Dosimetric comparison of IMRT and VMAT treatment plans for breast cancer with 1-2 sentinel lymph node metastasis

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▶ ***Original article***

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# Kaining Yao and Meijiao Wang contributed equally to this work.

ABSTRACT

Background: To compare the dosimetry of Intensity-Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) techniques for breast cancer patients with 1-2 sentinel lymph node metastases. ***Materials and Methods:*** A total of 90 breast cancer patients (left:33, right:57) receiving post-operative radiotherapy were retrospectively included. IMRT and VMAT treatment plans were designed for each patient with same prescriptions and dose-volume constraints. Key dose-volume histogram (DVH) metrics in target volumes and organs-at-risks (OARs) were analyzed and compared in groups. ***Results:*** Compared with IMRT, VMAT showed superior target coverage and dose conformity, particularly for planning target volume (PTV) and axillary levels 1-2 lymph nodes in both left- and right-sided cancers. For left-sided cases, VMAT significantly reduced mean dose (Dmean) to the heart and left coronary artery ($p<0.001$), with a 33% decrease in V40% for left coronary artery. For right-sided cases, VMAT showed a modest Dmean increase to these structures due to dose spillage, though all values remained within clinical constraints. Compared with IMRT, VMAT demonstrated superior dose sparing for the ipsilateral lung and humeral head. While both techniques achieved comparable dose coverage for axillary level 3 lymph nodes ($p > 0.05$), VMAT required significantly fewer monitor units (MU) ($p < 0.001$). ***Conclusion:*** The dosimetric analysis demonstrates VMAT's superiority over IMRT in breast cancer patients with 1-2 sentinel lymph node metastases, offering improved target coverage, enhanced organ sparing, and greater delivery efficiency.

INTRODUCTION

Breast cancer is one of the most common female cancers all over the world [1], and the systematic treatment of breast cancer typically involves surgery, chemotherapy, and radiotherapy. For patients receiving breast-conserving surgery but with 1-2 positive sentinel lymph node biopsy, a viable treatment option is adjuvant radiotherapy with axillary irradiation. For these patients, the target volume in radiotherapy includes the ipsilateral breast and the axillary lymph node region [2-6].

The axillary lymph node region is anatomically composed of three sub-regions indexed as level 1, level 2, and level 3, respectively. The expanded and anatomically complex target volume poses challenges for treatment planning. Early studies [7, 8] using 3D-conformal radiotherapy (3D-CRT) with tangential fields demonstrated adequate dose delivery to the primary breast target but insufficient coverage of axillary levels, as these regions were not defined as target volume in early planning protocols. Nitsche *et al.* [9] expanded the target volume definition to include axillary levels 1-3 to address these coverage gaps. They evaluated target dose coverage and organ-at-risk (OAR) exposure in tangential-field radiation. Similarly, Alco *et al.* [10] adjusted the position of the multi-leaf collimator (MLC) in tangential fields to enhance the dose to axillary levels 1 and 2. While these strategies improved axillary coverage, they also inadvertently increased the dose of OARs.

With the advent of Volumetric Modulated Arc Therapy (VMAT), several studies have demonstrated improved conformity and uniformity in target volume coverage, along with enhanced OAR sparing [11-15]. Tuomas *et al.* showed that VMAT significantly reduced dose to the heart and ipsilateral lung in left-sided breast cancer patients [16]. Moreover, Mikel *et al.* found that tangential VMAT field arrangements were viable for patients with breast or chest wall involvement and internal mammary nodal disease [17]. Also, Boman *et al.* compared different radiation field arrangements, and their results showed that the split-arc VMAT technique offered dosimetric advantages for the target volumes, heart, and ipsilateral lung [18]. These findings indicated that utilizing multiple partial-arc fields in VMAT planning might have dosimetric advantages.

However, dosimetric studies on treatment techniques are rare for patients receiving axillary levels 1-2 radiation, and the optimal VMAT planning strategy still needs to be discovered. This study evaluates partial-arc VMAT techniques with diverse field arrangements for breast cancer radiotherapy targeting axillary levels 1-2, comparing plan quality with conventional tangential IMRT.

MATERIALS AND METHODS

Cohort description

This work retrospectively enrolled 90 breast cancer patients receiving post-operative radiotherapy at Peking University Cancer Hospital between January 2018 and December 2023. The selection criteria were: 1) confirmation of breast cancer through pathology; 2) presence of 1-2 positive sentinel lymph nodes without lymph node dissection; 3) prescription with a simultaneous boost to the ipsilateral tumor bed. Over the cohort, 33 cases were left-sided breast cancer, and 57 were right-sided. Patients aged 30 - 73 (median = 49.5) had clinically staged T1-2N1M0, whose pathology diagnosis was invasive ductal carcinoma (IDC). This study was approved by the Institutional Review Board (IRB) of Peking University Cancer Hospital (Approval number: 2022YJZ100).

Target delineation

Patients were immobilized using a breast board with thermoplastic mask. Simulation CT scans (5-mm slice thickness, 0.7 × 0.7 mm resolution) were acquired for planning. Target volumes were contoured following ESTRO guidelines and institutional protocols [19], with all delineations reviewed by a senior physician panel prior to planning. Two clinical target volumes (CTV) were defined for each case:

CTV_{breast}, encompassing the entire ipsilateral breast and axillary levels 1 and 2, while level 3 was considered an OAR.

CTV_{boost}, including the breast tumor bed to be boosted.

Before treatment plan designing, two planning target volumes (PTV_{breast} and PTV_{boost}) were generated from their respective CTVs using anisotropic margins: 3 mm anteriorly/laterally and 5 mm in other directions, followed by a 2 mm skin retraction. Over the cohort, the average volume of PTV_{breast} and PTV_{boost} (mean ± standard deviation) was 962.89±258.12 cm^3, 112.87±51.41 cm^3, respectively.

To reduce PTV_{breast} hot spots, we created a control structure named $PTV_{b/b}$, which was defined as the region by subtracting PTV_{boost} from PTV_{breast} and then expanding by 1 cm isotopically. Meanwhile, axillary levels 1-3 regions (termed LNAxillaryLvI, LNAxillaryLvII, and LNAxillaryLvIII) were defined according to the anatomical structure.

Treatment planning

Target dose prescription: The dose prescriptions for CTV_{breast} and CTV_{boost} were 50 Gy/25 fractions and 60 Gy/25 fractions (simultaneously boost). The coverage requirements for CTV and PTV are $D_{100\%} \geq$ 99% and $D_{100\%} \geq$ 95%, respectively.

IMRT and VMAT planning: For each patient, treatment plans were designed using IMRT and VMAT techniques on the Eclipse (Version 15.6, Varian, Palo Alto, California, USA) treatment planning system, and delivered on a VitalBeam linear accelerator (Varian, Palo Alto, California, USA). The plan optimization utilized the PO (Progressive Optimization) engine enabling jaw tracking, and the dose calculation was performed using the AcurosXB algorithm.

IMRT field setup: For IMRT planning, all patients received 6 MV photon therapy. Since the target volumes of the left-sided breast cancer were close to the heart and left coronary artery, 4-5 fixed fields were employed to minimize cardiac dose, while 3-4 fixed fields were employed for patients with right-sided breast cancer. Please see Figure 1 for the beam arrangement.

VMAT field setup: All VMAT plans utilized 6 MV flattening filter-free beams with 4 partial-arc fields. For left-sided cases, arcs were positioned at: 179° counterclockwise (CCW)→70°, 70° clockwise (CW)→179°, 300°CW→350°, and 350°CCW→300°. Right-sided cases used: 181°CW→290°, 290°CCW→181°, 60°CCW→10°, and 10°CW→60° (please see Figure 2). The collimator Y-axis was aligned parallel to CTV_{breast}'s long axis for optimal delivery. This arc arrangement ensured precise and efficient radiation delivery to the target volumes.

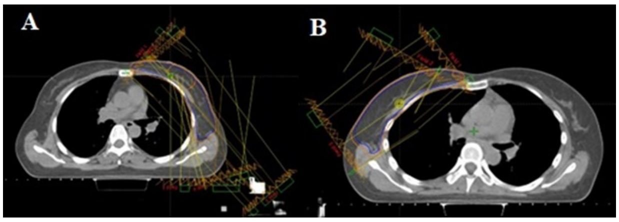

Figure 1. Treatment fields setup for IMRT plan. **(A)** Left-sided breast -IMRT; **(B)** Right-sided breast -IMRT.

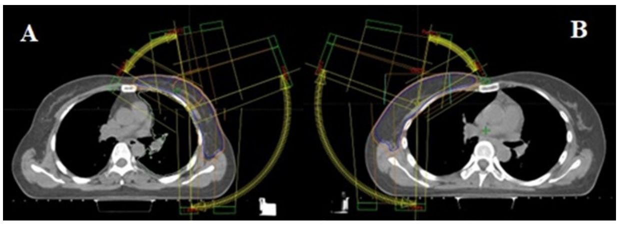

Figure 2. Treatment fields setup for VMAT plan. **(A)** Left-sided breast -VMAT; **(B)** Right-sided breast -VMAT.

Evaluation metrics

To identify the strengths and limitations of both treatment techniques, target coverage, dose distribution, and OAR sparing were compared. For the target, $D_{100\%}$, $D_{95\%}$, $V_{107\%}$, D_{max}, D_{mean}, D_{min} and Conformity Index (CI) were calculated respectively. $D_{100\%}$ means dose to 100% of the target volume. $D_{95\%}$

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means dose to 95% of the target volume. $V_{107\%}$ means the volume receiving 107% of the prescribed dose. D_{max} means maximum dose, D_{mean} means average dose and D_{min} means minimum dose. Note that CI was defined as [20, 21]:

$$CI = \frac{V_{PTV50}}{V_{PTV}} * \frac{V_{PTV}}{V50} \quad (1)$$

In Equation (1), V_{PTV50} represented the volume of the PTV receiving the prescription dose (50 Gy), V_{PTV} denoted the PTV volume, and V_{50} referred to the total volume receiving the prescription dose (50 Gy). A CI value closer to 1 indicated better conformity.

For $PTV_{b/b}$, V_{50}%, V_{54}%, and V_{55}% (Vx % means the volume receiving x Gy) were calculated. We used V_5, V_{20}, V_{40}, D_{max}, and D_{mean} to evaluate the OAR sparing. The monitor units (MU) of the IMRT and VMAT plans were also compared.

Statistical analysis

The statistical analysis was performed using SPSS 26.0. We first used Shapiro-Wilk and Kolmogorov-Smirnov tests to verify the data normality, with significance criteria set at 0.05, where $p < 0.05$ indicates non-normality. Wilcoxon signed-rank test was then used to compare the, with a statistical significance threshold set at $p < 0.05$.

RESULTS

DVH overview and representative cases

Figure 3 compares the average dose-volume histograms (DVHs) between VMAT and IMRT, demonstrating significant dosimetric differences for both target volumes and OARs. Furthermore, representative cases in Figures 4-5 show VMAT's superior PTV_{breast} and axillary level conformity compared to IMRT. The DVH data of left- and right-sided patients were collected, the average values were calculated, and the graph was created. The solid line represents the IMRT plan, and the dashed line represents the VMAT plan (figure 3).

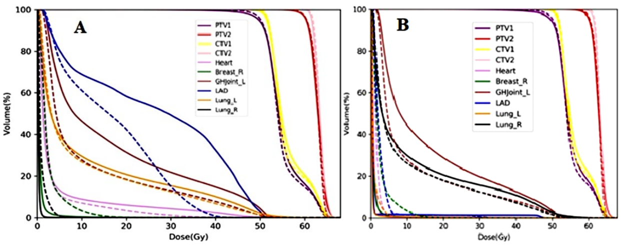

Figure 3. The average DVH for left- and right-sided breast cancer patients. **(A)** The average DVH of left-sided patients. **(B)** The average DVH of right-sided patients.

Comparison of target volume doses

CTV & PTV

The evaluated DVH parameters of the target volumes included the $D_{95\%}$, $V_{107\%}$, D_{max}, D_{mean}, and D_{min} for CTV_{breast}, CTV_{boost}, PTV_{breast}, PTV_{boost}, and $PTV_{b/b}$, along with CI for PTV_{breast} and PTV_{boost}. Table 1 presents the target volumes dose comparison for left-sided breast cancer patients. VMAT demonstrated: (1) higher CTV_{breast} $D_{100\%}$ and D_{min} but lower D_{mean} versus IMRT; (2) superior PTV_{breast} $D_{95\%}$ meeting prescription requirements; (3) reduced $V_{107\%}$ for both PTV_{breast} and PTV_{boost}; (4) lower $PTV_{b/b}$ V_{54} and V_{55} values; (5) improved CIs (PTV_{breast}: 0.79 vs 0.70; PTV_{boost}: 0.68 vs 0.59). These results confirm VMAT's dosimetric advantages in target coverage and conformity.

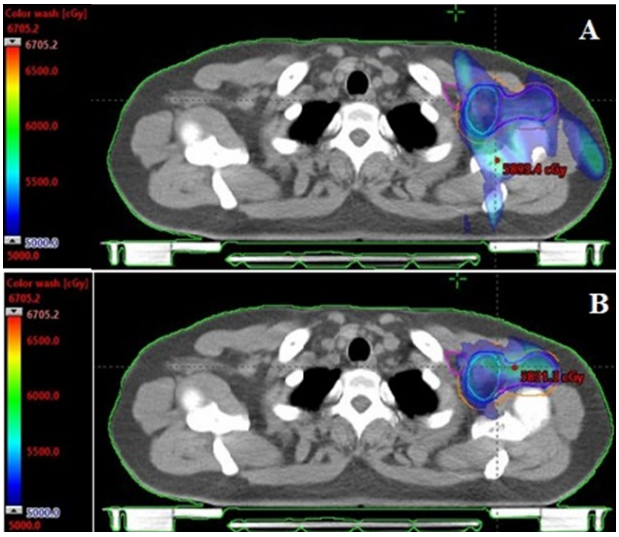

Figure 4. A representative case of a left-sided breast cancer patient. **(A)** Transverse plane dose of IMRT plan. **(B)** Transverse plane dose of VMAT plan.

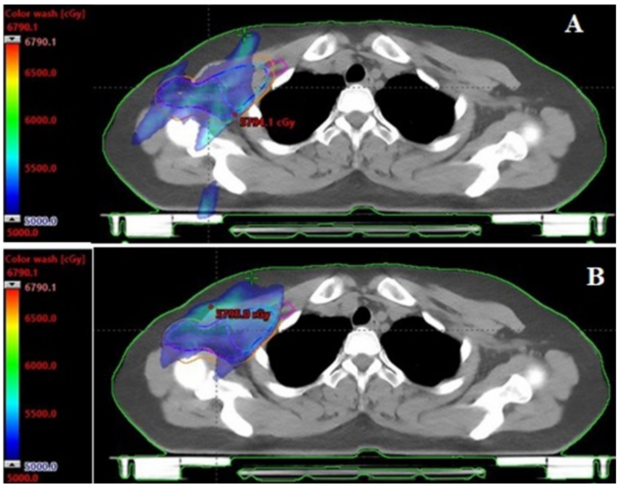

Figure 5. A representative case of a right-sided breast cancer patient. **(A)** Transverse plane dose of IMRT plan. **(B)** Transverse plane dose of VMAT plan

Table 2 presents the target volumes dose comparison for right-sided breast cancer patients. VMAT demonstrated: (1) lower CTV_{breast} D_{mean} but higher $D_{100\%}$ and D_{min} compared to IMRT; (2) improved PTV_{breast} and PTV_{boost} $D_{95\%}$, meeting prescription requirements; (3) reduced PTV_{boost} $V_{107\%}$ and PTV_{breast} D_{mean}; (4) decreased $PTV_{b/b}$ V_{54} and V_{55}; (5) superior CIs (PTV_{breast}: 0.79 vs 0.71; PTV_{boost}: 0.70 vs 0.60). These findings further support VMAT's dosimetric advantages for right-sided cases.

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Table 1. Dosimetric comparison of target volumes for left-sided breast cancer patients.

Structure	Metrics	IMRT	VMAT	p-value
		Mean ± SD	Mean ± SD	
CTV_{breast}				
	$D_{100\%}$ (Gy)	42.87 ± 4.88	47.02 ± 1.66	**<0.001**
	D_{max} (Gy)	67.14 ± 1	67.3 ± 0.84	0.432
	D_{mean} (Gy)	56.09 ± 0.74	55.81 ± 0.69	**0.002**
	D_{min} (Gy)	42.86 ±4.89	47.01 ± 1.66	**<0.001**
CTV_{boost}				
	$D_{100\%}$ (Gy)	59.32 ± 1.16	59.46 ± 1.04	0.915
	D_{max} (Gy)	66.4 ± 0.95	66.46 ± 0.72	0.734
	D_{mean} (Gy)	63.39 ± 0.51	63.35 ± 0.33	0.592
	D_{min} (Gy)	59.32 ± 1.16	59.46 ± 1.04	0.915
PTV_{breast}				
	$D_{95\%}$ (Gy)	49.68 ± 0.67	50.12 ± 0.11	**0.001**
	$V_{107\%}$ (%)	60.3 ± 5.54	57.9 ± 5.82	**0.042**
	D_{max} (Gy)	67.49 ± 1.03	67.39 ± 0.85	0.617
	D_{mean} (Gy)	55.12 ± 0.59	54.91 ± 0.54	**0.024**
	D_{min} (Gy)	20.83 ± 7.25	33.35 ± 4.52	**<0.001**
	CI	0.7 ± 0.04	0.79 ± 0.03	**<0.001**
PTV_{boost}				
	$D_{95\%}$ (Gy)	60.36 ± 0.48	60.4 ± 0.16	0.802
	$V_{107\%}$ (%)	18.96±13.29	12.1 ± 8.22	**0.014**
	D_{max} (Gy)	67.01 ± 0.95	66.85 ± 0.67	0.352
	D_{mean} (Gy)	62.89 ± 0.42	62.83 ± 0.21	0.532
	D_{min} (Gy)	52.58 ± 2.96	53.12 ± 2.08	0.335
	CI	0.59 ± 0.12	0.68 ± 0.1	**0.001**
$PTV_{b/b}$				
	V_{54} (%)	41.34 ± 7.18	35.79 ± 6.69	**0.001**
	V_{55} (%)	24.74 ± 7.76	16.63 ± 6.33	**<0.001**

*Abbreviations: SD: standard deviation; Dmax: maximum dose; Dmean: average dose; Dmin: minimum dose; D100%: dose to 100% of the target volume; D95%: dose to 95% of the target volume; V107%: the volume receiving 107% of the prescribed dose; V54: the volume receiving 54 Gy; V55: the volume receiving 55 Gy; CI: Conformity Index.

Table 2. Dosimetric comparison of target volumes for right-sided breast cancer patients.

Structure	Metrics	IMRT		VMAT		p-value
		Mean	SD	Mean	SD	
CTV_{breast}						
	$D_{100\%}$ (Gy)	42.69	4.17	46.49	1.7	**<0.001**
	D_{max} (Gy)	66.89	1.21	66.98	0.9	0.617
	D_{mean} (Gy)	56.14	0.76	55.81	0.65	**<0.001**
	D_{min} (Gy)	42.68	4.18	46.49	1.7	**<0.001**
CTV_{boost}						
	$D_{100\%}$ (Gy)	58.88	1.56	59.07	1.4	0.238
	D_{max} (Gy)	66.25	1.17	66.39	0.71	0.195
	D_{mean} (Gy)	63.29	0.55	63.21	0.27	0.567
	D_{min} (Gy)	58.88	1.56	59.07	1.4	0.24
PTV_{breast}						
	$D_{95\%}$ (Gy)	49.61	0.61	50.15	0.18	**<0.001**
	$V_{107\%}$ (%)	60.28	7.04	58.68	5.14	0.137
	D_{max} (Gy)	67.11	1.22	67.07	0.85	0.956
	D_{mean} (Gy)	55.12	0.67	54.94	0.53	**0.009**
	D_{min} (Gy)	19.41	6.82	34.2	3.4	**<0.001**
	CI	0.71	0.05	0.79	0.03	**<0.001**
PTV_{boost}						
	$D_{95\%}$ (Gy)	60.23	0.32	60.36	0.2	**<0.001**
	$V_{107\%}$ (%)	16.36	13.77	8.98	7.14	**<0.001**
	D_{max} (Gy)	66.8	1.05	66.86	0.67	0.541
	D_{mean} (Gy)	62.8	0.44	62.72	0.21	0.243
	D_{min} (Gy)	52.68	2.15	52.57	2.21	0.617
	CI	0.6	0.09	0.7	0.07	**<0.001**
$PTV_{b/b}$						
	V_{54} (%)	40.56	9.43	35.02	6.54	**0.001**
	V_{55} (%)	23.9	9.44	14.89	6.16	**<0.001**

*Abbreviations: SD: standard deviation; Dmax: maximum dose; Dmean: average dose; Dmin: minimum dose; D100%: dose to 100% of the target volume; D95%: dose to 95% of the target volume; V107%: the volume receiving 107% of the prescribed dose; V54: the volume receiving 54 Gy; V55: the volume receiving 55 Gy; CI: Conformity Index.

LNAxillaryLvI & II

As axillary levels 1-2 are encompassed within CTV_{breast}, their dosimetry was evaluated separately. Tables 3 and 4 demonstrate that for both left- and right-sided cases: (1) VMAT achieved comparable or superior V_{50} and CI values versus IMRT; (2) VMAT showed higher D_{min} for left-sided axillary levels 1-2; (3) VMAT consistently reduced D_{mean} for right-sided axillary levels 1-2.

Table 3. Dosimetric comparison of LNAxillaryLvI & II for left-sided breast cancer patients.

Structure	Metrics	IMRT		VMAT		p-value
		Mean	SD	Mean	SD	
LNAxillaryLvI	V_{50} (%)	99.00	0.98	99.48	0.52	**0.027**
	D_{max} (Gy)	61.86	3.09	60.22	3.11	**0.017**
	D_{mean} (Gy)	53.53	0.55	53.32	0.46	0.097
	D_{min} (Gy)	45.12	4.20	47.85	1.78	**<0.001**
	CI	0.11	0.21	0.12	0.21	**<0.001**
LNAxillaryLvII	V_{50} (%)	99.05	1.45	99.76	0.56	**0.04**
	D_{max} (Gy)	63.07	3.37	63.07	3.43	**0.02**
	D_{mean} (Gy)	54.37	1.24	54.23	0.76	0.68
	D_{min} (Gy)	48.01	2.38	48.95	1.83	**0.03**
	CI	0.04	0.01	0.04	0.01	**<0.001**

*Abbreviations: LNAxillaryLvI: the axillary levels 1; LNAxillaryLvII: the axillary levels 2; SD: standard deviation; Dmax: maximum dose; Dmean: average dose; Dmin: minimum dose; V50: the volume receiving 50 Gy; CI: Conformity Index.

Table 4. Dosimetric comparison of LNAxillaryLvI & II for right-sided breast cancer patients.

Structure	Parameter	IMRT		VMAT		p-value
		Mean	SD	Mean	SD	
LNAxillaryLvI	V_{50} (%)	98.74	1.39	99.47	0.57	**< 0.001**
	D_{max} (Gy)	63.58	3.24	61.25	3.30	**< 0.001**
	D_{mean} (Gy)	53.76	0.87	53.41	0.70	**0.001**
	D_{min} (Gy)	44.87	3.84	44.87	1.78	**< 0.001**
	CI	0.10	0.02	0.11	0.02	**< 0.001**
LNAxillaryLvII	V_{50} (%)	98.79	1.74	99.83	0.29	**< 0.001**
	D_{max} (Gy)	63.91	3.28	63.22	3.34	0.40
	D_{mean} (Gy)	54.67	1.27	54.53	0.81	**0.02**
	D_{min} (Gy)	47.83	2.43	48.27	2.25	0.348
	CI	0.04	0.01	0.05	0.13	**< 0.001**

*Abbreviations: LNAxillaryLvI: the axillary levels 1; LNAxillaryLvII: the axillary levels 2; SD: standard deviation; Dmax: maximum dose; Dmean: average dose; Dmin: minimum dose; V50: the volume receiving 50 Gy; CI: Conformity Index.

Comparison of OAR doses

Table 5 summarizes heart and left coronary artery dose comparisons for left- and right-sided breast cancer patients. For left-sided patients, VMAT demonstrated: (1) reduced heart D_{mean}; (2) significant left coronary artery D_{mean} reduction (Δ9.51 Gy vs IMRT); (3) 33% decrease in left coronary artery V_{40}. For right-sided patients, the D_{mean} for the heart and left coronary artery slightly increases in the VMAT plan compared to the IMRT plan but remained within an acceptable range.

Ipsilateral OARs

Table 6 indicates that the D_{mean} for ipsilateral humeral head and lung are reduced to varying degrees in the VMAT plan compared to the IMRT plan. For left-sided breast cancer patients, the D_{mean} for the

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ipsilateral humeral head and lung is reduced by 5.47 Gy and 1.2 Gy in the VMAT plan compared to the IMRT plan. The V_{20}, V_{40}, and V_5 for the ipsilateral lung decreased from 20.76%, 10.01%, and 40% in the IMRT plan to 18.12%, 6.78%, and 38.02% in the VMAT plan. For right-sided breast cancer patients, the D_{mean} for the ipsilateral humeral head and lung is reduced by 4.36 Gy and 1.42 Gy in the VMAT plan compared to the IMRT plan. The V_{20}, V_{40}, and V_5 for the ipsilateral lung decreased from 20.94%, 10.96%, and 41.12% in the IMRT plan to 18.19%, 7.24%, and 37.93% in the VMAT plan. Importantly, there is no statistically significant difference in the dose of LNAxillaryLvIII between the VMAT and IMRT plans.

Table 5. Dosimetric comparison of heart and left coronary artery for left- and right-sided breast cancer patients.

Structure	Parameter	IMRT		VMAT		p-value
		Mean	SD	Mean	SD	
Heart_L	D_{mean} (Gy)	4.21	1.5	3.48	1.07	**<0.001**
LAD_L	V_{40} (%)	33.23	25.63	0.75	1.35	**<0.001**
	D_{mean} (Gy)	26.32	9.36	16.97	5.71	**<0.001**
Heart_R	D_{mean} (Gy)	0.77	0.19	1.47	0.3	**<0.001**
LAD_R	D_{mean} (Gy)	0.48	0.15	2.24	0.72	**<0.001**

*Abbreviations: Heart_L: heart for left-sided breast cancer patients. LAD_L: left coronary artery for left-sided breast cancer patients. Heart_R: heart for right-sided breast cancer patients. LAD_R: left coronary artery for right-sided breast cancer patients. SD: standard deviation; Dmax: maximum dose; Dmean: average dose; Dmin: minimum dose; V40: the volume receiving 40 Gy.

Table 6. Dosimetric comparison of ipsilateral OARs for breast cancer patients.

	Structure	Parameter	IMRT		VMAT		p-value
			Mean	SD	Mean	SD	
Left-sided	Ipsilateral GHJoint	D_{mean} (Gy)	16.41	8.53	10.94	6.16	**<0.001**
	Ipsilateral Lung	V_{20} (%)	20.76	2.24	18.12	2.35	**<0.001**
		V_{40} (%)	10.01	2.62	6.78	1.51	**<0.001**
		V_5 (%)	40	4	38.02	3.9	**<0.001**
		D_{mean} (Gy)	11.05	0.99	9.85	0.89	**<0.001**
	LNAxillaryLvIII	D_{max} (Gy)	56.84	1.98	56.41	1.48	0.29
		D_{mean} (Gy)	46.81	6.42	45.54	4.34	0.28
Right-sided	Ipsilateral GHJoint	D_{mean} (Gy)	15.27	6.62	10.91	4.92	**<0.001**
	Ipsilateral Lung	V_{20} (%)	20.94	2.17	18.19	2.17	**<0.001**
		V_{40} (%)	10.96	2.07	7.24	1.52	**<0.001**
		V_5 (%)	41.12	3.88	37.93	3.36	**<0.001**
		D_{mean} (Gy)	11.37	1.05	9.95	0.89	**<0.001**
	LNAxillaryLvIII	D_{max} (Gy)	55.86	2.27	56.11	1.36	0.49
		D_{mean} (Gy)	46.22	5.22	46.94	5.14	0.09

* Abbreviations: LNAxillaryLvIII: the axillary levels 3; SD: standard deviation; Dmax: maximum dose; Dmean: average dose; Dmin: minimum dose; V20: the volume receiving 20 Gy; V40: the volume receiving 40 Gy; V5: the volume receiving 5 Gy.

Contralateral OARs

Table 7 demonstrates that the D_{max}/D_{mean} for the contralateral breast and D_{mean} for the contralateral lung slightly increased in the VMAT plan compared to the IMRT plan but remained within an acceptable range.

Comparison of MU values

For left-sided patients, the MU values are 1089.15 ± 262 ($p < 0.01$) and 840.73 ± 49.25 ($p < 0.01$) for IMRT and VMAT plans. For right-sided patients, the MU values are 1008.38 ± 220.85 ($p < 0.01$) and 839.98 ± 31.07 ($p < 0.01$) for IMRT and VMAT plans. The result indicates that the MU values are higher for the IMRT plan than the VMAT plan, and there are more significant variations in the IMRT plan.

Table 7. Dosimetric comparison of contralateral OARs for breast cancer patients.

	Structure	Parameter	IMRT		VMAT		p-value
			Mean	SD	Mean	SD	
Left-sided	Contralateral Breast	D_{max} (Gy)	18.92	13.44	23.61	9.64	**0.026**
		D_{mean} (Gy)	0.64	0.27	2.53	0.8	**<0.001**
	Contralateral Lung	D_{mean} (Gy)	0.35	0.09	0.96	0.17	**<0.001**
Right-sided	Contralateral Breast	D_{max} (Gy)	15.55	9.68	22.73	8.1	**<0.001**
		D_{mean} (Gy)	0.64	0.3	2.39	0.74	**<0.001**
	Contralateral Lung	D_{mean} (Gy)	0.29	0.04	0.81	0.19	**<0.001**

DISCUSSION

Radiotherapy is widely used for breast-conserving surgery patients with 1-2 sentinel lymph node metastases, demonstrating comparable efficacy to surgical intervention with fewer side effects [22]. The National Comprehensive Cancer Network (NCCN) guidelines [23] recommend whole-breast tangential IMRT for this patient case. However, the expanded target volume limits this technique's ability to achieve optimal dose conformity and distribution. This study evaluated the clinical benefits of partial-arc (four-field) VMAT versus conventional tangential IMRT in breast-conserving surgery patients with 1-2 sentinel lymph node metastases. Results demonstrated VMAT's superior prescription dose conformity, enhanced target coverage, and improved organ-at-risk sparing compared to IMRT.

For both left- and right-sided breast cancers, VMAT demonstrated superior target coverage compared to IMRT, as evidenced by higher $D_{95\%}$ values for both PTV_{breast} and $PTV_{boost,}$ and improved V_{50} coverage of axillary levels 1-2. While IMRT often failed to achieve the prescription dose, these findings highlight VMAT's advantage in ensuring optimal dose delivery to target volumes.

VMAT plan also demonstrated better conformity indices (CIs) for PTV_{breast}, PTV_{boost}, and axillary levels 1-2 compared to IMRT. A higher CI indicated better dose conformity [20, 21]. Notably, VMAT also achieved significantly lower high-dose volumes (V_{54}/V_{55} for $PTV_{b/b}$; $V_{107\%}$ for $PTV_{breast/boost}$, $p < 0.05$), indicating reduced high-dose spillage. These improvements may decreased risks of early edema and late fibrosis [24], while aligning with established VMAT advantages in breast radiotherapy [25-27].

Consistent with previous research [13, 18, 28, 29], VMAT significantly reduced dose to OARs in this study. For left-sided cases, VMAT lowered heart and left coronary artery exposure, while all cases demonstrated reduced ipsilateral lung and humeral

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head doses. These dosimetric advantages might decrease radiation-induced complications (e.g., pneumonitis) and potentially reduce secondary radiotherapy risks [30, 31]. Although VMAT increased contralateral breast/lung doses slightly, these doses remained within acceptable limits [18, 29, 32-34].

Although utilizing a similar number of fields, VMAT demonstrated significantly lower monitor unit (MU) requirements than IMRT [35–37]. This reduction offered two key advantages: (1) simplified treatment planning through fewer segments, potentially enhancing delivery efficiency and accuracy [38, 39]; and (2) shorter treatment times, which might minimize target displacement risks from intrafraction motion.

For partial-arc fields, minor adjustments to arc angles might be clinically implemented based on target location and plan complexity, aiming to optimize target coverage while sparing surrounding healthy tissues. A limitation of this study was its focus on a specific case type; future research would investigate VMAT applications for other breast cancer scenarios.

CONCLUSIONS

This study demonstrates that VMAT is a reliable and effective radiotherapy technique for breast-conserving surgery patients with 1-2 sentinel lymph node metastases. Although VMAT may result in slightly higher doses to certain OARs compared to IMRT, treatment selection should be individualized based on target location, OAR considerations, and planning complexity.

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