses a Monte Carlo dose calculation algorithm. The objective functions available from Monaco were described by Qi *et al.*[14] For the selected cases with breast cancer, we used 1 or 2 partial anterior arcs (~200° clockwise) to cover the entire treatment area. A minimum MU per segment of 5 MUs, minimum dose rate

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