Comparison of 3D-conformal and intensity-modulated radiation therapy for left-sided breast cancer

**Background:** We compared 3D-conformal radiation therapy (3D-CRT) and intensity-modulated radiation therapy (IMRT) planning for left-sided post-mastectomy patients.

**Aim:** To compare the dose coverage of the planning target volume (PTV) and dose delivered to organs at risk (OAR) of 3D-CRT and IMRT plans.

**Setting:** Department of Oncology, central South Africa.

**Methods:** Twenty-six archived CT scans of patients with left-sided breast cancer were included. The 3D-CRT and IMRT plans were designed for each patient and compared using the Monaco® planning system (version 5.11.02). Statistical analysis was performed for PTV coverage ($V_{95\%}$, $V_{98\%}$, $V_{105\%}$) and radiation doses to the heart, ipsilateral lung, combined lungs, contralateral breast, and oesophagus.

**Results:** The $V_{95\%}$ and $V_{98\%}$ target volume dose coverage for the 3D-CRT plans were 67.07% and 0.21%, respectively, compared to 92.32% and 1.10% of the IMRT plans. However, the IMRT plans’ mean volume of PTV, receiving 95% of the prescribed dose (PD), was 7.68% compared to the 3D-CRT’s 32.93%. The IMRT plans resulted in a $V_{15\%}$ Gy < 10% for the heart, with a value of 4.15%. The $V_{18.6\%}$ Gy < 45% values for the ipsilateral and combined lungs were 28.09% and 13.70%, respectively. The 3D-CRT plans showed a lower dose to the oesophagus ($5.07\text{ Gy}$) and contralateral breast ($V_{15\%} = 3.51\%$).

**Conclusion:** It was shown that 3D-CRT and IMRT treatment planning can effectively achieve clinical goals for post-mastectomy left-sided breast cancer radiotherapy.

**Contribution:** The findings underscore the continuing relevance of 3D-CRT planning in oncology for optimal PTV dose coverage and low OAR dose.

**Keywords:** breast cancer; dosimetry; three-dimensional conformal radiation therapy; intensity-modulated radiation therapy; organs at risk.

**Introduction**

Worldwide, an estimated 18.1 million new cancer cases were reported in 2020. Breast cancer was the most commonly diagnosed cancer representing 11.7% of total cancer cases, and the third largest cause of death in women, with 2.3 million new cases and 684,996 deaths, respectively.¹ The National Cancer Registry (NCR) of South Africa listed breast cancer among the top five female cancers, with approximately 19.4 million women aged ≥ 15 years at risk of being diagnosed with breast cancer in their lifetime.²,³ The statistical data from the Department of Oncology in the Free State province, South Africa, indicated that from 2013 to 2017, 729 newly diagnosed patients had received post-mastectomy radiation therapy, of which 355 (47.8%) patients had left-sided breast cancer (personal communication; Department of Oncology, Universitas Academic Hospital Annex).

Radiotherapy is the standard of treatment care after radical surgery for patients with breast cancer.⁴ Conventional three-dimensional conformal radiation therapy (3D-CRT) has been successful in improving local control,⁵ yet normal tissue toxicities remain a concern. When treating left-sided breast cancer, the concave shape of the chest wall results in unavoidable irradiation to portions of the underlying lung and heart.Intensity-modulated radiation therapy (IMRT) offers the ability to mitigate these effects by providing more degrees of freedom in the planning process, allowing for improved dose homogeneity and decreased normal tissue irradiation.⁶ Intensity-modulated radiation therapy and 3D-CRT are the most frequently used radiation therapy planning techniques for breast cancer.⁷
With the introduction of IMRT technology in an oncology department in central South Africa, it was necessary to assess the differences in plan quality between 3D-CRT and IMRT plans for a standard treatment protocol for post-mastectomy, left-sided breast cancer patients. The department uses a hypofractionation protocol of a prescribed dose (PD) of 2.67 Gray (Gy) given in 15 fractions daily to a total dose of 40.05 Gy for 3D-CRT treatment delivery. The United Kingdom (UK) Standardisation of Breast Radiotherapy (START) trial B protocol is used instead of the conventional fractionation of 50 Gy/25 fractions.\(^8\) Jones et al.\(^9\) stated that many clinical situations occur in which radiobiological considerations can be usefully applied and all clinicians should be aware of the potential benefits of developing a quantitative radiobiological approach to their practices. Therefore, for this department, the initial biological effective dose (BED) values for the reference fractionation schedule of 60 Gy in 30 fractions are used to calculate the total dose and dose per fraction for the alternative schedule of 15 fractions. The results for alternative fractionation schedules are obtained from the solution of \(d\) in a rearrangement of the equation\(^9\):

\[
nd\left[1 + \frac{d}{(\alpha/\beta)}\right] = \text{BED} \quad \text{[Eqn 1]}
\]

The objectives of this research were to (1) create 3D-CRT and IMRT plans from the archived scans of patients with left-sided breast cancer; and (2) compare the dosimetric differences between the two plans regarding the planning target volumes and organs at risk (OAR).

**Methods**

**Case selection**

The archived computed tomography (CT) scans of 26 of the patients who underwent 3D-CRT for left-sided breast cancer between 01 January 2015 and 31 December 2017 were selected according to the inclusion criteria (Table 1). The CT scans in this research were from patients who had breast surgery and received adjuvant radiation therapy to reduce local recurrence and improve patient survival. The CT scans of each patient were used to design 3D-CRT and IMRT plans, respectively. These created plans contained the clinical target volume (CTV), planning target volume (PTV), and the OAR (heart, ipsilateral lung, combined lungs, contralateral breast and oesophagus).

**Position fixation and computed tomography scan**

The archived CT scans contained the images of patients with left-sided breast cancer scanned on the Breast STEPM\(^\text{T}\) positioning and immobilisation apparatus (IT-V Innovative Technology Völp; Innsbruck, Austria) in the supine position, both arms positioned above the head and a 0.5 cm superflab (tissue equivalent) placed over the mastectomy area as a bolus for the tangential (tan) fields. A 0.5 cm bolus was placed lateral to the sternomastoid muscle for the supraclavicular field when necessary. The CT scan ranged superior from the patients’ external auditory meatus level (5 cm superior to the superior border of the supraclavicular field) to the level of lumbar vertebra L2 (5 cm inferior to the inferior border of the tan field). The Toshiba Aquilion LB 1 (Toshiba Corporation; Tokyo, Japan) CT scanner was used for the procedure. The acquisition parameters were 120 kV and 200 mA with a scanning slice thickness of 0.2 cm.

**Research process**

**Contour and organs at risk delineation**

A radiation oncologist contoured and delineated the CTVs and OAR. The CTVs for both planning modalities included the chest wall (defined by the Radiation Therapy Oncology Group [RTOG] Breast Cancer Atlas),\(^10\) ipsilateral regional lymph nodes, and interconnecting lymphatic drainage routes. The CTV also included the mastectomy scar due to the risk of microscopic disease. The PTV for each patient included the supraclavicular region, with margins 3 mm – 5 mm medially, 5 mm – 10 mm laterally, 3 mm – 5 mm posteriorly, and 5 mm – 10 mm superiorly, inferiorly, and anteriorly (to include the skin surface). These margins for the PTV were only used for the purpose of this research as the department did not use PTV for 3D-CRT treatment delivery at the time of the study.

**Planning design and optimisation**

The CT scans of each patient, including the delineated CTVs and OAR, were used to design a 3D-CRT plan on the XiO treatment planning system\(^6\) (TPS) (Version 4.33.02) (Computed Medical Systems [CMS] Inc.; St. Louis, Missouri, United States) and an IMRT plan on the Monaco\(^\text{T}\) TPS (Version 5.11.02) (Elekta Solutions AB; Stockholm, Sweden), respectively. Conformal 3D planning was initially performed in the department using the XiO system before moving to Monaco’s TPS. The prescription dose was 40.05 Gy/15 fractions, and the dose per fraction was 2.67 Gy.\(^10\) The treatment plans were normalised to 40.05 Gy to 95% of the PTV, and the principal planning objective was to deliver the prescription dose to the CTV.

### Table 1: Inclusion and exclusion criteria for computed tomography scans investigated in the study.

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
<th>Exclusion criteria</th>
</tr>
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<tbody>
<tr>
<td>CT scans of post-mastectomy patients who received the hypofractionated protocol of 40.05 Gy in 15 fractions.</td>
<td>CT scans of patients with an intact breast who had no breast surgery.</td>
</tr>
<tr>
<td>CT scans of patients diagnosed with left-sided breast cancer.</td>
<td>CT scans of patients who received palliative treatment for breast cancer.</td>
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<tr>
<td>CT scans of patients treated with both tangential and supraclavicular fields.</td>
<td>CT scans of patients diagnosed with right-sided breast cancer.</td>
</tr>
<tr>
<td>CT scans of patients treated with a 3D-CRT plan.</td>
<td>CT scans of patients who received only tangential fields.</td>
</tr>
<tr>
<td>Inactive patients on the planning system who received breast cancer treatment.</td>
<td>CT scans of patients who underwent lumpectomies.</td>
</tr>
<tr>
<td>3D-CRT plans with PTV and OAR.</td>
<td>CT scans of male patients for breast cancer.</td>
</tr>
<tr>
<td>IMRT plans with PTV and OAR.</td>
<td>CT scans of bilateral breast cancer patients.</td>
</tr>
<tr>
<td>3D-CRT plans approved by a radiation oncologist.</td>
<td>Active patients in the planning system for breast cancer treatment.</td>
</tr>
<tr>
<td>IMRT plans approved by a radiation oncologist.</td>
<td>3D-CRT plans without PTV and OAR.</td>
</tr>
</tbody>
</table>

CT, computed tomography; Gy, Gray; 3D-CRT, three-dimensional conformal radiation therapy; OAR, organs at risk; PTV, planned target volume; IMRT, intensity-modulated radiation therapy.
dose to 95% of the PTV. The parts of the PTV breast covered with a radiation dose <95% of the prescription dose (V95 ≥ 95%) correspond to areas of underdosed volumes. The PTV's dose coverage targets and dose constraints to organs at risk are depicted in Table 2.

3D-conformal radiation therapy planning: The 3D-CRT planning technique used a single isocentre, a five to seven field plan to cover the PTV and obtain a homogeneous dose distribution. The isocentre was placed on the level of the sternal notch, anteriorly and laterally, as required per patient. The tangential fields were angled to cover the maximum area of the PTV. The tangential field consisted of a 20 cm offset field, with the superior border at 0 cm and the inferior border at 20 cm. The collimator angles were kept close to 0°, making it possible to use the multi-leaf collimators (MLCs) to cover areas of the exposed heart and lung. The MLCs were used to limit the dose received by the OAR and remain within organ tolerance. A compensating field was included to provide a homogeneous dose distribution (Figure 1a).

The supravacuicular and axillary fields were offset superiorly to cover the PTV superior to the sternal notch (Figure 1b). Virtual wedges were used where necessary. Filler or compensating fields were used to counteract hot or cold dose spots. Hot dose spots are areas on the plan containing more than 105% of the dose, and cold dose spots are areas with less than 95% of the dose. The humeral head was shielded with MLCs in the supravacuicular and axillary fields. Mastectomy scars not covered by the photon fields were treated with an additional electron beam.

Intensity-modulated radiation therapy planning: The IMRT planning technique employed a single isocentre and seven field plans with dynamic MLCs. The seven fields were used to deliver sufficient dose coverage for the PTV. The fields were static beams at a specific angle with the collimator rotation at a specific angle of 0°. The isocentre was positioned in the centre of the PTV. The dose prescription was to the PTV with constraints for over- and underdosing. Therefore, the hot and cold spots may not occupy more than 2% of the PTV. Parallel and serial dose constraints were used to prevent overdosing of the OAR. The plans were designed according to each patient’s unique anatomy but with a similar approach. The approach to patients’ plans was either ‘parieto’ (PTV first) or ‘constrained’ (OAR first). The beam orientation and isocentre placement are demonstrated in Figure 2.

Evaluation indicators
The 3D-CRT and IMRT plans were compared via the Monaco™ planning system (version 5.11.02), which is equipped to compare two planning modalities. For the radiation oncologist to approve the created plans, it was necessary for the PTVs to receive a minimum of 95% of the PD.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dose constraint†</th>
<th>Dose parameters</th>
<th>Mean dose</th>
<th>Dose maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target volume</strong></td>
<td></td>
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<tr>
<td>PTV</td>
<td>V95 ≥ 95%, 40.05 Gy</td>
<td>Dv &lt; 107%, 42.85 Gy</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>V98 ≥ 98%, 38.5 Gy</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>V2% &lt; 2%, 42.05 Gy</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td><strong>Organs at risk</strong></td>
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<tr>
<td>Heart</td>
<td>V4 ≤ 95% Gy</td>
<td>Dmax &lt; 4 Gy</td>
<td>Dv &lt; 43.5 Gy</td>
<td></td>
</tr>
<tr>
<td>Oesophagus</td>
<td>-</td>
<td>-</td>
<td>Dv &lt; 53.1 Gy</td>
<td></td>
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<tr>
<td>Ipsilateral lung</td>
<td>Vmax ≤ 95% Gy</td>
<td>-</td>
<td>-</td>
<td>Dv &lt; 15 Gy</td>
</tr>
<tr>
<td>Combined lungs</td>
<td>Vmax ≤ 95% Gy</td>
<td>-</td>
<td>-</td>
<td>Dv &lt; 15 Gy</td>
</tr>
<tr>
<td>Contralateral breast</td>
<td>V4 ≤ 95% Gy</td>
<td>-</td>
<td>-</td>
<td>Dv &lt; 30 Gy</td>
</tr>
</tbody>
</table>

3D-CRT, three-dimensional conformal radiation therapy; IMRT, intensity-modulated radiation therapy; PTV, planning target volume; V95 ≥ 95%, volume of PTV receiving ≥ 95% of prescribed dose; V98 ≥ 98%, volume of PTV receiving ≥ 98% of prescribed dose; V2% < 2%, volume of PTV receiving 100% (hot spot) of prescribed dose < 2%; V4 Gy < 30%, volume of combined lung receiving 18.87 Gy < 30%, V15%, volume of contralateral breast receiving 5 Gy ≤ 15%; Dv < 4 Gy, the mean dose to heart (V1% I) should be < 4 Gy; Dv < 43.5 Gy, the maximum dose to heart (V4 Gy) should be < 43.5 Gy; †, Dose tolerances derived from Milano, Constine & Okunieff. These dose constraints were adapted from 2 Gy/fractions to 2.67 Gy/fraction.
The dose volume histograms (DVH) and statistics were used to compare the dose distributions to the structures at different percentages and to evaluate the tolerance doses of the OAR according to dose parameters (Table 2). In the comparative analysis of the two planning techniques, the planning targets volumes of the 3D-CRT and IMRT plans were evaluated according to the 95%, 98% and 105% dose coverages and the planned dose delivered to the OAR. The comparisons between the 3D-CRT and IMRT plans were evaluated according to (1) minimum and maximum standard deviations (s.d.); and (2) specific goals set for the PTVs and OAR. Based on the DVH statistics, the PTV coverage was compared by evaluating the hot and cold dose spots. Finally, the doses for the OARs were compared in 3D-CRT and IMRT plans.

**Statistical analysis**

Statistical analysis was done using SAS version 9.2 (SAS Institute Inc., Cary, North Carolina, United States). Descriptive statistics, namely frequencies and percentages, were calculated for the categorical data and means, while s.d., medians, and percentiles were calculated for numerical data. The chi-square test was used to compare proportions, and Student’s t-test (or the Mann–Whitney U-test) was used to compare mean (or median) values. A significance level (α) of 0.05 was applied (p < 0.05).

**Ethical considerations**

The research was approved by the Health Sciences Research Ethics Committee (HSREC) of the University of the Free State (ethics approval number UFS-HSD2018/1164/3010). Due to the retrospective nature of the study and collecting data from archived patient records, informed consent was not required.

**Results**

Twenty-six created 3D-CRT and IMRT plans fulfilled the study’s inclusion criteria and were approved by the oncologist. Four plans were excluded due to inadequate PTV coverage and increased heart and lung doses.

**Dosimetric comparisons of the target volume**

The PTV coverage was used to compare the dosimetric differences for the 3D-CRT and IMRT plans. Table 3 illustrates the PTV coverage for the V\(_{95\%}\), V\(_{98\%}\), and V\(_{105\%}\) of the two plans. The mean volume of PTV, receiving 95% of the PD, was 7.68% for IMRT and 32.93% for 3D-CRT. The V\(_{95\%}\) minimum and maximum for the IMRT plans were 2.07% and 13.60%, respectively, compared to the 14.38% minimum and 44.00% maximum for the 3D-CRT plans (p < 0.0001). The 3D-CRT plans showed a lower mean (67.07% and 0.21%), minimum (56.00% and 0.00%) and maximum (85.62% and 1.00%) values for both the V\(_{95\%}\) and V\(_{105\%}\), respectively (see Table 3). The mean difference of 0.9% (V\(_{105\%}\)) indicated that the 3D-CRT plans had fewer areas of 105% coverage than the IMRT plans. The p-value for the V\(_{95\%}\), V\(_{98\%}\), and V\(_{105\%}\) of the 3D-CRT versus IMRT was p < 0.0001. There is, thus, a statistically significant difference in the PTV coverage between the 3D-CRT and the IMRT plans.

**Dosimetric comparisons of the organs at risk**

It is important to limit the dose delivered to OARs because they have a tolerance threshold beyond which permanent or irreversible damage may occur.13 This damage can lead to irreversible long-term radiation toxicity, potentially decreasing the quality of life, and eventually can cause mortality, depending on the organ involved.

**Heart V\(_{22}\) and mean dose**

Table 4 summarises the percentage of the volume of the heart receiving 22 Gy (V\(_{22}\)) and the mean dose to the heart received in 3D-CRT and IMRT plans. The mean volume of the heart receiving 22 Gy was 7.66% and 4.15% in 3D-CRT

| Table 3: Comparison in percentage of planning target volume coverage for 3D-conformal radiation therapy and intensity-modulated radiation therapy plans (n = 26). |
|---|---|---|---|---|
| PTVs for sample plans | 3D-CRT | IMRT | Mean difference | p-value |
| V\(_{95\%}\) | - | - | - | < 0.0001 |
| Mean | 32.93 | 7.68 | 25.25 | - |
| Minimum | 14.38 | 2.07 | - | - |
| Maximum | 44.00 | 13.60 | - | - |
| s.d. | 7.30 | 2.44 | - | - |
| V\(_{98\%}\) | - | - | - | < 0.0001 |
| Mean | 67.07 | 92.32 | 25.25 | - |
| Minimum | 56.00 | 86.40 | - | - |
| Maximum | 85.62 | 97.93 | - | - |
| s.d. | 7.30 | 2.44 | - | - |
| V\(_{105\%}\) | - | - | - | < 0.0001 |
| Mean | 0.21 | 1.10 | 0.9 | - |
| Minimum | 0.00 | 0.00 | - | - |
| Maximum | 1.00 | 2.24 | - | - |
| s.d. | 0.26 | 0.59 | - | - |

3D-CRT, three-dimensional conformal radiation therapy; IMRT, intensity modulated radiation therapy; PTV, planning target volume; V\(_{95\%}\), V\(_{98\%}\), V\(_{105\%}\), percentage volume of the PTV receiving 95% and 98% and 105% of the prescribed dose, respectively; Mean, average volume of the PTV receiving 95%, 98% and 105% of a prescribed dose; Minimum, the smallest volume of the PTV receiving 95%, 98% and 105% of a prescribed dose; Maximum, the largest volume of the PTV receiving 95%, 98% and 105% of a prescribed dose; s.d., standard deviation.
and IMRT plans, respectively (p = 0.1222). The mean dose for the IMRT plans was higher than the 3D-CRT plans, with a mean dose of 5.43 Gy versus 4.85 Gy. The s.d. for the mean heart dose was similar for both techniques (0.8 and 0.6). A statistically significant difference was observed between the 3D-CRT and IMRT plans (p < 0.0006).

Oesophagus

The mean dose delivered to the oesophagus was significantly lower in 3D-CRT plans (5.07 Gy) than in IMRT plans (9.30 Gy; p = 0.001). In contrast, the maximum dose was higher in IMRT plans, reaching 39.36 Gy, compared to 34.62 Gy in 3D-CRT plans. The s.d. for the mean dose was 1.86 and 2.16 for 3D-CRT and IMRT plans, respectively, while the s.d. for the maximum dose was 7.82 for 3D-CRT plans and 5.55 for IMRT plans.

Ipsilateral lung

The mean lung volume receiving 18.87 Gy was 33.47% for 3D-CRT plans and 28.09% for IMRT plans (p = 0.0002). The s.d. for the average lung volume receiving 18.87 Gy was 7.69 versus 7.18 for 3D-CRT and IMRT plans, respectively.

Combined lungs

According to the statistical analysis with p = 0.0002, the mean lung volume receiving a dose of 18.87 Gy was lower in IMRT plans (17.18%) than in 3D-CRT plans (16.11%). Additionally, the maximum lung volume receiving 18.87 Gy was lower in IMRT plans (17.18%) than in 3D-CRT plans (18.87%). The s.d. for the average lung volume receiving 18.87 Gy was similar for 3D-CRT and IMRT plans, with values of 1.68 and 1.71, respectively.

Contralateral breast

The findings showed that the mean volume of the opposite breast receiving 5 Gy was significantly lower in 3D-CRT plans (3.51%) compared to IMRT plans (11.35%; p = 0.0001). The maximum volume of the opposite breast receiving 5 Gy was also lower in 3D-CRT plans (16.36%) than in IMRT plans (22.02%). The s.d. for the average volume of the opposite breast receiving 5 Gy was 4.57 for 3D-CRT plans and 5.04 for IMRT plans.

Comparative computed tomography images of intensity-modulated radiation therapy versus 3D-conformal radiation therapy plans

The CT images presented in Figures 3a, 3b and 3c demonstrate dose conformity to the PTV and OAR in the transverse (3a), coronal (3b) and sagittal (3c) sections for IMRT and 3D-CRT plans, respectively. Figure 3a shows that the dose distribution for the IMRT plan conforms to the PTV, while the 3D-CRT plan shows the inclusion of a larger volume of the heart and lungs. This same trend is illustrated in Figures 3b (coronal plane) and 3c (sagittal plane). However, it must be noted that these figures illustrate the dose distribution to the PTV and OAR of one randomly selected patient.

Discussion

The goal of this research was to compare differences in breast radiotherapy planning dosimetry when using 3D-CRT and IMRT techniques for PTV and OAR. The primary focus was to evaluate the consistency of dose coverage delivered to the PTV and confirm that the PD constraints outlined in Table 2 for the OAR were met. The primary focus was to compare the achieved dose coverage for the PTV in terms of V15, V20 and V95% for both planning techniques, while also assessing the radiation dose delivered to the OAR.

Planning target volume

From Table 2, the expected PTV coverage goal for both 3D-CRT and IMRT plans was that 95% of the target volume must receive 95% of the PD (V95% ≥ 95%, 40.05 Gy). This means if the PTV received less than 40.05 Gy, the plans were underdosed. Table 3 shows a significant difference between the mean PTV volumes receiving 95% and 98% of the PD in 3D-CRT and IMRT plans (32.93% in 3D-CRT and 7.68% in IMRT). It is apparent that the PTV receiving 95% did not receive 40.0 Gy as intended. Similarly, the mean volume of the PTV receiving 98% of the PD was 67.07% in 3D-CRT plans and 92.32% in IMRT plans. This underdosing of the PTV was necessary to keep the heart dose within the set goals of V10 < 10% and mean dose < 5 Gy and also to reduce the dose to the contralateral breast. Therefore, the percentage volume for PTV receiving 98% of the PD was higher for IMRT plans.

The maximum volume of the PTV receiving 95% of the PD was 44.00% in 3D-CRT and 13.60% in IMRT plans. The
maximum volume of PTV receiving 98% of the PD was higher for IMRT plans, with 97.93%, as opposed to 3D-CRT plans, with 85.62%. The maximum volume of the PTV receiving 105% of the PD was higher for IMRT with 2.24% than 3D-CRT plans with 1.00%. Nevertheless, both 3D-CRT and IMRT plans included no areas that received more than 107% (42.8 Gy) of the PD.

There was a significant difference between 3D-CRT and IMRT plans in the mean volume of the PTV receiving 105% of the PD. The mean volume of the PTV receiving 105% of the PD was 0.21% in 3D-CRT plans and 1.10% in IMRT plans, resulting in a mean percentage difference of 0.9% with \( p < 0.0001 \). This means the hot spots for both 3D-CRT and IMRT plans were less than 2% on average.

An advantage of IMRT planning is the ability to adjust the dose distribution in different regions of the target area, resulting in improved radiation dose uniformity and conformity within the target area. This adjustment may result in a lower dose to normal tissues, decreasing the likelihood of radiation toxicity. Schubert et al. compared four different treatment planning techniques, including 3D-CRT and inverse IMRT, using a PD of 50 Gy in 25 fractions. The IMRT plans had similar PTV coverage to the 3D-CRT plans. In addition, the inverse IMRT plans had superior PTV homogeneity to the 3D-CRT plans and reduced the hot dose spots. However, the study by Schubert et al. was conducted on breast cancer patients with breast-conserving surgery and no mastectomy. The IMRT plan of the current research (PD = 40.05/15 fractions) had a uniform dose throughout the target area, with no significant hot spots (see Table 3).

Dose to organs at risk volumes

It was necessary to achieve a mean dose to the heart of less than 5 Gy and a \( V_{22} \) of less than 10% of the dose (\( V_{22} \text{ Gy} < 10\% \)) (see Table 4), which is the tolerance dose level for the heart. The mean percentage volume that received 22 Gy to the heart was 7.66% for 3D-CRT plans and 4.15% for IMRT plans (\( p = 0.1222 \)). The mean dose received by the heart in both the IMRT and the 3D-CRT plans exceeded the heart’s planning dose constraint goal (\( D_{\text{mean}} < 4 \text{ Gy} \)) (see Table 2). However, in both 3D-CRT and IMRT plans these doses were within an acceptable range. These results were similar to the study conducted by Beckham et al., who compared IMRT plans with conventional treatment plans or 3D-CRT. It turned out that the IMRT plans rendered less dose to the heart than the conventional treatment plans. The shortcoming in this comparative study was that the authors only considered the best of each treatment planning technique using 50 Gy in 25 fractions for their PD.

Radiation toxicity to the heart can lead to radiation-induced cardiac disease when the dose exceeds its tolerance. Radiation dose to the heart could lead to pericarditis, pericardial fibrosis, diffuse myocardial fibrosis and coronary artery disease. With the maximum total dose exceeding 20 Gy, evidence in the literature has confirmed that radiation-related heart disease could develop. The heart dose is important to consider when creating a plan for left-sided breast cancer patients.

Compared to the 3D-CRT plans, the IMRT plans resulted in a larger maximum and mean dose to the oesophagus (see Table 4). The planning target objective for this research was to keep the maximum dose to the oesophagus less than 5 Gy (\( D_{\text{max}} < 53.1 \text{ Gy} \)) (see Table 2). The mean oesophageal dose of 9.30 Gy in the IMRT plans and 5.07 Gy in the 3D-CRT plans was because a small part of the
The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors’ contributions
D.L. prepared the manuscript with inputs from H.F.-N. and N.M.P. H.F.-N. was the supervisor and D.L. and N.M.P. were the co-supervisors of a master’s degree research study from which the study was derived. S.L. completed the data collection.
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Data availability
Data supporting the findings of this study are available from the corresponding author, H.F.-N., on request.

Disclaimer
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References