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ARTICLE

Comparative Evaluation of Volumetric-Modulated Arc Therapy and Intensity-Modulated Radiotherapy in Postoperative Breast Cancer Treatment

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Abstract

Aims/Background Breast cancer (BC) is one of the most prevalent malignancies among women globally, with postoperative radiotherapy playing a pivotal role in its multidisciplinary management. Volumetric-modulated arc therapy (VMAT) and intensity-modulated radiotherapy (IMRT) are advanced radiotherapy techniques that improve dose distribution uniformity within the target volume while minimizing damage to surrounding normal tissues. This study aimed to compare the effects of VMAT and IMRT on immune function and prognosis in postoperative BC patients, providing a scientific basis for clinical decision-making and optimizing BC treatment strategies.

Methods Between January 2022 and January 2024, 265 postoperative BC patients who underwent radiotherapy with VMAT or IMRT at Nantong First People's Hospital were retrospectively analyzed. Based on the radiotherapy technique, patients were categorized into the VMAT group (129 cases) and the IMRT group (136 cases). The efficacies of the 2 radiotherapy techniques were compared by assessing overall radiotherapy effectiveness, levels of cancer biomarkers, levels of immune factors, quality of life and the incidence of adverse reactions.

Results The overall objective response rate (ORR) and disease control rate (DCR) were significantly higher in the VMAT (75.97% and 93.80%, respectively) compared to the IMRT group (63.24% and 86.03%, respectively, $p < 0.05$). Serum levels of cancer antigen 15-3 (CA15-3), human epidermal growth factor receptor 2 (HER2), carcinoembryonic antigen (CEA), and interleukin-6 (IL-6) significantly decreased in both groups at 1-, 3-, and 6-month post-radiotherapy compared to levels immediately after radiotherapy ($p < 0.05$). Conversely, levels of interleukin-2 (IL-2) and interferon-α (IFN-α) demonstrated a significant increase over the same time points ($p < 0.05$). Notably, at 1-month post-radiotherapy, the VMAT group exhibited significantly lower serum levels of CA15-3, HER2, CEA, and IL-6 and significantly higher levels of IL-2 and IFN-α compared to the IMRT group ($p < 0.05$). Post-radiotherapy, quality of life (QoL) scores encompassing mental health, physical health, environmental conditions, and social relationships significantly improved in both groups compared to pre-radiotherapy levels ($p < 0.05$). However, no statistically significant differences in QoL were observed between the two groups after treatment ($p > 0.05$). The incidence of adverse reactions was significantly lower in the VMAT group (9.30%) compared to the IMRT (19.12%) group ($p < 0.05$).

Conclusion VMAT and IMRT effectively improve cancer marker profiles, modulate immune factors, and enhance QoL in postoperative BC patients. VMAT exhibited superior efficacy, achieving higher ORR and DCR and a significant reduction in radiotherapy-related adverse reactions compared to IMRT. These findings highlight the advantages of VMAT in comprehensive BC treatment.

Key words: volumetric-modulated arc therapy; intensity-modulated radiotherapy; breast cancer; immune function; quality of life; adverse reactions; prognosis

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Introduction

Breast cancer (BC) is the most commonly diagnosed malignancy among women worldwide, surpassing lung cancer in incidence and ranking as the second leading cause of cancer-related deaths in females (Sung et al, 2021). BC is characterized by the malignant proliferation of epithelial cells in the mammary gland or ducts, with typical clinical manifestations that include breast lumps, nipple discharge, skin alterations, and lymph node enlargement (Sung et al, 2021; Tavakoli Pirzaman et al, 2023). The non-capsular growth and invasive metastatic behaviour of tumour cells play a pivotal role in BC onset and progression, necessitating comprehensive treatment approaches, with surgical resection combined with chemotherapy or radiotherapy being the standard treatment for BC (Boere et al, 2022; Burstein et al, 2021).

Postoperative radiotherapy for BC is a critical strategy to enhance local control rates, reduce recurrence and metastasis, and improve overall patient survival rates (Wang et al, 2023). However, traditional radiotherapy techniques often expose surrounding normal tissues and organs to radiation, particularly during regional nodal irradiation, and high-dose radiation to critical structures such as the heart and lungs increases the risk of non-BC-related mortality (Taylor et al, 2017). To address these challenges, advancements in radiotherapy techniques, including three-dimensional conformal radiotherapy, intensity-modulated radiotherapy (IMRT), and volumetric-modulated arc therapy (VMAT), have been developed in recent years (Peerawong et al, 2024).

VMAT integrates image guidance with traditional radiotherapy, allowing for dynamic adjustment of dose rate, field shape, and beam intensity during rotation. This approach enhances dose distribution uniformity and operational efficiency (Engstrøm et al, 2021). IMRT, a high-precision radiation therapy technique, delivers targeted doses to tumour areas while minimizing radiation exposure to adjacent normal tissue (Meattini et al, 2020). Notably, BC significantly impacts immune function due to complex interactions between the tumour microenvironment and immune cells, emphasizing the need for effective therapeutic strategies (Dieci et al, 2021). Current research on VMAT and IMRT in BC primarily focuses on dosimetric parameters and clinical feasibility, aiming to optimize tumour control rates while minimizing damage to normal tissues (Das Majumdar et al, 2022; Wang et al, 2024). However, the comparative efficacy of these techniques regarding their impact on immune function and prognosis in BC patients remains unclear.

Based on this premise, this study retrospectively analyzed clinical data from 265 BC patients who underwent surgery combined with VMAT or IMRT to evaluate the effects of these radiotherapy techniques on immune function and prognosis, providing evidence-based guidance for selecting appropriate radiotherapy approaches and developing individualized treatment plans for BC patients.

Methods

Research Participants

Between January 2022 and January 2024, a total of 265 BC patients who underwent surgical treatment followed by radiotherapy at Nantong First People's Hospital were retrospectively analyzed. Of these, 129 patients received VMAT, while 136 were treated with IMRT. This study was approved by the Ethics Review Committee of Nantong First People's Hospital (Approval No. 2023KT166) and conducted following the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants.

Inclusion and Exclusion Criteria

Patients eligible for inclusion in this study were exclusive of Han ethnicity and underwent comprehensive evaluations, including pathological, imaging, hematological, genomic examinations, and TNM (T: tumour; N: node; M: metastasis) staging. All participants demonstrated clear indications for surgery and met the eligibility criteria for adjuvant radiotherapy with VMAT or IMRT.

Inclusion Criteria

(1) Diagnosis of BC based on clinical symptoms, pathological examinations, and imaging findings following established clinical guidelines (Biganzoli et al, 2021); (2) Patients and their families were fully informed about the surgical procedures, and those who met the surgical indications voluntarily underwent surgery; (3) Patients requiring postoperative adjuvant therapy received either VMAT or IMRT; (4) Participants aged 18 years or older; (5) Patients with no prior systemic treatment for BC; (6) Patients with normal mobility of upper limbs, sufficient to meet radiotherapy positioning requirements; (7) Patients with no contraindications to radiotherapy; (8) Patients with availability of complete clinical data.

Exclusion Criteria

(1) Presence of other malignant tumours; (2) Neurological disorders such as Parkinson's disease, vascular dementia, or progressive supranuclear palsy that could contribute to cognitive decline; (3) Presence of pacemakers, aneurysm clips, prosthetic heart valves, metal fragments, or other foreign bodies in the eyes, skin, or body; (4) History of previous chemotherapy or radiotherapy treatment for BC; (5) Patients who chose chemotherapy or alternative radiotherapy modalities post-surgery; (6) Incomplete clinical data; (7) Recurrence or retreatment of BC; (8) Pregnant or lactating individuals; (9) Individuals with a history of alcoholism, substance abuse, or addiction within the past two years.

Research Methods

Upon admission, all patients underwent routine examinations to assess the location, size, and morphology of their lesions. Based on individual conditions, breast-conserving surgery or mastectomy was performed. Following surgery, the cohort of 265 patients was divided into two groups: 129 patients received VMAT treatment, and 136 underwent IMRT treatment.

During radiotherapy, patients were positioned supine with their hands crossed and elbows placed in front of their foreheads. Enhanced computed tomography (CT) simulation scanning was performed with a slice thickness of 3 mm. Immobilization was achieved using a carbon fibre plate and thermoplastic film, and body surface markings were applied in strict adherence to CT examination protocols. VMAT and IMRT treatment plans were then developed as follows:

VMAT plan: The plan was developed using the Monaco treatment planning system (version 5.11.02, Elekta, Stockholm, Sweden). This system modelled continuous gantry motion as multiple discrete angular segments, optimizing monitor units and multi-leaf collimator apertures dynamically during rotation. Variable dose rates were applied with an incremental gantry angle of 1°. The Monte Carlo dose calculation algorithm was employed with heterogeneity corrections and a grid resolution of 3 mm. A 1.5 cm automatic flash margin was added around the planning target volume (PTV) to extend the radiation flux beyond the body contour. The VMAT plan included two double arcs of 50°–60° with a fixed collimator angle of 0°. Optimization ensured that at least 95% of the PTV received 95% of the prescribed dose, and 90% of the PTV received the full prescribed dose while limiting the maximum spinal cord dose of 45 Gy. For treatment, a 6 MeV electron beam irradiated the chest wall target at a 30° angle. The supraclavicular target was treated with VMAT, with the plan centred on the affected chest wall and supraclavicular region.

IMRT plan: The IMRT plan was similarly developed using the Monaco treatment planning system (version 5.11.02, Elekta, Stockholm, Sweden). Inverse planning optimization was performed with dose calculations utilizing a Monte Carlo algorithm with a 3 mm grid resolution, and a 1.5 cm automatic flash margin was applied around the PTV to extend the flux beyond the body contour. Tissue heterogeneity was considered during optimization, which involved iterative adjustments to achieve the planning goals. Segments requiring $\leq$2 monitor units were excluded through semi-automatic segmentation. Based on the patient's condition, a highly conformal dose distribution was achieved using 5–9 fixed fields with dynamic multi-leaf collimator movements. A 6 MeV electron beam was used for chest wall irradiation, while the supraclavicular region was treated with IMRT. The centre of the IMRT plan was positioned on the chest wall and supraclavicular region to ensure uniform dose distribution within the target. Dose constraints ensured that at least 95% of the PTV received 95% of the prescribed dose. For organs at risk, less than 37% of the lung volume received 20 Gy, less than 40% of the heart volume received 30 Gy, and the maximum spinal cord dose was capped at 45 Gy.

Radiotherapy dose and monitoring: The prescribed radiotherapy dose for both groups ranged from 43–60 Gy, administered over 24–28 sessions at 1.80–2.90 Gy per session, with treatment delivered 4–5 times per week. Patient conditions were closely monitored throughout radiotherapy. In cases of severe radiotherapy-induced immune reactions, treatment was promptly terminated, and emergency interventions were provided based on the severity levels.

Data Collection

Trained researchers systematically collected the general clinical data of patients through standardized procedures, including reviewing medical records and administering questionnaires. The collected parameters included age, tumour location, tumour diameter, clinical cancer stage, lymph node stage, pathological type, complications, surgical method, overall treatment efficacy, and levels of cancer markers (cancer antigen 15-3 [CA15-3], human epidermal growth factor receptor 2 [HER2], and carcinoembryonic antigen [CEA]) immediately after radiotherapy (T_0), at 1 month (T_1), 3 months (T_2), and 6 months (T_3) post-radiotherapy.

Additionally, immune factors (interleukin-2 [IL-2], interleukin-6 [IL-6], and interferon-α [IFN-α]) were measured at the same time points (T_0, T_1, T_2, and T_3). For these measurements, 3 mL of fasting venous blood was collected at each time point, and serum was separated by centrifugation at 3000 rpm for 10 minutes. Quantitative analysis of cancer markers and immune factors was performed using an automated biochemical analyzer (BS-280, Mindray, Yangzhou, China).

Patient quality of life (QoL) was assessed before and after radiotherapy using the world health organization quality of life-100 (WHOQOL-100) scale. Adverse reactions to radiotherapy were systematically observed and documented. (1) Overall efficacy assessment: Comprehensive radiographic examinations were performed before initiating radiotherapy initiation and repeated approximately 1–3 months after treatment completion to evaluate therapeutic outcomes. Treatment efficacy was determined using the Response Evaluation Criteria in Solid Tumours (RESIST) 1.1 scale (Eisenhauer et al, 2009). Outcomes were classified as follows: Complete response (CR): Complete disappearance of all target lesions, or a reduction in the short diameter of any pathological lymph nodes (including target and non-target nodules) to less than 10 mm, with no recurrence for more than 1 month. Partial response (PR): A reduction of $\geq$30% in the sum of the longest diameters of target lesions compared to baseline, with no new lesions for more than 1 month. Disease progression (PD): An increase of $>$20% in the sum of major diameters of all target lesions, with an absolute increase of $>$5 mm, or the appearance of new lesions. Stable disease (DS): Corresponds to intermediate changes between PR and PD.

Efficacy rates were calculated as: Objective response rate (ORR) = [(CR + PR)/total number of cases] $\times$ 100%; Disease control rate (DCR) = [(CR + PR + DS)/total cases] $\times$ 100%.

(2) Quality of life: The WHOQOL-100 scale was utilized to evaluate QoL in BC patients, encompassing four domains: mental health, physical health, environmental factors, and social relationships. Each domain consisted of 24 facets, with each facet containing four items. Items were scored using a Likert scale ranging from 1 to 5, with the higher scores indicating better QoL (WHOQOL Group, 1995).

(3) Adverse reaction monitoring: Adverse reactions were scored based on the Radiation Therapy Oncology Group (RTOG) toxicity criteria (Cox et al, 1995). Severe adverse reactions (grades 3–4) were closely monitored, focusing on observing spinal cord suppression, gastrointestinal discomfort, neurotoxicity, and liver func-

tion impairment. Adverse reaction evaluations were completed one week after the completion of radiotherapy.

Statistical Analysis

All statistical analyses were performed using SPSS 26.0 software (IBM Corp., Chicago, IL, USA). The Shapiro-Wilk test was used to assess the normality of measurement data. Normally distributed data were presented as mean ± standard deviation (SD) and analyzed using independent-sample *t*-tests. Count data were expressed as frequencies and percentages (n, %) and compared using chi-square (χ^2) tests. Repeated measures analysis of variance (ANOVA) was used to evaluate repeated measurements, followed by multiple comparisons using the least significant difference (LSD) *t*-test. Mauchly's test of sphericity was conducted, and when violated, multivariate test results were reported. Origin software (Version 2024, OriginLab Corporation, Northampton, MA, USA) was used to generate plots. Statistical significance was set at $p < 0.05$.

Results

Baseline Characteristics

No statistically significant differences were observed between the VMAT and IMRT in age, tumour location, tumour TNM staging, pathological type, complications, and mode of surgery ($p > 0.05$, Table 1).

Comparison of Overall Radiotherapy Efficacy Rates between the Two Groups

The ORR and DCR in the VMAT group were 75.97% and 93.80%, respectively, compared to 63.24% and 86.03% in the IMRT group. The ORR and DCR were significantly higher in the VMAT group than in the IMRT group ($p < 0.05$) (Table 2).

Comparison of Cancer Biomarker Levels at Different Time Points Following Radiotherapy

The analysis revealed no significant differences in CA15-3, HER2, and CEA serum levels between the VMAT and IMRT groups at the T_0 time point ($p > 0.05$). However, at the T_1 time point following radiotherapy, the VMAT group exhibited significantly lower CA15-3, HER2, and CEA serum levels compared to the IMRT group ($p < 0.05$). No significant differences in these biomarker levels were observed between the two groups at the T_2 and T_3 time points ($p > 0.05$). Both groups showed significant reductions in CA15-3, HER2, and CEA serum levels at the T_1, T_2, and T_3 time points compared to the T_0 time point. Notably, serum levels of CA15-3, HER2, and CEA significantly decreased within each group at the T_2 and T_3 time points compared to the T_1 time point ($p < 0.05$) (Table 3 and Fig. 1).

Table 1. Baseline characteristics of patients in the VMAT and IMRT groups.

Characteristic/Group	VMAT group (n = 129)	IMRT group (n = 136)	t/χ^2 value	*p*-value
Age (mean ± SD, years)	51.36 ± 9.83	50.46 ± 10.28	0.728	0.467
Tumour location [n, (%)]			1.226	0.542
Left chest	61 (47.28)	72 (52.94)		
Right chest	57 (44.19)	51 (37.50)		
Bilateral	11 (8.53)	13 (9.56)		
T stage [n, (%)]			0.554	0.907
T_1	37 (28.68)	37 (27.21)		
T_2	73 (56.59)	78 (57.35)		
T_3	12 (9.30)	11 (8.09)		
T_4	7 (5.43)	10 (7.35)		
N stage [n, (%)]			0.573	0.902
N_0	55 (42.64)	57 (41.91)		
N_1	35 (27.13)	37 (27.21)		
N_2	20 (15.50)	25 (18.38)		
N_3	19 (14.73)	17 (12.50)		
M stage [n, (%)]				
M_0	129 (100)	136 (100)		
Pathological type [n, (%)]			0.311	0.958
Invasive ductal carcinoma	110 (85.27)	114 (83.82)		
Ductal carcinoma *in situ*	9 (6.98)	9 (6.62)		
Invasive lobular carcinoma	5 (3.88)	7 (5.15)		
Invasive mucinous carcinoma	5 (3.88)	6 (4.41)		
Comorbidities [n, (%)]			0.622	0.987
Hypertension	19 (14.73)	19 (14.05)		
Diabetes	16 (12.40)	14 (10.29)		
Arthritis	4 (3.10)	3 (2.20)		
Osteoporosis	7 (5.43)	8 (5.88)		
Other	8 (6.20)	9 (6.62)		
None	75 (58.14)	83 (61.03)		
Surgical mode [n, (%)]			0.125	0.724
Mastectomy	41 (31.78)	46 (33.82)		
Breast-conserving surgery	88 (68.22)	90 (66.18)		

Note: VMAT, volumetric-modulated arc therapy; IMRT, intensity-modulated radiotherapy.

Comparison of Immune Factor Levels between the Two Groups at Different Time Points Following Radiotherapy

No significant differences were observed in serum levels of IL-2, IL-6, and IFN-α between the VMAT and IMRT groups at the T_0 time point ($p > 0.05$). At the T_1 time point, the VMAT group exhibited significantly higher serum levels of IL-2 and IFN-α and a significantly lower serum level of IL-6 compared to the IMRT group ($p < 0.05$). No significant differences in these immune factors were observed between the two groups at the T_2 and T_3 time points ($p > 0.05$). Both groups showed significant increases in serum levels of IL-2 and IFN-α and signifi-

Table 2. Comparison of overall radiotherapy efficacy between the two groups [n, (%)].

Characteristic/Group	CR	PR	DS	PD	ORR	DCR
VMAT group (n = 129)	50 (38.76)	48 (37.21)	23 (17.83)	8 (6.30)	98 (75.97)	121 (93.80)
IMRT group (n = 136)	41 (30.15)	45 (33.09)	31 (22.79)	19 (13.97)	86 (63.24)	117 (86.03)
χ^2 value					5.058	4.367
p-value					0.025	0.037

Note: CR, complete response; PR, partial response; DS, stable disease; PD, disease progression; ORR, objective response rate; DCR, disease control rate.

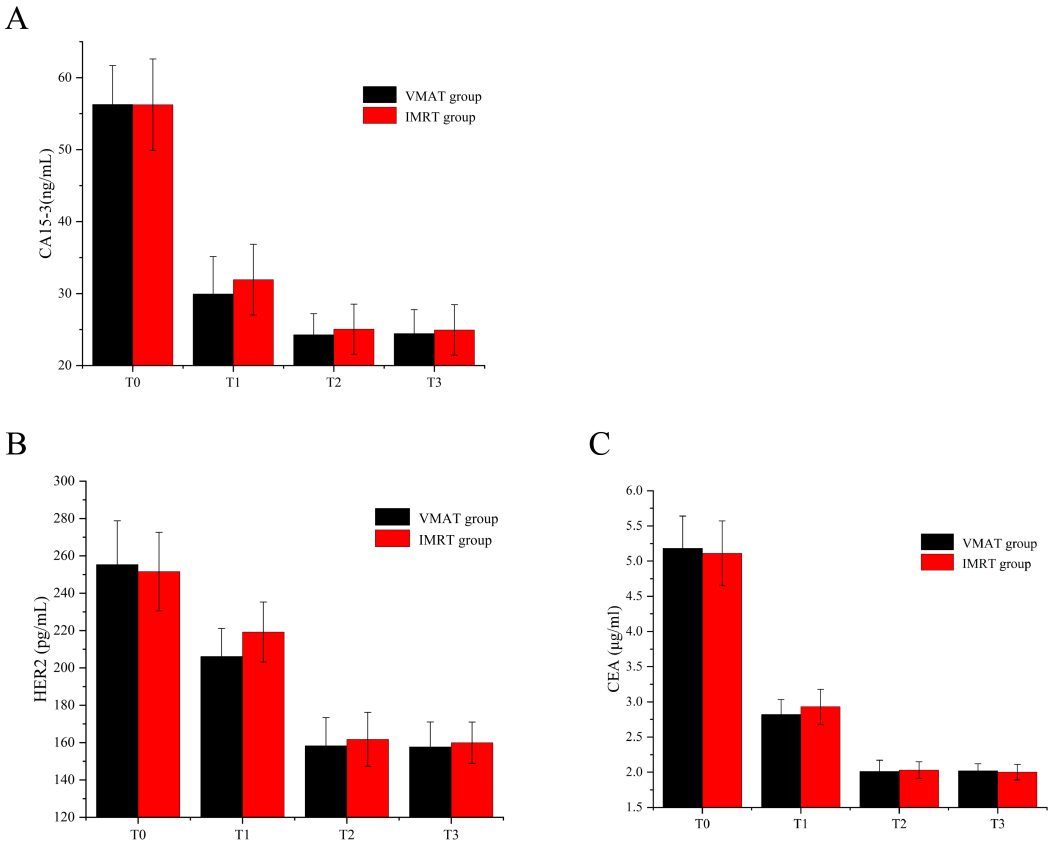

Fig. 1. Variations in serum levels of cancer markers in the VMAT and IMRT groups at different time points after radiotherapy. (A) cancer antigen 15-3 (CA15-3), (B) human epidermal growth factor receptor 2 (HER2), and (C) carcinoembryonic antigen (CEA). Each bar chart column shows the mean value of the respective cancer marker level at the corresponding time point, with error bars indicating the standard error of the mean value.

cant decreases in IL-6 levels at the T_1, T_2, and T_3 time points compared to the T_0 time point ($p < 0.05$). Within each group, serum levels of IL-2 and IFN-α were significantly higher, and IL-6 levels were significantly lower at the T_3 time point compared to the T_1 time point ($p < 0.05$) (Table 4 and Fig. 2).

Comparison of Quality of Life between the Two Groups

Before radiotherapy, no statistically significant differences were observed in the scores for mental health, physical health, surrounding environment, or social

relationships between the VMAT and IMRT groups ($p > 0.05$). After radiotherapy, both groups demonstrated significant improvements in these scores compared to their pre-radiotherapy scores ($p < 0.05$). However, post-radiotherapy scores across all dimensions showed no statistically significant differences between the two groups ($p > 0.05$) (Table 5).

Comparison of Adverse Reaction Incidence between the Two Groups

The specific adverse reactions observed in the VMAT and IMRT groups are summarized in Table 6. The incidence of adverse reactions was significantly lower in the VMAT group compared to the IMRT group (9.30% vs. 19.12%, $p < 0.05$).

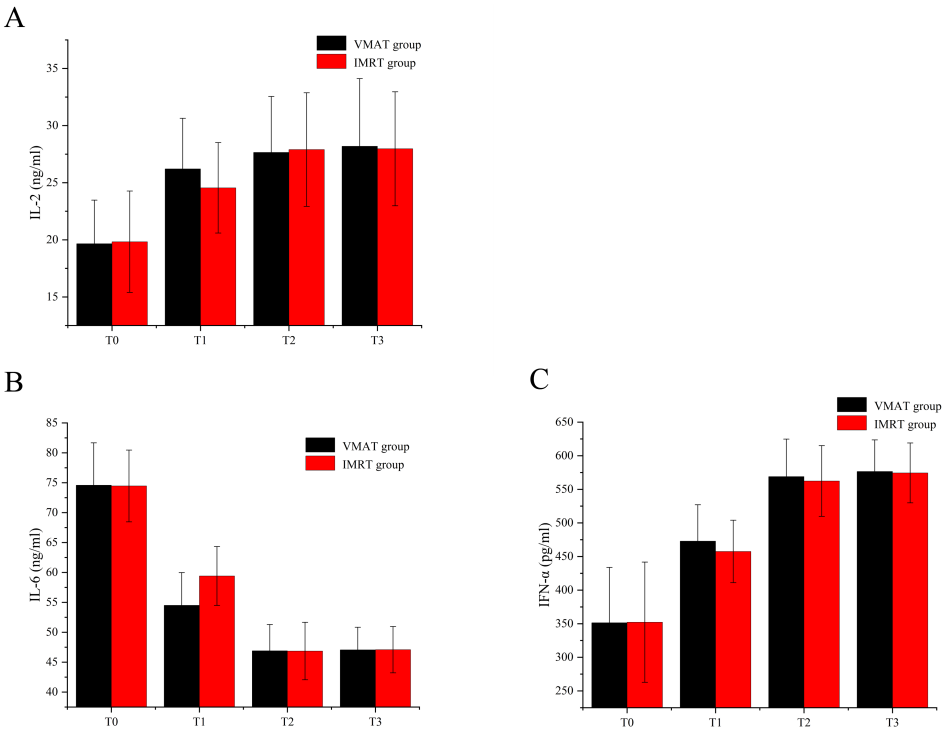

Fig. 2. Variations in serum levels of immune factors in the VMAT and IMRT groups at different time points after radiotherapy. (A) IL-2, (B) IL-6, and (C) IFN-α. Each bar chart column represents the mean value of the respective immune factor at the corresponding time point, with error bars indicating the standard error of mean value (SEM).

Discussion

In contemporary clinical oncology research, VMAT and IMRT have emerged as advanced alternatives to traditional three-dimensional conformal radiation therapy, offering improved target volume coverage and enhanced protection of normal tissues in BC patients (Wang et al, 2022). The comparative evaluation of these techniques is crucial, as it guides clinicians in developing precise and individualized treatment plans. This study contributes to the growing body of evidence, underscoring the comparative benefits of VMAT over IMRT in BC treatment, especially in enhancing immune responses and the overall well-being of patients.

Table 3. Comparison of cancer biomarker levels at different time points post-radiotherapy (mean ± SD).

Characteristic/Group	VMAT group (n = 129)	IMRT group (n = 136)	F_{time}/p-value	$F_{interclass}/p$-value	$F_{interaction}/p$-value
CA15-3 (ng/mL)					
T_0	56.28 ± 5.40	56.24 ± 6.35			
T_1	29.95 ± 5.19^{b}	31.93 ± 4.91^{ab}			
T_2	24.28 ± 2.93^{bc}	25.05 ± 3.48^{bc}	2218.576/<0.001	7.291/0.007	2.066/0.105
T_3	24.45 ± 3.32^{bc}	24.94 ± 3.51^{bc}			
F/*p*-value	1585.184/<0.001	1346.256/<0.001			
HER2 (pg/mL)					
T_0	255.32 ± 23.46	251.57 ± 21.05			
T_1	206.13 ± 14.97^{b}	219.19 ± 16.05^{ab}			
T_2	158.32 ± 15.06^{bc}	161.71 ± 14.46^{bc}	1623.386/<0.001	1.448/0.230	2.616/0.052
T_3	157.67 ± 13.39^{bc}	159.94 ± 11.04^{bc}			
F/*p*-value	946.899/< 0.001	1115.298/<0.001			
CEA (μg/mL)					
T_0	5.18 ± 0.46	5.11 ± 0.46			
T_1	2.82 ± 0.21^{b}	2.93 ± 0.25^{ab}			
T_2	2.01 ± 0.16^{bc}	2.03 ± 0.12^{bc}	4809.862/<0.001	0.406/0.525	5.853/<0.001
T_3	2.02 ± 0.10^{bc}	2.00 ± 0.11^{bc}			
F/*p*-value	4025.646/<0.001	3453.855/<0.001			

Note: CA15-3, cancer antigen 15-3; HER2, human epidermal growth factor receptor 2; CEA, carcinoembryonic antigen; T_0, immediately after radiotherapy; T_1, 1 month after radiotherapy; T_2, 3 months after radiotherapy; T_3, 6 months after radiotherapy. In comparison to group VMAT at the same time point, there is a statistically significant difference with $^{a}p < 0.05$. In comparison of the same group at the T_0 time point, there is a statistically significant difference with $^{b}p < 0.05$. In comparison of the same group at the T_2/T_3 and T_1 time points, there is a statistically significant difference with $^{c}p < 0.05$.

Table 4. Changes in immune factor levels observed at different time points post-radiotherapy (mean ± SD).

Characteristic/Group	VMAT group (n = 129)	IMRT group (n = 136)	F_{time}/p-value	$F_{interclass}/p$-value	$F_{interaction}/p$-value
IL-2 (ng/mL)					
T_0	19.66 ± 3.81	19.83 ± 4.44			
T_1	26.21 ± 4.43^{b}	24.55 ± 3.96^{ab}			
T_2	27.65 ± 4.90^{b}	27.90 ± 4.97^{bc}	185.466/<0.001	1.643/0.201	2.837/0.039
T_3	28.19 ± 5.92^{bc}	27.97 ± 4.99^{bc}			
F/p-value	85.652/<0.001	93.951/<0.001			
IL-6 (ng/mL)					
T_0	74.59 ± 7.08	74.46 ± 6.00			
T_1	54.50 ± 5.47^{b}	59.41 ± 4.92^{ab}			
T_2	46.90 ± 4.39^{bc}	46.86 ± 4.81^{bc}	1387.525/<0.001	14.589/<0.001	14.772/<0.001
T_3	47.06 ± 3.77^{bc}	47.08 ± 3.87^{bc}			
F/p-value	773.216/<0.001	889.791/<0.001			
IFN-α (pg/mL)					
T_0	351.39 ± 82.43	352.26 ± 89.50			
T_1	472.82 ± 54.18^{b}	457.51 ± 46.48^{a}			
T_2	568.94 ± 55.78^{bc}	562.34 ± 52.61^{bc}	708.607/<0.001	2.113/0.147	1.013/0.387
T_3	576.49 ± 47.05^{bc}	574.40 ± 44.52^{bc}			
F/p-value	379.267/<0.001	393.038/<0.001			

Note: IL-2, interleukin-2; IL-6, interleukin-6; IFN-α, interferon-α. In comparison to group VMAT at the same time point, there is a statistically significant difference with $^{a}p < 0.05$. In comparison of the same group at the T_0 time point, there is a statistically significant difference with $^{b}p < 0.05$. In comparison of the same group at the T_1 time point, there is a statistically significant difference with $^{c}p < 0.05$.

Table 5. Comparison of quality of life between the two groups (mean ± SD, points).

Characteristic/Group	Mental health		Physical health		Surrounding environment		Social relations	
	Before radiotherapy	After radiotherapy	Before radiotherapy	After radiotherapy	Before radiotherapy	After radiotherapy	Before radiotherapy	After radiotherapy
VMAT group (n = 129)	11.08 ± 3.26	19.03 ± 2.46*	12.32 ± 3.20	16.83 ± 3.57*	13.10 ± 3.77	18.21 ± 3.09*	11.72 ± 3.64	19.19 ± 3.37*
IMRT group (n = 136)	11.30 ± 3.20	18.55 ± 2.61*	12.57 ± 3.12	17.05 ± 3.24*	13.97 ± 3.49	17.84 ± 3.02*	11.28 ± 2.83	19.91 ± 2.96*
t value	0.531	1.518	0.655	0.533	1.956	0.974	1.100	1.853
p-value	0.596	0.130	0.513	0.594	0.051	0.331	0.272	0.065

Note: Compared with baseline, $^{*}p < 0.05$.

Table 6. Comparison of adverse reaction incidence between the two groups [n, (%)].

Characteristic/Group	Spinal cord inhibition	Gastrointestinal reactions	Neurotoxicity	Liver function injury	Incidence rate
VMAT group (n = 129)	3 (2.33)	6 (4.65)	1 (0.78)	2 (1.55)	12 (9.30)
IMRT group (n = 136)	7 (5.15)	11 (8.09)	3 (2.21)	5 (3.68)	26 (19.12)
χ^2 value					5.192
p-value					0.023

Our findings demonstrate that VMAT and IMRT effectively improve tumour marker levels, modulate immune factors, and improve the quality of life in post-operative BC patients. However, VMAT was associated with superior treatment efficiency, a higher DRC, and a lower incidence of radiotherapy-related adverse reactions compared to IMRT.

Our retrospective analysis included data from 129 BC patients treated with VMAT and 136 BC patients treated with IMRT. Both groups exhibited ORR exceeding 60% and DCR exceeding 85%. VMAT, which utilizes rotational irradiation of tumours over a 360° angular range through single or multiple arcs, demonstrates significant advantages. The technique shortens treatment time and achieves optimized dose distribution through dynamic modulation of multi-leaf collimators and dose rates. This flexibility allows VMAT to conform to complex tumour geometries, reducing radiation exposure to surrounding normal tissues (Voyant et al, 2024; Zhang et al, 2021). In comparison, IMRT employs computer-controlled X-ray linear accelerators to deliver three-dimensional radiation precisely tailored to tumour morphology. By modulating radiation intensity according to the shaping devices, IMRT achieves accurate dose distribution, concentrating higher radiation doses in the tumour area while minimizing exposure to surrounding normal tissues (Azharuddin et al, 2022; Forster et al, 2021). Despite its precision, our study revealed that VMAT outperformed IMRT in terms of ORR, DCR, and adverse reaction incidence, highlighting its potential to more effectively reduce tumour burden and control disease progression. These results align with the existing literature. For example, a study comparing PTV coverage and organ at-risk dose differences between IMRT and VMAT in left-sided BC patients undergoing mastectomy demonstrated that VMAT exhibited superior PTV coverage, reduced exposure to the lungs and comparable cardiac dose (Das Majumdar et al, 2022). The improved outcomes associated with VMAT may be attributed to its precision in dose distribution and target coverage, which accommodates complex tumour shapes and inter-patient anatomical variability (Cheng et al, 2020; He et al, 2023).

CA15-3, HER2, and CEA are biomarkers associated with BC, providing insights into disease progression and therapeutic responses (Anoop et al, 2022; Gamble et al, 2021). Innate immunity, the first line of defense against foreign genetic material, is crucial in the immune response induced by tumours (Ying-Rui et al, 2023). Among cytokines, IL-6 is a multifunctional molecule involved in immune regulation, inflammation, and tumourigenesis. Elevated levels of IL-6 in serum from BC patients have been consistently associated with unfavourable clinical out-

comes (Guo et al, 2023; Shimura et al, 2019). IL-2, primarily produced by T and B cells, regulates the immune system by promoting immune cell proliferation and activation (Mavroudis et al, 2024). Similarly, IFN-γ, a cytokine secreted by activated natural killer and T cells, is essential for T cell activation, clonal expansion, and memory development (Zhou et al, 2022). Reduced levels of IFN-γ and IL-2 indicate impaired immune cell function, primarily diminished T cell activity (Toney et al, 2023).

Our findings indicate that radiotherapy with VMAT and IMRT significantly improves cancer biomarker levels and immune factor profiles in BC patients within one to six months post-treatment. These findings suggest that both approaches effectively reduce tumour burden. Notably, the impact of radiotherapy extends beyond direct toxicity to the irradiated tumour. Emerging evidence underscores the role of radiotherapy in modulating the immune system, enhancing adaptive immunity, and reshaping the tumour microenvironment to elicit systemic antitumour responses (Liang et al, 2013; Ngwa et al, 2018; Sharabi et al, 2015). Interestingly, one-month post-radiotherapy, the VMAT group exhibited significantly greater improvements in tumour biomarkers and immune factors compared to the IMRT group. This may be related to the high precision of VMAT and its better biological effects (McClelland, 2020). By reducing treatment time and minimizing high-dose, large-volume exposure to critical organs such as the lungs and heart, VMAT mitigates immunosuppression and enhances overall treatment tolerance. These attributes reduce daily cellular damage and limit immune-related injuries and adverse reactions (Pasler et al, 2013).

In this study, the WHOQOL-100 questionnaire was used to evaluate the quality of life in patients following radiotherapy. The WHOQOL-100 is a reliable and validated tool for assessing QoL in women with breast-related health challenges, demonstrating strong internal consistency and homogeneity across its item content. It evaluates multiple dimensions of QoL, including physical health, psychological well-being, social relationships, and environmental factors, providing a comprehensive profile that extends beyond disease-specific impacts (Den Oudsten et al, 2009). Our findings indicate significant improvements in mental health, physical health, social relationships, and environmental dimensions compared to their baseline assessments. These improvements may be attributed to the precision of VMAT and IMRT technologies, which deliver targeted dose distributions that minimize damage to surrounding healthy tissues, thereby reducing the side effects of radiotherapy (Azharuddin et al, 2022; Forster et al, 2021). Furthermore, the enhanced accuracy and efficiency of these advanced radiotherapy techniques may alleviate patients' anxiety and fear, further contributing to improved QoL.

While the WHOQOL-100 provides a holistic assessment, other instruments, such as the Functional Assessment of Cancer Therapy-Breast (FACT-B) and BREAST-Q, offer disease-specific evaluations tailored to BC patients. The FACT-B measures health-related QoL across five domains: physical, social, emotional, functional well-being, and BC-specific concerns (Brady et al, 1997). The BREAST-Q, developed in 2009, consists of surgery-specific modules designed to assess outcomes in breast surgery patients, including enhancement, reduction, and reconstruction pro-

cedures (Pusic et al, 2009). Although these disease-specific tools effectively capture specific aspects of BC patients, they may not comprehensively capture overall health and non-cancer-related factors. Additionally, their applicability and interpretability can be limited across diverse cultural and linguistic contexts. Given the multifaceted impact of BC and the significance of evaluating overall well-being of the patients. Therefore, the WHOQOL-100 was adopted for this study. It offers a broad perspective on QoL while maintaining cross-cultural validity and scientific recognition (Skevington et al, 2024).

However, this study had several limitations. The reliance on historical data and existing medical records for patient selection may introduce sample selection bias, affecting the generalizability of the findings. Moreover, incomplete or inaccurate records could lead to information bias, impacting the accuracy of treatment outcome assessments. Additionally, the primary focus on short-term efficacy limits the ability to evaluate the long-term effects of the two radiation therapy techniques. Future studies should incorporate long-term follow-up to assess the durability of QoL improvements, evaluate long-term survival rates, and provide a more comprehensive understanding of the relative efficacy of these advanced radiotherapy techniques.

Conclusion

VMAT and IMRT effectively improve cancer biomarker levels and immune factor profiles, enhance the quality of life, and achieve therapeutic objectives in postoperative BC patients. However, VMAT demonstrates distinct advantages over IMRT, including a higher overall response rate and disease control rate. Additionally, patients in the VMAT group experience a significantly lower incidence of radiotherapy-related adverse reactions, contributing to enhanced overall treatment efficacy. These findings underscore the potential of VMAT as a more efficient and precise radiotherapy approach for optimizing outcomes in BC management.

Key Points

- VMAT and IMRT can effectively improve the levels of tumour markers and immune factors in postoperative BC patients.
- VMAT and IMRT significantly enhance postoperative BC patients' quality of life, including aspects of mental health, physical health, environmental conditions, and social relationships.
- Compared with IMRT, VMAT exhibits higher ORR and DCR in postoperative BC patients.
- Compared with IMRT, VMAT can significantly reduce radiation-related adverse reactions in postoperative BC patients.

Availability of Data and Materials

The data used to support the findings of this study are available from the corresponding author upon request.

Author Contributions

LZ and YJJ designed the research study and drafted the first draft. DDJ and XMH performed the research. LZ and DDJ analyzed the data. All authors contributed to the important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study has been approved by the Ethics Review Committee of Nantong First People's Hospital (Approval No. 2023KT166) and strictly adheres to the principles outlined in the Declaration of Helsinki. The patients included in the study have signed the informed consent form.

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Conflict of Interest

The authors declare no conflict of interest.

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