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Dosimetry Comparison between Tangential—Intensity Modulated Radiotherapy and Volumetric Modulated Arc Therapy: A Deep Inspiration Breath Hold (DIBH) Study for Treatment of a Left-Sided Breast Cancer Using the FAST FORWARD UK Hypo-Fractionated Protocol

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Abstract

Research background: The FAST FORWARD protocol is a hypo-fractionated treatment regimen for early breast cancer, generally involving fewer sessions with higher doses per fraction compared to traditional regimens. Application of DIBH minimize radiation exposure to the heart and lungs during treatment of left-sided breast cancer. **Research objectives:** The aim of the present study, was to compare the dosimetric goals properties of the restricted tangential Intensity Modulated Radiotherapy (t-IMRT), with Volumetric Modulated Arc Therapy (VMAT) techniques, using the deep inspiration breath hold (DIBH) for whole breast irradiation using the hypo-fractionated regimen. **Methods:** In this retrospective analysis, a total of thirty individuals diagnosed with breast cancer on the left side but without any spread to the lymph nodes were chosen. Thorough training and patient support was provided for DIBH to assist the patients successfully integrate this technique into their treatment regimen. DIBH Computed tomography (CT) data was used to generate VMAT and t-IMRT plans using Monaco planning system. The prescribed dose was 26 Gy in 5 fractions. Dose volume histograms (DVH) were examined to assess the Planning Target Volume (PTV) and the organs at risk. UK FAST FORWARD constrains parameters of the dose distributions were compared for VMAT and t-

IMRT using two-tailed paired t-test. **Results:** The fact that there is no significant difference in the Homogeneity Index between t-IMRT and VMAT means that both techniques are similarly effective in delivering a uniform dose within the target volume. This is beneficial as it indicates both methods provide comparable dose distribution uniformity. VMAT Shows Improvement ($p < 0.001$): VMAT has a significantly better Conformity Index compared to t-IMRT. A higher Conformity Index indicates that VMAT is better at matching the radiation dose distribution to the shape of the target volume, which can enhance dose delivery accuracy to the tumor while minimizing exposure to surrounding healthy tissues. Higher in VMAT Plans: V1.5 < 30% refers to the volume heart doses. A higher value in VMAT plans suggests that VMAT is not complying with the hypo-fractionated protocol. **Conclusions:** The DIBH t-IMRT hypo-fractionated technique is the most effective method for achieving a radiation dose coverage to PTV. It also significantly reduce doses to the heart organ.

Subject Areas

Oncology

Keywords

Dosimetry Comparison, Breast Cancer, VMAT, t-IMRT, DIBH, Hypo-Fractionation

1. Introduction

The FAST FORWARD protocol is a hypo-fractionated treatment regimen for early breast cancer, generally involving fewer sessions with higher doses per fraction compared to traditional regimens. Application of DIBH minimize radiation exposure to the heart and lungs during treatment of left-sided breast cancer.

In the context of treating left-sided breast cancer with the FAST FORWARD UK hypo-fractionated protocol and using DIBH, VMAT and t-IMRT often have the advantage of better OAR sparing and more efficient treatment delivery. However, individual patient factors and clinical preferences can influence the choice of technique. Both techniques can be effective, and the decision may also depend on specific dosimetric goals and the overall treatment plan, hence the study focused on these two treatment techniques.

In our study we specifically compared the organs at risk (OAR) doses, between tangential Intensity modulated radiotherapy (t-IMRT) and volumetric Modulated arc therapy (VMAT) radiation treatment planning techniques for left-sided adjuvant breast cancer patients at Public hospital. Moreover, Popescu CC *et al.* [1] was found that VMAT could enhance dose accuracy and cut down the duration of treatment when contrasted with traditional intensity modulated radiotherapy for the local treatment of breast cancer on the left side and the nodes within the internal mammary.

Heart problems can arise up to a decade after undergoing radiation treatment.

They are often seen in women who have cancer in their left breast [2]-[5]. These issues lead to a 30% rise in deaths related to the heart following a 10-year window after undergoing radiation treatment [3]. The decreased chance of side effects linked to radiation therapy is linked to lowering the dose and the area of the body exposed to radiation in vital organs [4]-[6]. The greater the amount of the heart exposed to radiation, or the more radiation the heart receives, the more likely it is to suffer from heart damage, which can result in ischemic heart disease and death from heart-related causes [7]. Darby *et al.* [8] discovered a direct connection between the average heart dose (MHD) and the frequency of significant heart attacks, which rose by 7.4% for every Gy of the MHD. The use of IMRT has been demonstrated to lower the radiation exposure to the heart [9] [10]. This research examined the dose metrics for organs at risk in patients with left-sided breast cancer planned with t-IMRT and VMAT treatments.

Breath holding under deep inspiration, with gated, has been suggested as a method to lower the risk to the heart and coronary arteries [11] [12]. Research suggests that individuals with breast cancer on the left side could gain advantages from the DIBH method, however, not every patient experiences identical outcomes, and the extent of reduction in MHD has varied between 26.2% and 75% in past research [13] [14].

Moreover, the growing reliance on hypo-fractionation has also raised the need for uniformity in dose distribution in breast cancer radiotherapy [15]. Because there are no guidelines on the safe amounts of radiation dose for the heart, methods to reduce the heart's exposure are necessary [16].

2. Aim

This research aims to evaluate the DIBH t-IMRT technique versus the DIBH VMAT planning method in terms of the radiation dose delivered to vital organs in patients with early-stage breast cancer undergoing breast-conserving treatment.

3. Materials and Methods

3.1. Research Design and Instrumentation

Objective: To compare the dosimetric outcomes of t-IMRT and VMAT for left-sided breast cancer using DIBH, within the FAST FORWARD UK hypofractionated protocol.

Study Type: Comparative, observational, or prospective study.

Patient Population: Patients with left-sided breast cancer eligible for the FAST FORWARD UK protocol.

Patients were scanned using Toshiba Aquilion Large Bore CT-simulator model TSX-201A (Toshiba, 2019). The CT-simulator scanner producing 32 slices per rotation, with 0.5 mm detector element, gantry aperture of 90 cm, and patient couch that can accommodate 205 kilograms' patient. The Toshiba Aquilion Large Bore was equipped with internal and external lasers as well as the couch top that was

compatible with ELEKTA LINAC MACHINES to mirror the treatment positions without compromise and enabling a breast board tilt of up to 25 degrees. The treatment plans were generated using Monaco Treatment Planning System. Patients were treated with DIBH technique using ABC ELEKTA system. Mosaiq was used as a record and verification system.

3.2. Study Setting

The study site is a public hospital in Johannesburg area, in Park-town, South Africa. It is a referral hospital in Johannesburg metropolitan and is accessible to the public. The hospital has a radiation oncology clinic that provides breast cancer diagnostics and therapeutic services. It saves as a referral Centre for various hospitals in Gauteng province of South Africa. The hospital is equipped with advance high-definition linear accelerators (LINAC's) machines which are deployed to treat cancer patients from within Gauteng region and neighboring regions. This public hospital is with the highest patient load in Gauteng province. Currently is the only public hospital that treats patients using DIBH (Active breath control) (ABC) system treatment technique.

3.3. Patient Selection

Inclusion Criteria:

- Diagnosed with left-sided breast cancer.
- Suitable for the FAST FORWARD UK hypofractionated protocol (5 fractions of 5.2 Gy each).
- Able to undergo treatment with DIBH.
- Informed consent provided.

3.4. Ethical Issues and Informed Consent

Any study that includes people as participants carried out in the hospital must comply with ethical guidelines. This guarantees that the way clinical trials are carried out meets global-accepted ethical and scientific criteria. In order to comply with this requirement, ethical approval was obtained from a Human sub-committee of North West University (NWU) Medical Research Ethics Committee MREC (NWU-00274-21-S1) and WITS MREC (M230852). The study was also evaluated and approved by CMJAH and Gauteng department of health (GP_202310_020).

3.5. Simulation and Delineation

In this retrospective analysis, a total of thirty patients (under the age of 60) diagnosed with breast cancer on the left side but without any involvement of the lymph nodes were chosen. The patients underwent CT scans while lying down with their arms raised. The CT scans captured images from the mandible to the base of the lungs, with each slice being 5 mm thick. In the simulation, indicators were set up to outline the surgical limits of the left breast; the inner edge at the patient's center line, the outer edge at the center of the armpit, the top edge at the lower part of

the collarbone-shoulder joint, and the bottom edge 1.5 centimeters beneath the underarm area. The tracking indicators on the patient's skin in relation to the coronal laser were applied prior to the CT scan.

Each patient was imaged with two CT data scanning techniques; one conventional FB and the other one was DIBH using Elekta ABC gating breathing system. All CT data sets were taken on a breast board.

3.6. Target and Organ at Risk (OAR) Delineation

A 5-millimeter margin was incorporated into the Clinical Target Volume (CTV), achieving the intended target planning volume (PTV). The areas beyond the body shape and within the lungs were removed from the PTV. Moreover, for the purposes of assessing the plan and standardizing it, a 5 mm margin from the skin's surface was removed from the PTV (this led to the resulting PTVin). PTVin was additionally utilized as a target volume in optimizing VMAT and t-IMRT strategies to prevent excessive skin exposure. Tissues at high risk (TAR) pinpointed through this study encompassed lungs on both sides, heart on the opposite side, breasts on the opposite side, and normal tissue, all defined by excluding the PTV from the calculation of body surface area (Body-PTV) (Figure 1).

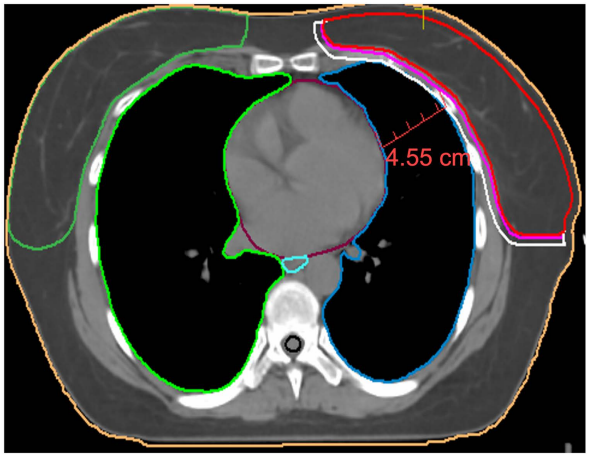

Figure 1. A computed tomography scan image showing a transversal plane displaying the heart position and the organs at risk acquired during DIBH technique.

3.7. Dose Objectives and Constraints

The prescription dose was 26 Gy in 5 fractions. The main goal in designing the treatment was to ensure at least 95% of the dose was delivered to the PTV, reaching a total of 24.7 Gy (V24.7). VMAT and t-IMRT plans were optimized in Monaco® TPS in a constrained mode and biological cost functions were used as constraints. The volumes of doses from UK FFWD protocol constraints V5 < 5% and V1.5 < 30% as well as the mean dose were minimized for heart. Specific goal functions were outlined for every patient to achieve the optimal attainable treatment strategy. Treatment planning goals were to achieve the same dose objectives by using the t-IMRT and VMAT planning technique.

Comparison of planning treatment techniques (t-IMRT and VMAT) was done using dose volume histogram (DVH). The fast-forward prescription protocol was utilized for radiation treatment planning. 26 Gy in five fractions for only one week to the whole breast or chest wall, was planned for DIBH technique. The maximum dose of 110% or less was considered.

3.8. Treatment Planning

Treatment plans were created for Elekta Versa HD accelerator (Elekta AB, Stockholm, Sweden) with 5 mm Agility® MLC. The treatment energy of 6 MV was selected. Two separate treatment plans with an identical isocenter were created to each patient. A t-IMRT with four static tangential fields, left Medial tangential field 1 and field 2 at a gantry angles between 310˚ and 335˚ respectively and left lateral tangential field 1 and field 2 at a gantry angles of 130˚ and 105˚. VMAT treatment plans with two dual half arc from 297˚ - 197˚ and 132˚ - 197˚ for both FB and DIBH data sets. The highest limit for the number of control points in the plan was established at 170. A standard deviation of 0.5% was applied in the Monte Carlo (MC) dose calculation, utilizing a dose grid of 3.0 mm. The doses directed to the OARs were reduced to the lowest possible level while ensuring the PTV coverage remained adequate, as suggested by QUANTEC. Every treatment plan was adjusted to align with the average dose of PTVin.

3.9. Plan Evaluation

- Dosimetric Analysis:
  - Homogeneity Index (HI): Evaluate the uniformity of dose distribution within the target.
  - Conformity Index (CI): Assess how well the dose conforms to the shape of the target.
  - Treatment plans assessment and evaluation of all dose constrains using UK FAST FORWARD protocol.

3.10. Statistical Analysis

The dosimetric measurement information for the left sided breast, heart, and lung were examined for comparison. Despite the small number of participants, a standard statistical evaluation of the importance of the findings was conducted. A two-tailed, paired t-test was applied to determine the statistical significance of the variances among the groups. Continuous data were shown as mean ± standard deviation and examined with the paired t-test. The statistical analysis was carried out using SPSS 16.0 (IBM, Armonk, NY, US), with two-sided P-values being deemed statistically significant.

4. Results

We can use the standard t test, $t = 27.119$, $p \leq 0.001$. The test indicates that there is a significant difference because the p-value is less than 0.05 (See **Table 1**). We

then conclude that there is not a significant difference between VAMT vs t-IMRT. On the other hand, there is no significant difference between VMAT vs t-IMRT on the homogeneity index.

Table 1. Conformity index and homogeneity index comparison between t-IMRT and VMAT treatment plans.

	t	95% Confidence Interval		p-value
CONFORMITY INDEX				
VAMT vs t-IMRT	−27.119	−0.464	−0.397	<0.001
HOMOGENEITY INDEX				
VAMT vs t-IMRT	−0.825	−0.016	0.007	<0.210

Additionally, in Table 2, Ipsilateral lung V8 < 15% was higher in t-IMRT plans (t-IMRT: 0.662% ± 2.776%) compared with VMAT plans (VMAT: 0.147% ± 0.005%). The heart V7 < 7% was significantly better in the VMAT plan (0.032% ± 0.026%) than in other plans (t-IMRT: 0.079% ± 0.342%). Also, V1.5 < 30% was higher in VMAT plans (VMAT: 2.653% ± 10.852%) compared with t-IMRT plans (t-IMRT: 0.240% ± 0.031%). A comparison of mean dose indicated that t-IMRT plans are better plans than VMAT plans. Table 2 describes the results in detail.

Table 2. Dosimetric parameters comparison of Heart FFWD Constraints in Gy and Ipsilateral lung.

	t-IMRT		VMAT		t-IMRT vs VMAT	
	Mean	SD	Mean	SD	95% Confidence Interval	p-value
Ipsilateral lung V8 < 15%	0.662	2.776	0.147	0.005	0.515 (−0.541, 1.570)	0.163
Heart V7 < 7%	0.079	0.342	0.032	0.026	0.048 (−0.079, 0.177)	0.221
V1.5 < 30%	0.240	0.031	2.653	10.852	−2.413 (−6.464, 1.638)	0.116
Mean dose	1.634	0.381	11.316	48.294	−9.682 (−27.708, 8.346)	0.141

5. Discussion

Based on the dosimetric comparison between Tangential Intensity Modulated Radiotherapy (t-IMRT) and Volumetric Modulated Arc Therapy (VMAT) for left-sided breast cancer using Deep Inspiration Breath Hold (DIBH) with the FAST FORWARD UK hypofractionated protocol, our findings shows that VMAT conformity index (CI) p-value < 0.001, indicating a significant improvement in dose conformity for VMAT compared to t-IMRT [17]. VMAT achieved better conformity across all Planning Target Volumes (PTVs), suggesting that VMAT is

more effective in aligning the radiation dose with the shape of the target volume. The t-IMRT CI p-value < 0.210, suggesting no significant improvement in conformity compared to VMAT. The t-IMRT was less effective in achieving the same level of dose conformity.

No significant difference between t-IMRT and VMAT in terms of Homogeneity index (HI). Both techniques provided similar dose homogeneity within the target volumes, meaning the dose distribution was comparably uniform.

The t-IMRT resulted shows a significantly lower mean heart dose compared to VMAT. This indicates that t-IMRT is more effective at minimizing radiation exposure to the heart, which is crucial for reducing the risk of cardiac side effects. **Figure 2:** Illustrates this difference, showing that t-IMRT provided better protection for the heart.

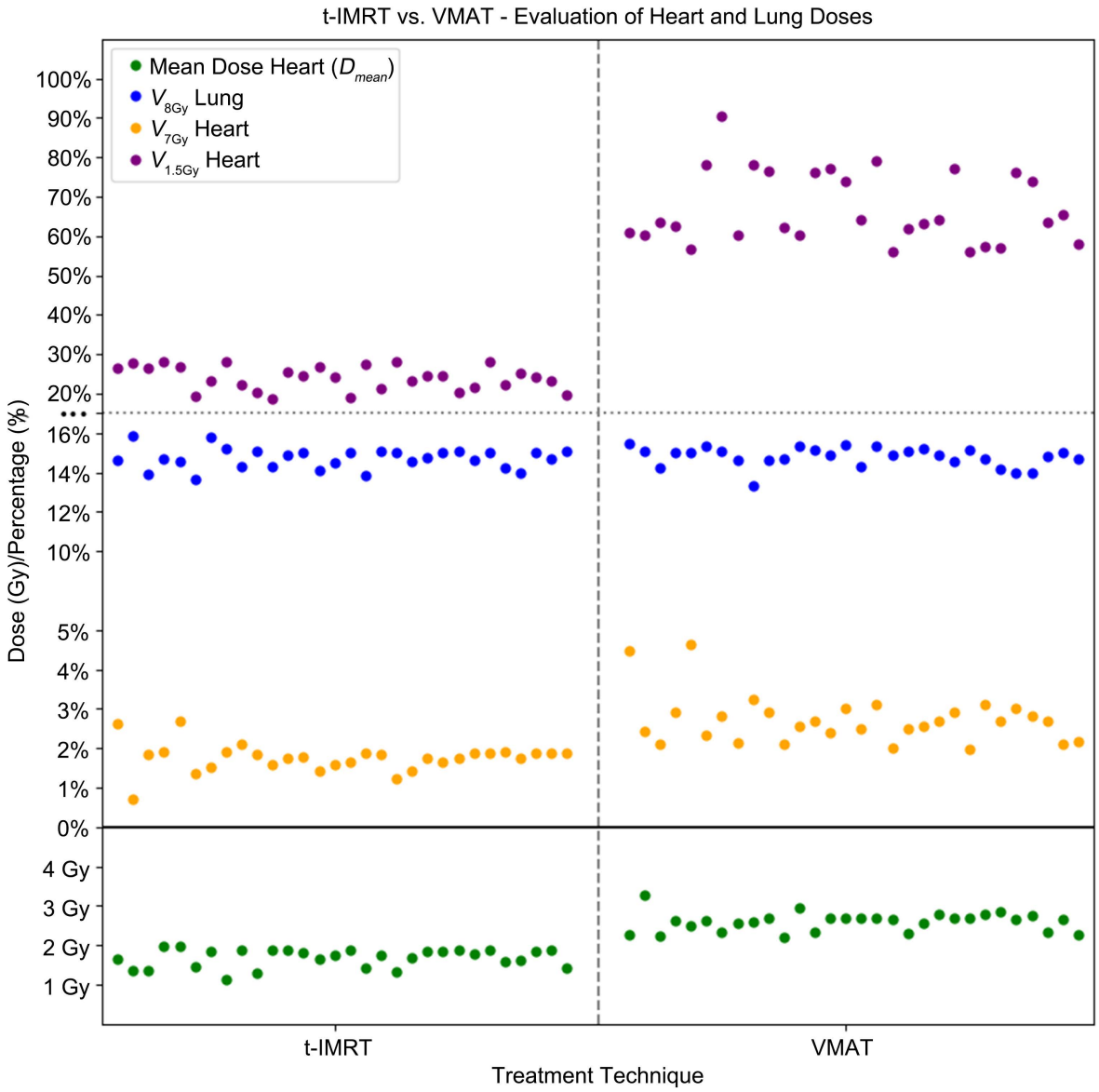

Figure 2. t-IMRT and VMAT organs at risk dose comparisons.

The t-IMRT also shows significantly lower man dose (1.634 Gy) compared to VMAT (11.316 Gy). This suggesting a lower dose to the heart volume. Dose to the Heart V7 < 7% VMAT shows better (0.032) compared to t-IMRT (0.079). VMAT shows superior performance in limiting the dose to the heart's volume.

Table 2 Displays this data, highlighting VMAT's advantage in sparing the heart from high doses of radiation. VMAT results in better sparing of the ipsilateral lung, reducing the risk of lung-related side effects. The t-IMRT's lower mean heart dose which very crucial for reducing cardiac toxicity. The significant difference suggests that t-IMRT may offer better long-term cardiac protection, which is an important consideration in breast cancer radiotherapy. The t-IMRT shows better performance in heart sparing for V1.5 < 30%, suggest that it may be preferable in minimizing dose to this organs. This could be beneficial in reducing the risk of secondary malignancies and lung complications.

The t-IMRT provides better heart dose control and limits high-dose volumes within the target, making it advantageous for minimizing cardiac and high-dose region-related risks.

The choice between t-IMRT and VMAT should be tailored to individual patient needs, considering the balance between target coverage, OAR sparing, and overall treatment goals.

6. Recommendations

Radiation therapy given as a follow-up treatment after a breast-conserving surgery for breast cancer lowers the chance of the cancer coming back and boosts the chances of living longer [18]. Regrettably, many patients experience complications related to radiation, including breast fibrosis, alterations in breast appearance, and late pulmonary and cardiovascular complications [19]. Even though the number of problems caused by radiation has gone down as radiotherapy methods have improved, new approaches are still required to successfully lower the radiation dose to the heart and the same side of the lung. This study could still be taken further to investigate treatment planning techniques like t-IMRT and VMAT on different breast sizes and their shapes. That will assist on creating treatment templates based on the volume size of the breast.

The use of hypo-fractionation increases the demand of requirement for the dose homogeneity and the organ at risk dose reduction for the left sided breast cancer. Because there are no guidelines on the safe amounts of medication for the heart, methods to reduce the heart's exposure are necessary [20].

We will also recommend it to be used for **FAST FORWARD UK hypo fractionated protocol** of 5.2 Gy per fraction for only one week.

7. Conclusion

The t-IMRT provides better heart dose control and limits high-dose volumes within the target, making it advantageous for minimizing cardiac and high-dose region-related risks.

Conflicts of Interest

There are no conflicts of interest.

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