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Volumetric Modulated Arc Therapy Versus Intensity Modulated Radiotherapy on the Left-Sided Chest Wall and Loco-Regional Nodes Irradiation in Treating Post Mastectomy Breast Cancer Patients: A Comparative Dosimetric Analysis

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Abstract

Purpose: This study aimed to compare the suitable treatment plan for left-sided chest wall, regional node's irradiation by using the Intensity Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT).

Materials and methods: Fifteen patients CT data set was import into the treatment planning system (Oncentra). Two plans were generated for each patient, the first one using the VMAT technique with two partial arcs and the second one using the IMRT technique with seven co-planner radiation portals using 3D-Oncentra TPS with 6 MV photons, step and shoot treatment delivery technique with 80 leaf multi-leaf collimator and 1 cm leaf width at the isocenter.

The VMAT plans optimized using the collapsed cone (GPU) algorithm and IMRT plans optimized using a collapsed cone algorithm. A hypofractionated prescription dose of 40 Gy/15# was using. The VMAT and IMRT plans were compared for PTV Target Coverage, Homogeneity Index, Conformity Index, MUs were evaluated. The OAR doses also compared.

Results: A comparable PTV coverage (V95%), mean PTV doses were observed between VMAT and IMRT plans. The PTV maximum dose was higher within IMRT than the VMAT. We observed a better Homogeneity Index for VMAT plans. Conformity Index comparable plans non-significant differences were observed. MU values of VMAT are higher than the IMRT treatment in this study.

However, VMAT plans show significantly better right lung, heart, and larynx sparing when compared to the IMRT plans. No significant difference was observed in both groups of plan for the right breast and spinal cord. The maximum dose for left humerus head were comparable for both groups of plans.

Conclusion: VMAT is dosimetrically superior to the IMRT for irradiation of left-sided chest wall and regional nodes patients in terms of target coverage and OAR sparing.

Keywords: Radiotherapy; Photons; Tomophan; Radiation oncology

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Abbreviations

IMRT: Intensity Modulated Radiotherapy; VMAT: Volumetric Modulated Arc Therapy; CI: Conformity Index; HI: Homogeneity Index; BCS: Breast-Conserving Surgery; CTV: Clinical Target Volume; DVH: Dose-Volume Histogram

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Introduction

Breast cancer is the most common cancer and is the leading cause of cancer deaths in women worldwide [1]. Most early-stage patients can be treated with Breast-Conserving Surgery (BCS) followed by systemic treatment and adjuvant radiotherapy. Few patients undergo mastectomy followed by adjuvant chemotherapy and radiotherapy as per recommendations [2]. Large prospective trials and a meta-analysis have shown that adjuvant radiotherapy of the chest wall improves local control and survival in node-positive breast cancer patients after mastectomy [3]. The adjuvant radiotherapy of the left-sided chest wall is commonly delivered by three-dimensional conformal radiotherapy (3DCRT) with a field-in-field technique [4]. Increased cardiac morbidity and mortality have been seen in patients treated with radiotherapy for left-sided breast cancer compared to right-sided, due to the higher cardiac dose [5].

VMAT belongs to rotational IMRT and there are several works of literature have shown that VMAT can produce dose distribution similar superior to IMRT. VMAT can achieve highly conformal dose distribution by simultaneously changing the position of the MLC, dose rate, and gantry speed during patient treatment. The important advantage of VMAT when compared to IMRT was a substantial reduction in treatment time. In the treatment of left-sided chest wall patients, VMAT treatment improves target coverage, Homogeneity Index and reduces high dose in ipsilateral lung and heart but increases low dose region for contralateral organs compared to 3DCRT [6].

In this study, we compared the dosimetric parameters between VMAT and IMRT in a patient with left-sided chest wall with loco-regional lymph nodes irradiation.

Materials and Methods

Retrospectively fifteen consecutive left breast cancer patients were planned for adjuvant radiotherapy to the left-sided chest wall with the inclusion of mastectomy scar and loco regional lymph nodes. All patients were immobilized while free breathing using a thermoplastic mould in supine position over a breast board fixed on the couch with both arms extended above their head onto the armrests, the patient's head turned to the right side. Radio opaque wires were used to mark the mastectomy scar.

Planning CT images were acquired from the level of the mandible to the lung base on a CT scanner (Siemens dual slice Somatom Spirit CT) with a slice thickness of 2.5 mm. All the images were exported to the 3D-Oncentra treatment planning system (version 4.3) for contouring and treatment planning.

The Clinical Target Volume (CTV) includes the left chest wall, mastectomy scar, supraclavicular region, and other regional lymph nodes. The CTV was extended by 5 mm circumferentially to create the planning target was restricted to underneath the skin. The OARs such as ipsilateral and both lung, heart, left humeral head, esophagus, and opposite breast were contoured as per RTOG recommendation [7-9].

Planning

The VMAT plans consisted of two coplanar partial arcs (2P-VMAT), one with clockwise direction from 315° to 175° and the other arc counter-clockwise direction from 160° to 325° used. The 2P-VMAT plans were optimized using a collapsed cone (GPU) algorithm.

For all IMRT plans generated using seven fields (312°, 307°, 315°, 150°, 135°, 125°, 40°) and optimized using the collapsed cone algorithm using 6 MV photons with a dose rate of 600 MU. A hypofractionated prescription dose of 40 Gray in 15 fractions was used for all patients. Treatment planning was performed to achieve at was least 95% of PTV volume received 95% of the prescription dose (40 Gy) and with less than 2% of PTV volume receiving <107% of the prescribed dose.

Plan evaluation

The VMAT and IMRT Plans were compared and evaluated for PTV Target Coverage, Homogeneity Index, Conformity Index and number of MU, Doses of the Left Lung (V5 Gy<50%, V10 Gy<30%, V20 Gy<20%, V30 Gy<10%), Heart (V5 Gy<50%, V10 Gy<20%,V20 Gy<15%, V30 Gy<20%), Right Lung (V5 Gy<10% and mean), maximum dose to the spinal cord, right breast, left humeral head, and mean dose to the larynx.

DVH parameters were studied in details.

ICRU 83 is used to evaluate target volume coverage and its conformity.

The Homogeneity Index (HI) was calculated according to the following formula:

$$HI=(D2\%-D98\%)/D50\%$$

Where, D2%, D98% and D50%=dose to 2%, 50% and 98% of the volume respectively.

Values of HI closer to 0 indicate greater dose homogeneity within the volume of PTV, while large

Values indicate more heterogeneous dose distribution.

The Conformity Index (CI) was calculated according to the following formula:

$$CI=VRI/TV$$

Where, VRI: Volume of the prescription reference isodose, TV: Total PTV Volume.

The closer the values of CI close to 1.0, the better the dose conformity.

Statistical analysis

A Wilcoxon Sign Rank Test was used to compare the VMAT and IMRT techniques in respect of dose to the target and normal structures with significance declared for a $p<0.05$ (**Table 1**).

Results

Dose distributions between IMRT and VMAT plans are presented in **Figure 1** and Dose-Volume Histograms are shown in **Figure 2**.

PTV

We observed PTV coverage that VMAT and IMRT plan V95% (cc) PTV was 985.20 cc (781.29 cc ± 1258.37 cc) for VMAT vs. 980.95 cc (774.43 ± 1260.73) for IMRT (p=0.286) and mean PTV was 40.75 (40.53 ± 40.94) for VMAT vs. 40.82 (40.42 ± 41.07) for IMRT (p=0.286) are non-significant difference. Maximum dose to PTV was 45.18 Gy (44.38 ± 45.77) for VMAT vs. 45.50 Gy (44.45 ± 46.34) for IMRT (p=0.016) are significant difference. In comparison between two plans, the PTV maximum dose was higher with IMRT than in the VMAT shown in **Table 1**.

Homogeneity Index PTV was 0.14 (0.12 ± 0.17) for VMAT versus 0.15 (0.14 ± 0.18) for IMRT (p=0.021) significant difference for both techniques means Homogeneity Index was better in VMAT plans in **Figure 1** and **Table 1**. Conformity Index PTV was 0.97 (0.95 ± 0.99) for VMAT versus 0.97 (0.94 ± 0.98) for IMRT (p=0.286) are non-significant difference for both techniques shows in **Figure 2** and **Table 1**.

MU was 962.48 (775.95 ± 1063.67) in VMAT versus 824.38 (448.90 ± 960.12) in IMRT (p=0.010) has a significant difference for both techniques. In our study, MU of VMAT is significantly higher than the IMRT techniques shows in **Figure 3** and **Table 1**.

Left lung

However, the OARs sparing was better with the VMAT plans when compared to the IMRT plans. The V5 Gy (47.93 VMAT vs. 53.70 IMRT), V10 Gy (31.61 VMAT vs. 33.24 IMRT), V20 Gy (20.74 VMAT vs. 23.74 IMRT) and V30 Gy (11.17 VMAT vs. 13.93 IMRT), for the left lung were significantly higher for the IMRT plans when compared to VMAT plans (p=0.005, p=0.013, p=0.009, p=0.005) as shown **Table 2** and **Figure 4**.

	VMAT				IMRT				Wilcoxon sign rank test
PTV	Mean	Std. deviation	Minimum	Maximum	Mean	Std. deviation	Minimum	Maximum	
D98%	37.43	0.36	36.83	37.99	37.27	0.67	35.68	37.89	0.424
D2%	43.01	0.37	42.66	43.9	43.48	0.29	43.15	43.92	0.008*
D50%	40.61	0.09	40.45	40.73	40.77	0.12	40.68	41.04	0.003*
V95% (cc)	985.2	141.7	781.29	1258.37	980.95	146.13	774.43	1260.73	0.286
Mean PTV	40.75	0.12	40.53	40.94	40.82	0.21	40.42	41.07	0.286
MU	962.48	95.49	775.95	1063.67	824.38	154.58	448.9	960.12	0.010*
HI	0.14	0.02	0.12	0.17	0.15	0.02	0.14	0.18	0.021*
CI	0.97	0.01	0.95	0.99	0.97	0.01	0.94	0.98	0.286
Maximum PTV	45.18	0.52	44.38	45.77	45.5	0.75	44.45	46.34	0.016*

Note: *=p<0.05, according to the Wilcoxon's sign rank test, V95%=Prescription of the PTV receiving at least 95% of the prescription dose, D50%=The minimum dose received by 50% of the target volume, D98%=The minimum dose received by 98% of the target volume, D2%=The minimum dose received by 2% of the target volume.

Abbreviations: MU:Monitor Unit; HI: Homogeneity Index; CI: Conformity Index; PTV: Planning Target Coverage

Table 1: Comparison of VMAT and IMRT in terms of PTV parameters.

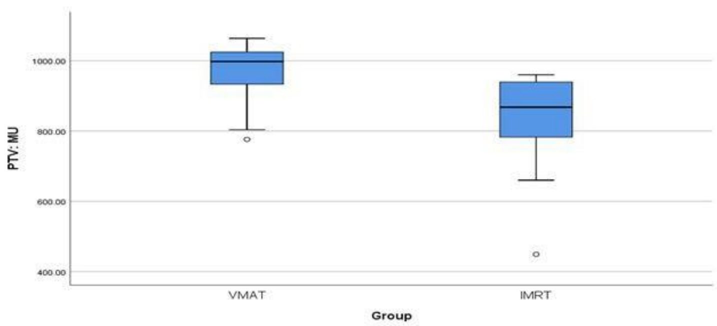

Figure 1: Comparison between VMAT and IMRT plans according to MU.

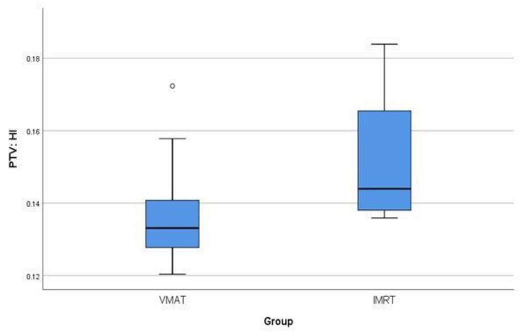

Figure 2: Comparison between VMAT and IMRT plans according to Homogeneity Index.

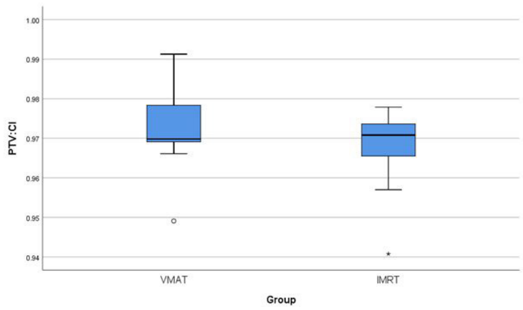

Figure 3: Comparison between VMAT and IMRT plans according to Conformity Index.

	VMAT				IMRT				Wilcoxon sign rank test
Left lung	**Mean**	**Std. deviation**	**Minimum**	**Maximum**	**Mean**	**Std. deviation**	**Minimum**	**Maximum**	
V5 Gy	47.93	2.56	45.22	52.69	53.7	4.58	49.85	65.99	0.005*
V10 Gy	31.61	1.51	29.55	33.47	33.24	1.89	30.56	35.52	0.013*
V20 Gy	20.74	1.84	18.87	23.32	23.74	2.03	21.17	27.22	0.009*
V30 Gy Heart	11.17	1.4	10	13.61	13.93	1.52	12.12	16.38	0.005*
V5 Gy	35.66	4.97	30.21	46.51	45.29	6.61	34.44	52.87	0.005*
V10 Gy	18.07	2.72	12.88	21.53	24.26	2.86	19.74	28.39	0.005*
V20 Gy	9.72	2.95	4.22	13.73	15.71	3.27	11.98	22.75	0.005*
V30 Gy	5.41	9.43	1.03	32	7.9	2.3	4.58	13.05	0.074
Note: *=p<0.05, according to the Wilcoxon's sign rank test, Vn Gy (%)=Percentage of volume receiving n Gy.									

Table 2: Comparison of VMAT and IMRT plans in terms of OARs (left lung and heart).

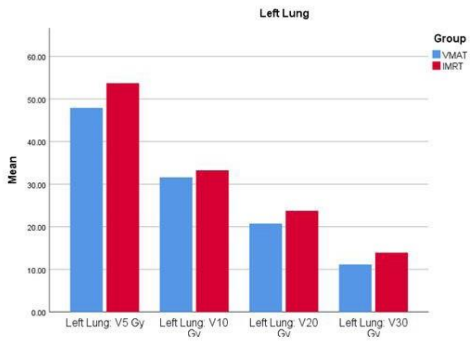

Figure 4: Comparison between VMAT and IMRT plans according to left lung.

Heart

Similarly, the V5 Gy (35.66 VMAT vs. 45.29 IMRT), V10 Gy (18.07 VMAT vs. 24.26 IMRT) and V20 Gy (9.724 VMAT vs. 15.71 IMRT) and higher for the IMRT plans when compared to VMAT plans (p=0.005, p=0.005, p=0.005) and V30 Gy (5.41 VMAT vs. 7.90 IMRT), for the the heart was a non-significant difference between two plans (p=0.074) as shown **Table 2** and **Figure 5**.

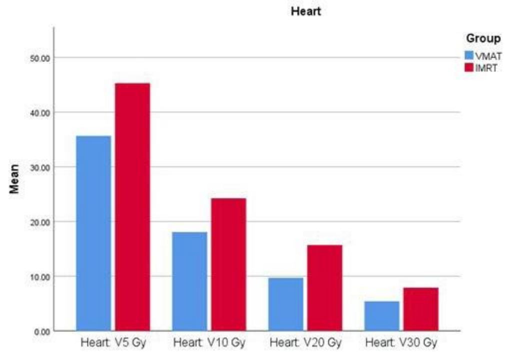

Figure 5: Comparison between VMAT and IMRT plans according to heart.

Right lung and larynx

Table 3 and **Figure 6** shows the V5 Gy (8.49 VMAT vs. 9.84 IMRT), mean (2.32 VMAT vs. 2.68 IMRT) for Right lung, mean (14.04 VMAT vs. 14.49 IMRT) for Larynx (p=0.005, p=0.022, p=0.028) was significant difference between for the VMAT plans and IMRT plans.

Spinal cord and right breast

Table 3 and **Figure 6** shows the maximum dose for spinal cord (6.85 VMAT vs. 7.11 IMRT), p=0.221, maximum dose for right breast (2.51 VMAT vs. 2.68 IMRT) p=0.083 was non-significant difference.

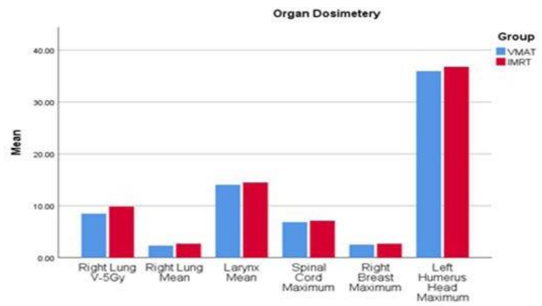

Figure 6: Comparison between VMAT and IMRT plans according to OARs.

Left humeral head

Table 3 and **Figure 6** shows the maximum dose for left humerus head (35.95 VMAT vs. 36.79 IMRT), p=0.007 was a significant difference between the VMAT plans and IMRT plans.

An example of dose distribution between IMRT and VMAT left sided chest wall treatment plans are shown in **Figure 7** and an example of the cumulative dose-volume histogram (DVH) of VMAT and IMRT plans for Left sided chest wall is shown in **Figure 8**.

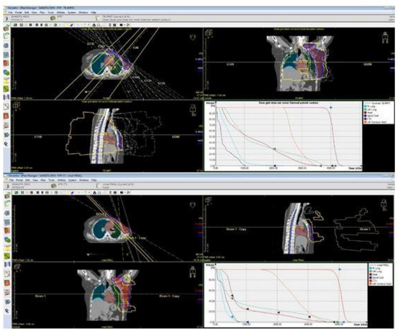

Figure 7: An example of dose distribution between IMRT and VMAT Left sided chest wall treatment plans.

	VMAT				IMRT				Wilcoxon sign rank test
	Mean	Std. deviation	Minimum	Maximum	Mean	Std. deviation	Minimum	Maximum	
Right lung V5 Gy	8.49	0.95	7.48	10.73	9.84	1.57	8	13.32	0.005*
Right lung mean	2.32	0.18	2.1	2.61	2.68	0.4	1.78	3.19	0.022*
Larynx mean	14.04	1.78	10	16.12	14.49	1.87	10.41	16.5	0.028*
Spinal cord maximum	6.85	1.18	5.25	8.73	7.11	1.64	5.58	10.8	0.221
Right breast maximum	2.51	0.26	2.12	2.8	2.68	0.25	2.3	3	0.083
Left humerus head maximum	35.95	1.39	33.17	37.78	36.79	1.49	34.65	39.2	0.007*
Note: *=p<0.05, according to the Wilcoxon's sign rank test, V5 Gy (%)=Percentage of volume receiving 5 Gy									

Table 3: Plan comparison parameters, mean values and range for VMAT and IMRT for this study in terms of OARs.

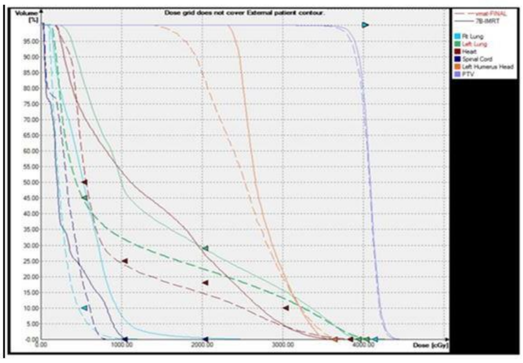

Figure 8: An example of the cumulative Dose-Volume Histogram (DVH) of VMAT and IMRT plans for Left sided chest wall.

Discussion

In the context of breast cancer, critical OAR includes contralateral breast, lungs, and heart.

VMAT techniques that use full rotation arc around the patients are likely to increase radiation received by these structures, albeit the lower isodose. But even this low dose can be detrimental to the heart and the normal breast in the long term. It is for this reason that in our VMAT techniques we used only partial arc, with tight control overdose deposition to vulnerable OARS.

Literature suggests the importance of radiation therapy in controlling the loco-regional disease for the overall survival of breast cancer patients [10,11]. Simultaneously, there is literature evidence of some detriment by radiation to critical OARs such as the heart and contralateral breast [12-14]. It is, therefore, crucial to plan carcinoma breast patients meticulously by radiotherapy to attain good loco-regional control and spare side effects.

In this study, we reported of dosimetric comparison between two techniques including two partial Arc-VMAT and IMRT of ten consecutive breast cancer patients. It can shape the dose to the concave target on the left-sided chest wall including loco-regional lymph node.

In the present study, statistically significant improvement was noted in Homogeneity Index with VMAT plans compared to IMRT plans. However, no significant difference is noted in the Conformity Index. The results of our study demonstrate that VMAT techniques have lower doses to mentioned OARs as compared to IMRT. VMAT plans consistently scored significantly lower values for all the evaluated parameters for the left lung in terms of V5 Gy (p=0.005), V10 Gy (p=0.013), V20 Gy (p=0.009) and V30 Gy (p=0.005) and for the heart V5 Gy (p=0.005), V10 Gy(p=0.005), V20 Gy (p=0.005) except for V30 Gy (p=0.07).

VMAT has been revealed to deliver lower doses to the ipsilateral breast and lung and offer better dose co VMAT plans consistently scored significantly lower values for all the evaluated parameters for the left lung conformity than a 3D-CRT technique for partial breast irradiation patients [15]. In our study, VMAT plans as compared to IMRT showed lower values in all parameters of left lung dose.

Significantly lower values of mean doses with VMAT also have been observed for right lung larynx; maximum dose for the left humeral head.

Previous studies showed that there was high long term risk of developing the secondary malignancy of contralateral breast, and the mean dose to the contralateral breast was 3.2 Gy with RapidArc. In our study, a slightly the lower mean dose of 2.5 Gy was observed with VMAT, which may be the results of different dose calculation algorithms or inhomogeneity correction in the two treatment planning systems [12].

In this study, Non-significant difference was found between two groups of the plan for the Maximum dose of the contralateral breast (P=0.08) and spinal cord (p=0.2).

Conclusion

VMAT is dosimetrically superior to the IMRT for left-sided chest wall and regional nodes patients owing to its comparable PTV coverage and better sparing of heart, lung, and left humerus head, larynx.

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Conflict of Interest

All the authors declare that they have no conflict of interest.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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