DOSIMETRIC COMPARISON IN A HYBRID STUDY OF PATIENTS AND PHANTOM: IMRT VS. FIELD-IN-FIELD (3DCRT)

A.M. Baidoo[1], S.N.A. Tagoe[1,3], E.K. Sosu[2], S.B. Boateng[1], R.B. Awotwe[1], A. Mamoud[1], J.F. Nanevi[4], P.Odonkor[5], A.M. Fatormah[6]

[1] Sweden Ghana Medical Centre/Department of Radiation Oncology, Medical Physicist, Accra, Ghana
[2] University of Ghana/Department of Medical Physics, Head of Department, Accra, Ghana
[3] University of Ghana/Department of Radiography, Exam Officer, Accra, Ghana
[4] Catholic Hospital Battor /Department of Medical Imaging, Radiation Protection Officer, Battor, Ghana
[5] Korle Bu Teaching Hospital/National Centre for Radiotherapy and Nuclear Medicine, Medical Physicist, Accra, Ghana
[6] University of Ghana/Department of Biomedical Engineering, PhD Candidate, Accra, Ghana

***Abstract*—Due to its location, breast radiotherapy necessitates a high degree of accuracy in order to protect adjacent organs at risk while maximizing doses to the tumor. Numerous studies have been conducted to determine the most effective treatment planning technique that results in an optimal breast treatment. In all these research works, data sets and the medium for treatment planning were either a collection of patients or a phantom. Thus far, no study has been conducted to compare the dosimetry of these techniques using both phantom and real patients. The goal of this study is to investigate the dosimetric superiority between 3DCRT Field-in-Field and IMRT techniques for whole breast radiotherapy in a hybrid study of anthropomorphic phantom and real patients. A female Rando Alderson anthropomorphic phantom and image sets of thirty breast cancer patients that have completed whole breast radiotherapy were planned using tangential IMRT and 3DCRT Field-in-Field techniques using a prescribed dose of 50Gy in 25 fractions. The dosimetric superiority between the two treatment planning techniques were investigated by examining the quality of plans generated by each technique, using as criteria, target coverage, OAR sparing, conformity index (CI) and homogeneity index (HI). With an assessment score of 18/18 for real patients, the IMRT technique demonstrates superior dosimetry in terms of the dose parameters designated for this study. Both treatment planning techniques achieved an evaluation score of 15/18 for the phantom, with the IMRT scoring higher in OAR sparing and the FiF outperforming the IMRT in target coverage. The findings of this research indicates that tangential IMRT possesses superior dosimetry for breast cancer radiotherapy since it has the potential to dramatically lower radiation doses to OARs while maximizing target doses compared to 3DCRT FiF.**

Keywords— **Dosimetric parameters, Contralateral breast, Tangential Beam, Phantom.**

I. INTRODUCTION

Approximately 50% of cancer cases globally are treated with radiation therapy[1]. In order to achieve a greater cure rate with acceptable morbidity, the most fundamental principle is to deliver maximum dose to the tumor with minimum dose to the surrounding normal structures. The treatment planning technique and algorithm are among the most essential elements that determine the quality of radiation therapy. With 25.8% of all newly detected cases in 2020 being diagnosed with breast cancer, it is the most common cancer among women globally[2]. Meanwhile, because of its location, radiotherapy of the breast necessitates extraordinary caution in order to protect critical organs at risk (OARs) while delivering maximum doses to the breast treatment volume. Studies have noted that the rate of ischemic heart disease that follows radiation therapy for breast cancer is higher when the heart is exposed to ionizing radiation[3]. Other studies have similarly reported lung toxicities following breast irradiation involving exposure to large volumes of lung[4]. Ensuring the best technique accessible for treatment planning of breast cancer radiation therapy is essential to eliminating the aforementioned complications.

The goal of this study is to investigate the dosimetric superiority between 3DCRT Field-in-Field (FiF) and IMRT techniques for whole breast radiotherapy in a hybrid study of anthropomorphic phantom and real patients. Numerous studies have been carried out to compare the dosimetric superiority of 3DCRT-FiF and IMRT for breast cancer radiotherapy, and the findings of these investigations are being used as a basis for clinical decisions regarding the most effective technique for the best radiation dosimetry of breast cancer treatment. In all these, data sets and the medium for treatment planning were either a collection of patients or a phantom. No research has been done up to this point that compared the dosimetry of the two techniques using both phantom and real patients. The female anthropomorphic phantom is a good representation when taking into account the total PTV of the whole breast that are reported by the majority of these investigations[3]. The total PTV of the phantom in this study was 565.52 cc. However, the whole breast of the female anthropomorphic phantom is significantly smaller than the average breast size of the patients whose data were used as a representation of a typical West African woman, despite the phantom's tissue-equivalent properties. Thus, in order to present both the idealized and the clinically realistic data that might accurately represent the dosimetry of the two techniques

globally, this study was conducted using both patients and the anthropomorphic phantom.

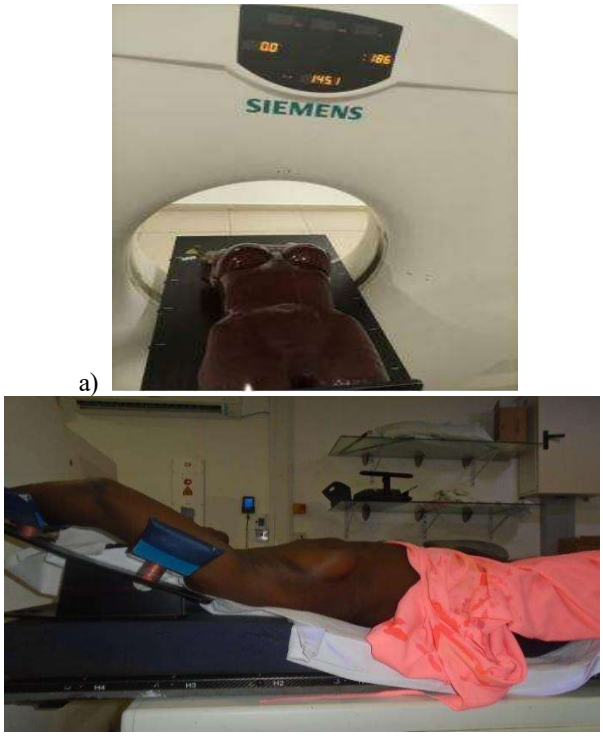
II. MATERIALS AND METHODS

Study design

A female Rando Alderson anthropomorphic phantom was used together with data from images of thirty (30) randomly selected patients, comprising of fifteen (15) each of left and right sided breast cancer patients that have completed intact breast radiation treatment for this study.

Radiotherapy Imaging and Contouring

In this study, an in-house Computed Tomography (CT) simulator, Siemens CT (Somatom Emotion 16 slice scanner) was used to scan a female Rando Alderson anthropomorphic phantom. The patient (same for phantom) was immobilized on an inclined breast board on a flat couch as shown in Figure 1. A wire was placed on the midline at the sternum of the phantom to define boundaries of both breasts. Axial CT scans using slice thickness of 3mm were acquired for the thoracic wall. The image data were exported to a treatment planning system, and 3D reconstruction was digitally obtained.



a)

b)

Figure 1: CT Setup: a) Female anthropomorphic phantom; b) Patient Setup

Delineation of the Clinical Target Volume (CTV), Planning Target Volume (PTV) and all OARs including heart, lungs and contralateral breast were done using the Monaco® workstation. For patients unlike the phantom, the CTV could as well include all axillary and parasternal lymph nodes based on tumor histological features, staging and individual characteristics. These were done according to the Radiation Therapy Planning Consensus Definitions of Breast Cancer Atlas of the Radiation Therapy Oncology Group (RTOG)[5] and the Evidence-Based Guideline for Radiation Therapy for the Whole Breast by the American Society for Radiation Oncology (ASTRO)[6]. All contours were made by the same radiation oncologist. The total PTV for the phantom was 565.52 cc. The maximum PTV for the patients was 2197.10 cc, the smallest was 653.22 cc and the average of all thirty (30) patients was 1352.37±845.53 cc. The study involved whole breast radiotherapy without supraclavicular nodes. The prescribed dose was 50.0 Gy in 25 fractions, prescribed according to the ICRU Report 50 recommendations[5], and the dose limits for all OARs were defined according to our clinical protocol.

Ethical considerations

Without any clinical application, the various treatment techniques were applied to the dataset of patients. The regulations of our institution do not require an ethical clearance for this activity.

Treatment Planning

All plans were completed in Elekta Treatment Planning System (Monaco® version 5.11.03) commissioned with beam parameters from an Elekta Synergy® linear accelerator. 3DCRT Field-in-Field (FiF) and Intensity Modulated Radiotherapy (IMRT) treatment planning techniques were used to generate treatment plans for each patient and the phantom. The primary optimization parameters for both planning techniques were the same, and these parameters were adjusted based on individual challenges pertaining to the realization of the dosimetric results with respect to treatment objectives. The planning objectives of both treatment planning techniques were generated following RTOG recommendations and are shown in Table 1. Treatment planning in both techniques for the phantom were completed independently by three Medical Physicists, unlike the patients where all plans were completed by the same Physicist.

Table 1: Optimization Objective for Treatment Planning

Structure	**Planning Aim**
PTV	$V_{50Gy} \geq 90\%$, $V_{47.5Gy} \geq 95\%$, $D_{50\%} \geq 50Gy$, $V_{51Gy} \leq 25\%$, $V_{53Gy} \leq 10\%$
Contralateral breast	$D_{max} \leq 3$ Gy, $V_{5Gy} \leq 15$ %
Ipsilateral lung	$V_{20Gy} \leq 45\%$, $V_{30Gy} \leq 35\%$
Lung (Total volume)	$V_{20Gy} \leq 30$ %, $V_{30Gy} \leq 20\%$
Heart	$D_{max} \leq 40$ Gy, $D_{average} \leq 26$ Gy, $V_{5Gy} \leq 45$ %, $V_{20Gy} \leq 20$ %

3DCRT Field-in-Field Technique

The FiF plans were generated using eight and ten beams for right and left breasts respectively with a single isocenter at the center of mass of the PTV. It involved the use of two open tangential fields and multiple field-in-fields to achieve an optimal dose distribution and desired homogeneity through complex manual fluence map optimization as shown in Figure 3.

The gantry angles of the open tangential fields were selected using the beam's-eye-view (BEV) projections to ensure complete coverage of the PTV, yet minimum beam coverage for lung and heart (for left breast) volumes. The angles were also selected to ensure that the contralateral breast is completely out of the beam with the help of the wire placed on the midline at the sternum during simulation as shown in Figure 2. With the fields carefully selected to encompass less than 2 cm of the affected lung volume from its outermost side in each axial view, the line of intersection of the two tangential fields had no overlap with the contralateral breast. There was an addition of 2 cm jaw margin to the surface of the skin. The open fields used 6MV photons for all calculations. The technique also involved calculation and plan optimization to achieve desired dose distribution with the two open fields. The open fields were given equal weighting, contributing to the entire dose distribution before introduction of the subfields. Plan dose optimization involved identification of the appropriate calculation point within the target to achieve desired dose distribution using global normalization.

When isodose lines were displayed on the 3D viewer interphase, the regions of overdose within the target became clear. A subfield was introduced for each of the two open fields with which the part of the lung that was within the beam was fully blocked with MLCs. In the case of the left breast, another subfield per angle was employed to shield the heart in a similar process to that of lung blocking.

Regarding the treatment planning of the phantom, three (3) subfields each were added, resulting in five (5) subfields per angle. These subfields were created with 15 MV photons to manually cover hot areas in a reduction sequence such as 112%, 109%, 106% using MLCs. The beam weight per subfield was 5% of its corresponding open field, and the equivalent monitor unit (MU) was 12.50. Monitor units for the subfields were calculated and the resulting isodose distribution was observed.

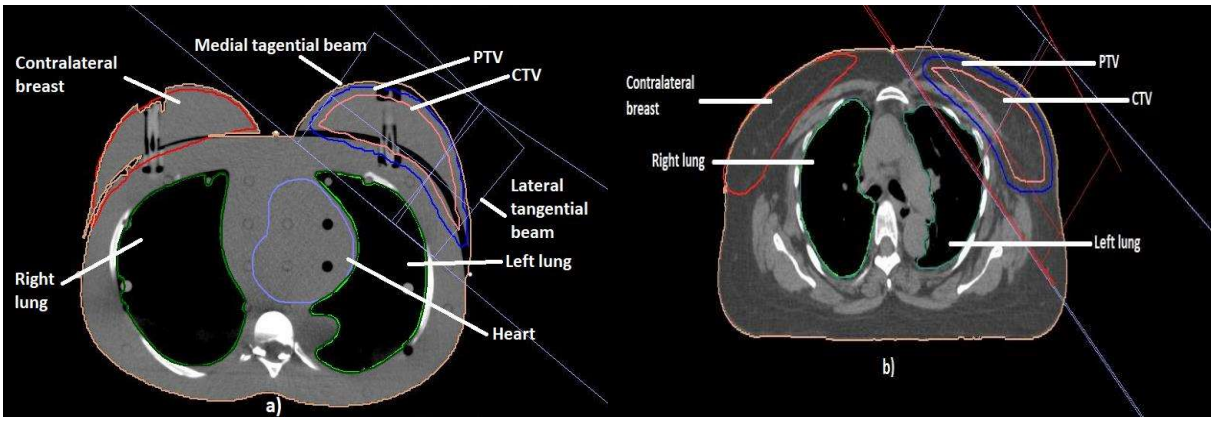
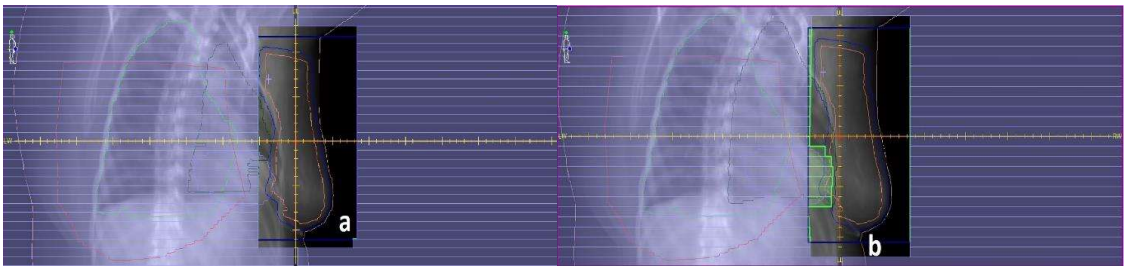


Figure 2: Axial view of 3DCRT beam arrangements: a) Phantom; b) Actual patient



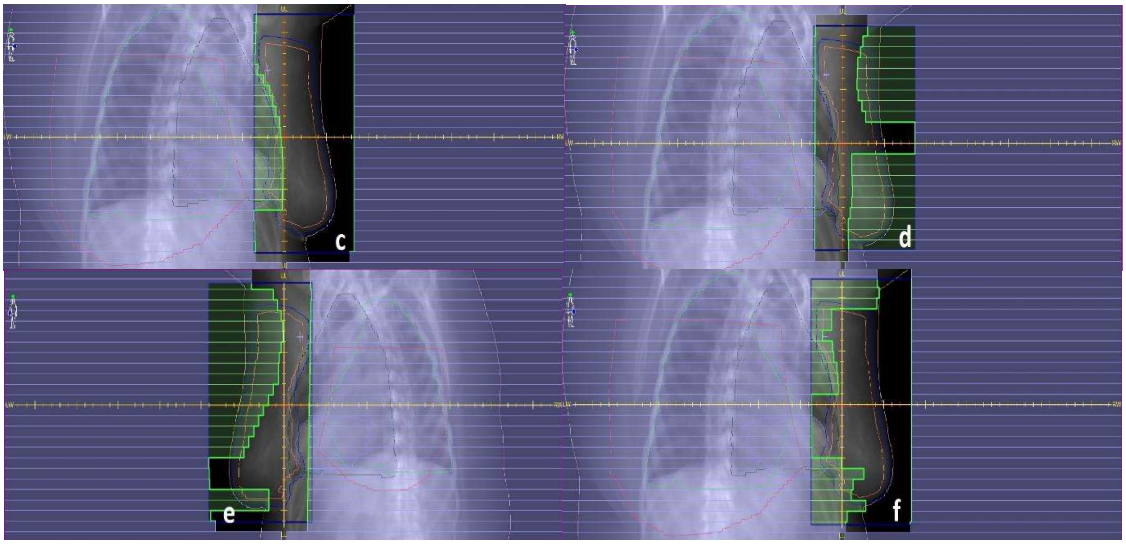


Figure 3: Manual fluence map optimization steps: a) Open field; b) Heart block; c) Lung block; d) 115% isodose block; e) 112% isodose block; f) 109% isodose block

The procedure, involving treatment fields and number of subfields used for the treatment planning of the patients were the same as that used for the phantom, except that there was no heart blocking field for right sided breast cancer patients. The subfield MUs per patient varied depending on their individual response to beam weighting. Nonetheless, the subfields were carefully weighted to reduce the respective open field MU by a percentage that was useful in maintaining good coverage and reducing hot spots. Each subfield was used in the most optimal way to acquire the best PTV coverage, homogeneity and OAR sparing.

Intensity Modulated Radiotherapy (IMRT) Technique

The IMRT gantry angles and the field parameters were similar to that of the FiF, with analogous planning goals leading to comparable initial optimization parameters to achieve the best realistic plan. As a result, the IMRT technique employed tangential IMRT (T-IMRT) planning approach, and the optimization objective is shown in Table 1.

For the phantom, the tangential IMRT (T-IMRT) plans were generated in the Monaco TPS using two tangential beams (306^0 and 129^0) with a single isocenter at the center of mass of the PTV as shown in Figure 4. This was achieved by introducing the best achievable optimization parameters to augment the medial and lateral tangential fields. The gantry angles were selected to avoid direct exposure to the contralateral breast.

For each patient, the T-IMRT plan was generated in imitation of the treatment planning of the phantom. The difference, however, is that the tangential beams had no fixed angles for all patients, as they were individually selected to suit the varying breast sizes, shapes and contours to achieve the planning objectives whilst avoiding the contralateral breast. All IMRT plans were generated in constrained optimization mode, and the appropriate optimization parameters were to make treatment planning faster and less tedious.

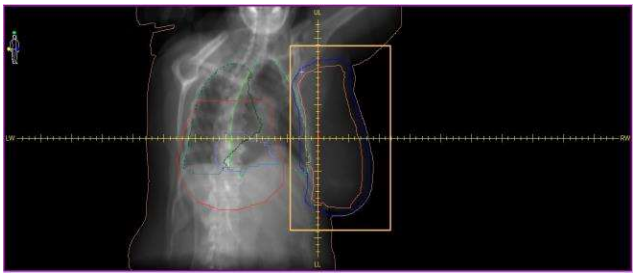


Figure 4: Lateral tangential IMRT beam

Dosimetric Criteria and Analytical Method

Global maximum dose (GD_{max}), prescription dose coverage (V_{50Gy}), conformity index (CI) and homogeneity index (HI) were then compared between FiF and IMRT as well as the percentage of target volumes receiving at least 95% of the prescribed dose ($V_{47.5Gy}$). Values for these parameters were obtained from the display of DVH statistics of the individual plans. DVH statistics were displayed, and the degree of OAR sparing between the two techniques were compared.

The conformity index (CI) was defined as the ratio of the reference isodose (95% isodose) volume to the target (PTV) volume[7], using the ICRU recommendations[5] and the ideal value was 1. Following the RTOG criteria for a defined range of CI values, and juxtaposing it with our clinical protocols, a CI range of 0.9 to 1.1 was considered tolerable. The CI was estimated as:

Conformity Index, $CI = \frac{V_{RI}}{TV}$ (equation 1),

where V_{RI} is the reference isodose volume and TV is the target volume.

The homogeneity index (HI) was defined as the ratio of the global maximum dose to the prescription dose, and the ideal value was 1[7]. In this case, it was ensured that the global maximum dose was within the target volume. A range of 0.95 to 1.07 was considered acceptable in this study. The HI was estimated as:

Homogeneity Index, $HI = \frac{GD_{max}}{D_p}$ (equation 2),

where GD_{max} is the maximum point dose and D_p is the prescription dose[8].

All data were recorded on Microsoft Excel 2016, which was used for the statistical analysis of the dosimetric parameters. The t-test comparative analysis was used to compare the dosimetric parameters and evaluate the differences between the two techniques, and a p value of 0.05 was considered statistically significant. Mean values of dose parameters were considered for 30 patients except the heart which was considered for 15 left sided breast cancers. The dose parameters presented for the phantom were mean values of the independent treatment plans generated by three Medical Physicists. With the phantom, only the left sided breast was considered.

III. RESULTS

Table 2 presents the FiF and IMRT dose parameters for target coverage. It shows the dose parameters recorded for treatment planning of the anthropomorphic phantom, and that of the 30 patients. The dosimetric values recorded for all OARs in the study are expressed under their respective techniques in Table 3. All values in Table 2 and 3 are expressed in mean ± standard deviations. Assessment of all dosimetric parameters in consideration for this study have been presented in Table 4, with 0 and 1 representing failed and passed objectives respectively.

Figure 5 provides a visual display of the performance of the two techniques on patients through their Dose Volume Histograms (DVH).

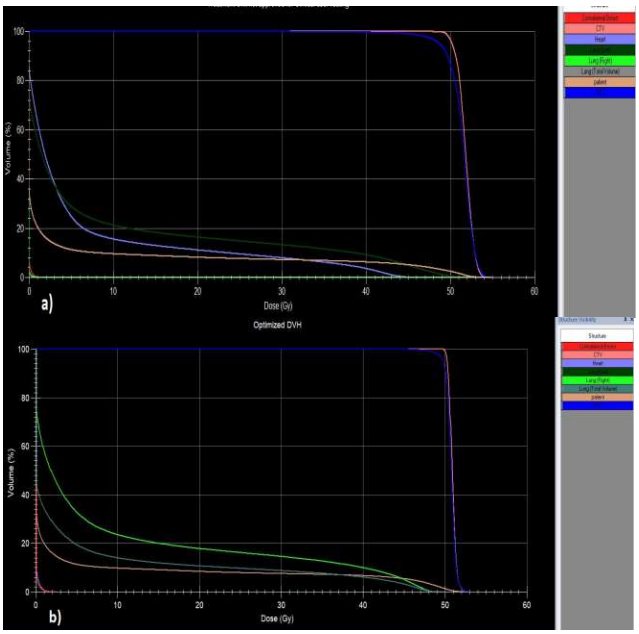


Figure 5: Dose Volume Histograms (DVH): a) 3DCRT FiF Patient DVH; b) IMRT Patient DVH

Table 2: PTV Dosimetric Parameters for FiF and IMRT ($\bar{x}$±SD)

Ptv Optimization Objective	Phantom		Patient	
	FiF	IMRT	FiF	IMRT
GD_{max} (Gy)	53.55 ± 0.28	52.19 ± 0.16	53.09 ± 0.78	51.92 ± 0.92
V_{53Gy} (%)	3.04 ± 0.90	0.03 ± 0.05	7.90 ± 1.43	0.91 ± 1.52
V_{51Gy} (%)	44.71 ± 12.58	0.78 ± 0.66	31.30 ± 9.80	23.96 ± 7.56
V_{50GY} (%)	91.69 ± 5.24	86.29 ± 5.32	83.22 ± 8.68	94.05 ± 2.64
$V_{47.5GY}$ (%)	95.94 ± 1.53	96.04 ± 2.23	96.94 ± 1.47	98.77 ± 0.81
$D_{50\%}$ (GY)	50.96 ± 0.32	49.98 ± 0.49	50.74 ± 0.50	50.64 ± 0.38
CI	0.96 ± 0.02	0.96 ± 0.02	0.97 ± 0.01	0.99 ± 0.01
HI	1.07 ± 0.01	1.04 ± 0.00	1.06 ± 0.02	1.04 ± 0.02

Table 3: OAR Dosimetric Parameters for FiF and IMRT ($\bar{x}$±SD)

Structure	OAR Constraints	Phantom		Patient	
		FiF	IMRT	FiF	IMRT
Contralateral breast	D_{max} (Gy)	4.77 ± 0.23	1.20 ± 0.23	2.73 ± 1.16	1.75 ± 0.90
	V_{5Gy} (%)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Ipsilateral lung	V_{20Gy} (%)	9.75 ± 2.20	4.16 ± 0.16	17.45 ± 2.23	13.57 ± 2.07
	V_{30Gy} (%)	6.31 ± 0.32	3.95 ± 0.13	13.52 ± 1.63	11.29 ± 1.27
Lung (Total volume)	V_{20Gy} (%)	4.02 ± 0.24	1.90 ± 0.31	9.24 ± 0.99	7.69 ± 0.74
	V_{30Gy} (%)	2.22 ± 0.31	1.00 ± 0.09	7.20 ± 1.29	4.56 ± 0.73
Heart	D_{max} (Gy)	9.55 ± 0.69	7.68 ± 1.04	42.06 ± 2.64	39.50 ± 2.63
	$D_{average}$ (Gy)	1.49 ± 0.34	0.92 ± 0.17	6.79 ± 1.07	4.59 ± 0.69
	V_{5Gy} (%)	0.58 ± 0.37	0.09 ± 0.04	25.12 ± 3.18	20.07 ± 3.15
	V_{20Gy} (%)	0.00 ± 0.00	0.00 ± 0.00	10.09 ± 1.35	7.80 ± 0.29

Table 4: Assessment Table Based on Optimization Objectives for Both Techniques on Phantom and Patients

Structure	Optimization Objective	Phantom		Patients	
		FiF	IMRT	FiF	IMRT
PTV	GD_{max} (Gy)	0	1	0	1
	V_{53Gy} (%)	1	1	1	1
	V_{51Gy} (%)	0	1	0	1
	V_{50Gy} (%)	1	0	0	1
	$V_{47.5Gy}$ (%)	1	0	1	1
	$D_{50\%}$ (Gy)	1	0	1	1
	CI	1	1	1	1
	HI	1	1	1	1
Contralateral breast	D_{max} (Gy)	0	1	1	1
	V_{5Gy} (%)	1	1	1	1
Ipsilateral lung	V_{20Gy} (%)	1	1	1	1
	V_{30Gy} (%)	1	1	1	1
Lung (Total volume)	V_{20Gy} (%)	1	1	1	1
	V_{30Gy} (%)	1	1	1	1
Heart	D_{max} (Gy)	1	1	0	1
	$D_{average}$ (Gy)	1	1	1	1
	V_{5Gy} (%)	1	1	1	1
	V_{20Gy} (%)	1	1	1	1

IV. DISCUSSIONS

This study compared the dose parameters between the two treatment planning techniques taking into consideration the volume of the PTV covered by the prescribed dose (V_{50Gy}) and at least 95% of the prescription ($V_{47.5Gy}$), the conformity index (CI) and homogeneity index (HI), as well as OAR sparing. The OAR sparing criteria involved D_{max} (Gy) and V_{5Gy} (%) of the contralateral breast, V_{20Gy} (%) and V_{30Gy} (%) of the ipsilateral lung, V_{20Gy} (%) and V_{30Gy} (%) of the whole lung, D_{max} (Gy), $D_{average}$ (Gy), V_{5Gy} (%) and V_{20Gy} (%) doses to the heart.

The global maximum dose (GD_{max}) that resulted in the best possible treatment plans were higher in FiF. The IMRT produced relatively lower GD_{max} for a desired coverage, as shown in Table 2, with a p-value of 0.00. The FiF plans of the phantom had a GD_{max} slightly above 53.5Gy (107% of prescription dose). Considering the planning objectives of the study, based on our departmental protocols, using as a guide the ICRU report 50 recommendations[5], this is above

the required range for acceptable plans. However, the result was different when the technique was applied on real patients. Although the GD_{max} for the FiF plans remained relatively higher compared to the IMRT in real patients, the patients FiF plans produced a GD_{max} (Gy) of 53.09 ± 0.78, which is clinically acceptable. Although, it has been shown that using FiF can greatly improve dose uniformity and reduce hot spots in comparison to other techniques such as tangential wedge fields (TW)[9], this study suggests that it is easier to achieve a global maximum dose that falls within the ICRU recommendations (95% to 107%) of the prescribed dose in IMRT than in FiF. Getting a good GD_{max} in FiF is possible with the use of the sub-fields to manually block hot areas within the target, but this process is sometimes difficult to achieve depending on patient characteristics. Sometimes, in treatment planning, it becomes impossible to achieve the desired GD_{max} without compromising on complete coverage of the PTV. This limitation is mostly observed in FiF technique than in IMRT, which makes the latter preferable in realizing the best global maximum dose without compromising on coverage. Additionally, in cases where the hot spot gets so close to the point of normalization, where blocking with MLC will lead to covering the norm point in FiF, achieving a desired global maximum dose become extremely difficult. In order to achieve quality radiotherapy treatment by minimizing normal tissue toxicities, it is recommended that the global maximum dose falls within a range of 95% to 107% according to the report 50 of the ICRU[5]. Although, the ICRU report 62 recommends a smaller range of values for IMRT planning[5], it was necessary to use a common criteria for the comparison of the two techniques in the study. Conversely, recent studies have suggested that local radiotherapy for cancer can cause spontaneous regression of non-directly treated malignancies, implying the involvement of systemic antitumor immune responses. So even though, some investigations have suggested that the FiF approach reduces hot spots in PTV, as reported by a dosimetric study conducted for whole breast irradiation[10], the results from this study has proven the supremacy of IMRT over FiF in terms of lower global maximum doses.

Table 2 also shows the percentage of the PTV receiving the full prescribed dose (V_{50Gy} (%)) for both techniques with a p-value of 0.00. The FiF recorded higher coverage of the prescribed dose in the phantom with 91.69 ± 5.24 than the IMRT with 86.29 ± 5.32, which implied that the IMRT could not meet the V_{50Gy} objective of the study. The higher FiF V_{50Gy} (%) value recorded in the phantom could possibly be influenced by the corresponding high global maximum dose, as clinical experience prior to this study suggests that in FiF planning, higher GD_{max} have the tendency to retain prescribed doses to a larger target volume. Despite this observation being clinically common, it could not be applied to patients, though the patients' GD_{max} was equally higher in FiF than IMRT. Rather, the IMRT produced better prescribed dose coverage in real patients with 94.05 ± 2.64 than the FiF which recorded 83.22 ± 8.68. This current study shows that target coverage in IMRT is not influenced by higher GD_{max}. This is in accordance with other findings that highlight the potential for IMRT techniques to enhance PTV uniformity and coverage[8]. This is also reinforced by a recent study which revealed that, the tangential IMRT plans, which have fewer monitor units and a shorter delivery period, is an appropriate plan for treating left sided breast cancer because they achieve good coverage of the PTV and spare OARs other than the heart and coronary arteries[11]. Consequently, IMRT has presented a dosimetric advantage of complete coverage with desirable global maximum doses in human tissues, resulting in very steep PTV curves in DVH as displayed in Figure 5. Results from the treatment planning of the phantom and that of the patient have presented conflicting results for prescription dose coverage of the PTV, this may require further investigation.

The results show that the percentage of target volumes receiving at least 95% of the prescribed dose ($V_{47.5Gy}$ (%)) was higher in IMRT than in FiF in both media. This is evident in Table 2, as the FiF produced 95.94 ± 1.53 and 96.94 ± 1.47 for phantom and patients, with the IMRT producing 96.04 ± 2.23 and 98.77 ± 0.81 for phantom and patients respectively, and 0.00 p-value. Regarding the phantom, the two treatment techniques produce contrasting results for V_{50Gy} and $V_{47.5Gy}$. Just as it was explained earlier that higher GD_{max} has the tendency to retain prescribed doses to a larger target volume, it was as well expected that the FiF would result in a higher PTV $V_{47.5Gy}$ (%) in the phantom. Yet the IMRT technique resulted in a higher $V_{47.5Gy}$ in both treatment planning media. The comparative results of $V_{47.5Gy}$ between the two techniques is consistent with the preceding results of V_{50Gy} in patients. It is also consistent with the $V_{47.5Gy}$ coverage that have been reported in literature for a range of planning studies to be from 90% to 97% of the PTV[12].

The conformity index (CI) values were observed to be better in IMRT, recording 0.99 ± 0.01 for patients, extremely close to the ideal value of 1. Since improved conformity could aid in providing the lowest exposure to OARs and the maximum dose to the target volume[13], it generates a preceding hypothesis that IMRT might be a superior technique in terms of organ sparing. Even though the CI for the FiF resulted in a competitive value of 0.97 ± 0.01 for the patients, it was slightly lower than that of the IMRT, with 0.00 p-value. The CI in this case was useful in estimating, on one hand the extent to which adjacent healthy tissues around the breast are exposed to radiation, and on the other hand the extent of coverage of the breast target volume depending on whether the CI value was greater or less than 1 respectively. It is apparent that both techniques produce seemingly equitable CI values, and this is evidenced by the equivalent CI values recorded by the two techniques in the phantom. Using the understanding that conformity indices help to assess how well treatment plans correspond to the parameters of contemporary radiation treatment, which stipulate that a 95% isodose should cover the PTV, the mathematical expression of CI in this study

makes it directly proportional to the percentage of target volumes receiving at least 95% of the prescribed dose ($V_{47.5Gy}$). It is as well a common observation that the percentage of target volumes receiving at least 95% of the prescribed dose increases with better dose conformity. Consequently, the IMRT technique yields superior CI values since it demonstrates higher values for $V_{47.5Gy}$, especially regarding calculations for the actual patients. Recent research works have also shown that IMRT significantly improves CI when compared to 3DCRT. But there was no significant change in HI[14]. So while the homogeneity between the two techniques stays comparable in that study, IMRT significantly increased the plan's conformity[14].

The homogeneity index (HI) values recorded by the IMRT plans were closer to the ideal value of 1 with approximately a constant value of 1.04 ± 0.00 for calculations in both phantom and patients. Since the HI was used to analyze the uniformity of dose distribution within the target[8], the IMRT proved to provide a more uniform dose. The HI values for the FiF technique were equally close to the ideal value with 1.07 ± 0.01 and 1.06 ± 0.02 for calculations in phantom and patients respectively, and a p-value of 0.00. This is inconsistent with the report of a study that suggested that IMRT did not significantly improve either HI or CI[15]. This dosimetric tool was necessary to confirm that the entire treatment volume was being irradiated with approximately the same amount of tolerable radiation dose. The formula used for HI in this study makes it solely reliable on the global maximum dose. This suggests that the HI value is determined by how close the GD_{max} is to the prescription. The closer the GD_{max}, the better the homogeneity, and the closer the HI will be to the ideal value, and the vice versa. Accordingly, the worst HI value observed from Table 2 is that of the FiF plan of the phantom which correspondingly recorded the highest GD_{max} of 53.55 ± 0.28, approximately 107.1%. Similarly, the best HI value recorded is that of the IMRT plan of the patients, recording 51.92 ± 0.92, approximately 103.84%. This mathematical expression of HI makes it a coherent dosimetric parameter in treatment planning in the patients. Work done by Beckham et al. found that IMRT considerably improved both CI and HI[16]. Additional studies comparing the dosimetric characteristics of IMRT to 3D-CRT for the chest wall have shown that the conformity and homogeneity indices have improved[10].

Both treatment planning techniques present competitive advantages in terms of target coverage, conformity and homogeneity for whole breast radiotherapy planning. Nevertheless, the IMRT technique demonstrates superior dosimetry regarding the dose parameters for the real patients in this study. Also, just as it has been reported by similar studies, since the treatment planning system can do automatic fluence optimization to obtain the ideal dose distribution, inverse planning techniques are typically simpler than forward planning[9]. The FiF outperformed the IMRT when the phantom was used as the treatment planning medium. This is consistent with other previous works but differs in some parameters with others[3]. It has equally been reported that when treating breast cancer following a mastectomy and immediately after breast reconstruction, the IMRT technique is appropriate[17]. Also, following breast conserving surgery, patients who received IMRT showed improved clinical outcomes and acceptable acute toxicity[17]. In contrast to the conventional technique, T-IMRT plans significantly improved the PTV, HI, heart, and whole lung sparing in another research comparing 2D plans for adjuvant radiotherapy of the whole breast in cases with early breast cancer[10].

The contralateral breast in this study has far more been spared by IMRT than FiF as shown by the D_{max} of the contralateral breast recorded for both techniques in phantom and patients in Table 3. The FiF recorded D_{max} of 4.77 ± 0.23 in the phantom and 2.73 ± 1.16 in patients. The IMRT recorded D_{max} of 1.20 ± 0.23 and 1.75 ± 0.90 for phantom and patients respectively. This implies that the D_{max} constraint for the contralateral breast was met by all IMRT plans. Other findings imply that compared to other techniques, T-IMRT and FFF-IMRT techniques may be able to lower the exposure dose and volume to contralateral breast[17]. Considering the phantom, the FiF recorded a higher D_{max} for the contralateral breast with a value above the limits of the planning objectives in Table 1. The FiF however recorded an acceptable D_{max} value in patients although the value is relatively higher compared to the IMRT value recorded in patients. Both treatment techniques also met the contralateral breast's V_{5Gy} constraint, as they both recorded 0.00 ± 0.00 in phantom and patients. This value is consistent with their corresponding D_{max} values, since all contralateral breast D_{max} values were less than 5Gy. The IMRT outperforms the FiF in this objective, making it reliable for prevention of secondary cancer probability since a number of studies have reported that the risk of developing a secondary cancer rises as the radiation exposure to the contralateral breast increases[18]. According to some research works, when IMRT was used instead of traditional 3DCRT, the contralateral breast dose was decreased. Another study confirmed this, with tangential IMRT demonstrating lower contralateral breast doses than 3DCRT. With 5-field IMRT, on the other hand, this is not the case because more fields were used, which led to a low dose spill to a larger contralateral breast volume. Given that patients under 40 are more likely to develop secondary contralateral breast cancer, this can be quite important[19]. Other studies, however, discovered that the scatter dose to the contralateral breast is highly influenced by the size of the ipsilateral breast[3].

The IMRT resulted in lesser ipsilateral and whole lung doses than the FiF in both media. Observing from Table 3, the FiF plans recorded V_{20Gy} (%) of 9.75 ± 2.20 for phantom and 17.45 ± 2.23 for patients, whilst the IMRT recorded 4.16 ± 0.16 and 13.57 ± 2.07 for phantom and patients respectively for the ipsilateral lung. With the ipsilateral lung V_{30Gy} (%), the FiF resulted in 6.31 ± 0.32 for phantom and

13.52 ± 1.63 for patients, whilst the IMRT recorded relatively lesser values of 3.95 ± 0.13 and 11.29 ± 1.27 for phantom and patients respectively. Concerning the whole lung doses as shown in Table 3, the V_{20Gy} (%) of the FiF resulted in 4.02 ± 0.24 and 9.24 ± 0.99 for phantom and patients respectively, with the IMRT producing significantly smaller values of 1.90 ± 0.31 for phantom and 7.69 ± 0.74 for patients. Similarly, the FiF technique recorded relatively higher V_{30Gy} (%) values of 2.22 ± 0.31 and 7.20 ± 1.29 for phantom and patient respectively, whilst the IMRT recorded 1.00 ± 0.09 for phantom and 4.56 ± 0.73 for patients. Considering how small the recorded V_{20Gy} and V_{30Gy} lung doses are for both treatment techniques, it is easier for one to overlook the comparative differences between the two, however, it is significant to make a decision about the dosimetric superiority between them using as part of the factors, the constraint in question. It is also obvious that both planning techniques have lung sparing advantages based on the results of Table 3, though, the IMRT is incredibly a good choice based on this study.

The IMRT technique proved to possess heart sparing advantages than the FiF in all the aspects of heart constraints specified for the study. Generally, the heart doses recorded for the phantom were significantly low for both techniques with the V_{20Gy} (%) constraint in the phantom recording 0.00 ± 0.00 for both techniques. In the patients, the heart D_{max} (Gy) values were very high for both planning techniques, with the FiF failing to meet the planning objective with a heart D_{max} of 42.06 ± 2.64. In spite of the fact that the IMRT doses were lesser and fairly within the specified limit, the recorded D_{max} of 39.50 ± 2.63 is still high and very close to the limit. The other heart constraints such as the $D_{average}$ (Gy), V_{5Gy} (%) and V_{20Gy} (%) were all lesser in IMRT than FiF. This upholds the report of previous studies suggesting that the use of IMRT offers the possibility of better local-regional treatment without increasing cardiac toxicity[19]. In line with the report of Liu et al., who discovered that double-arcs VMAT and 5-field IMRT both had larger cardiac doses than 3DCRT, a recent study demonstrated that tangential beam approaches can result in lower heart doses, underscoring the benefit of enhanced organ sparing in comparison to the usage of multi-fields or arcs employing methodologies[20]. Consequently, Rudat et al. reports that, tangential beam IMRT significantly decreased the mean heart dose by 20% and the V55 by an average of 43%[21]. This is similar to the findings of Beckham et al. who suggested that, IMRT substantially reduced the volume of the heart that receive more than 30 Gy[16].

The lung and heart doses were observed to be quite minimum in phantom than in patient for both treatment techniques. This observation could be as a result of a number of things. Visible among these factors is how close the target is to the heart and lungs. This hypothesis resulted in a further analysis to investigate the cause of the above-stated observation by physically examining the distances between the breast target and the OARs in question. The breast PTV of the phantom encompassed the whole breast, but the breast PTV of the patients encompassed the whole breast and sometimes covered axillary and parasternal lymph nodes depending on the clinical need. Thus, the patients' PTV were averagely huge and closer to the heart and lungs than that of the phantom. Considering that the volume of the phantom PTV was 565.52 cc, whilst the average PTV of all 30 patients was 1352.37±845.53 cc, it advances to suggest that treatment of smaller breast sizes has lower the risk of exposure to the lung and heart. Although this investigation proved to uphold this notion based on visual comparison of PTV-to-OAR distance and breast treatment volumes of the 30 patients involved in the study, the fear of digressing from the objectives of this study kept the work from such further investigation. But generally, the IMRT technique ensures higher target volume coverage while minimizing the exposure to contralateral breast, with tolerable doses to the ipsilateral lung and heart, according to recent study findings[17]. Finally, compared to 3DCRT, IMRT offers the possibility of a large reduction in the mean dose and high-dose volumes of the ipsilateral lung and heart, even when used for chest wall irradiation in patients with left-sided breast cancer who have undergone a mastectomy[14].

Each treatment planning technique has been evaluated based on its overall score on various dose parameters that are part of the comparative criteria in Table 4, with 0 and 1 signifying failed and passed objectives, respectively. With an assessment score of 18/18 for real patients, the IMRT stands out as the best technique in human tissues. Both techniques receive an evaluation score of 15/18 for the phantom, with the IMRT scoring higher in OAR sparing and the FiF outperforming it in target coverage. While 3DCRT is often recommended for radiation treatment of breast cancer, research indicates that IMRT use can dramatically lower radiation doses to OARs while providing superior target coverage over 3DCRT[17]. In terms of target coverage, mean dose, and OAR sparing in early breast cancer, a comparison study between 3DCRT and IMRT treatment plans found that the IMRT technique significantly reduced the dose to OARs and normal tissue, with a better target coverage than 3DCRT[14]. In a single therapy delivery phase, IMRT provides an opportunity to increase doses to specific regions within the target volume. For normal tissues or critical structures around the target volume, the treatment technique offers improved dose sparing[22]. According to other studies, over 90% of patients continue to live disease-free for years following IMRT, indicating that the patient's quality of life either stays stable or improves with time[23]. In radiotherapy, IMRT is known for its steep in-field dose gradient, which promotes improved OAR sparing and dose conformity to the PTV. Based on many dosimetry investigations on linac-based IMRT treatments of various anatomical sites, it provides substantial dosimetric advantages over conventional techniques. Numerous studies have documented the potential benefits of IMRT over 3DCRT, including the decrease in the probability of an in-

field recurrence, the reduction of treatment-related morbidity, and the enhancement of local control[22]. Baidoo reported that while IMRT might potentially improve target dose conformity, reduce exposure to normal tissues, and allow for dose escalation, it has superior dosimetric advantages over 2D and 3DCRT techniques, and that includes FiF planning[22]. Several studies have also addressed the decision-making process about radiation therapy for breast cancer and have been suggested that T-IMRT is the optimum method for treatment[3].

Limitations

It is imperative to acknowledge the following as part of the key limitations in this study. First of all, the procedure followed to conduct the investigation is a standard one, yet it is subject to our perfection to avoid human errors. As a result, additional research may be necessary to confirm the study's methodology while taking the resources into account. Secondly, although the results regarding the phantom may be able to offer a standardized and universal representation, the entire work may not be able to provide such a global representation of breast dosimetry because all the patients involved in this study, with the exception of one, were natives of the West African region.

V. CONCLUSIONS

This study shows that T-IMRT planning results in low global maximum doses for the desired target coverage in both anthropomorphic phantom and actual human tissues. Regarding the percentage of target volume covered by the prescribed dose (100% isodose), the two planning techniques show contradictory results in the two media, with the IMRT providing the best coverage in human tissues and the FiF outperforming it in the phantom, an observation that may require further investigation in the field. But generally, the IMRT demonstrates superior dosimetry in terms of PTV coverage, CI and HI in real patients.

Inasmuch as both treatment planning techniques demonstrate organ sparing competences, the T-IMRT results in lesser ipsilateral and whole lung doses than FiF in phantom and patients. The findings of the study suggest that the T-IMRT has a better heart sparing significance in both media, and a higher potential to spare the contralateral breast. Consequently, IMRT demonstrates superior advantage of OAR sparing to FiF.

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Contacts of the corresponding author:

Author:	Alhassan Mohammed Baidoo
Institute:	Sweden Ghana Medical Centre
Street:	East Legon Hills
City:	Accra
Country:	Ghana
Email:	ambaidoo1@gmail.com