Comparison of tangential-intensity modulated radiotherapy (t-IMRT) and volumetric modulated arc therapy (VMAT) for different sizes of left breast cancer #21

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Abstract

Radiotherapy treatment is an essential part of the management of left-sided breast cancer, and this requires an optimal balance in target volume coverage and organs at risk, such as the ipsilateral lung and the heart. Advanced techniques such as tangential-IMRT and VMAT are commonly used. However, the dosimetric performance of tangential-IMRT and VMAT for varying breast sizes has been poorly characterised. The aim of this study was to compare the effectiveness of tangential-IMRT and VMAT for hypo-fractionated left-sided breast cancer across small, medium, and large breast sizes.

Background

Radiotherapy for left-sided breast cancer is more complex, and avoiding overlapping and reducing radiation damage to normal tissue without missing target area should be a basic radiotherapy requirement (Liu et al., 2016). In addition, achieving a uniform radiation dose distribution within the planning target volume (PTV) is challenging due to the PTV's complex anatomy and surrounding structures. The left breast has a complex three-dimensional (3D) shape and is surrounded by important organs at risk (OARs), such as the lung and the heart on the same side (Liu et al., 2020). The configuration and size of the breast can affect the distribution of radiation dose in postoperative breast radiotherapy, and the coverage of the left breast target can be more challenging due to the proximity of the heart as an OARs (Karageorgiou et al., 2022). It is challenging to adopt a treatment planning technique that achieves good radiation dose conformity within the target volume while minimizing the dose to organs at risk (Inoue et al., 2020). Treatment planning techniques, such as tangential-intensity modulated radiotherapy (t-IMRT) or volumetric modulated arc therapy (VMAT), minimize dose to healthy tissue OARs and achieve a homogeneous dose distribution in low-dose regions.

In some cases, treatment planning for retrospective dose evaluation may include only the heart as a single structure, without delineating its sub-volumes. The dose distribution within the heart itself in left breast cancer radiotherapy is often not homogeneous (Ratosa et al., 2018). Few treatment planning studies have reported a very small difference in mean heart dose across breast sizes and modalities, such as t-IMRT and VMAT, which can all increase the mean heart dose depending on the patient's anatomy. Most clinical trials providing this evidence use two-dimensional radiotherapy or three-dimensional conformal radiotherapy (3D-CRT). They base these techniques on a tangential approach that uses two opposed, uniform photon beams and wedges to create a homogeneous dose distribution within the breast. Tangential-IMRT improves both dose homogeneity and sparing of surrounding normal tissue, representing a major shift in radiation therapy practice since the 1990s (Ahrouch et al., 2021).

Clinical investigations have shown that VMAT is a possible treatment for breast radiotherapy and reduces the dose to the ipsilateral lung in left-sided treatments and to the heart in left-side targets. However, VMAT limits the allowance for tissue deformations (Rossi et al., 2018). Although t-IMRT has been increasingly popular for the treatment of breast cancer.

Among the advanced advantages are improved target coverage and homogeneity, sparing surrounding OARs from high doses, and lower doses to the heart and lungs (Noblet et al., 2022). Early breast cancer treatment are more challenging for tangential-IMRT techniques that may provide less dose conformity and homogeneity to both whole breasts and boost PTVs than VMAT-based techniques (Zeverino et al., 2023).

Methods

Study Design

Planning Computed Tomography datasets of 30 left-sided breast cancer female patients who were treated between 2020 and 2024 in the Department of Radiation Oncology, Steve Biko Academic Hospital, Pretoria, South Africa, were used for this study. The diversity in the size and shape of the treated breasts in the selected cases was assessed, with 30 left-sided cases. The mean breast volume of the selected patients was 781.014 cc, ranging from 235.969 cc to 1471.019 cc. This parameter was not a selection criterion, as we sought information on irradiation techniques with respect to breast size. Breast sizes were categorised as follows: small breasts ≤ 589.77 cc, medium breasts between 590 and 900 cc, and large breasts ≥ 900 cc. For each of the 30 patients, two treatment plans were generated: t-IMRT and VMAT. All modulated techniques were planned and calculated on a Monaco (version 6.2.2.0, Elekta AB, Stockholm, Sweden) treatment planning system (TPS) using a Monte Carlo calculation algorithm.

Design of the Treatment Plans

Both VMAT and t-IMRT dose calculations were performed using a 6 MV Elekta HD linear accelerator, on which all contouring of the PTV and OARs had already been done in the TPS. Final dose calculations were then performed. These procedures enable comparison of VMAT and t-IMRT plans in a single DVH, and consequently, the selection of the plan that appears more acceptable from a clinical perspective, with a median PTV dose of 26 Gy, fractionated to 5.2 Gy per day to ensure good comparability between the two plans. According to the Fast-Forward protocol, PTV parameters are as follows: D2% (Gy) ≥ 107%, D5% (Gy) ≥ 105%, D95% (Gy) ≥ 95%, and Dmax (Gy) < 110%. For the ipsilateral lung (V8Gy < 15%) and heart (V7Gy < 5% and V1.5Gy < 30%) (Zhang et al., 2024). All plans were optimised and evaluated for optimal target coverage, conformality, homogeneity, and dose limits of OARs (as low as possible without compromising target coverage or conformity) (Abo-Madyan et al., 2014).

Tangential-IMRT Plans

For all 30 cases, the t-IMRT plans were generated using four fixed beams arranged in a butterfly configuration: two medial beams at 310° and 195°, and two lateral beams at 130° and 145° to ensure the best possible coverage of the breast tissue and to minimise dose to the adjacent critical structures. Treatment delivery employed a dynamic Multi-leaf Collimator technique and dose calculation based on the Monte Carlo algorithm. The "isocentre" of the treatment machine was positioned at the geometric centre of the PTV for left-sided breast treatments. Both the collimator and couch angles were set to 0°, and the field configuration was automatically defined as shown in Figure 1a. After achieving the optimal dose distribution, the TPS created hotspot volumes. Subfields were created to reduce these hotspots and improve the dose homogeneity in the PTV.

VMAT Plans

The VMAT plans were designed for all 30 cases and consisted of two coplanar arcs delivered in clockwise and counterclockwise directions. The gantry angles for the plans were chosen based on the curvature of the Planning Target Volume (PTV), with angles of 291° and 146°, each covering 215°. The calculations were performed using the Monte Carlo algorithm. The isocenter of the treatment machine was positioned at the geometric centre of the PTV for left-sided breast treatments. Both the collimator and couch angles were set to 0, and the field configuration was defined automatically as shown in Figure 1b. After achieving the optimal dose distribution, the TPS created hotspot volumes. Subfields were created to reduce these hotspots and improve the dose homogeneity in the PTV.

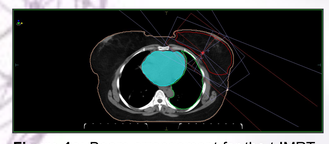

Figure 1a: Beam arrangement for the t-IMRT technique includes two medial beams (310° and 195°) and two lateral beams (130° and 154°).

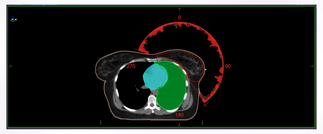

Figure 1b: Beam arrangement for the VMAT technique includes dual beams, clockwise 291° , counterclockwise 146° , with an arc of 215.

Results

Target Volume Comparison Analysis

The dosimetric parameters of the target volume, including D2%, D5%, D95%, Dmax, Conformity index (CI), and Homogeneity index (HI), were compared across small, medium, and large breast sizes to evaluate the quality of target dose coverage. The results of the comparison between tangential-IMRT and VMAT are shown in Table 1 below.

Table 1: Planning Target Volume Parameters for Small, Medium, and Large Breasts

Parameter	Breast Size	T-IMRT (Mean ± SD)	VMAT (Mean ± SD)	P-Value
D2% (Gy)	Small	27.18 ± 0.02	27.33 ± 0.02	0.026
	Medium	27.16 ± 0.04	27.19 ± 0.04	0.716
	Large	27.08 ± 0.04	26.95 ± 0.03	0.143
D5% (Gy)	Small	26.97 ± 0.02	27.17 ± 0.02	0.006
	Medium	26.95 ± 0.04	27.02 ± 0.04	0.489
	Large	26.88 ± 0.04	26.80 ± 0.03	0.333
D95% (Gy)	Small	23.20 ± 2.34	25.94 ± 0.07	0.001
	Medium	22.98 ± 1.81	25.57 ± 0.16	<0.001
	Large	23.41 ± 2.66	25.21 ± 0.17	0.003
Dmax (Gy)	Small	28.33 ± 0.05	28.59 ± 0.03	0.012
	Medium	28.52 ± 0.05	28.55 ± 0.08	0.802
	Large	28.44 ± 0.09	28.51 ± 0.06	0.591
CI	Small	0.55 ± 0.02	0.89 ± 0.00	<0.001
	Medium	0.49 ± 0.02	0.84 ± 0.01	<0.001
	Large	0.57 ± 0.04	0.68 ± 0.02	0.138
HI	Small	0.66 ± 0.03	0.37 ± 0.01	<0.001
	Medium	0.78 ± 0.01	0.56 ± 0.04	0.005
	Large	0.77 ± 0.02	0.65 ± 0.02	0.090

Both t-IMRT and VMAT techniques met the hot-spot constraints of D2% < 107% and D5% < 105%. However, VMAT provided better D95% coverage across all breast sizes than t-IMRT. Additionally, VMAT provided better CI and HI results, with a significant improvement in small and medium breasts.

Organs at Risk (OARs) Comparison Analysis

The dosimetric parameters for organs at risk (OARs) focused on the heart (V7Gy < 5% and V1.5Gy < 30%) and the ipsilateral lung (V8Gy < 15%). The findings are reported in Table 2, corresponding to small, medium, and large breast volumes, respectively, for both treatment modalities.

Table 2: Organs at Risk Parameters for Small, Medium, and Large Breasts

Characteristics	Breast Size	T-IMRT (Mean ± SD)	VMAT (Mean ± SD)	P-Value
Heart (V7Gy < 5%)	Small	4.39 ± 2.71	3.98 ± 0.11	0.455
	Medium	5.17 ± 1.91	4.46 ± 0.14	0.133
	Large	4.55 ± 2.55	4.39 ± 0.05	0.766
Heart (V1.5Gy < 30%)	Small	0.94 ± 0.08	2.91 ± 0.09	<0.001
	Medium	1.71 ± 0.04	3.35 ± 0.15	<0.001
	Large	1.08 ± 0.01	3.31 ± 0.09	<0.001
Ipsilateral lung (V8Gy < 15%)	Small	3.38 ± 4.24	5.12 ± 0.88	0.026
	Medium	4.20 ± 1.98	6.07 ± 0.05	0.001
	Large	5.29 ± 4.13	5.94 ± 0.45	0.349

Heart

In terms of cardiac sparing, the dose constraint for the tangential-IMRT was met, as (V7Gy < 5% and V1.5Gy < 30%). The (V7Gy < 5%) heart doses for the tangential-IMRT plans for small, medium, and large breasts were **4.39± 2.71 Gy**, **5.17±1.91 Gy**, and **4.55±2.55 Gy**, respectively. The VMAT plans had slightly lower heart doses, with V5% < 7 Gy values of **3.98±0.11 Gy**, **4.46±0.14 Gy**, and **4.39±0.05 Gy** for the small, medium, and large breasts, respectively. This shows a minor improvement in the dose delivered to the heart.

On the other hand, at higher dose levels, VMAT significantly exceeded the cardiac dose relative to t-IMRT. To be precise, the (V1.5Gy < 30%) dose for the heart with t-IMRT was **0.94±0.08 Gy, 1.71±0.04 Gy**, and **1.08±0.01 Gy** for small, medium, and large breasts, respectively, whereas the V30% dose for the heart with VMAT was **2.91±0.09** Gy, **3.35±0.15 Gy**, and **3.31±0.09 Gy** for the corresponding size groups.

Ipsilateral lung

Both techniques met the institution's lung constraint (V8Gy < 15%) for all breast sizes. However, t-IMRT demonstrated lower mean lung doses than VMAT for all cohorts. For small, medium, and large breast sizes, the ipsilateral lung (V8Gy < 15%) values using t-IMRT were **3.38±4.24 Gy**, **4.20±1.98 Gy**, and **5.29±4.13 Gy**, respectively, compared with **5.12±0.88 Gy, 6.07±0.05 Gy**, and **5.94±0.45 Gy** using VMAT. The greatest dose reduction with t-IMRT was observed in small and medium breasts, with a smaller benefit in large breasts.

Conclusion

Tangential-IMRT showed superior ipsilateral lung sparing and a significant reduction in high-dose region cardiac exposure when compared with VMAT for all breast sizes. Although VMAT provided slightly lower heart (V7Gy < 5%) values, higher (V1.5Gy < 30%) doses did not improve its clinical benefit. Thus, t-IMRT may be preferred for breast radiotherapy when OAR is prioritised.

VMAT showed better coverage of the planning target volume across all breast sizes, while t-IMRT showed better sparing of the lungs and heart, particularly in the high-dose region. This study has demonstrated a trade-off between the two techniques in terms of PTV coverage and sparing of OARs. It has also been shown that the choice of technique relies on individual patient anatomy and clinical requirements.

VMAT is preferable when target coverage is critical, whereas t- IMRT is advantageous when cardiac and pulmonary sparing is prioritised, particularly in patients with higher baseline cardiovascular risk. More studies have shown that Deep Inspiration Breath Hold (DIBH) can help reduce dose to the heart and lungs, so t-IMRT could meet the coverage requirement if DIBH is used (Wu et al., 2025).

Where VMAT is chosen on clinical judgment criteria to provide sufficient target dose coverage, it is highly recommended that this is achieved in combination with Deep Inspiration Breath Hold (DIBH) techniques that physically move the heart away from the high dose area of the thorax, potentially minimising the high Heart (V1.5Gy < 30%) that was observed in this study using the VMAT technique.

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