ENHANCING BREAST RADIOTHERAPY: EVALUATING THE INFLUENCE OF HEART LIMITATION ON TARGET COVERAGE AND DOSIMETRY FOR IMPROVED TREATMENT OUTCOMES

A.M. Baidoo[1], E.K. Sosu[2], S.N.A. Tagoe[1,3], R.B. Awotwe[1], S.B. Boateng[1], B. Djan[4], A. Mamoud[1], A.K. Arthur[5]

[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] Ghana Atomic Energy Commission/Radiation Protection Institute, Research Scientist, Accra, Ghana
[5] Tiwnikli International Senior High School/Department of Science, Physics Tutor, Accra, Ghana

Abstract— **An optimal radiotherapy plan must primarily ensure comprehensive target coverage in order to inhibit the possibility of recurrence. Complete coverage in breast radiotherapy has over the years remained a challenge due to its location. This work aims to determine the impact of a heart limitation on complete target coverage, and to look into how breast position affects its dosimetry in radiotherapy. Treatment plans for fifteen (15) each of left and right-sided breast cancer patients, with similar body thickness and breast sizes, that have completed intact breast radiotherapy were generated, and dose parameters regarding target coverage were assessed for both breast locations. Treatment plans for the left breast patients were regenerated, in which the heart d_{max} constraint was varied with five different values whilst recording the target dosimetry at each variation. It was easier to achieve complete coverage in right breasts than the left, in terms of 100% and 95% reference isodose. Treatment planning for right breasts likewise resulted in relatively preferred dose conformity. Meanwhile, the left breasts produced relatively higher mean doses and better homogeneity. Target coverage did not vary significantly with changing heart constraints in IMRT planning, with some parameters staying nearly constant throughout the variation. This implies that, using IMRT, heart constraints have negligible effect on target coverage for breast radiotherapy. There were highly significant changes in target dosimetry when heart constraints were varied in 3DCRT planning, suggesting that heart constraint imposes substantial effect on target coverage in 3DCRT breast radiotherapy. The value of the heart D_{max} constraints used in treatment planning may limit complete target coverage in breast radiotherapy. The degree of this limitation, however, depends on the treatment planning technique. The additional restriction imposed by the heart constraint in left breast radiotherapy results in relatively poor target coverage and lower dose conformity.**

Keywords— **Prescription, Coverage, Dosimetry, Conformity, Homogeneity.**

I. INTRODUCTION

The quality of every radiotherapy treatment is determined by complete target coverage, normal tissue sparing, dose conformity and homogeneity[1]. Additional variables such as Normal Tissue Complication Probability (NTCP) and Secondary Cancer Complication Probability (SCCP) depend on Conformity Index (CI) and Homogeneity Index (HI) of the treatment plan respectively[2]. To prevent recurrence of the disease, an optimal radiotherapy plan must essentially provide comprehensive target coverage. Concurrently, clinical evidence suggests that the extent to which total coverage may be achieved depends on the kind and number of adjacent organs at risk (OAR).

Complete coverage in breast radiotherapy has over the years remained a challenge due to its location, and this is frequently seen in treatment planning for left breasts. It is only important to investigate complete coverage between the left and right breasts, as well as the effect of some OARs on complete coverage for breast radiotherapy plans using similar patient thickness and breast sizes, since several factors, such as sizes and shapes of breasts, patient thickness, size of the planning target volume (PTV), beam energy and beam weighting, can all affect the complete coverage in breast radiotherapy[3].

The purpose of this work is to determine the impact of a heart limitation on complete target coverage, and to look into how breast position affects its dosimetry in radiotherapy.

II. METHODOLOGY

Radiotherapy planned image data from Siemens CT simulator (Somatom Emotion 16 slice scanner) for 15 each of left and right-sided breast cancer patients, with similar body thickness and breast sizes, that have completed intact

breast radiotherapy were selected for this study. The images were exported to a treatment planning system, where 3D reconstruction were digitally obtained for the sagittal, coronal and axial images of the patients.

All contours except the PTV were completed by a Radiation Oncologist using the Monaco® version 5.11.03 workstation. The PTV was created by a Medical Physicist by expanding the CTV using the auto margin contouring feature of the TPS by an isotropic margin of 10 mm in three dimensions and contracting laterally to 5 mm under the skin. The maximum and the minimum PTVs for all images involved in the study were 1285.43 cc and 1204.78 cc respectively. The prescribed dose was 50.0 Gy in 25 fractions for all patients, and the prescription was done according to the ICRU Report 50 recommendations[4], with 95% isodose line of the prescribed dose required to cover 95% of the PTV (V95%≥47.5Gy). The OAR constraints were defined according to our clinical protocol as expressed in Table 1.

Treatment plans for all 30 patients were generated in an Elekta TPS Monaco® version 5.11.03. The Monaco TPS works on a network of two main high-performance computers (Intel® Xeon® Gold 6132 2.60GHz processor, 128GB DDR3 RAM, 1TB Storage), with both connected to the center's central server.

In phase 1 of the study, 3DCRT Field-in-Field (FiF) and Intensity Modulated Radiotherapy (IMRT) techniques were used to complete the treatment plans for all patients by the same medical physicist, taking into consideration the OAR objectives of Table 1. In phase 2 of the study, the aforementioned treatment planning techniques were employed to generate plans for the fifteen (15) left sided breasts, using the same OAR objectives in Table 1 except the heart. The heart D_{max} constraint in phase 2 was varied between $D_{max} \leq 48$ Gy, $D_{max} \leq 44$ Gy, $D_{max} \leq 40$ Gy, $D_{max} \leq 36$ Gy and $D_{max} \leq 32$ Gy.

The Field-in-Field (FiF) technique used a 3D conformal forward planning technique that employs electron density calibration curve to determine homogeneous media and density in the body using Collapsed Cone Convolution dose calculation algorithm. It involved the use of two tangential open fields and multiple field-in-fields that were repeated until the desired dose homogeneity was achieved within the target.

The IMRT technique used an inverse planning method that relies on electron density calibration curve to define homogeneous media and body density using Monte Carlo dose calculation algorithm for a segmented treatment. The Monaco TPS combined Monte Carlo dose calculation accuracy with robust optimization tools to generate IMRT plans with fast calculation speed using calculation properties of 3mm grid spacing and 3% Statistical Uncertainty per control point. All IMRT plans were generated with only two tangential beams in constrained optimization mode to stimulate normal tissue priority. The biological and physical cost functions were rightfully employed to make treatment planning faster and less tedious. Dose volume histogram (DVH) statistics was used along with the IMRT constraints tab to identify conflicts that makes it difficult to meet the planning goal following the isoconstraint, isoeffect and the relative impact display. The multicriterial optimization tool were selected for some cost functions to spare OARs as much as possible while maintaining target coverage.

The global maximum dose accepted was 107% of the prescribed dose with the isodose distribution being symmetrical in all axial planes considering ICRU report 50 recommendations. The DVH for each plan was displayed for plan analysis.

Table 1: Phase 1 OAR Optimization Objective

Structure	**Optimization Goal**
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, $V_{5Gy} \leq 45$ %, $V_{20Gy} \leq 20$ %

The dosimetry for both breasts were studied by examining the PTV dose coverage for all 30 plans generated by each technique, using as criteria, full prescribed dose coverage, 95 % prescribed dose, mean dose, conformity index (CI) and homogeneity index (HI).

The conformity index is expressed in equation 1 as the ratio of the reference isodose (95% isodose) volume to the PTV, where V_{RI} is the reference isodose volume and TV is the target volume. Using the ICRU recommendations[5], the ideal value was 1.

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

The homogeneity index is expressed in equation 2 as the ratio of the maximum PTV dose to the prescribed dose[6], where $PTV\ D_{max}$ is the maximum point dose and D_p is the prescription dose, with 1 as the ideal value .

Homogeneity Index, $HI = \frac{PTV\ D_{max}}{D_p}$ (2),

Microsoft Excel 2016 version was used to record and analyze all dosimetric information collected from the study, and one-way ANOVA test was used to compare the dose parameters between the two set of patients with a p-value of 0.05 being statistically significant.

Ethical clearance

Using the dataset of the selected previously treated patients, treatment plans were created using the treatment planning system only without any clinical application. This activity does not require ethical clearance according to our institution's policies.

III. RESULTS

Table 2 presents the dosimetric parameters for PTV coverage for the left and right breasts for both treatment techniques. It expresses the dose parameters for TPS calculations in both techniques recorded for the treatment plans produced for all patients in phase 1. The results of phase 2 of the treatment planning of the left breast recorded for each of the dosimetric objectives achieved with the variation of the heart D_{max} constraint are expressed in Table 3. Values in Table 2 and 3 are all expressed in mean ± standard deviations. In Figure 1, a sagittal view of the isodose distribution on the TPS interphase have been displayed for the designated heart D_{max} constraints in phase 2. Figure 2 provides an illustration of the limitation the heart imposes on target coverage through a graph of Heart Dmax constraint versus the designated PTV dose parameters for both 3DCRT FiF and IMRT techniques for treatment planning of the left breast.

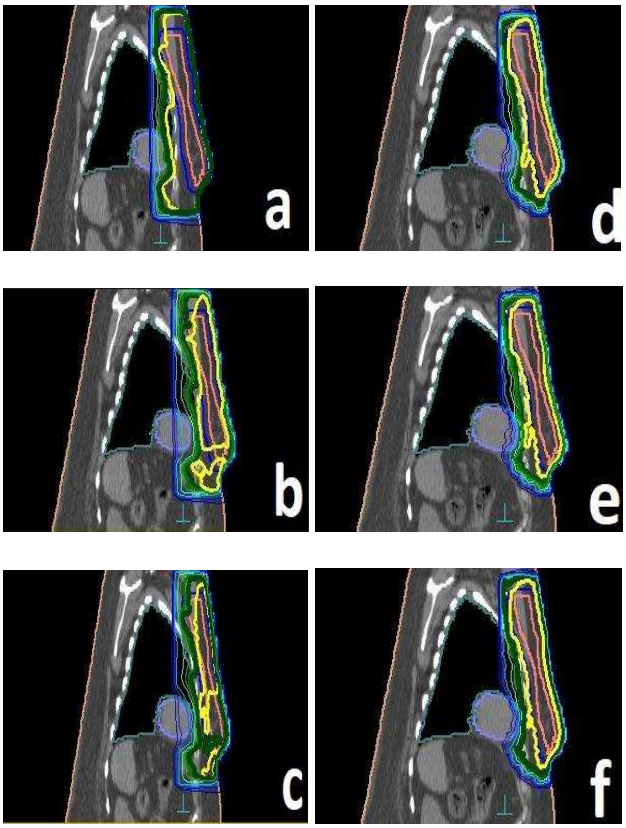

Figure 1: Dose display of variation in heart D_{max} constraint in a sagittal view: a) D_{max} = 48Gy in 3DCRT; b) D_{max} = 40Gy in 3DCRT; c) D_{max} = 32Gy in 3DCRT; d) D_{max} = 48Gy in IMRT; e) D_{max} = 40Gy in IMRT; f) D_{max} = 32Gy in IMRT

Table 2: Parameters for Target Coverage in Left and Right Sided Breasts in Phase 1 ($\bar{x}$±SD)

OBJECTIVE	3DCRT FIF		IMRT	
	Left Breast	Right Breast	Left Breast	Right Breast
V_{50GY} (%)	82.61 ± 9.07	83.83 ± 8.23	93.72 ± 2.31	94.38 ± 2.89
$V_{47.5GY}$ (%)	96.55 ± 1.33	97.33 ± 1.49	98.29 ± 0.73	99.24 ± 0.59
$D_{50\%}$ (GY)	50.84 ± 0.55	50.64 ± 0.42	50.78 ± 0.40	50.50 ± 0.30
CI	0.97 ± 0.01	0.97 ± 0.01	0.98 ± 0.01	0.99 ± 0.01
HI	1.06 ± 0.02	1.07 ± 0.02	1.04 ± 0.02	1.04 ± 0.02

Table 3: Changes in Target Coverage for Left Breasts over Varying Heart D_{max} in Phase 2 ($\bar{x}$±SD)

Parameter for Target Coverage	Heart D_{max}	3DCRT FiF	IMRT
V_{50Gy} (%)	D_{max} = 48 Gy	95.26 ± 2.64	93.91 ± 2.16
	D_{max} = 44 Gy	91.36 ± 2.13	93.79 ± 1.65
	D_{max} = 40 Gy	65.78 ± 1.35	93.56 ± 2.15
	D_{max} = 36 Gy	64.41 ± 2.06	93.47 ± 0.87
	D_{max} = 32 Gy	30.30 ± 3.63	93.45 ± 1.58
$V_{47.5Gy}$ (%)	D_{max} = 48 Gy	98.60 ± 1.04	98.70 ± 0.56
	D_{max} = 44 Gy	97.46 ± 2.07	98.68 ± 0.59
	D_{max} = 40 Gy	94.76 ± 1.16	98.67 ± 0.68
	D_{max} = 36 Gy	94.49 ± 3.01	98.64 ± 0.97
	D_{max} = 32 Gy	90.28 ± 1.45	98.59 ± 0.89
$D_{50\%}$ (Gy)	D_{max} = 48 Gy	53.12 ± 1.08	50.94 ± 0.60
	D_{max} = 44 Gy	52.21 ± 1.19	50.93 ± 0.34
	D_{max} = 40 Gy	50.43 ± 2.00	50.92 ± 0.68
	D_{max} = 36 Gy	50.39 ± 0.72	50.89 ± 0.24
	D_{max} = 32 Gy	49.48 ± 1.16	50.87 ± 0.71
CI	D_{max} = 48 Gy	0.99 ± 0.08	0.99 ± 0.00
	D_{max} = 44 Gy	0.97 ± 0.03	0.99 ± 0.01
	D_{max} = 40 Gy	0.95 ± 0.04	0.99 ± 0.01
	D_{max} = 36 Gy	0.94 ± 0.05	0.99 ± 0.01
	D_{max} = 32 Gy	0.90 ± 0.10	0.99 ± 0.02
HI	D_{max} = 48 Gy	1.09 ± 0.04	1.04 ± 0.01
	D_{max} = 44 Gy	1.07 ± 0.01	1.04 ± 0.01
	D_{max} = 40 Gy	1.05 ± 0.05	1.04 ± 0.01
	D_{max} = 36 Gy	1.05 ± 0.02	1.04 ± 0.00
	D_{max} = 32 Gy	1.03 ± 0.09	1.04 ± 0.01

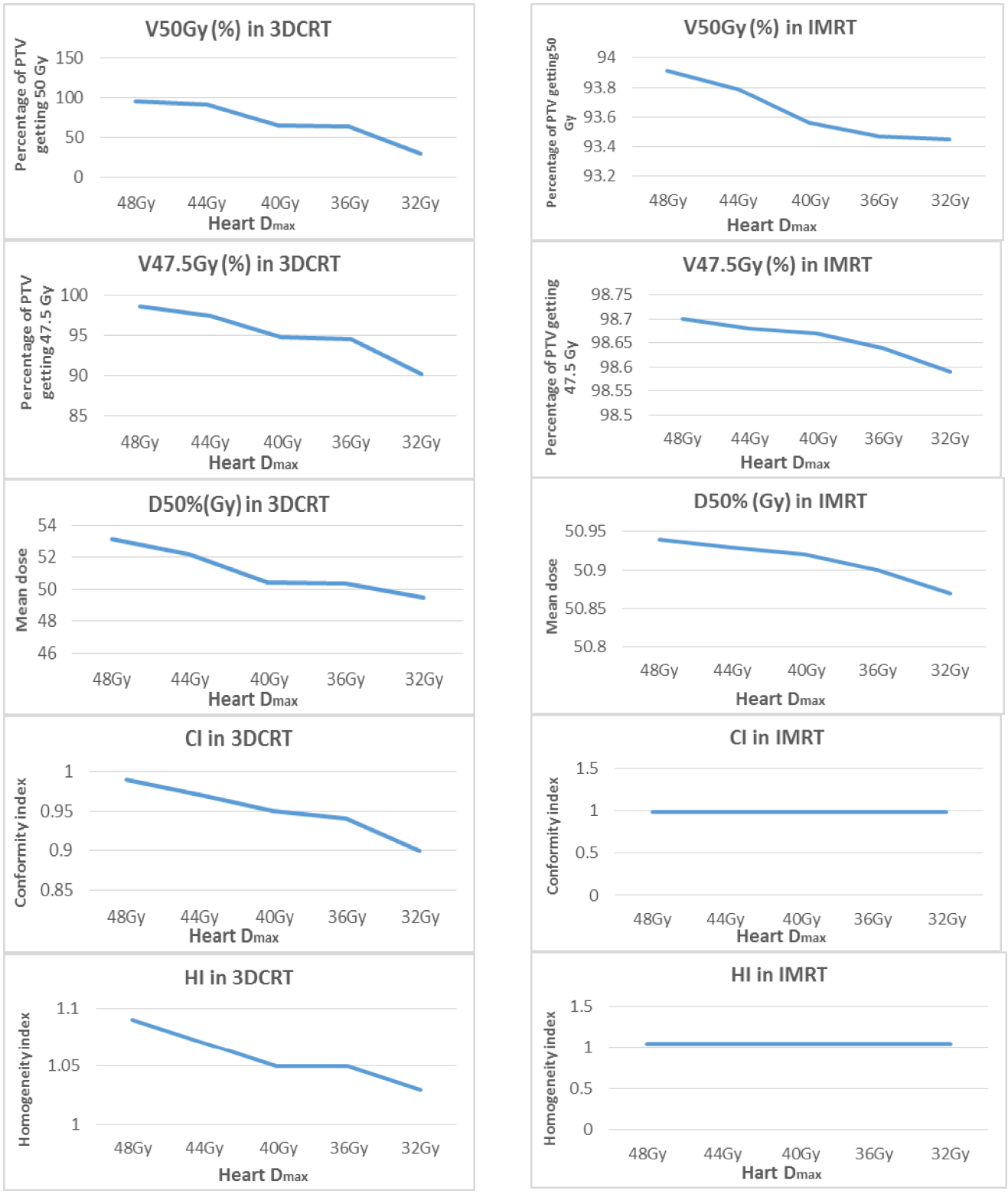

Figure 2: Graph of Heart Dmax constraint versus the designated PTV dose parameters for both 3DCRT FiF and IMRT techniques for treatment planning of the left breast

IV. DISCUSSIONS

Phase 1

In phase 1 of this study, PTV dose parameters were compared between the left and right-sided breasts to investigate the influence of breast position on PTV dosimetry for breast radiotherapy. This was realized by comparing the dosimetric parameters in terms of percentage of PTV covered by the full prescription dose (V_{50Gy}) as well as the 95% of the prescription ($V_{47.5Gy}$), the mean PTV dose ($D_{50\%}$), the Conformity Index (CI) and the Homogeneity Index (HI), taking into account the OAR objectives in Table 1.

The percentage of target volume that was covered by the full prescription dose was mostly higher in right breasts than in the left breasts, with all OARs passing the constraints, with a p-value of 0.00. This is seen in the results of V_{50Gy} (%) objective of Table 2 for both treatment planning techniques. The left breast recorded 82.61 ± 9.07 in 3DCRT and 93.72 ± 2.31 in IMRT whilst the right breast recorded 83.83 ± 8.23 in 3DCRT and 94.38 ± 2.89 in IMRT. Based on this, it is obvious that for similar breast sizes, achieving the full prescription in right breasts is easier than the left.

Following the ICRU recommendations where the 95% of the PTV is recommended to receive 95% of the prescription, both the left and right breasts in this study presented very good results, with a p-value of 0.00. However, the right breasts recorded a higher coverage of $V_{47.5Gy}$ (%) with 97.33 ± 1.49 in 3DCRT and 99.24 ± 0.59 in IMRT than the left breasts with 96.55 ± 1.33 in 3DCRT and 98.29 ± 0.73 in IMRT, with all OARs meeting their specified constraints in Table 1.

With a p-value of 0.01, the mean PTV doses were higher in left breasts than in right breasts for both planning techniques. The left breasts produced $D_{50\%}$ (Gy) values of 50.84 ± 0.55 in 3DCRT and 50.78 ± 0.40 in IMRT whilst the right breasts produced 50.64 ± 0.42 in 3DCRT and 50.50 ± 0.30 in IMRT. The outcomes of the mean dose values in both techniques are inconsistent with the V_{50Gy} (%) and $V_{47.5Gy}$ (%) outcomes, with a possible implication that mean dose values are generally higher in left breast radiotherapy plans than the right sided.

In the 3DCRT technique, both the left and the right breasts recorded seemingly equal CI values of 0.97 ± 0.01 and a p-value of 0.00. However, this is as result of a decimal approximation on the part of the left breast whose $V_{47.5Gy}$ (%) value was 96.55 ± 1.33. Due to the mathematical rule employed in the calculation of the CI values as stated in equation 1, the CI could be expressed as a mere fraction of the percentage value recorded in the $V_{47.5Gy}$ (%), thus a decimal approximation to two decimal places results in 0.97 rather than 0.9655. It becomes a bit clearer to understand that the CI value was ideally higher in right breasts than in left breasts for 3DCRT planning. In the IMRT technique also, the right breasts recorded a higher CI than the left breasts with 0.99 ± 0.01 for right breasts and 0.98 ± 0.01 for left breasts.

The dose homogeneity is the same for both left and right breasts in IMRT with an HI value of 1.04 ± 0.02. In 3DCRT technique, the left breasts produced a homogeneous value than the right breasts with a p-value of 0.01. The HI recorded 1.06 ± 0.02 and 1.07 ± 0.02 for left and right breasts respectively.

Based on the results of this study, it is quite deductible that it is easier to achieve complete coverage in right breasts than in left-sided ones in terms of 100% and 95% isodose in the target. Similarly, treatment planning for right breasts results in higher dose conformity than left breasts. Despite these results, it is ostensibly clear that left breasts result in higher mean doses and better dose homogeneity than right breasts.

Phase 2

In phase 2, the PTV dose parameters for the left breasts were recorded as the heart D_{max} constraints were varied to investigate the influence of the heart constraint on radiotherapy left breast target coverage. The percentage of PTV covered by the full prescription dose (V_{50Gy}), the 95% of the prescription ($V_{47.5Gy}$) dose coverage, the mean PTV dose ($D_{50\%}$), the CI and the HI, were investigated with each of the heart constraint variations, taking into account the other OAR objectives of Table 1.

Generally, PTV dosimetry did not vary significantly with the changing heart constraints in IMRT planning for V_{50Gy} (%), $V_{47.5Gy}$ (%) and $D_{50\%}$ (Gy) as displayed in Figure 2, with CI and HI values staying nearly constant throughout the variation. The V_{50Gy} (%) parameter recorded values ranging from 93.45 ± 1.58 to 93.91 ± 2.16, the $V_{47.5Gy}$ (%) recorded a range of PTV coverage between 98.59 ± 0.89 and 98.70 ± 0.56, whilst a dose range of 50.87 ± 0.71 to 50.94 ± 0.60 was recorded for $D_{50\%}$ (Gy) with the variation of the heart D_{max} in the IMRT planning. The CI and HI values remained approximately constant with 0.99 and 1.04 throughout the variation. The results of the present study suggest that heart constraints have minimal influence on target coverage for breast radiotherapy when using IMRT.
Conversely, the PTV dosimetry witnessed a highly significant change with variation of the heart constraints in 3DCRT planning as shown in Table 3. The V_{50Gy} (%) parameter recorded values ranging from 30.30 ± 3.63 to 95.26 ± 2.64, the $V_{47.5Gy}$ (%) recorded a range of PTV coverage between 90.28 ± 1.45 and 98.60 ± 1.04, with a dose range of 49.48 ± 1.16 to 53.12 ± 1.08 recorded for $D_{50\%}$ (Gy) in the course of varying the heart D_{max} constraint in the 3DCRT planning. The CI values were in the range of 0.90 ± 0.10 to 0.99 ± 0.08 whilst the HI values ranged from 1.03 ± 0.09 to 1.09 ± 0.04 throughout the variation study. It is evident that the heart constraint imposes substantial effect on target coverage in breast radiotherapy during 3DCRT planning, as presented by Figure 2.

V. CONCLUSIONS

The results obtained so far points to the fact that target coverage in breast radiotherapy can be limited by the value of the heart D_{max} constraint used in treatment planning. However, the extent of this limitation depends on the treatment planning technique. Heart constraints have minimal influence on target coverage for breast radiotherapy when using IMRT but imposes substantial effect on target coverage during 3DCRT planning. The results also reveals that the poor target coverage and lower dose conformity in left breast radiotherapy is due to the additional restriction imposed by the heart constraint in radiotherapy treatment planning of the left breast.

ACKNOWLEDGMENT

Our sincere gratitude to Mr. Joseph Kwadjo Lano for his support in terms of imaging setup on the CT machine.

REFERENCES

1. Hernandez V, Hansen CR, Widesott L. What is plan quality in radiotherapy? The importance of evaluating dose metrics, complexity, and robustness of treatment plans. *Radiother Oncol*. 2020;153:26-33. doi:10.1016/j.radonc.2020.09.038

2. Abo-Madyan Y, Aziz MH, Aly MMOM. Second cancer risk after 3D-CRT, IMRT and VMAT for breast cancer. *Radiother Oncol*. 2014;110(3):471-476. doi:10.1016/j.radonc.2013.12.002

3. Hansen CR, Hussein M, Bernchou U, Zukauskaite R, Thwaites D. Plan quality in radiotherapy treatment planning – Review of the factors and challenges. *J Med Imaging Radiat Oncol*. 2022;66(2):267-278. doi:10.1111/1754-9485.13374

4. Jones D. ICRU Report 50—Prescribing, Recording and Reporting Photon Beam Therapy. *Med Phys*. 1994;21(6):833-834. doi:10.1118/1.597396

5. Newhauser W. International Commission on Radiation Units and Measurements Report 78: Prescribing, Recording and Reporting Proton-beam Therapy. *Radiat Prot Dosimetry*. 2009;133(1):60-62. doi:10.1093/rpd/ncp005

6. Petrova D, Smickovska S, Lazarevska E. Conformity Index and Homogeneity Index of the Postoperative Whole Breast Radiotherapy. *Open Access Maced J Med Sci*. 2017;5(6):736-739. doi:10.3889/oamjms.2017.161

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