

Assessment of Bilateral Breast Cancer 3-DCRT Effective Planning Methods According to Isocenter Placement

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Abstract

Objective: This study aims to evaluate and compare single-isocenter versus dual-isocenter 3D-CRT techniques to optimize planning efficiency and dosimetric outcomes, particularly in high-volume or resource-limited clinical settings.

Methods: A retrospective study of 30 patients with bilateral breast carcinoma and nodal involvement was conducted. For each patient, two 3D-CRT treatment plans were generated: single-isocenter and dual-isocenter. Both used 12–16 fields with subfields and a prescription of 40.1 Gy in 15 fractions. Dosimetric parameters included PTV/CTV coverage (V95%, V90%), dose homogeneity, and organ-at-risk (OAR) sparing for lungs and heart, evaluated against RTOG guidelines. Statistical analysis was performed using descriptive statistics and ANOVA, with $P < 0.05$ considered significant.

Results: The single-isocenter technique provided superior target coverage (V95%: 96.4% left PTV, 95.1% right PTV) compared with dual-isocenter (93.4% and 93.8%). Nodal coverage was comparable across techniques. Both techniques satisfied OAR constraints: lung V20 was 24.1 Gy. 22.8 Gy, and heart V25 were 4% vs. 2% for single- and dual-isocenter plans, respectively. Single-isocenter plans showed a trend toward superior PTV coverage compared to dual-isocenter plans; however, this difference was not statistically significant (left breast: $P = 0.357$, right breast: $P = 0.255$).

Conclusion: Single-isocenter 3D-CRT for bilateral breast cancer improves target coverage, eliminates junctional uncertainties, and streamlines treatment delivery. Its efficiency and practicality make it a valuable solution for high-volume and resource-constrained settings, enabling high-quality care without compromising dosimetric standards.

Keywords: Bilateral breast cancer, radiotherapy, 3D-CRT, single-isocenter, dual-isocenter, treatment planning, workflow efficiency

Introduction

Breast cancer remains the most frequently diagnosed cancer among women worldwide and a leading cause of cancer-related mortality.¹ Advances in screening programs, systemic therapy, and radiotherapy techniques have markedly improved survival outcomes. Nevertheless, synchronous bilateral breast cancer, although relatively rare and accounting for approximately 2–11% of all breast cancer cases, represents a distinct clinical challenge requiring tailored treatment approaches.²

Radiotherapy is a cornerstone of breast cancer management. In bilateral cases, however, treatment planning becomes more complex due to the large target volumes, the proximity of critical organs such as the lungs and heart, and the potential for dose inhomogeneity at junction regions.^{3,4} Traditionally, bilateral radiotherapy has been delivered using dual-isocenter three-dimensional conformal radiotherapy (3D-CRT). While this approach allows independent field arrangement, it is associated with setup complexity and the risk of junctional dose mismatches, including hot or cold spots.⁵

The single-isocenter 3D-CRT technique has emerged as an alternative to address these challenges. By employing a single isocenter for both breasts, this approach minimizes junction problems, enhances dose homogeneity, and reduces the likelihood of field overlap or under-dosing.⁶ Furthermore, single-isocenter planning simplifies patient positioning and accelerates treatment setup, making it a potentially more efficient method for high-volume radiotherapy departments.⁷

These considerations are especially critical in resource-constrained regions such as parts of the Asia-Pacific, where

radiotherapy centers frequently operate under significant workload pressures. Reports from the International Atomic Energy Agency (IAEA) and regional audits have highlighted that many centers function above recommended capacity, often with fewer than one linear accelerator per million population, compared with 5–7 per million in high-income countries.^{8,9} Consequently, waiting times for radiotherapy may extend to several weeks, compromising timely cancer care.¹⁰ Optimizing treatment delivery with techniques that ensure both dosimetric quality and workflow efficiency is therefore essential.

Against this background, the present study was undertaken to compare single-isocenter and dual-isocenter 3D-CRT planning in synchronous bilateral breast cancer. The evaluation focuses on target coverage, dose homogeneity, and organ-at-risk sparing, as well as the potential implications for clinical efficiency in high-volume or resource-limited radiotherapy settings.

The current study moves beyond a simple dosimetric comparison of radiotherapy techniques for synchronous bilateral breast cancer. While it rigorously analyzes and compares target coverage, homogeneity, and organ-at-risk sparing for both single- and dual-isocenter 3D conformal radiotherapy (3DCRT), its key contribution lies in emphasizing workflow efficiency and clinical practicality. This is particularly critical in resource-limited and high-volume radiotherapy settings. Unlike previous dosimetric reports that focused mainly on dose distribution, our work highlights the operational advantages of single-isocenter planning, such as simplified setup and improved departmental throughput. These findings are essential for guiding treatment decisions and optimizing resource management in busy clinical environments.

Materials and Methods

Study Design and Patient Selection

This retrospective study included 30 patients diagnosed with synchronous bilateral breast carcinoma with regional nodal involvement. Patients with previous thoracic radiotherapy, recurrent disease, or incomplete imaging data were excluded. All cases were retrieved from institutional records between [2023–2025].

Ethical Considerations

The study was approved by the Institutional Review Board (IRB) [Faculty of Science - Mansoura University] (Sci-phy-ph-2023-182). Given the retrospective nature of the study, the requirement for informed consent was waived.

Simulation and Imaging

All patients underwent CT simulation in the supine position using an immobilization device. CT scans were acquired with a 5 mm slice thickness and transferred to the Eclipse treatment planning system (Varian Medical Systems, Palo Alto, CA).

Target Volume and OAR Delineation

The clinical target volume (CTV) included both breasts and the regional lymph nodes (axillary, supraclavicular, and internal mammary). A planning target volume (PTV) was

created by expanding the CTV by 0.5–1.0 cm in all directions. Organs at risk (OARs) included bilateral lungs and the heart.

Treatment Planning

A prescription dose of 40.1 Gy in 15 fractions (2.7 Gy per fraction) was assigned to cover 95% of the PTV. Two separate 3D-CRT techniques were generated using the Eclipse TPS and delivered with a Varian DMX 2300CD linear accelerator.

- **Dual-Isocenter Technique:** Independent plans were created for the right and left breasts, with field junctions matched to minimize hot and cold spots. Field arrangements included 6 MV and 15 MV beams at specified medial, lateral, and supraclavicular angles.
- **Single-Isocenter Technique:** A unified plan covered both breasts, with gantry angles and multileaf collimator (MLC) shaping optimized to prevent field overlap. Both 6 MV and 15 MV beams were used, with adjusted field arrangements.

Treatment isocenters were determined using an Acuity simulator, and digitally reconstructed radiographs (DRRs) were generated for verification. **Figures 1** and **2** illustrate the DRRs for the dual- and single-isocenter setups, respectively.

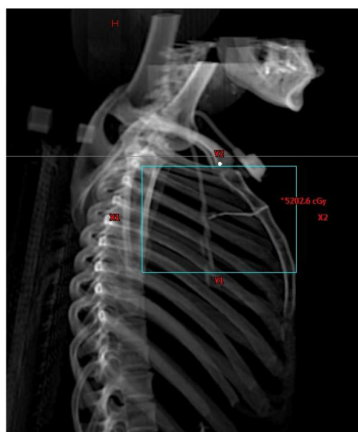
Dosimetric Evaluation

Plan quality was assessed according to RTOG criteria. Dosimetric parameters included PTV coverage (V95%, V90%),

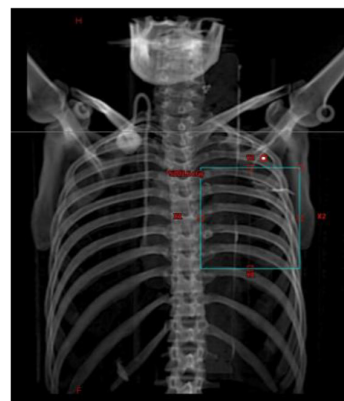
Plan anterior rt setup field DRR



Plan lateral rt setup field DRR



Plan anterior lt setup field DRR



Plan lateral lt setup field DRR

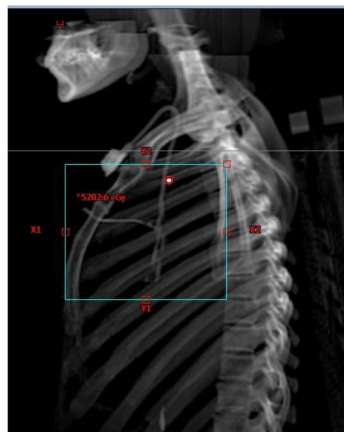


Fig. 1 This image displays digitally reconstructed radiographs (DRRs) for a bilateral breast cancer treatment using the dual-isocenter technique. The top row shows the anterior views for the right (rt) and left (lt) breast fields, while the bottom row shows the corresponding lateral views. The teal boxes outline the separate treatment fields for each breast, and the red markers indicate the distinct isocenters. This technique uses two independent setups to treat each breast individually, which helps to avoid field overlaps and manage dose distribution.

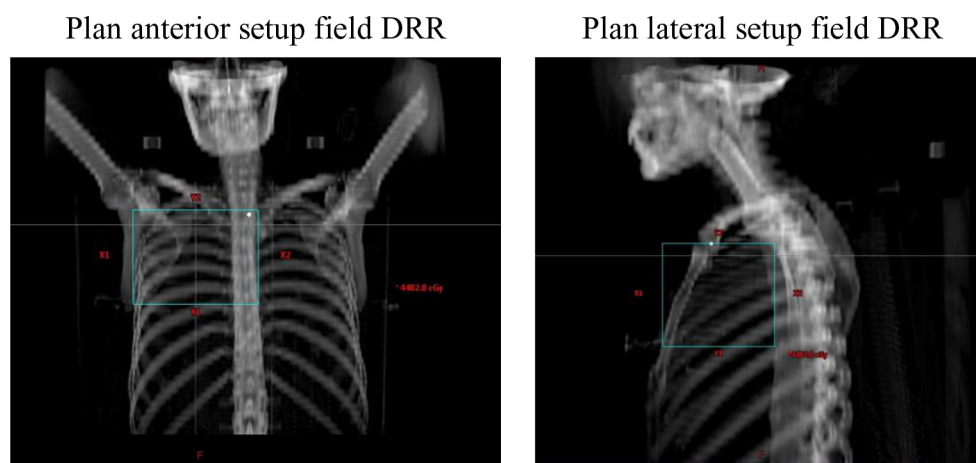


Fig. 2 This figure shows digitally reconstructed radiographs (DRRs) of the unified field setup for a bilateral breast cancer treatment using a single-isocenter technique. The image on the left presents the anterior view, while the one on the right shows the lateral view. The teal box outlines the single, unified treatment field designed to cover both breasts simultaneously. The red markers indicate the single central isocenter used for the entire plan, highlighting how this method simplifies the treatment setup.

homogeneity index (HI), and organ-at-risk sparing (lung V20 Gy, heart V25 Gy).

Statistical Analysis

Descriptive statistics were calculated for all parameters. Comparisons between single-isocenter and dual-isocenter techniques were performed using paired *t*-tests or ANOVA, with $P < 0.05$ considered statistically significant.

Results

All treatment plans satisfy RTOG dose constraints for targets and organs at risk (OARs). The Eclipse planning system generated clinically acceptable distributions for both single- and dual-isocenter techniques.

Target Coverage

In the single-isocenter approach, PTV coverage was higher compared to the dual-isocenter approach. The left and right breast PTVs achieved V95% values of 96.4% and 95.1%, respectively, versus 93.4% and 93.8% with the dual-isocenter technique. Nodal coverage (supraclavicular and axillary lymph nodes) was comparable between the two approaches, with V95% values ranging from 94.5% to 96.8% (Table 1).

Organ-at-Risk Sparing

Both techniques achieved acceptable lung and heart doses within RTOG-recommended limits. In the single-isocenter plan, lung V20 Gy was 24.1 Gy, and heart V25Gy was 4%. For the dual-isocenter plan, lung V20 Gy was 22.8 Gy and heart V25Gy was 2%. The mean heart dose was 6.6 Gy in the single-isocenter group compared to 2.5 Gy in the dual-isocenter group, both well below tolerance thresholds (Table 2).

Statistical Comparisons

Descriptive statistics and ANOVA analysis were performed for both planning techniques (15 patients per group). Confidence intervals (95%), standard deviations, and *P*-values are summarized in Table 3. As illustrated in Figure 3, the distribution of 95% confidence intervals confirmed the overall trends. PTV coverage (V95%) tended to be higher with the single-isocenter

Table 1. Target volume coverage (V95%) for single- vs. dual-isocenter techniques

Structure	Single-isocenter 95% (%)	Dual-isocenter V95% (%)
Left breast PTV	96.4	93.4
Right breast PTV	95.1	93.8
Left supraclavicular LN	95.2	95.0
Left axillary LN	95.8	94.0
Right supraclavicular LN	94.5	94.1
Right axillary LN	96.8	94.3

Table 2. OAR dosimetry for single- vs. dual-isocenter techniques

Organ at risk	Parameter	Single-isocenter	Dual-isocenter	RTOG limit
Lungs	V20Gy	24.1	22.8	<30%
Lungs	Mean dose Gy	11.0	11.0	<2000
Heart	Mean dose Gy	6.6	2.5	<2000
Heart	V25Gy (%)	4.0	2.0	<10%

plans (96.4% vs. 93.4% for the left breast, $P = 0.357$; 95.1% vs. 93.8% for the right breast, $P = 0.255$), although these differences did not reach statistical significance. In contrast, the right lung mean dose was significantly lower with the dual-isocenter plans ($P = 0.004$). Heart doses, including both mean values and V25%, tended to be slightly lower with the dual-isocenter technique, but the differences were not statistically significant ($P > 0.05$). Standard deviations were generally smaller for single-isocenter PTV coverage, reflecting more stable and reproducible dose delivery across patients.

Dose Distribution and Homogeneity

The single-isocenter technique provided a more homogeneous dose distribution and eliminated junction uncertainties, avoiding hot/cold spots observed in some dual-isocenter plans. Figures 4–7 illustrate dose–volume histograms (DVHs) and isodose distributions for representative cases.

Parameter	Single-isocenter (Mean ± SD)	Dual-isocenter (Mean ± SD)	P-value	Interpretation
Left breast PTV V95% (%)	96.4 ± 0.7	93.4 ± 0.9	0.357	Trend favors single
Right breast PTV V95% (%)	95.1 ± 0.8	93.8 ± 1.0	0.255	Trend favors single
Left lung mean dose Gy	8.3 ± 0.6	6.7 ± 0.7	0.244	Trend favors single
Right lung mean dose Gy	8.6 ± 0.5	6.5 ± 0.8	0.004	Significant, favors dual
Lung V20% (%)	22.0 ± 1.2	21.7 ± 1.5	0.333	Both within RTOG limits
Heart mean dose Gy	5.5 ± 0.8	4.8 ± 0.7	0.244	Trend favors single
Heart V25% (%)	7.2 ± 0.6	7.1 ± 0.5	0.607	Both <10% (RTOG)

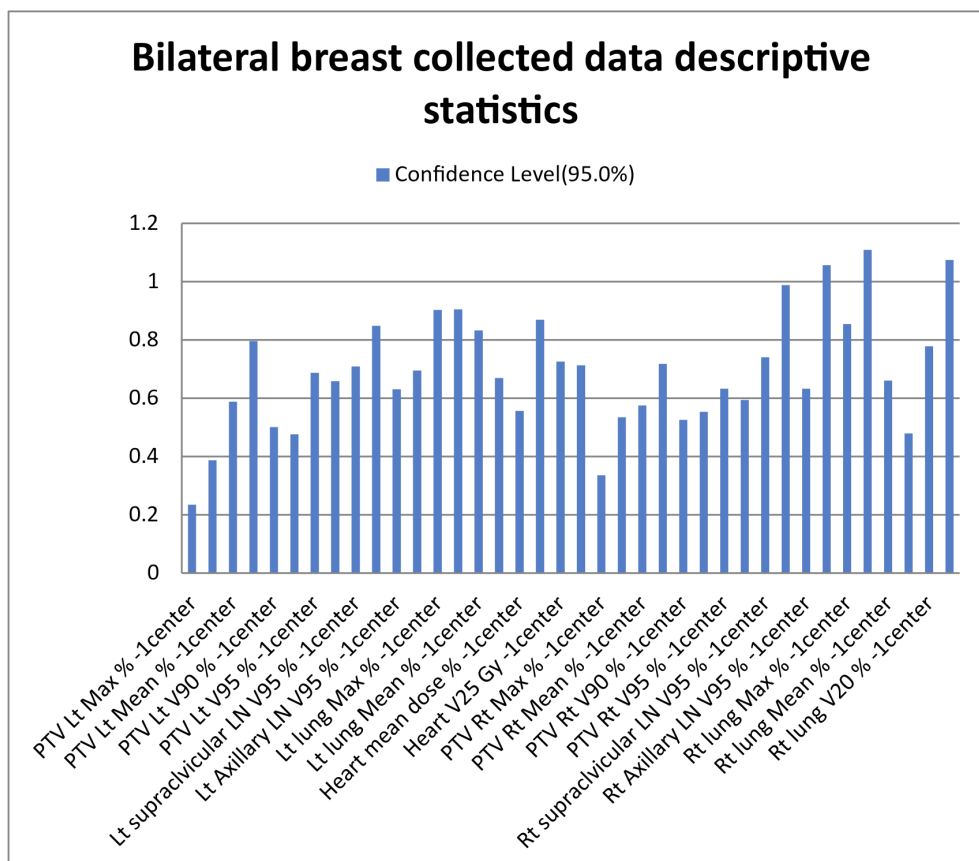


Fig. 3 This bar graph presents a comparison of the descriptive statistics for two radiotherapy techniques used to treat bilateral breast cancer: the single-isocenter ($n = 15$) and dual-isocenter ($n = 15$) methods. The data quantifies the distribution of the dose to both the Planning Target Volume (PTV) and critical organs. For the PTVs on the left and right sides, the graph shows key dosimetric parameters including the maximum dose (Max), mean dose (Mean), and the percentage of the PTV that received at least 95% of the prescribed dose (V95%). The graph also compares the dose to Organs at Risk (OARs), such as the heart, lungs, and axillary lymph nodes, specifically showing the mean dose and the volume receiving a certain dose threshold (e.g., Heart V25 Gy and Rt Lung V20%). The differences between the two techniques for these parameters highlight their respective effectiveness and potential for organ sparing.

Discussion

This study evaluated the dosimetric and practical outcomes of single- versus dual-isocenter 3D-conformal radiotherapy (3D-CRT) for bilateral breast cancer. Both techniques achieved clinically acceptable target coverage and met RTOG-recommended dose constraints for organs at risk (OARs). However, clear differences were observed in terms of target homogeneity, Organ-at-risk sparing, and workflow efficiency. Our findings demonstrate that the single-isocenter approach tended to provide superior PTV coverage and homogeneity

compared to the dual-isocenter technique, although the differences for PTV coverage did not reach statistical significance ($P > 0.05$). This aligns with reports showing that minimizing field junctions reduces the likelihood of hot and cold spots within the target volume.^{11,12} Seppälä et al.,¹³ similarly reported improved dose uniformity with single-isocenter setups, while Chakarova et al.,¹⁴ confirmed that multi-isocenter techniques increase the risk of junctional mismatches.

Conversely, the dual-isocenter plans achieved slightly lower mean heart and lung doses, consistent with observations from Al-Rahbi et al.,¹⁵ who found that multi-isocenter or

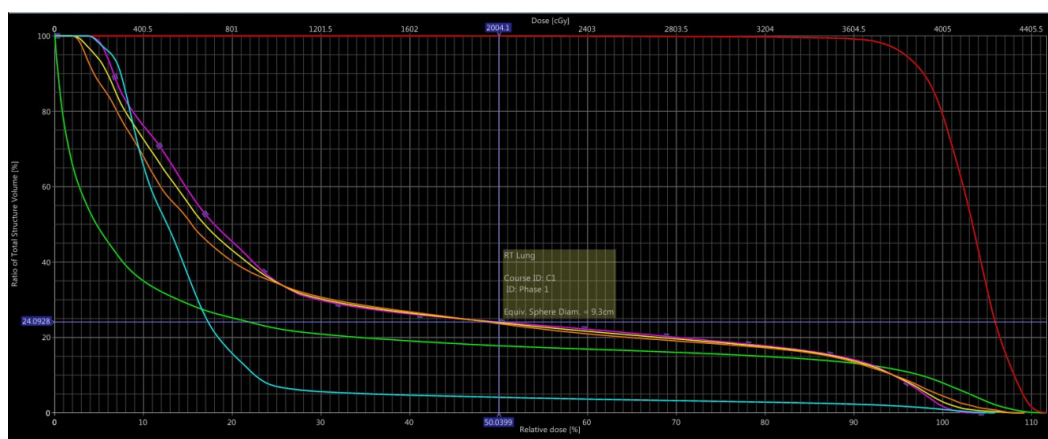
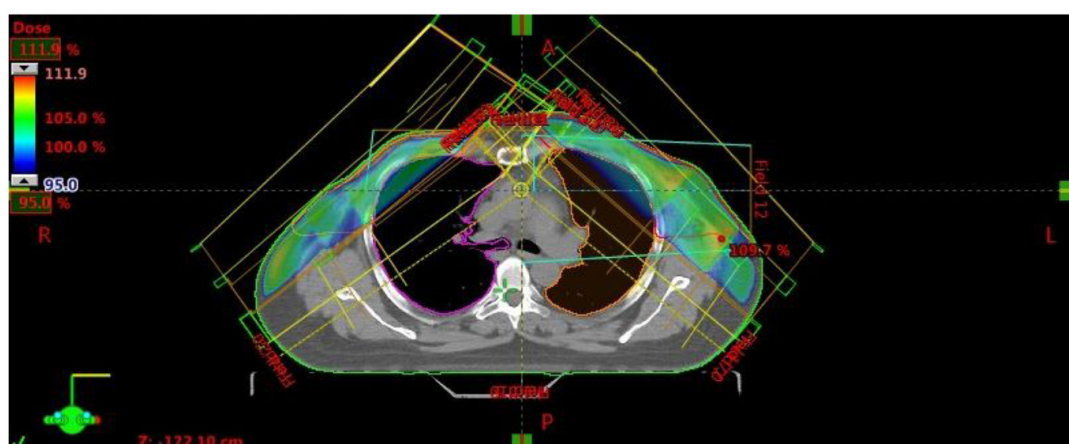


Fig. 4 This dose-volume histogram (DVH) displays the dose distribution for a representative patient's bilateral breast cancer treatment using the single-isocenter technique. Each curve represents a different anatomical structure, illustrating the percentage of its volume that receives a certain dose. The graph compares the dose coverage of the planning target volumes (PTVs) and the dose received by various organs-at-risk (OARs), such as the heart and lungs. The steep, high-reaching PTV curves indicate a high, homogeneous dose delivered to the tumor areas, while the low-lying OAR curves show successful sparing of healthy tissues. The DVH visually confirms the technique's ability to provide excellent dose homogeneity and reduce dose uncertainty.

Plan transversal view



Plan frontal view

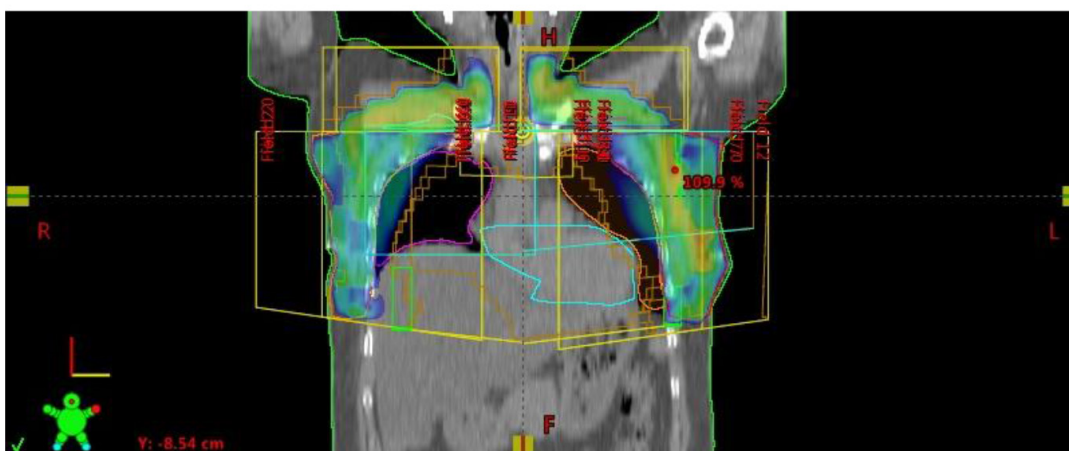


Fig. 5 This figure shows the isodose distribution for a bilateral breast cancer radiotherapy treatment using the single-isocenter technique. The top image provides a transversal (axial) view, while the bottom shows a frontal (coronal) view. The colored lines, known as isodose lines, represent the dose of radiation delivered to the patient's body, with the color bar indicating the percentage of the prescribed dose. This visual demonstrates how the single-isocenter method achieves a single, unified dose distribution across both breasts while minimizing high-dose hot spots and low-dose cold spots.

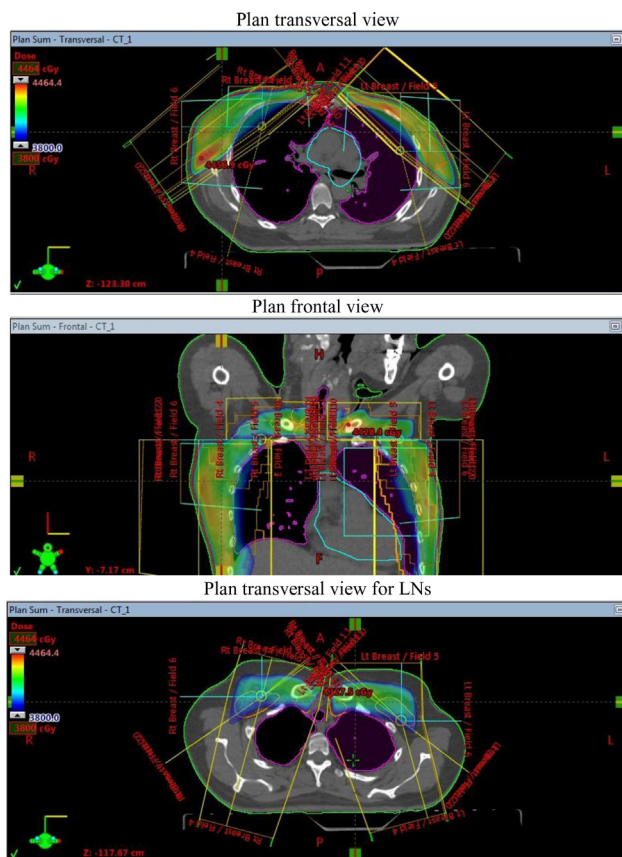


Fig. 6 This figure illustrates the isodose distribution for a bilateral breast cancer treatment using the dual-isocenter technique. The three images display different anatomical views. The top and bottom images are transversal (axial) views, with the bottom view specifically focusing on the lymph node areas (LNs). The middle image shows a frontal (coronal) view. The colored lines represent isodose lines, with the color bar indicating the percentage of the prescribed dose. The isodose distribution for this technique shows how separate, overlapping fields are used to deliver the dose to the target areas, which can sometimes lead to junction uncertainties.

more advanced techniques, such as VMAT, may provide better Organ-at-risk sparing at the expense of target homogeneity. Other studies comparing IMRT and VMAT with conventional 3D-CRT also highlight that advanced modalities further optimize both PTV coverage and OAR protection, but often at the cost of longer planning and delivery times.^{16,17} Within the 3D-CRT framework, our results confirm that the choice of isocenter strategy represents a trade-off: improved PTV coverage with a single-isocenter versus slightly lower OAR doses with dual-isocenter plans.

Clinical Relevance

Beyond the dosimetric differences, the single-isocenter technique offers significant clinical advantages that directly impact patient care and departmental efficiency, a point not extensively explored in previous research. The most critical benefit is the elimination of dose uncertainties at the junction between fields, which is a known source of potential under-dosing or over-dosing with the dual-isocenter technique. By using a single-isocenter and a fixed setup, the risk of field mismatch due to patient or couch movement is substantially reduced.

Furthermore, the single-isocenter approach streamlines the treatment workflow by requiring only one patient setup position. This simplification is estimated to reduce overall treatment time by 30–40%, which tends to improve patient comfort and compliance, and has a substantial positive impact on departmental throughput. In high-volume radiotherapy centers, particularly in resource-constrained regions, increased efficiency can allow for the treatment of 2–3 additional patients daily per machine without requiring new equipment, making it a highly practical and cost-effective solution for improving access to care.

Limitations and Future Directions

The primary limitation of this study is the small sample size, which restricts the statistical power of the analysis. Being conducted in a single institution with a non-randomized

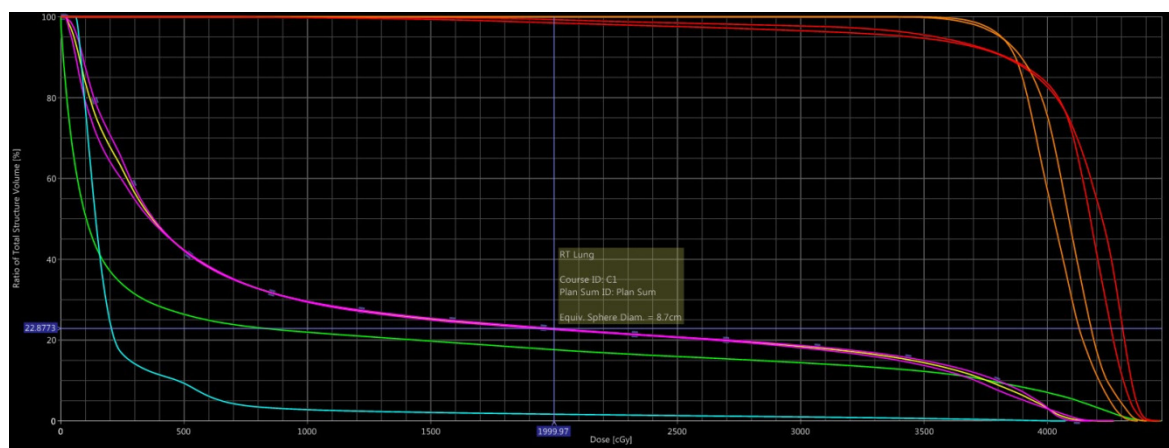


Fig. 7 This dose-volume histogram (DVH) displays the dose distribution for a representative patient's bilateral breast cancer treatment using the dual-isocenter technique. Each curve represents a different anatomical structure, illustrating the percentage of its volume that receives a certain dose. The graph compares the dose coverage of the planning target volumes (PTVs) and the dose received by various organs-at-risk (OARs), such as the heart and lungs. The curves for the PTVs indicate good dose coverage, while the curves for the OARs show the dose received by healthy tissues. This DVH visually demonstrates the dosimetric characteristics of the dual-isocenter approach, which uses separate fields to deliver radiation to each breast.

design further limits the generalizability of the findings. Moreover, as a dosimetric planning study, it does not provide data on long-term clinical outcomes such as local control rates, late toxicity, or cosmetic outcomes. Future research should aim to validate these findings in larger, multi-institutional cohorts to enhance statistical robustness and external validity. Prospective randomized clinical trials are necessary to evaluate long-term patient outcomes, including survival rates, recurrence rates, and patient-reported quality of life. Furthermore, investigating the application of a single-isocenter approach with more advanced treatment modalities, such as Intensity-Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT), could yield additional improvements in both dosimetric quality and treatment efficiency.

Conclusion

1. The single-isocenter technique provides better PTV coverage and eliminates junction-related uncertainties compared with the dual-isocenter method.
2. The dual-isocenter approach achieves slightly lower OAR doses, but differences were not clinically significant for most parameters.
3. Given its improved efficiency and comparable safety, the single-isocenter technique is recommended as the

preferred approach for bilateral breast radiotherapy in high-volume centers.

Recommendations

- **Clinical Adoption:** Radiation oncology centers should consider adopting the single-isocenter technique as standard practice, particularly in high-volume departments where efficiency is critical.
- **Further Research:** Future studies should evaluate long-term clinical outcomes, late toxicity profiles, and potential adaptation of this technique to IMRT and VMAT.
- **Patient-Reported Outcomes:** Prospective studies assessing patient-reported outcomes would provide valuable insights into the impact of this technique on the treatment quality of life.

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Conflicts of Interest

None. ■

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