Clinical and Experimental Obstetrics & Gynecology

Clin. Exp. Obstet. Gynecol. **2026**; 53(3): 45937
https://doi.org/10.31083/CEOG45937

Original Research

Retrospective Dosimetric Comparison of TomoDirect and Intensity-Modulated Radiotherapy in Hypofractionated Radiotherapy With Simultaneous Integrated Boost for Left-Sided Breast Cancer: Implications for Organ Sparing and Treatment Optimization

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Academic Editor: Michael H. Dahan
Submitted: 20 August 2025 Revised: 31 October 2025 Accepted: 30 December 2025 Published: 16 March 2026

Abstract

Background: TomoDirect (TD) and intensity-modulated radiotherapy (IMRT) are advanced techniques used in hypofractionated radiotherapy with simultaneous integrated boost (HFRT-SIB) for patients undergoing breast-conserving surgery. This study evaluates the dosimetric impacts of TD and IMRT on the target volume areas and organs at risk (OARs). **Methods**: This study is a retrospective dosimetric comparison. Thirty patients were enrolled. Computed tomography (CT) images were acquired with a slice thickness of 5 mm. The CT data were subsequently exported to the Pinnacle treatment planning system. IMRT plans were developed using Pinnacle. The TomoHD^{TM} planning station was used for TD planning. For each patient, three treatment plans were generated: TD (field width [FW] = 2.5 cm), TD (FW = 5 cm), and IMRT. The HFRT-SIB prescription was administered as follows: a cumulative dose of 43.5 Gy was delivered to the planning target volume (PTV); a cumulative dose of 49.5 Gy was delivered to the planning gross target volume (PGTV). **Results**: For both the PGTV and PTV, the homogeneity index (HI) values were lowest with TD (FW = 2.5 cm). The conformity index (CI) values were highest with IMRT for both the PGTV and PTV. Mean target volume coverage met the requirements for the PGTV and PTV across TD with a FW of 2.5 cm, TD with a FW of 5 cm, and IMRT. For the left lung and heart, V_5, V_{10}, V_{20}, V_{30}, and the mean dose (D_{mean}) were the lowest with TD (FW = 2.5 cm). The maximum dose (D_{max}) and D_{mean} for the left anterior descending coronary artery (LAD) were also lowest with TD (FW = 2.5 cm). TD (FW = 5 cm) provided slightly less protection for OARs than TD (FW = 2.5 cm). The average treatment time was 5 minutes for TD (FW = 5 cm) and 9 minutes for TD (FW = 2.5 cm). **Conclusions**: Compared with IMRT, TD provides better protection of cardiopulmonary function while maintaining target area quality. Overall, when employing TD for HFRT-SIB, a FW of 5 cm is recommended.

Keywords: breast cancer; HFRT-SIB; TomoDirect; IMRT; dosimetry

1. Introduction

For early breast cancer patients, radiation therapy following breast-conserving surgery is essential. The conventional fractionated radiotherapy (CFRT) in postoperative breast cancer patients involves delivering 50 Gy in 25 fractions over five weeks [1]. With the advancement of radiotherapy techniques, hypofractionated radiotherapy (HFRT) is being increasingly applied in the treatment of breast cancer, which delivers a total dose of 40–42.72 Gy in 15–16 fractions [2,3]. HFRT aims to increase the dose per fraction while reducing the total dose, thus shortening overall treatment time. The study shows that HFRT can offer a curative effect comparable to, or in some cases, even superior to conventional radiotherapy [4,5]. Simultaneous integrated boost (SIB) in radiotherapy involves delivering a higher dose to high-risk lesions while administering a specific baseline dose to the overall treatment area. Compared to sequential radiotherapy, SIB significantly shortens treatment time [6], while also being effective in treating tumors. HFRT with simultaneous integrated boost (HFRT-SIB) has a higher prescription dose, which may result in a higher dose to the heart. In recent years, deep inspiration breath hold (DIBH) has been shown to reduce the mean heart dose and mean left anterior descending artery dose [7]. However, a portion of patients cannot tolerate DIBH [8].

Intensity-modulated radiotherapy (IMRT), volumetric modulated arc therapy (VMAT), helical tomotherapy (HT), and Tomodirect (TD) represent the most advanced radiotherapy technologies currently in use. While VMAT and HT are known to improve target volume conformity and uniformity, they also increase low-dose radiation exposure to typical structures [9,10], making some clinicians hesitant about using these modalities in patient treatment. In contrast, both IMRT and TD, as advanced fixed-field irradiation methods, can reduce the exposure volume to normal organs.

IMRT, as denoted in reference [11], utilizes a traditional C-arm accelerator and computer-controlled blades. These blades selectively block portions of the treatment volume and enable the delivery of radiation fields with varying intensities tailored to individual therapeutic needs. TD delivers radiation doses from fixed gantry positions, using a modulated irradiation approach through a moving bed and multileaf collimators. The adjacent leaf pairs of these collimators rapidly open and close to achieve robust modulation capability. Therefore, IMRT and TD exhibit distinct characteristics in radiotherapy.

Tang *et al*. [12] compared the application of TD and fixed-field IMRT (ff-IMRT) in breast cancer radiotherapy. However, their prescribed doses were 50.4 Gy in 28 fractions for the PTV and 60.2 Gy in 28 fractions for the PTV boost. Zeverino *et al*. [13] also compared TD with IMRT, but their prescribed dose was 42.4 Gy in 16 fractions for the PTV, with no PTV boost. Squires *et al*. [14] directly compared TD with IMRT; however, the prescribed dose was 50 Gy in 25 fractions, and the irradiation fields used in the study consisted of two tangent fields. Our study is the first to compare IMRT and TD for HFRT-SIB after breast-conserving surgery with left breast cancer.

In TD, collimators are required to prevent radiation leakage and protect normal tissues. It can adopt field widths (FW) of 1.0 cm, 2.5 cm, and 5.0 cm. The larger the FW, the more limited the planned modulation capability becomes, but the treatment time is shortened. When employing TD for breast cancer radiotherapy, Kadhim *et al*. [15] set the FW at 5 cm, resulting in shorter treatment times, whereas other studies [12,14] set the FW at 2.5 cm, yielding better plan quality. This study compared TD (FW = 5 cm) with TD (FW = 2.5 cm) to determine a reasonable FW setting for HFRT-SIB.

2. Materials and Methods

2.1 Patients

This study is a retrospective analysis of dosimetric comparison. Thirty patients diagnosed with left-sided breast cancer were enrolled between April 2021 and September 2024 in the Department of Radiotherapy of the Affiliated Hospital of Inner Mongolia Medical University. All patients underwent breast-conserving surgery and were indicated for adjuvant whole-breast radiotherapy. The inclusion criteria for patients: left-sided invasive breast cancer, 18–80 years old, negative surgical margin, and breast-conserving surgery. The exclusion criteria for patients: severe underlying diseases, not tolerating radiotherapy-related procedures or toxic reactions, previous radical radiotherapy to the chest wall or breast area, unhealed local wound, or active bleeding and necrosis after breast-conserving surgery. All patients were positioned on a breast board in the supine position, with both arms elevated above their heads and allowed to breathe freely. Images were then acquired using a computed tomography (CT) scanner with a slice thickness of 5 mm. The CT data were subsequently exported to the Pinnacle.

2.2 Target and OAR

We adhered to the Radiation Therapy Oncology Group (RTOG) guidelines for breast cancer to contour target volumes. The tumor bed was delineated according to preoperative images, operative notes, and scar tissue, and encompassed metal clips placed during breast cancer surgery or the post-operative residual seroma. The planning gross target volume (PGTV) was created by a 5-mm expansion in all directions of the delineated tumor bed. Nevertheless, PGTV should not extend beyond PTV. The clinical target volume (CTV) included the whole breast tissue. The planning target volume (PTV) for the entire breast was created by a 5-mm expansion of CTV in all directions around the tumor bed. PTV did not penetrate the interior of the lung, and there should also be a 5 mm retraction beneath the skin. The average volume of PGTV was 57 cm^3, and the average volume of PTV was 655 cm^3. The organs at risk (OARs) included the left and right lungs, the heart, the left anterior descending coronary artery (LAD), and the contralateral breast.

2.3 Treatment Schemes

The prescription of HFRT-SIB was administered as follows: a cumulative dose of 43.5 Gy was delivered in single doses of 2.9 Gy to PTV; a cumulative dose of 49.5 Gy was delivered in 15 fractions (3.3 Gy per fraction) to the PGTV [16].

2.4 Plan Creation

Ninety treatment plans were generated, with each of the 30 patients receiving three plans: one using the Pinnacle planning system (n = 30) and the other two using the TD planning system (n = 60, with FW = 2.5 cm and FW = 5 cm).

We hypothesized that TD can reduce the radiation dose to OARs compared to IMRT, while maintaining the quality of the target volume. Therefore, after achieving an optimal IMRT plan, we then developed a TD plan to observe whether the TD plan could outperform the IMRT plan.

Each plan typically included four beams: two tangential beams and two additional beams placed outside of each tangential beam at intervals of 12–15 degrees. IMRT, TD (FW = 2.5 cm), and TD (FW = 5 cm) had the same irradiation angles.

TD technology used the TomoHD^{TM} planning station (version 5.1.1.6, Accuray Inc., Sunnyvale, CA, USA) to create the plan. Parameter settings of TD (FW = 2.5 cm) were FW = 2.5 cm, picth = 0.251, and a modulation factor of 2–3. Parameter settings for TD (FW = 5 cm) were FW = 5 cm, pitch = 0.5, and a modulation factor of 2–3. Dose calculation was performed with a convolution/superposition al-

gorithm. The final dose calculation was performed using a fine-dose grid.

Therapeutic plans employing IMRT technology were devised using Pinnacle (version 9.2; Philips Medical Systems, Eindhoven, The Netherlands). Dose calculation was performed with the Collapsed Cone algorithm. A dose grid of $4 \times 4 \times 4$ mm^3 was used.

2.5 Plan Evaluation

The conformity index (CI) [17] is determined for both the PGTV and the PTV to assess the precision with which the prescribed dose conforms to the target area. CI is calculated using the formula: CI = $V_1{}^2$ / ($V \times V_2$), where V_1 represents the target volume enclosed by the prescribed iso-dose line, V_2 represents the total volume enclosed by the prescribed iso-dose line, and V is the volume of either PTV or PGTV. The CI ranges from 0.0 to 1.0, with 1.0 indicating perfect conformity.

For PGTV and the area included in the PTV but not directly encompassed by the PGTV (PTV-PGTV), homogeneity is described using the homogeneity index (HI = (D2 – D98) / D50, where D2, D50, and D98 represent the doses covering 2%, 50%, and 98% of the target region, respectively) [18]. An optimum HI is zero, indicating perfect homogeneity, while higher values suggest decreased homogeneity.

Evaluation parameters of the target area: D_{max} and D_{mean}. We also evaluated $V_{49.5}$ of PGTV and $V_{43.5}$ of PTV.

Besides, the dose parameters were evaluated in OARs, including: V_5, V_{10}, V_{20}, V_{30} of the lung left and heart; D_{max} and D_{mean} of the lung left, lung right, heart, LAD, and contralateral breast.

2.6 Statistical Methods

If the data follow a normal distribution, it is represented as Mean $\pm$ SD. If the data does not follow a normal distribution, it is represented as Median (Interquartile Range). A paired-sample *t*-test was used for pairwise comparison and analysis to determine if the two sets of data were normally distributed. If the two sets of data did not follow a normal distribution, a Wilcoxon signed-rank test was employed. The Shapiro-Wilk test was used to confirm the normality of the data. A significance threshold set at $p < 0.05$. All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) (version 20.0, IBM Corp., Chicago, IL, USA).

3. Results

3.1 Target Dosimetry

Fig. 1 illustrates the dose distributions for IMRT, TD (FW = 5 cm), and TD (FW = 2.5 cm) for one patient. The dose constraints of the target area and OAR are shown in Table 1.

The average target volume coverage had met the requirements for PGTV and PTV in TD (FW = 2.5 cm), TD (FW = 5 cm), and IMRT. V49.5 for PGTV were 95.483%, 95.223%, and 95.314% in TD (FW = 2.5 cm), TD (FW = 5 cm), and IMRT. V43.5 for PTV were 95.613%, 95.554%, and 94.534% in TD (FW = 2.5 cm), TD (FW = 5 cm), and IMRT, respectively (Table 2).

Table 1. Dose constraints of the target area and OARs.

	Dose constrain	Accept dose
PGTV	$V_{49.5}$ >95%	$V_{49.5}$ >92%
	V_{53} <5%	V_{53} <11%
PTV-PGTV	$V_{43.5}$ >95%	$V_{43.5}$ >92%
	V_{47} <25%	V_{47} <30%
	$V_{49.5}$ <5%	$V_{49.5}$ <8%
Left lung	V_5 <40%	V_5 <45%
	V_{20} <20%	V_{20} <25%
	D_{mean} <10 Gy	D_{mean} <11 Gy
Right lung	V_5 <5%	V_5 <8%
Heart	V_{20} <5%	V_{20} <8%
	D_{mean} <5 Gy	D_{mean} <6 Gy
Contralateral breast	D_{mean} <4 Gy	D_{mean} <7 Gy
LAD	D_{mean} <25 Gy	D_{mean} <25 Gy

Abbreviation: LAD, left anterior descending coronary artery; OARs, organs at risk; D_{mean}, mean dose.

For PGTV, the values of HI were 0.057, 0.057, and 0.068 for TD (FW = 2.5 cm), TD (FW = 5 cm), and IMRT. The values of CI were 0.637, 0.630, and 0.703 for TD (FW = 2.5 cm), TD (FW = 5 cm), and IMRT. For PTV-PGTV, the values of HI were 0.153, 0.159, and 0.162 for TD (FW = 2.5 cm), TD (FW = 5 cm), and IMRT, respectively. For PTV, the values of CI were 0.815, 0.768, and 0.870 for TD (FW = 2.5 cm), TD (FW = 5 cm), and IMRT, respectively (Table 2).

3.2 Dosimetry of OAR

V_5, V_{10}, V_{20}, V_{30} for the left lung and heart were lower in TD (both FW = 2.5 cm and FW = 5 cm) than IMRT ($p < 0.05$), except for V_{20} of the heart was higher in TD (FW = 5 cm) than IMRT (Table 3).

V_5, V_{10}, V_{20}, and V_{30} for the left lung and heart were lower or equal in TD (FW = 2.5 cm) than in TD (FW = 5 cm), except for V_{10} of the heart. Except for V_5 of the left lung, and V_5 of the heart, all $p > 0.05$ (Table 3).

D_{max} and D_{mean} of LAD were lower in TD (both FW = 2.5 cm and FW = 5 cm) than in IMRT and D_{mean} of LAD were lower in TD (FW = 5 cm) than in TD (FW = 2.5 cm). Except for D_{max} and D_{mean} between FW = 2.5 cm and FW = 5 cm, all other values showed significant differences (Table 3).

D_{max} of the contralateral breast were all lower or equal in TD (both FW = 2.5 cm and FW = 5 cm) than in IMRT and D_{mean} was higher in TD (FW = 5 cm) than IMRT, but this difference was minimal. D_{max} and D_{mean} of the contralateral breast were slightly higher in TD (FW = 5 cm) than in TD (FW = 2.5 cm) ($p = 0.551$ and 0.005) (Table 3).

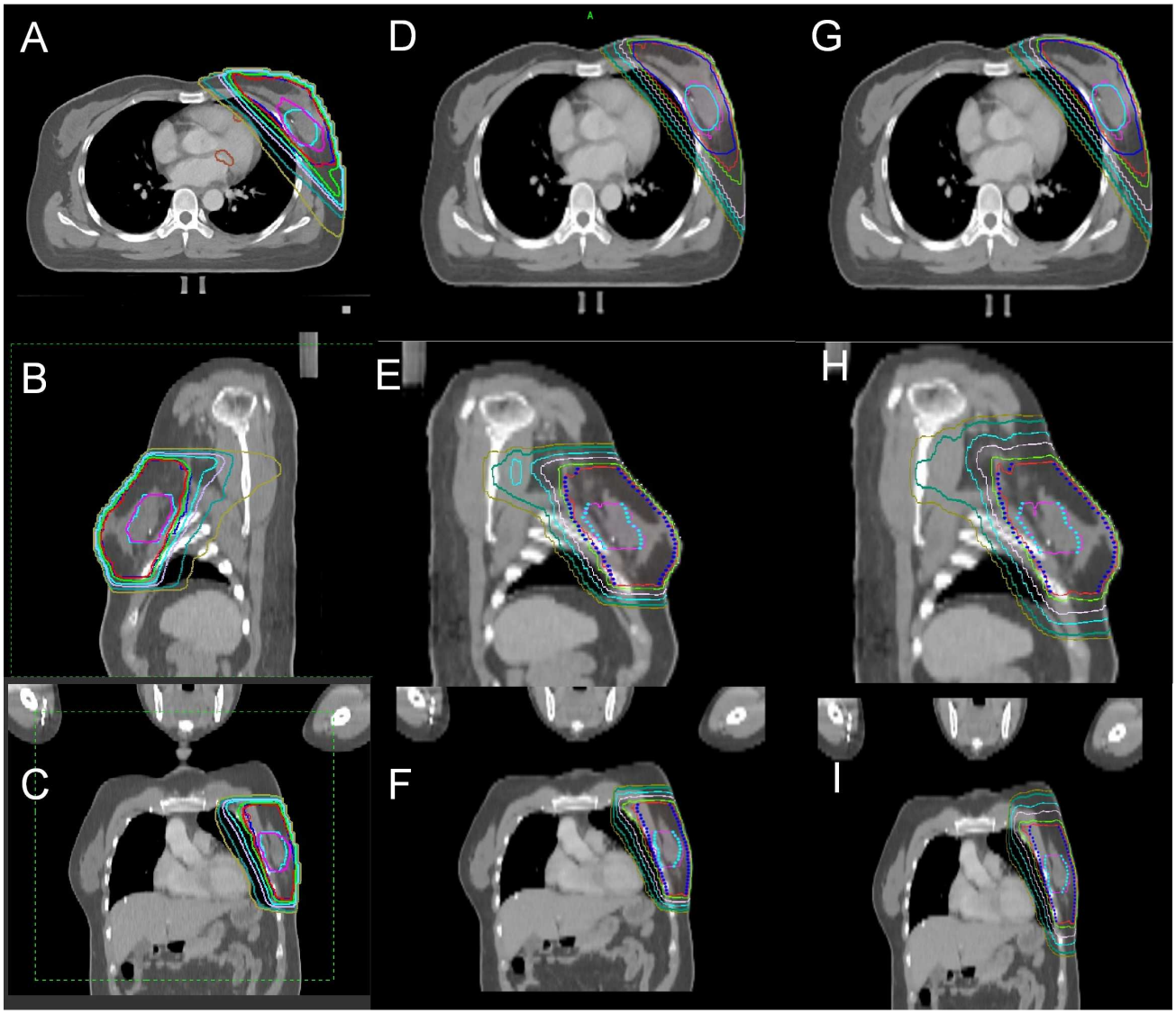

Fig. 1. Dose distribution comparison for IMRT, TD (FW = 2.5 cm), TD (FW = 5 cm). (A–C) represent axial, sagittal, and coronal slices of IMRT, respectively. (D–F) represent axial, sagittal, and coronal slices of TD (FW = 2.5 cm), respectively. (G–I) represent axial, sagittal, and coronal slices of TD (FW = 5 cm), respectively. The pink line represents 49.5 Gy, the red line represents 43.5 Gy, the green line represents 40 Gy, the light purple line represents 30 Gy, the light blue line represents 20 Gy, the dark teal line represents 9 Gy, and the light brown line represents 5 Gy. The light green area at the center of the dose lines represents the PGTV, while the blue area represents the PTV. IMRT, intensity-modulated radiotherapy; PGTV, planning gross target volume; PTV, planning target volume; FW, field width; TD, Tomo Direct.

3.3 Treatment Time

The average treatment time for TD (FW = 5 cm) was 5 min, while for TD (FW = 2.5 cm), it was 9 min.

4. Discussion

Radiotherapy is an essential and important component of breast cancer comprehensive treatment [7]. Study has shown that the increase in coronary events is related to the mean heart dose (7.4 Gy) occurring within 5 years of radiotherapy [19]. IMRT and VMAT have been reported to minimize the high dose to the lung and heart. DIBH gating is an additional selection technology in breast cancer radiotherapy [20]. It has confirmed a reduction of 25–67% and 20–73% in mean heart doses and mean LAD doses by using DIBH in breast cancer radiotherapy [21]. However, some patients cannot tolerate DIBH. Although patients have undergone training, 29% of 72 patients cannot complete a DIBH CT scan [8]. Therefore, our research investigated the dosimetric comparison of TD and IMRT in left-sided breast cancer with free breathing.

HI for 49.5 Gy and 43.5 Gy in TD (FW = 2.5 cm) and TD (FW = 5 cm) were all slightly lower or equal to IMRT. This suggested that TD achieved superior dose uniformity.

Table 2. Dosimetric parameters and *p* values of the target area in IMRT and TD.

	Parameters	Mean ± SD or Median (Interquartile Range)			*p* value		
		IMRT (n = 30)	TD (FW = 2.5 cm) (n = 30)	TD (FW = 5 cm) (n = 30)	IMRT vs. TD (FW = 2.5 cm)	IMRT vs. TD (FW = 5 cm)	TD (FW = 2.5 cm) vs. TD (FW = 5 cm)
PGTV	D_{max} (Gy)	53.261 (1.928)◇	52.610 (1.820)	52.400 (1.763)◇	0.004	<0.001	0.144
	D_{mean} (Gy)	50.861 ± 0.377	50.579 ± 0.447	50.592 ± 0.467	<0.001	0.005	0.824
	HI	0.068 (0.030)◇	0.057 (0.034)	0.057 (0.035)◇	<0.001	<0.001	0.629
	CI	0.703 (0.170)◇	0.637 (0.170)	0.630 (0.111)◇	0.019	0.002	0.032
	$V_{49.5}$ (%)	95.314 ± 0.817	95.483 ± 2.539	95.223 ± 2.412	0.736	0.872	0.737
PTV-PGTV	D_{max} (Gy)	52.039 (1.625)◇	51.900 (1.058)◇	51.835 (1.195)	0.187	0.241	0.781
	D_{mean} (Gy)	46.112 (0.238)◇	45.815 (0.602)◇	45.975 (0.395)	<0.001	0.742	0.002
	HI	0.162 (0.020)	0.153 (0.017)◇	0.159 (0.021)◇	0.009	0.116	0.047
PTV	CI	0.870 ± 0.030	0.815 ± 0.059	0.768 ± 0.049	<0.001	<0.001	<0.001
	$V_{43.5}$ (%)	94.534 ± 0.870	95.613 ± 0.373	95.554 ± 0.492	<0.001	<0.001	0.539

Abbreviation: SD, standard deviation; D_{max}, maximum dose; HI, homogeneity index; CI, conformity index.

◇ means that the data does not follow a normal distribution, it is represented as Median (Interquartile Range). In the first three columns of data, if the data is represented as Mean ± SD, it means that the data follows a normal distribution.

Table 3. Dosimetric parameters and *p* values of OAR in IMRT and TD.

	Parameters	Mean ± SD or Median (Interquartile Range)			*p* value		
		IMRT (n = 30)	TD (FW = 2.5 cm) (n = 30)	TD (FW = 5 cm) (n = 30)	IMRT vs. TD (FW = 2.5 cm)	IMRT vs. TD (FW = 5 cm)	TD (FW = 2.5 cm) vs. TD (FW = 5 cm)
Left lung	V_5 (%)	27.223 ± 6.079	22.558 ± 5.362	23.113 ± 5.094	<0.001	<0.001	0.043
	V_{10} (%)	18.623 ± 5.157	16.929 ± 4.649	17.185 ± 4.478	<0.001	<0.001	0.118
	V_{20} (%)	10.912 ± 4.033	10.369 ± 3.603	10.531 ± 3.524	0.002	0.043	0.162
	V_{30} (%)	5.635 (4.870)	5.390 (4.525)	5.400 (4.200)◇	<0.001	<0.001	0.618
Heart	V_5 (%)	13.330 (9.763)◇	9.100 (9.600)◇	10.000 (9.125)◇	<0.001	<0.001	0.016
	V_{10} (%)	6.730 (8.063)◇	5.500 (5.625)◇	5.250 (6.125)◇	<0.001	<0.001	0.959
	V_{20} (%)	2.535 (3.190)◇	1.900 (2.703)◇	2.650 (3.100)◇	0.006	0.050	0.217
	V_{30} (%)	0.905 (0.958)◇	0.574 (1.292)◇	0.650 (0.853)◇	0.004	0.003	0.986
Left lung	D_{max} (Gy)	47.580 (2.777)	48.770 (2.880)◇	48.750 (2.535)◇	0.014	0.011	0.886
Heart		43.005 (5.174)◇	42.765 (5.705)◇	42.615 (7.980)◇	0.170	0.600	0.902
Right lung		2.450 (4.724)◇	1.500 (2.238)◇	1.800 (2.188)◇	0.002	0.002	0.567
LAD		29.790 (25.369)◇	25.565 (30.830)◇	25.745 (29.988)◇	<0.001	0.001	0.066
Contralateral breast		4.605 (4.221)◇	2.615 (10.025)◇	2.700 (10.200)◇	0.261	0.175	0.551
Left lung	D_{mean} (Gy)	6.147 ± 1.533	5.712 ± 1.421	5.807 ± 1.430	<0.001	<0.001	0.019
Heart		2.726 (1.626)◇	2.260 (1.510)◇	2.330 (1.301)◇	<0.001	<0.001	0.008
Right lung		0.200 (0.090)◇	0.230 (0.115)◇	0.240 (0.113)◇	<0.001	<0.001	<0.001
LAD		4.765 (7.282)◇	4.245 (6.733)◇	4.160 (6.393)◇	<0.001	0.004	0.469
Contralateral breast		0.275 (0.305)◇	0.240 (0.270)◇	0.285 (0.243)◇	0.309	0.356	0.005

◇ means that the data does not follow a normal distribution, it is represented as Median (Interquartile Range). In the first three columns of data, if the data is represented as Mean ± SD, it means that the data follows a normal distribution.

This finding aligned with previous studies [14,15]. Research indicated that inhomogeneity within the target volume can increase the incidence of acute adverse events and negatively impact cosmetic outcomes in adjuvant breast cancer radiotherapy [22]. TD technology offers better dose uniformity, which is more beneficial to patients in terms of reducing acute radiotherapy reactions and improving skin cosmetic outcomes.

TD exhibited a lower CI than IMRT. Fiandra *et al*. [23] indicated that the poorer the target conformity, the greater the volume of OARs adjacent to the target that receive high radiation doses. This study also showed similar results. TD (FW = 5 cm) and TD (FW = 2.5 cm) demonstrated superior performance in terms of low-dose exposure to the lung and heart but were slightly superior to IMRT regarding high-dose exposure, as shown in Table 3. However, the high-dose volume for TD (FW = 5 cm) and TD (FW = 2.5 cm) remained within the dose-limiting range, having a minimal negative impact on patients' radiation treatment.

V_5, V_{10}, V_{20}, V_{30}, and D_{mean} for the left lung and heart were all lower in TD than in IMRT, except for V_{20} of the heart was higher in TD (FW = 5 cm) than IMRT. They are shown in Table 3. D_{max} and D_{mean} of CA in TD (FW = 5 cm) and TD (FW = 2.5 cm) were all lower than IMRT. A study has shown that V_5, V_{20}, and D_{mean} of the lung were associated with radiation-induced lung injury [24]. During radiotherapy for left-sided breast cancer, due to the proximity of the target area to the heart, ischemic events may be induced because the coronary artery and heart are irradiated [25]. Mireștean *et al*. [26] also indicated that special attention should be paid in the future to limiting the toxic effects of radiotherapy on the heart and coronary arteries in HFRT. In this conclusion, TD can offer better protection to the lungs and heart.

Since the total dose of HFRT for breast cancer was slightly smaller, V_{30} of the lung and heart was smaller than that of CFRT. In the Pinnacle planning system, EUD (equivalent uniform dose) considers the corresponding volume values at various dose points (such as 5 Gy, 10 Gy, 20 Gy, and 30 Gy), minimizing V_5, V_{20}, and V_{30}. However, this function is not available in the TD planning system. TD planners should pay more attention to it and increase its proportion, which would further reduce the value of V_{30} relatively.

When comparing TD (FW = 5 cm) and TD (FW = 2.5 cm), minimal differences were observed in terms of homogeneity and conformity of the target and protection of the left lung, and LAD, with the latter being slightly superior. D_{max} of the contralateral breast were 2.700 Gy and 2.615 Gy in TD (FW = 5 cm) and TD (FW = 2.5 cm), while D_{mean} of the contralateral breast were 0.285 Gy and 0.240 Gy. Although D_{max} and D_{mean} of the contralateral breast in TD (FW = 5 cm) were slightly higher, the differences were minimal. When creating a tomotherapy plan with TD (FW = 5 cm), the beam angles can be adjusted to reduce the dose received by the contralateral breast. However, this approach may compromise the plan quality for the target volume and increase the dose delivered to other OARs. However, in our study, the doses received by the OAR were far below the constraint values, and there was still room for reducing the dose to the contralateral breast.

Fields *et al*. [27] indicated that increasing the value of FW can reduce dose hotspots outside the target volume. In this study, there was no significant improvement in the maximum dose to OARs outside the target volume when comparing TD (FW = 5 cm) with the other two. A possible distinction could be that the technique used in the literature was Tomotherapy Direct–Three Dimensional Conformal Radiation Therapy (TD-3DCRT), whereas in this study, the technique employed was TD with intensity-modulated.

However, the average treatment time for TD (FW = 5 cm) was 5 min, while for TD (FW = 2.5 cm), it was 9 min. TD (FW = 5 cm) can significantly reduce treatment time while having minimal impact on plan quality. Therefore, in general, when employing TD technology for HFRT-SIB, FW can be chosen as 5 cm.

Limitations

This study has two significant limitations. Firstly, the sample size is relatively small (30 cases were included in this study), which may affect the statistical power and generalizability of the research findings. Small-sample studies pose constraints on the reliability of the analysis, and future multi-center, large-sample studies are needed to verify the universality of our conclusions. Secondly, this study did not conduct a quantitative assessment of cardiac substructures; instead, it only evaluated the dose exposure for overall cardiac parameters and the left anterior descending artery. Among female patients with left-sided breast cancer who undergo radiotherapy, the risk of cardiovascular disease-related mortality gradually increases as their survival duration extends. Moreover, the radiation dose received by the heart is not uniformly distributed. Therefore, investigating the relationship between cardiac substructures and radiation-induced cardiac injury is significant.

5. Conclusions

TD technology can better protect cardiopulmonary function without compromising the quality of the target area. In general, when employing TD technology for HFRT-SIB, FW can be chosen as 5 cm.

Abbreviations

TD, TomoDirect; IMRT, intensity-modulated radiotherapy; HFRT-SIB, hypofractionated radiotherapy with simulation integrated boost; OAR, organs at risk; Vx, The percentage of receiving the x value of dose; FW, field width; D_{max}, maximum dose; D_{mean}, mean dose; CFRT, conventional fractionated radiotherapy; HFRT, hypofractionated radiotherapy; VMAT, volumetric modulated arc

therapy; HT, helical tomotherapy; CT, computed tomography; PGTV, planning gross target volume; CTV, clinical target volume; PTV, planning target volume; CA, coronary artery; CI, conformity index; HI, homogeneity index; PTV-PGTV, the area included in the PTV but not directly encompassed by the PGTV; EUD, equal uniform dose; TD-3DCRT, Tomotherapy Direct–Three Dimensional Conformal Radiation Therapy.

Availability of Data and Materials

The datasets generated and analyzed during the present study are available from the corresponding author upon reasonable request.

Author Contributions

YNB designed the study; JW performed the investigation; JXG, ZHL, and JGZ collected the data; LHW and XLW contributed to the data analysis. All authors contributed to 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 was approved by the ethics committee of the Affiliated Hospital of Inner Mongolia Medical University and ID: KY2025162. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was waived by the ethics committee of The Affiliated Hospital of Inner Mongolia Medical University due to the retrospective nature of the study.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

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