

Optimizing Contralateral Breast Sparing: A Comparative Study of Single- versus Dual-PTV Configuration Across Modern Radiotherapy Techniques

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HOW TO CITE:

Rozhan A. Hamadsaeed,
Fatiheea F. Hassan (2026).
Optimizing Contralateral Breast
Sparing: A Comparative Study of
Single- versus Dual-PTV
Configuration Across Modern
Radiotherapy Techniques.
International Journal of Special
Education, 41(14s), 1188-1200

ABSTRACT:

Background: In breast cancer radiation therapy, target delineation strategy and treatment technique significantly influence the treatment quality and organ at risk sparing.

Objectives: This study aimed to compare dosimetric outcomes between single and double planning target volume PTV approaches using three-dimensional conformal radiotherapy and volumetric modulated arc therapy.

Methods: Ten breast cancer patients were retrospectively re-planned using the four-planning strategy and techniques per patient. Plans were assessed in relation to Planning target cover, Homogeneity index, Conformity index, Monitor unit, Hotspots, other PTV doses, and contralateral breast as a sensitive organ at risk. Data were extracted from the DVH dose-volume histogram.

Results: The results found that all planning strategies efficiently covered PTV, whereas double PTV planning demonstrated improved dose distribution compared with single PTV in both techniques. In the 3DCRT technique, the separation of PTVs significantly reduced contralateral breast dose ($p = 0.021$). Similarly, the VMAT technique showed a statistically significant reduction with double PTV planning ($p = 0.002$). However, VMAT plans delivered significantly higher contralateral breast doses compared with 3DCRT in both single and double PTV approaches ($p < 0.001$). Whereas VMAT provided improved homogeneity and conformity to the target, it was associated with increased low-dose spread to surrounding normal tissues.

Conclusion: Double PTV planning enhances dose optimization and improves contralateral breast sparing in both 3DCRT and VMAT techniques. Although VMAT offers superior target conformity, 3DCRT demonstrates better protection of the contralateral breast. Careful selection of target segmentation strategy and technique is essential to balance target coverage and contralateral breast sparing in breast radiotherapy.

Keywords: Breast cancer, single-PTV planning strategy, dual-PTV planning strategy, Three-dimensional conformal radiation therapy, Volumetric modulated arc therapy.

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1. Introduction

Globally, the most prevalent sort of cancer among women is breast cancer (Devi, 2025). One of the most effective sorts of breast cancer treatment is RT Radiation therapy, its effectiveness for the treatment is directing the ionized radiation so that enough dose delivers to the targeted region (cancerous region) to kill the cancerous cells whereas surrounding anatomical structures (OAR) organ at risk keep safe and maintain the damage level as small as possible (Komorowska, Zaczek, Kalenik, & Rodacka, 2024; Miller et al., 2022). The contralateral breast is a critical organ at risk in breast cancer radiotherapy and it is radiosensitive organ (Lin, Yang, Huang, & Xu, 2025). Despite not being part of the treatment target, contralateral breast can absorb incidental radiation from scatter and leakage associated with beam configuration and dose modulation. Such exposure may increase the likelihood of developing secondary malignancies over the long term, particularly in younger patients with higher tissue radiosensitivity like breast (Paganetti et al., 2020). Breast tissue is recognized as a radiosensitive organ. In the context of external beam radiotherapy, inevitable scatter and head leakage radiation result in low but non-negligible dose deposition to the contralateral breast. These exposures have been related to an elevated long-term risk of developing secondary contralateral breast cancer, especially among younger patients. (Veiga et al., 2026). Despite extensive comparisons of radiotherapy delivery techniques for breast cancer, the influence of PTV configuration on especially contralateral breast irradiation remains inadequately explored. Most existing studies focus primarily on technique-dependent dose differences, whereas the role of target segmentation strategy, single composite PTV versus anatomically separated dual PTVs, has received limited attention. Because inverse and forward planning algorithms respond differently to geometric constraints, PTV configuration may substantially influence dose gradients, conformity, hotspot formation, and low-dose spread to adjacent organs at risk (Alanyali et al., 2023). In a single-

PTV approach, primary breast and regional nodal volumes are optimized as a unified structure, potentially limiting flexibility in dose modulation across spatially distinct regions. In contrast, a dual-PTV strategy permits an independent optimization objectives and weighting, which might improve local dose control and minimize unintended irradiation of nearby radiosensitive tissues such as the contralateral breast (Cg Maladenige et al., 2025). However, the magnitude and consistency of this effect through different radiotherapy techniques, containing 3DCRT and VMAT, have not been comprehensively characterized (Kasetthamrongrat et al., 2025). Therefore, the study set out to systematically evaluating the dosimetric impact of single versus dual PTV strategies in both 3DCRT and VMAT technique, with particular emphasis on contralateral breast exposure. The studies objective was to determine whether the choice of planning strategy significantly influences radiation exposure to this critical organ at risk and to offer guidance for optimizing treatment planning in order to reduce potential secondary cancer risk while maintaining adequate target coverage.

2. Methodology

2.1. Design

This study employed a quantitative, in-silico dosimetric comparative design. It was structured to systematically evaluate and compare the dosimetric outcomes of different planning target volume (PTV) configurations and radiotherapy delivery techniques, with a primary focus on optimizing contralateral breast sparing.

2.2. Participants/Sample

The study sample consisted of 10 post-mastectomy right-sided breast cancer patients who underwent computed tomography (CT) simulation for radiotherapy planning at the Awat Radiation Oncology Center in Erbil. Patients were selected based on the following inclusion criteria: pathological stage II (T2-T3, N0-N1, M0) and stage III (T3-T4, N2-N3, M0). The PTV volumes of the selected patients ranged

from 234.86 cm³ to 914.21 cm³, with a mean volume of 600.75 cm³.

2.3. Instruments

In this dosimetric study, the "instruments" comprised the imaging hardware, treatment planning software, dose calculation algorithms, and the dosimetric evaluation indices used to assess plan quality. CT simulation was performed using a 16-slice CT scanner, and treatment planning was executed using a mono-isocenter technique with the Monaco Treatment Planning System (TPS) version 6.1.4.0 (Elekta Solutions AB, Stockholm, Sweden). Dose calculations were performed using the Collapsed Cone algorithm for the 3D-CRT technique and the Monte Carlo algorithm for the VMAT technique. Plan evaluation was based on Dose-Volume Histograms (DVHs), and the dosimetric parameters for the PTV are detailed in Table 1.

Furthermore, dose uniformity and conformity were quantified using the Homogeneity Index (HI) and Conformity Index (CI), based on ICRU and RTOG guidelines. The HI was calculated using point-dose values according to the formula described by Lingling et al. (2019) (Yan et al., 2019), where values closer to zero indicate an ideal homogeneous dose distribution:

$$HI = \frac{D2\% - D98\%}{D50\%}$$

The CI was calculated to evaluate the overlap between the target and the prescription isodose volume as described by Menzel (2014) (Menzel, 2014). An ideal CI is 1; CI > 1 indicates overdose (over-coverage), and CI < 1 indicates under-coverage, calculated as:

$$CI = \frac{VRI}{TV}$$

where VRI is the volume of tissue receiving the reference isodose (typically 95% of the prescribed dose), and TV is the Target Volume of the PTV.

Table (1) the dosimetric parameter for PTV and their definition

Dosimetric parameter for PTV	Meaning
Min dose	The lowest dose received by any part of PTV, used to assess under dosage and cold spots.
Max dose	The highest dose received by any point of PTV, used to assess hot spots or risks of overdose.
Mean dose	The average dose received by PTV, used to evaluate over all dose coverage quality.
D2	Maximum dose covered at a minimum 2% of the PTV.
D50	Median dose at least covered 50% of the PTV.
D98	Minimum dose covered not less than 98% of the PTV.
V%95	≥95% of the prescribed dose to receive by PTV.
V%107	Percentage of the PTV volume that received a dose ≤107% of prescribed dose to receive by PTV.
HI (homogeneity index)	Measure how uniform is the dose within the PTV.
CI (conformity index)	Measures how good the treatment dose conform to the shape of PTV.
MU (monitor units)	Measuring and controlling dose delivery (it tells the machine how much radiation to deliver depending on many factors.

2.4. Procedure

The study procedure was conducted in the following sequential steps. First, for simulation and immobilization, patients were positioned supine on breast boards with their arms raised above their heads to increase the angle between the head and the chest. CT images were acquired with a slice thickness of 5 mm, covering the region from the superior neck to the inferior diaphragm.



Figure 1: CT simulation unit and breast board at Awat Radiation Oncology Center, Erbil

Second, for contouring, the PTV, contralateral breast, and other organs at risk (OARs) were delineated by experienced radiation oncologists

at the Awat Radiation Oncology Center. PTV definitions strictly followed institutional and ICRU guidelines.

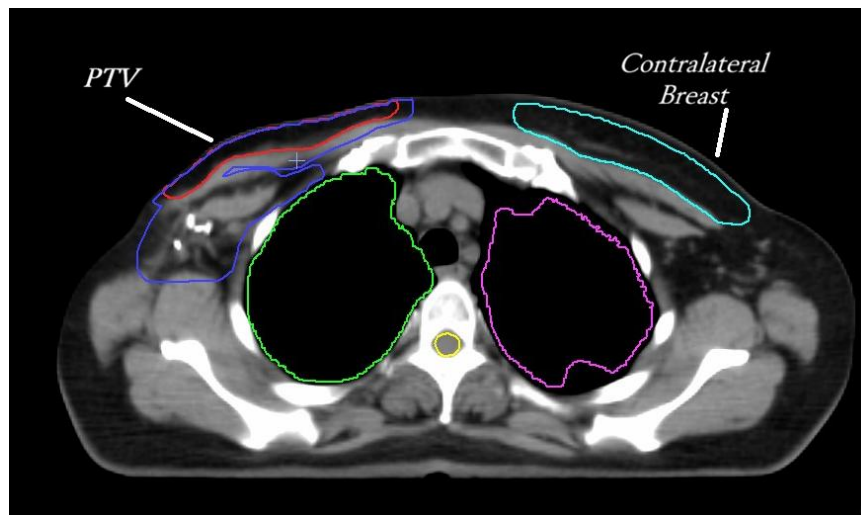


Figure 2: Patient contouring showing PTV and Contralateral Breast for one of the study participants

Third, for treatment planning scenarios, four distinct treatment plans were generated for each patient by combining two planning strategies with two delivery techniques: (1) Single-PTV + 3D-CRT, where breast and supraclavicular volumes were combined into a single optimization structure; (2) Dual-PTV + 3D-CRT, where breast and supraclavicular targets were optimized separately to enhance dose distribution control and reduce low-dose spread toward the contralateral breast; (3) Single-PTV + VMAT, using a combined optimization structure with the VMAT delivery technique; and (4) Dual-PTV + VMAT, with separate optimization for breast and supraclavicular

targets utilizing the VMAT technique. Fourth, regarding dose prescription and constraints, the prescribed dose was 4005 cGy delivered in 15 fractions (267 cGy per session) over 3 weeks, adhering to the ASTRO/Clinical Oncology dose fractionation guidelines (2024) (Shaitelman et al., 2024). The primary planning objective was to deliver 95% of the prescribed dose to the PTV while strictly minimizing exposure to the contralateral breast. Based on NRG Oncology (2021) protocols (Oncology, 2021), the maximum dose (Dmax) to the contralateral breast was constrained to ≤ 3.0 – 3.1 Gy, with additional low-dose volume constraints applied to mitigate the risk of secondary malignancies.

2.5. Data Analysis

Statistical analyses were performed to evaluate the differences in PTV coverage and contralateral breast doses across the four planning strategies and techniques. Data normality was assessed using the Shapiro–Wilk test. Descriptive statistics were expressed as mean $\pm$ standard deviation (SD). Differences between two related groups were analyzed using the paired-sample t-test, while comparisons among the four treatment planning techniques were conducted using a one-way analysis of variance (ANOVA). All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 27. A p-value of < 0.05 was considered statistically significant.

3. Results

Dosimetric analysis was performed for ten post mastectomy right sided breast cancer patients. Four treatment plans were generated for each patient to evaluate the effects of planning

strategy and delivery technique. The strategies included single and dual PTV configurations using 3D-CRT and VMAT.

Table 2 presents the dosimetric parameters for the target volume using the 3D-CRT technique. The dual PTV strategy yielded a slight improvement in target coverage compared to the single configuration (96.23 percent versus 95.95 percent, $p = 0.043$). The homogeneity index was significantly lower in the dual plan (0.125 versus 0.13, $p = 0.001$), and the conformity index also showed improvement (0.965 versus 0.96, $p = 0.001$). The volume receiving more than 107 percent of the prescribed dose was significantly reduced in the dual plan ($p = 0.002$). Maximum and mean doses were significantly lower in the dual configuration ($p < 0.001$ and $p = 0.001$, respectively), while the minimum dose increased slightly ($p = 0.023$). Monitor units did not differ significantly between the two approaches ($p = 0.207$).

Table (2): The dosimetric values and p-values for Single and Dual PTV in 3DCRT techniques.

DP of PTV	Single PTV		Dual PTV		P-value
3DCRT	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	
PTV Cover	3.13	95.95 $\pm$ 0.925	3.2	96.23 $\pm$ 0.881	0.043
HI	0.043	0.13 $\pm$ 0.012	0.032	0.125 $\pm$ 0.01	0.001
CI	0.035	0.96 $\pm$ 0.01	0.028	0.965 $\pm$ 0.008	0.001
V%107cc	2.6	1.67 $\pm$ 1.03	2.4	1.48 $\pm$ 0.911	0.002
Min dose (cGy)3D	1675	2440.62 $\pm$ 497.97	1665.6	2466.78 $\pm$ 502.65	0.023
Max dose (cGy)	163.5	4355 $\pm$ 52.86	188.7	4272.26 $\pm$ 62.59	<0.001
Mean dose (cGy)	66.4	4062.09 $\pm$ 20.44	63.4	4058.44 $\pm$ 20.01	0.001
Monitor Units	30.85	298.08 $\pm$ 11.09	32	297.53 $\pm$ 10.95	0.207

Table 3 displays the dosimetric parameters for the VMAT technique. Target coverage was significantly higher in the dual PTV plans (98.3 percent versus 97.52 percent, $p = 0.018$). The homogeneity index was significantly lower in the dual group (0.101 versus 0.106, $p < 0.001$). The conformity index showed no significant difference between the two approaches ($p =$

0.961). The volume receiving high doses and the minimum dose remained stable between the groups ($p = 0.795$ and $p = 0.395$). However, the maximum dose was significantly higher in the dual plan ($p = 0.002$), and the mean dose was significantly reduced ($p < 0.001$). Monitor units were significantly higher in the dual PTV group ($p < 0.001$).

Table (3) the dosimetric values and p-values for *Single* and Dual PTV in VMAT technique

DP of PTV	Single PTV		Dual PTV		P-value
VMAT technique	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	
TV Cover	3.92	97.52 $\pm$ 1.253	4	98.3 $\pm$ 0.91	0.018
HI	0.054	0.106 $\pm$ 0.018	0.055	0.101 $\pm$ 0.019	<0.001
CI	0.039	0.975 $\pm$ 0.013	0.039	0.976 $\pm$ 0.012	0.961
(V%107cc)	2.57	0.708 $\pm$ 0.987	2.67	0.717 $\pm$ 1.06	0.795
Min dose (cGy)3D	1259.2	2955.52 $\pm$ 469.38	1174	2900.05 $\pm$ 450.67	0.395
Max dose (cGy)	116.7	4413.26 $\pm$ 37.42	122.5	4416.36 $\pm$ 37.99	0.002
Mean dose (cGy)	431.6	4014.84 $\pm$ 124.24	378.5	3978.52 $\pm$ 115.47	<0.001
Monitor Units	229.52	759.06 $\pm$ 71.21	228.4	764.19 $\pm$ 71.61	<0.001

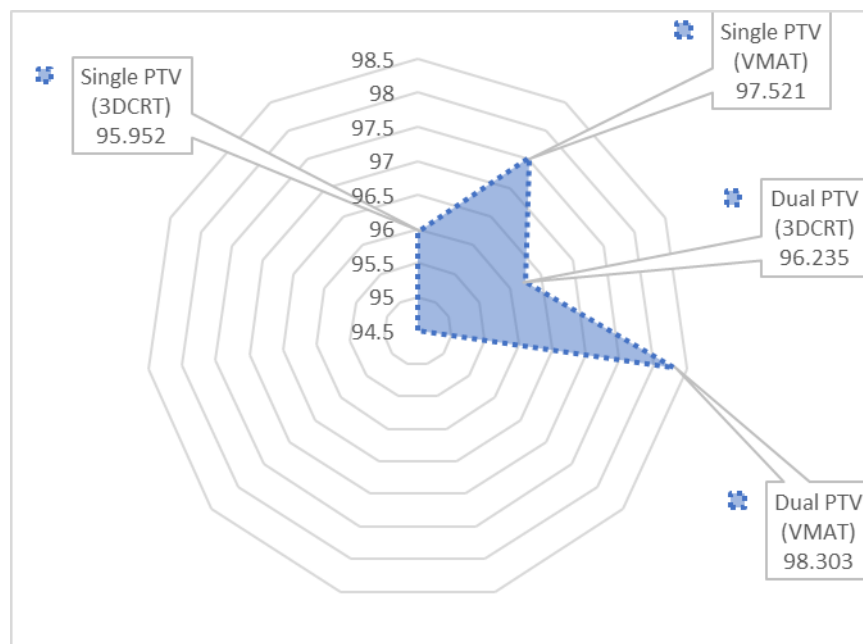
**Figure 3. Radar plot of mean PTV coverage (%) for single and dual PTV using both 3DCRT and VMAT technique.**

Figure 3 illustrates the mean PTV coverage for all approaches. The coverage increased from 95.95 percent in the single 3D-CRT plan to 96.23 percent in the dual configuration. For

VMAT, the mean coverage increased from 97.52 percent in the single plan to 98.30 percent in the dual plan.

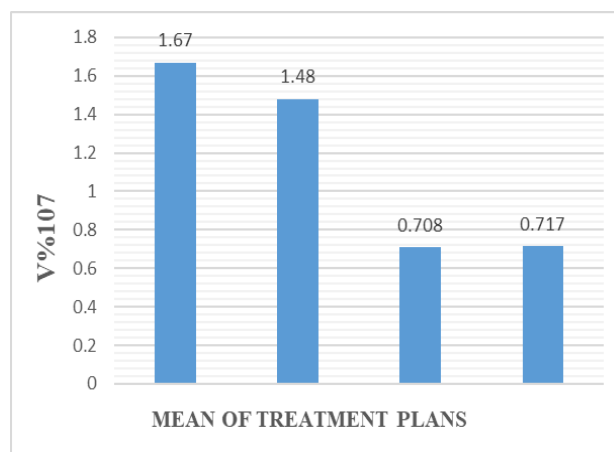


Figure 4. Distribution of the V%107 of the PTV for all plans.

Figure 4 shows the distribution of the volume receiving more than 107 percent of the prescribed dose. The single PTV plans exhibited higher hotspot volumes, with mean values of

1.67 for 3D-CRT and 1.48 for VMAT. The dual planning strategy reduced this volume to 0.708 in 3D-CRT and 0.717 in VMAT.

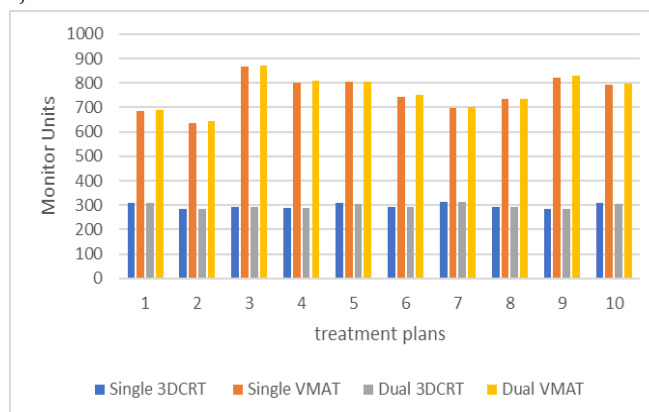


Figure 5. Distribution of the monitor units for all studied treatment plans.

Figure 5 presents the distribution of monitor units across all treatment plans. A two way repeated measures analysis of variance demonstrated a significant main effect of technique on monitor units ($p < 0.001$), with VMAT plans requiring significantly higher monitor units compared to 3D-CRT. A

significant main effect of the planning strategy was also observed ($p < 0.001$). The interaction effect between technique and planning strategy was significant ($p < 0.001$), indicating that separating the PTV increased monitor units predominantly in the VMAT plans.

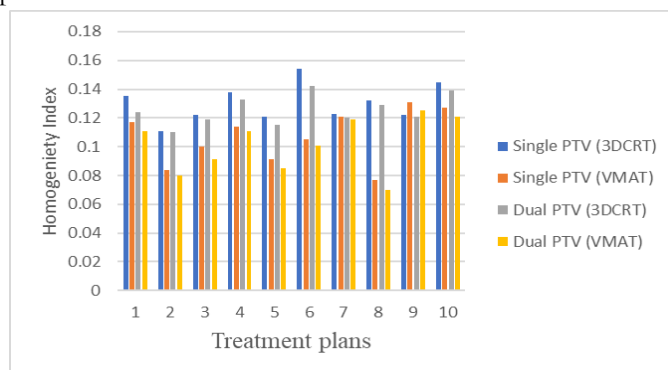


Figure 6. Comparison of the homogeneity index across the 3DCRT and VMAT technique.

Figure 6 compares the homogeneity index across the evaluated techniques. The single 3D-CRT plan showed the highest homogeneity index values. VMAT plans, particularly the dual

PTV configuration, demonstrated the lowest homogeneity index values, indicating improved dose uniformity within the target volume.

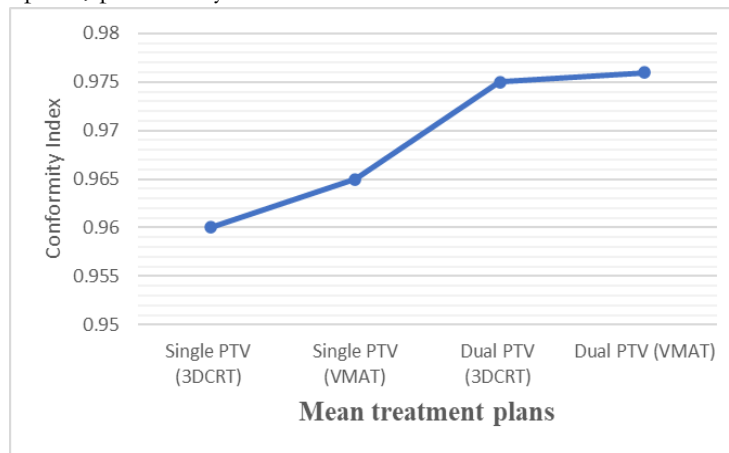


Figure 7 Conformity index comparison across the 3DCRT and VMAT technique.

Figure 7 displays the average conformity index for the four planning strategies. The lowest conformity index value was observed in the single 3D-CRT plan (0.96). The value increased slightly in the single VMAT plan (0.965) and the dual 3D-CRT plan (0.974). The highest conformity was recorded in the dual VMAT plan (0.975).

Table 4 summarizes the dosimetric parameters for the contralateral breast. The dual PTV

strategy significantly reduced the mean dose to the contralateral breast in both techniques. In 3D-CRT, the mean dose decreased from 2.55 Gy to 1.92 Gy ($p = 0.021$). In VMAT, the mean dose decreased from 35.83 Gy to 34.75 Gy ($p = 0.002$). Comparisons between the techniques revealed that VMAT delivered significantly higher doses to the contralateral breast than 3D-CRT in both single and dual planning strategies ($p < 0.001$).

Table (4) the dosimetric parameters to contralateral Breast

Dosimetric parameter	Single PTV		Double PTV		P-Value
	Range	Mean±SD	Range	Mean±SD	
Contralateral Breast 3DCRT	6.05	2.55±2.01	3.96	1.92±1.42	0.021
Contralateral Breast VMAT	41.56	35.83±14.1	39.51	34.75±13.51	0.002

*p-value between single 3DCRT vs single VMAT and dual 3DCRT vs dual VMAT were <0.001

4. Discussion

The primary objective of this study was to systematically evaluate the dosimetric impact of single versus dual PTV strategies in 3D-CRT and VMAT, with a specific focus on contralateral breast exposure. The main finding of this investigation is that separating the breast

and supraclavicular targets into a dual configuration improves dose homogeneity and significantly reduces radiation exposure to the contralateral breast in both delivery techniques. Furthermore, while VMAT provides superior target conformity and coverage, it is associated

with a higher low dose spread to the contralateral breast compared to 3D-CRT.

The separation of the PTV into distinct breast and supraclavicular structures allowed for independent optimization objectives. In the 3D-CRT technique, this separation resulted in a modest improvement in target coverage. This marginal benefit is likely due to the reliance of 3D-CRT on forward planning with fixed beam arrangements, which limits the flexibility of dose modulation. The improvement in coverage primarily reflects better geometric field matching rather than complex optimization. Conversely, VMAT demonstrated a more pronounced improvement in target coverage when using the dual configuration. Because VMAT utilizes inverse planning with dynamic multileaf collimator modulation, defining two separate targets allows the optimization algorithm to assign distinct priorities to each region. These findings are consistent with previous studies indicating that VMAT provides superior PTV coverage and overall planning quality compared to 3D-CRT (Huang et al., 2023; Lee et al., 2026; Namratha, Narayanan, Arpitha, Sindhu, & Kumar, 2025).

The increased complexity of optimizing separate targets in VMAT was reflected in the monitor unit analysis. Separating the PTV significantly increased the total monitor units required for VMAT plans, while having minimal impact on 3D-CRT. In 3D-CRT, beam geometry and field weighting remain unchanged regardless of target segmentation. In contrast, VMAT requires greater multileaf collimator modulation and beam intensity variation to fulfill independent dose objectives for the separated targets. This aligns with the findings of Zhang et al. (2021) (Zhang et al., 2021), who reported significantly higher total monitor units for VMAT compared to 3D-CRT. The reduction of monitor units in 3D-CRT is clinically relevant, as fewer monitor units result in less scatter radiation from the accelerator head, potentially decreasing the integral dose to the patient.

The dual PTV strategy significantly improved dose homogeneity and reduced high dose

regions in both techniques. The volume of the target receiving more than 107 percent of the prescribed dose was substantially lower in the dual configurations, indicating better hotspot control. VMAT plans, particularly the dual configuration, exhibited the lowest homogeneity index values, suggesting highly uniform dose distribution within the target. This superiority of VMAT in dose homogeneity and normal tissue protection is supported by the literature. Wu et al. (2023) (Wu et al., 2023) demonstrated similar improvements in homogeneity for advanced techniques in bilateral breast radiotherapy. Additionally, Thakur et al. (2024) (Thakur et al., 2024) reported that VMAT improves dose homogeneity and provides better protection for normal tissues compared to intensity modulated radiotherapy in complex breast irradiation.

The conformity index also improved when transitioning from single to dual PTVs and from 3D-CRT to VMAT. The highest conformity was achieved with the dual VMAT approach. Das Majumdar et al. (2022) (Majumdar et al., 2022) observed comparable results, showing better conformity and homogeneity indices for VMAT. The physical basis for this superiority lies in the dose calculation algorithms. As explained by Liang et al. (2024) (Liang et al., 2024), 3D-CRT approximates photon scatter and attenuation to achieve a relatively uniform dose distribution. VMAT employs more sophisticated calculation models that accurately simulate photon interactions and dose deposition within heterogeneous tissues, where density variations significantly influence scattering and attenuation. Consequently, combining the dual PTV strategy with VMAT plays a critical role in maximizing conformity and minimizing high dose regions, as also supported by Chen et al. (2025) (Chen et al., 2025) for composite breast and nodal treatments.

The most critical finding of this study pertains to the radiation dose delivered to the contralateral breast. The dual PTV strategy significantly reduced the mean dose to the contralateral breast in both 3D-CRT and VMAT. By separating the targets, the optimization algorithm can more effectively

shape the dose gradients and minimize low dose spread toward the medial aspects of the contralateral breast. However, when comparing the two delivery techniques, VMAT delivered significantly higher doses to the contralateral breast than 3D-CRT in both single and dual configurations. This increased exposure is attributed to the rotational beam delivery of VMAT, which inevitably increases the low dose bath to surrounding normal tissues.

These results highlight a fundamental clinical trade off. While VMAT offers clear dosimetric benefits regarding target coverage, homogeneity, and conformity, 3D-CRT provides superior protection for the contralateral breast. The average radiation dose to the contralateral breast was significantly lower with 3D-CRT. This observation is consistent with the work of Attallah et al. (2021) (Attallah et al., 2021), who reported lower organ at risk doses with 3D-CRT. Other studies by Salim et al. (2023) (Salim et al., 2023) and Ahmad et al. (2022) (Ahmad et al., 2022) suggest that VMAT can match or improve organ at risk sparing only when advanced optimization constraints are strictly applied, but the low dose spread often remains higher. The extended low dose exposure associated with VMAT is a significant concern, particularly for younger patients, as it may increase the lifetime risk of radiation induced secondary malignancies (Adeneye & Akpochafor, 2023; Huang et al., 2023). Therefore, the selection of the treatment technique must be individualized. VMAT is highly appropriate when precise conformity and homogeneous target coverage are the primary clinical priorities. Conversely, 3D-CRT should be strongly considered for younger individuals with a long life expectancy to limit unnecessary low dose irradiation to the contralateral breast and reduce the risk of secondary cancers (Benmessaoud et al., 2023).

Despite the significant dosimetric findings, this study has several limitations that should be acknowledged. First, the sample size was relatively small, consisting of only ten patients, which may limit the generalizability of the results. Second, this was a single center in silico dosimetric study, and the findings require clinical validation through prospective trials with larger cohorts. Third, the study focused exclusively on right sided post mastectomy breast cancer patients, and the dosimetric outcomes might differ in left sided cases where cardiac sparing is a primary concern. Future multi center studies with larger sample sizes are recommended to validate these dosimetric advantages in clinical practice.

5. Conclusion

This comparative dosimetric study evaluated the impact of single versus dual PTV configurations on target coverage and contralateral breast sparing in 3D-CRT and VMAT techniques. The findings demonstrate that separating the breast and supraclavicular targets into a dual PTV configuration significantly improves dose homogeneity and reduces radiation exposure to the contralateral breast in both delivery techniques. While VMAT provides superior target conformity and homogeneity, it is associated with a higher low dose spread to the contralateral breast compared to 3D-CRT. Therefore, the selection of the optimal planning strategy and delivery technique must be individualized. VMAT is highly recommended when precise target coverage and dose conformity are the primary clinical objectives. Conversely, 3D-CRT should be strongly considered for younger patients with a long life expectancy to minimize the low dose bath and reduce the lifetime risk of secondary malignancies. Future prospective clinical studies with larger sample sizes are recommended to validate these dosimetric findings and assess their long term clinical outcomes.

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7. Acknowledgements (Optional)

The authors would like to express their sincere gratitude to the medical staff and radiation therapists at the Awat Radiation Oncology Center in Erbil for their invaluable technical assistance and support during the data collection phase of this study. Special appreciation is extended to the radiation oncologists who contributed to the accurate delineation of target volumes and organs at risk. The authors also acknowledge the College of Medicine at Hawler Medical University for providing the academic environment and institutional resources necessary to conduct this research. Finally, we extend our gratitude to all the patients whose anonymized clinical data made this dosimetric investigation possible. This research did not receive any specific grant from funding agencies in the public, commercial, or not for profit sectors.

8. Author Declaration

Originality and Authorship

The authors confirm that this manuscript is original, has not been published elsewhere, and is not currently under consideration for publication by any other journal. All authors have contributed significantly to the work and have approved the final version of the manuscript submitted. Rozhan A. Hamadsaeed was responsible for the study

concept, data collection, dosimetric planning, statistical analysis, and manuscript drafting. Fatiheea F. Hassan supervised the study design, provided critical revisions to the manuscript, and validated the dosimetric parameters. All authors have read and agreed to the published version of the manuscript.

Ethical Approval

The study protocol was reviewed and approved by the Committee of Research Ethics at the College of Medicine, Hawler Medical University (Approval No. 13, dated September 22, 2024), Erbil, Kurdistan Region, Iraq. Due to the retrospective and dosimetric nature of this study, the requirement for individual patient informed consent was waived by the ethics committee. All patient data were anonymized and handled in strict confidentiality in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. There are no conflicts of interest to disclose.