

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



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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 $V_{98\%}$ and $V_{105\%}$ 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 $V_{22\text{ Gy}} < 10\%$ for the heart, with a value of 4.15%. The $V_{18.87\text{ Gy}} < 45\%$ 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 Gy) and contralateral breast ($V_5\text{ Gy} < 15\% = 3.51\%$).

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 684996 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,^{5,6} 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.⁷ Intensity-modulated radiation therapy and 3D-CRT are the most frequently used radiation therapy planning techniques for breast cancer.⁸

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.⁹ Jones et al.¹⁰ 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 equation¹⁰:

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

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

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

Inclusion criteria	Exclusion criteria
<ul style="list-style-type: none"> CT scans of post-mastectomy patients who received the hypofractionated protocol of 40.05 Gy in 15 fractions. CT scans of patients diagnosed with left-sided breast cancer. CT scans of patients treated with both tangential and supraclavicular fields. CT scans of patients treated with a 3D-CRT plan. Inactive patients on the planning system who received breast cancer treatment. 3D-CRT plans with PTV and OAR. IMRT plans with PTV and OAR. 3D-CRT plans approved by a radiation oncologist. IMRT plans approved by a radiation oncologist. 	<ul style="list-style-type: none"> CT scans of patients with an intact breast who had no breast surgery. CT scans of patients who received palliative treatment for breast cancer. CT scans of patients diagnosed with right-sided breast cancer. CT scans of patients who received only tangential fields. CT scans of patients who underwent lumpectomies. CT scans of male patients for breast cancer. CT scans of bilateral breast cancer patients. Active patients in the planning system for breast cancer treatment. 3D-CRT plans without PTV and OAR. IMRT plans without PTV and OAR.

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.

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 STEP™ 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 Aquillion 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),¹¹ 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® (TPS) (Version 4.33.02) (Computed Medical Systems [CMS] Inc.; St. Louis, Missouri, United States) and an IMRT plan on the Monaco™ 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 95% of the PTV. The parts of the PTV breast covered with a radiation dose <95% of the prescription dose ($V_{95\%} \leq 95\%$) 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 20cm offset field, with the superior border at 0cm and the inferior border at 20cm. 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 supraclavicular 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 supraclavicular 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

TABLE 2: Dose constraints for planning target volume and organs at risk for three-dimensional conformal radiation therapy and intensity-modulated radiation therapy plans.

Variable	Dose constraint†	Dose parameters	Mean dose	Dose maximum
Target volume				
PTV	$V_{95\%} \geq 95\%$, 40.05 Gy	$D_{max} < 107\%$, 42.85 Gy	-	-
	$V_{98\%} \geq 98\%$, 38.5 Gy	-	-	-
	$V_{105\%} < 2\%$, 42.05 Gy	-	-	-
Organs at risk				
Heart	$V_{22} \text{ Gy} < 10\%$	-	$D_{mean} < 4 \text{ Gy}$	$D_{max} < 43.5 \text{ Gy}$
Oesophagus	-	-	-	$D_{max} < 53.1 \text{ Gy}$
Ipsilateral lung	$V_{18.87} \text{ Gy} < 45\%$	-	-	-
Combined lungs	$V_{18.87} \text{ Gy} < 30\%$	-	-	$D_{max} < 15 \text{ Gy}$
Contralateral breast	$V_5 \text{ Gy} < 15\%$	-	-	$D_{max} < 30 \text{ Gy}$

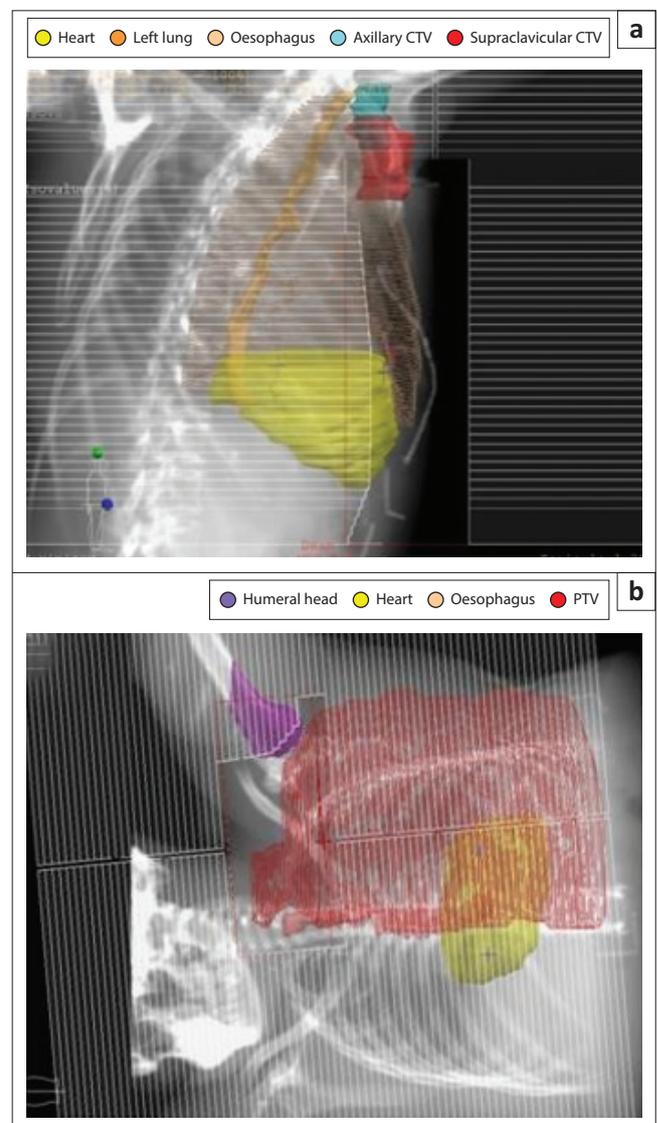
3D-CRT, three-dimensional conformal radiation therapy; IMRT, intensity-modulated radiation therapy; PTV, planning target volume; $V_{95\%} \geq 95\%$, volume of PTV receiving $\geq 95\%$ of prescribed dose; $V_{98\%} \geq 98\%$ Gy, volume of PTV receiving $\geq 98\%$ of prescribed dose; $V_{105\%} < 2\%$, volume of PTV receiving 105% (hot spot) of prescribed dose < 2%; $V_{18.87} \text{ Gy} < 30\%$, volume of combined lung receiving 18.87 Gy < 30%; $V_5 < 15\%$, volume of contralateral breast receiving 5 Gy < 15%; $D_{mean} < 4 \text{ Gy}$, the mean dose to heart (V_{22}) should be < 4 Gy; $D_{max} < 43.5 \text{ Gy}$, the maximum dose to heart (V_{22}) should be < 43.5 Gy.

†, Dose tolerances derived from Milano, Constine & Okunieff.¹³ These dose constraints were adapted from 2 Gy/fractions to 2.67 Gy/fraction.

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).¹² 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.



CTV, clinical target volume; PTV, planning target volume.

FIGURE 1: Beam's eye view of (a) the lateral tangential field and (b) the supraclavicular field: screenshots from XiO treatment planning system® (TPS) (version 4.33.02) (Computed Medical Systems [CMS] Inc.; St. Louis, Missouri, United States).

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 target 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.

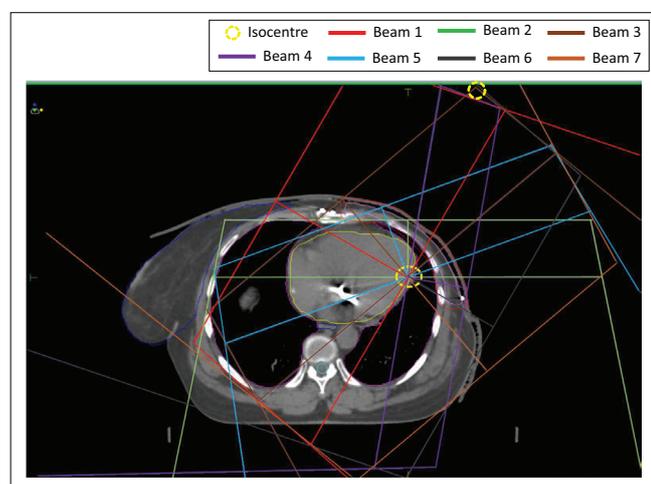


FIGURE 2: Example of beam orientation and isocentre placement: screenshot from the Monaco™ treatment planning system (version 5.11.02) (Elekta Solutions AB; Stockholm, Sweden).

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 $V_{98\%}$ 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	<i>p</i> -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.

TABLE 4: Comparison of organs at risk dose-volume metrics as a function of the planning technique.

Metric	3D-CRT	IMRT	Mean difference	p-value
Heart				
V_{22} Gy < 10%	7.66	4.15	3.51	0.1222
D_{mean} (Gy)	4.85	5.43	0.57	< 0.0006
D_{max} (Gy)	6.80	6.31	-	-
Oesophagus				
D_{mean} (Gy)	5.07	9.30	4.24	< 0.0001
D_{max} (Gy)	34.62	39.36	-	-
Ipsilateral lung				
$V_{18.87}$ Gy < 45%	33.47	28.09	5.39	0.0002
Maximum	40.71	34.23	-	-
Combined lungs				
$V_{18.87}$ Gy < 30%	16.11	13.70	2.41	< 0.0001
Maximum	18.87	17.18	-	-
Contralateral breast				
V_5 Gy < 15%	3.51	11.35	7.84	< 0.0001
Maximum	16.36	22.02	-	-

3D-CRT, three-dimensional conformal radiation therapy; IMRT, intensity-modulated radiation therapy; V_{22} Gy < 10%, Volume of heart receiving 22 Gy < 10%; $V_{18.87}$ Gy < 45%, Volume of combined lung receiving 18.87 Gy < 45%; $V_{18.87}$ Gy < 30%, Volume of combined lung receiving 18.87 Gy < 30%; V_5 Gy < 15%, Volume of contralateral breast receiving 5 Gy < 15%; D_{mean} (Gy), mean dose; D_{max} (Gy), Percentage volume of lung receiving 18.87 Gy; $D_{\text{max, Contralateral breast}}$ (%), Percentage volume of contralateral breast receiving 5 Gy.

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 and 28.09% for IMRT plans ($p = 0.0002$). The maximum lung volume receiving 18.87 Gy was 40.71% for 3D-CRT plans and 34.23% for IMRT plans. The s.d. for average lung volume receiving 18.87 Gy was 5.74 versus 4.70 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 (13.70%) 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.

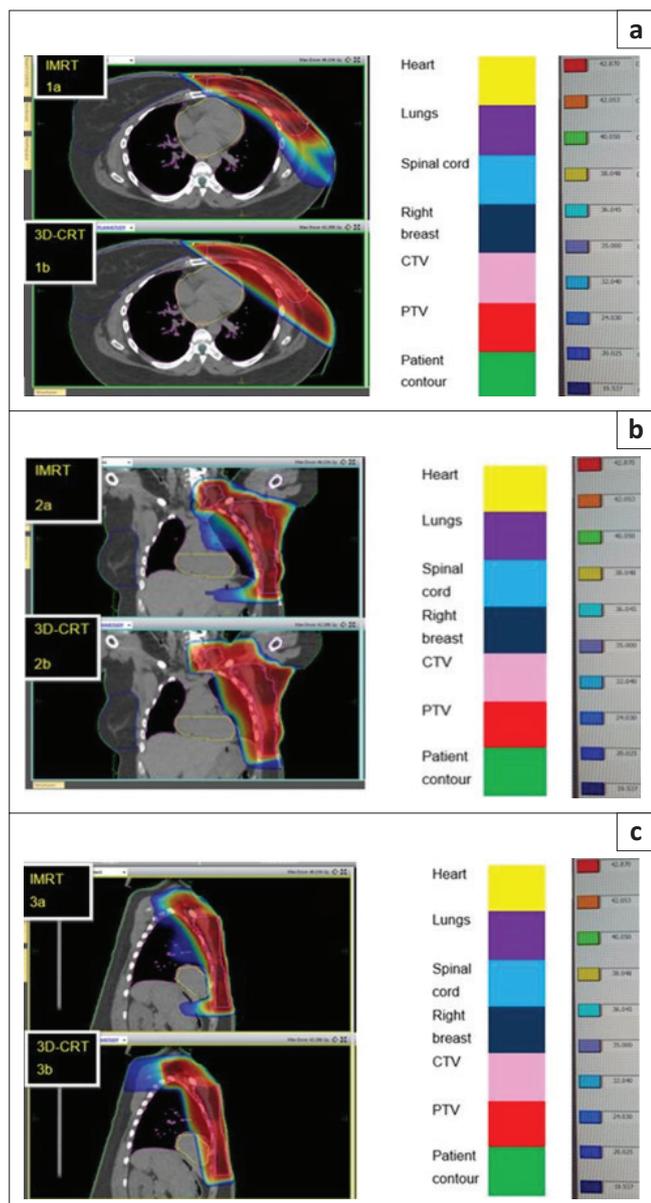
Discussion

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 $V_{95\%}$, $V_{98\%}$ and $V_{105\%}$ 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 ($V_{95\%} \geq 95\%$, 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 $V_{22} < 10\%$ 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



Note: Images: courtesy of the Department of Oncology, University of the Free State, UFS; Monaco™ treatment planning system (version 5.11.02) (Elekta Solutions AB; Stockholm, Sweden).

PTV, planning target volume; CTV, clinical target volume.

FIGURE 3: (a) Transverse plane indicating the dose coverage to the planning target volume and organs at risk for intensity-modulated radiation therapy and 3D-conformal radiation therapy. (b) Coronal plane indicating dose to the heart. (c) Sagittal plane indicating the dose conformity to the planning target volume and organs at risk for intensity-modulated radiation therapy and 3D-conformal radiation therapy.

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.¹⁴ Schubert et al. compared four different treatment planning techniques, including 3D-CRT and inverse IMRT, using a PD of 50 Gy in 25 fractions.⁴ 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.⁴ 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} 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 ($D_{\text{mean}} < 4$ 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.,¹⁵ 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.¹⁵

Radiation toxicity to the heart can lead to radiation-induced cardiac disease¹⁶ 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.¹⁷ 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 ($D_{\text{max}} < 53.1$ 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

oesophagus was included in the PTV. There was an insignificant difference in the s.d. values in 3D-CRT and IMRT plans for the dose to the oesophagus, indicating that the mean dose to the oesophagus was consistent in all the treatment plans.

Both the 3D-CRT and IMRT plans were able to remain within the set dose constraint for the ipsilateral left lung (V18.87 Gy < 45%) by maintaining the mean percentage volume of ipsilateral lungs receiving 18.87 Gy below 33.47% and 28.09%, respectively. The comparable volumes of the ipsilateral lung receiving 18.87 Gy can be attributed to the minor differences in reaching the dose constraint for the lung, as confirmed by the low s.d. difference of 1.04 between the two techniques. This confirms that the two techniques were similarly effective in achieving the desired treatment planning goal for the ipsilateral lung. Nevertheless, the maximum volume of the ipsilateral lung, which received 18.87 Gy, was higher in the 3D-CRT plans than in the IMRT plans. This finding is comparable to the results reported by Ayata et al.,¹⁸ with 3D-CRT techniques delivering a higher dose to the ipsilateral lung than IMRT techniques. It should be noted, however, that their study compared patients with breast-conserving surgery, not a mastectomy.

In order to comply with the dose constraint set for the 3D-CRT and IMRT breast radiotherapy plans in this research, the combined lung volume receiving a dose of 18.87 Gy should be limited to less than 30% (V18.87 Gy < 30%) (see Table 2). The mean percentage volume of combined lungs was within the set dose constraint goal for the two plans and demonstrated a statistically significant difference in the mean percentage volume of combined lungs receiving a radiation dose of 18.87 Gy. As the lungs are among the OAR during breast cancer radiotherapy planning, it is essential to prioritise reducing lung toxicity to prevent the development of late effects such as radiation pneumonitis. The most common pulmonary complication experienced by patients receiving breast radiotherapy is radiation pneumonitis, which can have a negative impact on their quality of life.¹⁹

According to Table 2 and Table 4, the 3D-CRT and IMRT plans met the set dose constraint of keeping the mean volume of the contralateral breast that received 5 Gy below 15%. It was observed that the IMRT plans resulted in a higher maximum volume of the contralateral breast receiving 5 Gy compared to the 3D-CRT planning technique. The higher dose delivered to the contralateral breast in the current research for the IMRT plans was similar to the findings of Beckham et al.,¹⁵ who reported that the IMRT plans had higher doses to the contralateral right breast than the 3D-CRT plans. The risk of developing contralateral breast cancer as late radiation toxicity from modern radiation therapy techniques is estimated to be significantly low, with an absolute risk of well below 1%. In addition,

the risk of death due to this late-stage radiation toxicity is expected to be even lower.²⁰

Conclusion

This research evaluated the 3D-CRT and IMRT plans according to the minimum and maximum s.d. and specific goals set for the PTVs and OAR. The advantage of IMRT plans to offer dose homogeneity and conformity to the PTV was evident in this research. As such, the IMRT plans delivered superior dose homogeneity to the PTV. In addition, the IMRT plans also reduced the volumes of the OAR receiving radiation, such as the heart, ipsilateral lung and combined lungs. On the other hand, 3D-CRT resulted in a significantly lower mean dose to the oesophagus and a considerably lower mean volume of the contralateral breast compared to IMRT.

The research included a limited number of patient plans. Although the radiation oncologists approved the treatment plans, they were not used for the patients' treatment. The ideal situation to add validity and reliability to the findings would be to repeat the research with an increased number of patients. Despite this limitation, the research demonstrated that 3D-CRT and IMRT plans for left-sided breast cancer patients after radical surgery can meet clinical requirements.

The research showed that 3D-CRT is a viable planning technique for breast radiotherapy if IMRT is unavailable. However, the use of either technique must be individualised, as there are trade-offs for both techniques. For example, with 3D-CRT, sparing of the OAR can be achieved with careful treatment planning, where the heart dose can be limited to the tolerance dose while still delivering acceptable dose coverage to the PTV. Nonetheless, the choice and accuracy of treatment planning techniques depend on the expertise and experience of the radiation oncology team.

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Competing interests

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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