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Intensity modulated radiotherapy versus volumetric modulated arc therapy in breast cancer: A comparative dosimetric analysis

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Technical Report

Abstract

Purpose: Intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) has the capacity to optimize the dose distribution. We analyzed the dosimetric differences of plans in treatment planning system (TPS) between VMAT and IMRT in treating breast cancer. **Methods**: Fourteen patients were simulated, planned, and treated with VMAT using single, double or partial arcs. IMRT treatments were generated using 4 to 5 tangential IMRT fields for the same patients. All treatment plans were planned for 50 Gy in 25 fractions. The VMAT and IMRT plans were compared using the planning target volume (PTV) dose and doses to the other organs at risk (OARs). **Results**: For the PTV, comparable minimum, mean, maximum, median, and modal dose as well equivalent sphere diameter of the structure (Equis) were observed between VMAT and IMRT plans and found that these values were significantly equal in both techniques. The right lung mean and modal doses were considerably higher in VMAT plans while maximum value was considerably lower when compared with IMRT plans. The left lung mean and modal doses were higher with VMAT while maximum doses were higher in IMRT plans. The mean dose to the heart and maximum dose to the spinal cord was lower with IMRT. The mean dose to the body was higher in VMAT plans while the maximum dose was higher in IMRT plans. **Conclusion**: Four field tangential IMRT delivered comparable PTV dose with generally less dose to normal tissues in our breast cancer treatment study. The IMRT plans typically had more favourable dose characteristics to the lung, heart, and spinal cord and body dose when compared with VMAT. The only minor advantage of VMAT for breast cases was slightly better PTV coverage.

Keywords: Breast Cancer; IMRT; VMAT

Introduction

The number of patients with breast cancer treated with radiation therapy has increased in the past few years. Normal tissue toxicities can limit the advantage of this treatment modality.[1-2] Standard tangential beams have resulted in excellent local control rates, low rates of cardiac and pulmonary complications, and excellent cosmetic results in the vast majority of patients.[3-7] Three-dimensional conformal radiotherapy (3D-CRT) and intensity-modulated radiotherapy (IMRT) techniques improve the treatment delivery by improving the target volume coverage and minimizing dose to other organs at risk (OARs).[8-18] With IMRT, it is possible to reduce the volume of the lung irradiated to full doses by tangential fields, and in left-sided cases, the heart can also be partially spared. Several publications on this topic have discussed advantages and disadvantages of IMRT versus volumetric modulated arc therapy (VMAT).[19-21]

The use of RapidArc or VMAT (Novalis Tx, Varian Medical Systems, Inc, Palo Alto, USA) is receiving increased attention as an advanced technique in radiotherapy for fast delivery treatment with improved dose distribution. In an effort to identify and characterize dosimetric differences between VMAT and IMRT techniques for the breast cancer, we analyzed the calculated dose characteristics of VMAT and simulated treatment plans of IMRT in 14 breast cancer patients. For the purpose of this analysis, we assumed similar mean dose within target produces similar tumor control with these two techniques.

Methods and Materials

Fourteen patients presented with breast cancer (eight left side and six right side). Twelve of these cases were intact breast and two cases were post mastectomy. Each patient was immobilized using full body Vaclok (IBA, Bahnhofstrasse, Schwarzenbruck, Germany) for simulation and subsequent treatment. Axial computed tomography (CT) images of 5 mm thickness were obtained on a Philips Brilliance big bore 16-slice CT simulator (Philips Health Care, DA Best, Netherlands). The data was then exported to the Eclipse work-

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station (Eclipse treatment planning system (TPS), version 8.6; Varian Medical Systems, Palo Alto, CA, USA) where normal tissue and tumor segmentation were performed through the use of the available contouring tools. The gross tumor volume (GTV) was defined using soft tissue window. The planning target volume (PTV) was created by a 0.5 cm axial and 1.0 cm longitudinal expansion of the GTV. The OARs including lungs, heart, and spinal cord were contoured.

The VMAT treatment plans were designed using partial, single or paired arcs in the Eclipse TPS to achieve optimal PTV coverage and minimal OAR dose. High definition multileaf collimation was optimized using beams-eye-view for each arc of every patient's plan. The plans were then normalized to 100% of the dose to the mean of the PTV. The prescription dose was 50 Gy in 25 fractions for all plans. The constraints for the OARs included maximum dose of 35 Gy, 30Gy, and 25 Gy to spinal cord, heart, and lung, respectively. The VMAT treatments were planned using the analytic anisotropic algorithm (AAA), Modified Batho algorithm for tissue heterogeneity corrections and AAA field volume dose algorithm for ARC calculations. Partial ARC, full ARC, and dual ARCs were used for planning to yield the best target coverage possible.

For comparative analysis, simulated treatment plans using 4 to 5 tangential intensity modulated beams were generated in Eclipse TPS. The same PTV and OAR structures as those defined at the time of VMAT treatment were used for the IMRT planning. Beams were manually selected to maximize access to the target while minimizing exposure to adjacent normal tissues. All the plans were optimized to allow for 95% coverage of PTV. Calculated dose characteristics to the PTV, spinal cord, lungs, and heart were compared. A two-tailed paired t-test was used to compare the VMAT and IMRT techniques in respect of dose to target and normal structures with a significance declared for a $p < 0.05$ (**Table 1**). Additionally, both the VMAT and IMRT plans were normalized to 200 cGy at isocenter for the QA purpose. Patient specific QA was done using 0.1 cc ionization chamber in a small cylindrical phantom.

Results

The IMRT plans demonstrated significantly lower mean doses to OARs and equivalent doses to the PTV when compared with VMAT plans. Representative dose distributions between VMAT treatment plans and IMRT plans are presented in (**Figure 1**) and dose volume histograms are shown in (**Figure 2**).

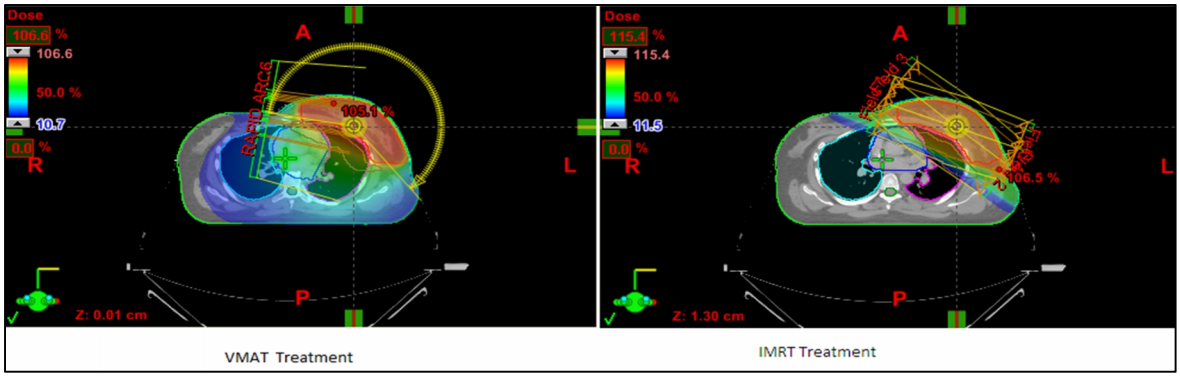

FIG. 1: An example of dose distribution between VMAT and IMRT breast cancer treatment plans

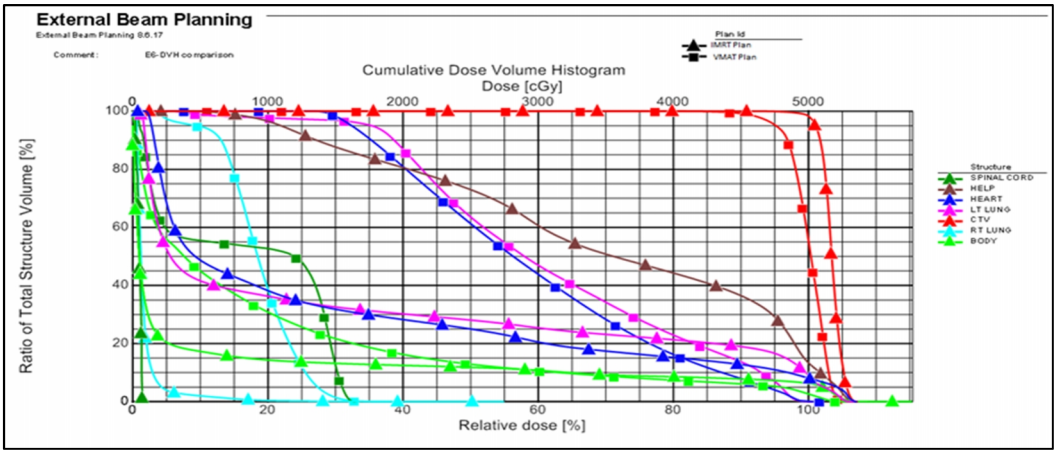

FIG. 2: An example of cumulative dose-volume histogram (DVH) of VMAT and IMRT plans for breast cancer.

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The IMRT plans exhibited equal minimum and mean doses for the PTV when compared to the VMAT plans. In comparison between the two plans, the PTV maximum doses were higher with in the IMRT plans than in the VMAT plans (**Figure 3**). **Table 1** shows that the mean and median doses to the right lung were significantly lower with IMRT, whereas the maximum dose was significantly lower with VMAT.

IMRT delivery comparisons between two IMRT delivery techniques for QA plans are shown in **Table 2**. There is a significant difference in the mean values of dose range between IMRT and VMAT in case of lungs. The minimum and mean doses were higher in VMAT for the heart and spinal cord. While the heart maximum and spinal cord maximum doses are lower. The IMRT plan yields a significantly lower mean and median dose to the body (**Table 1**). For the VMAT, the Standard Deviation in Percentage (STD %) is lower for the OARs and higher for the PTV with the exception of spinal cord. The maximum dose is higher in IMRT for all organs including the PTV. Equis is observed to be same for both techniques for target and the OARs. On average, the treatment MUs were 67% less with VMAT compared with IMRT for the selected 14 patients in this study (**Table 3**).

Discussion

The VMAT technology is the most recent innovative technology in conventional photon therapy and widely used treatment technique in the entire world. As the treatment time, beam on time, and the number of monitor units (MUs) are less compared with IMRT, more hospitals prefer VMAT compared to other treatment techniques in photon therapy. The results provided in our study provide evidence that IMRT treatments can be developed that provide target coverage as VMAT.

According to Ashraf *et al.*[22], the conformity to the PTV and critical structure sparing was better with 3DCRT than IMRT. In contrast to the Ashraf *et al.*[22], Moorthy *et al.*[23] published that, with the use of IMRT technique, there was an improvement in CI when compared to CI of 3DCRT. The study conducted by Popescu *et al.*[24] concluded that VMAT achieved similar PTV coverage and sparing of OARs, with fewer MUs and shorter delivery time than conventional IMRT. According to their study [24], the healthy tissue volume percentages receiving 5 Gy were significantly larger with VMAT (33.1% ± 2.1%) and IMRT (45.3% ± 3.1%) than with conventional modified wide-tangent technique (19.4% ± 3.7%). According to study conducted by Johansen *et al.*[25], a better homogeneity and conformation in PTV was observed in the VMAT plans. The highest minimum dose to PTV was observed in the conventional plans while no difference was observed for minimum significant doses D (98%) and D (99%) where D (X%) is the dose received by X% of the PTV volume. In terms of OAR sparing, the IMRT and RapidArc plans spare ipsilateral-lung better, but a 40% lower mean dose in the contra-lateral lung in the conventional plans is observed. The mean dose to the contra-lateral breast was lowest for the RapidArc plans as well as the V (10Gy) and the maximum dose.

RapidArc, however, is capable of producing better plans than IMRT for the test cases examined by Oliver *et al.*[26] According to them, the conformity of dose distribution to target is better in RapidArc compared with IMRT. But integral dose is more in tomotherapy compared to RapidArc and IMRT. According to Nicolini *et al.*[27], RapidArc showed dosimetric improvements with respect to IMRT. But they also have mentioned that mean dose to heart was 6.0 ± 2.7 Gy (RapidArc) and 7.4 ± 2.5 Gy (IMRT). We have also reported similar result in this study. We have demonstrated the pros and cons of the VMAT technique for breast cancer plans instead of just highlighting the only positive aspects of the VMAT.

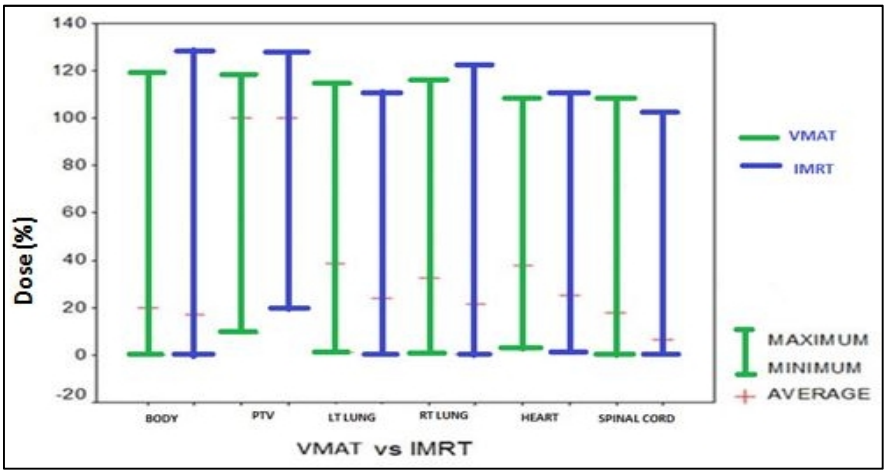

FIG. 3: Minimum, mean and maximum dose to PTV in VMAT and IMRT.

TABLE 1: Dose calculations to PTV, body and normal structures with VMAT and tangential four field IMRT. The results are averaged over fourteen breast cancer cases in this study.
[100% = prescribed dose; dose statistics obtained from the Eclipse TPS]

		VMAT (RapidArc)			IMRT		
		Median	Range	*p*-value	Median	Range	*p*-value
PTV	Dose coverage (%)	100	0	0.0001	100	0.4	0.0001
	Min value (%)	63.3	68.7	0.0001	58.6	62.5	0.0001
	Max value (%)	111	12.5	0.0001	114.7	20.8	0.0001
	Mean value (%)	100	0	0.0001	100	3.5	0.0001
	Modal D value (%)	101.1	5.8	0.0001	101	5.2	0.0001
	Median (%)	100.6	1.2	0.0001	100.4	4.3	0.0001
	STD (%)	4.6	3.5	0.0001	3.9	11	0.0001
	Equis (%)	12.9	7	0.0001	12.9	7	0.0001
RT lung	Dose coverage (%)	100	0	0.0001	100	0	0.0001
	Min value (%)	2.8	21.1	0.0026	0.6	4	0.0038
	Max value (%)	73.1	83.7	0.0001	93.7	103.9	0.0001
	Mean value (%)	18.7	59.7	0.0021	10.1	56.4	0.0021
	Modal D value (%)	14.9	86	0.0023	1.4	86	0.1324
	Median (%)	18.5	60.7	0.0001	9.4	63.9	0.0068
	STD (%)	7	23.8	0.0001	7.9	32.4	0.0004
	Equis (%)	12.4	1.8	0.0001	12.4	1.8	0.0001
LT Lung	Dose coverage (%)	100	0	0.0001	100	0	0.0001
	Min value (%)	2.5	15.6	0.0009	0.8	5.3	0.007
	Max value (%)	100.7	90	0.0001	102.5	90	0.0001
	Mean value (%)	48.1	49.6	0.0001	31.2	47.8	0.0003
	Modal D value (%)	21.9	93	0.0004	1.7	36.7	0.0522
	Median (%)	43.2	53.9	0.0001	7.8	43.7	0.0034
	STD (%)	24.7	26.7	0.0001	28.9	38.4	0.0001
	Equis (%)	11.5	2	0.0001	11.5	2	0.0001
Heart	Dose coverage (%)	100	0	0.0001	100	0	0.0001
	Min value (%)	7.7	17.2	0.0001	1.7	7.5	0.0006
	Max value (%)	101.1	29.4	0.0001	101.6	75.1	0.0001
	Mean value (%)	35.5	33	0.0001	25	41.6	0.0001
	Modal D value (%)	23.5	37.9	0.0001	2.5	32.7	0.0156
	Median (%)	31.4	39.3	0.0001	13.1	34.7	0.0001
	STD (%)	18.8	16.1	0.0001	22.5	32.7	0.0001
	Equis (%)	9.6	3	0.0001	9.6	3	0.0001
SC	Dose coverage (%)	100	0	0.0001	100	28.4	0.0001
	Min value (%)	0.7	18.4	0.0763	0.4	7.8	0.0658
	Max value (%)	11.6	77.8	0.0001	13.3	101	0.0035
	Mean value (%)	14.5	45.1	0.0001	2.4	43.4	0.0364
	Modal D value (%)	0.8	37.5	0.1176	1	18	0.0846
	Median (%)	15.1	41.5	0.0001	1.9	30.1	0.0389
	STD (%)	10.7	15.3	0.0001	1.1	29.3	0.0214
	Equis (%)	4.3	6.3	0.0001	4.3	6.3	0.0001
BODY	Dose coverage (%)	100	0	0.0001	96	33.9	0.0001
	Min value (%)	0	0.1	0.3343	0	0	0.0001
	Max value (%)	111.8	12.5	0.0001	120.9	19.3	0.0001
	Mean value (%)	18.5	14	0.0001	15.2	17.5	0.0001
	Modal D value (%)	0.6	1.7	0.0008	0.2	0.8	0.0028
	Median (%)	6.4	9.1	0.0001	1.2	4.6	0.0002
	STD (%)	27.3	10.9	0.0002	30.3	12.4	0.0001
	Equis (%)	34.4	8.3	0.0001	34.4	8.3	0.0001

Dose coverage (%) = percentage of the structure volume covered by the dose matrix, which is a three dimensional matrix with in which the dose distribution is calculated; p-value (typically ≤ 0.05) indicates strong evidence against the null hypothesis.

With the current beam arrangements calculations, it is reasonable to conclude that all of the analyzed IMRT approaches generally deliver fewer doses to adjacent normal tissues compared with VMAT without compromising target coverage. It was observed that a relatively larger volume of lung received a minimum dose and the prescribed dose limits with IMRT compared with VMAT. The absolute differences between mean doses were quite large approximately 17.5 Gy to 22 Gy. Body dose is more in VMAT when compared with IMRT treatments.

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TABLE 2: Comparisons between IMRT and VMAT delivery techniques.

Patient #	Dose in TPS at isocenter (cGy)	Dose with chamber in IMRT (cGy)	Dose with chamber in VMAT (cGy)	% Variation Between VMAT and IMRT
1	200	199	195	2
2	200	197	203	2.9
3	200	200	199	0.5
4	200	198	200	1
5	200	205	206	0.4
6	200	203	195	3.9
7	200	201	195	2.9
8	200	201	201	0
9	200	202	205	1.5
10	200	203	205	1.5
11	200	200	195	2.5
12	200	201	202	0.5
13	200	203	205	1.5
14	200	198	201	1.5

TABLE 3: Monitor units (MUs) comparisons between IMRT and VMAT techniques.

Patient #	IMRT (MU)	VMAT (MU)	% of variation between VMAT and IMRT (MU)
1	2024	594	70
2	420	240	43
3	1236	417	66
4	1334	283	79
5	1135	502	56
6	1050	181	83
7	680	492	28
8	2826	342	88
9	1590	473	70
10	1389	350	75
11	1402	467	67
12	1560	483	69
13	1227	495	60
14	2180	318	85

Conclusion

IMRT plans with four to five tangential beams provide comparable coverage of the PTV relative to VMAT plans in breast cancer. Typically comparable coverage was achieved by IMRT with less dose to adjacent normal tissue and integral dose. VMAT technique produced relatively larger volumes of lung, heart, and spinal cord exposed to the radiation.

Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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