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Estimation of Cardiac Doses during Breast Cancer Radiotherapy in Pakistan

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ABSTRACT

This study aims to estimate the absorbed radiation doses to the heart during breast cancer treatment with conventional radiotherapy. The cardiac doses of eighty-three patients during breast cancer radiotherapy were estimated, with fifty-two patients having left breast cancer and thirty-one having right breast cancer. For left breast cancer patients, a Treatment Planning System (TPS) was used to estimate the percentage volume of the heart receiving 20 Gy (V20%), 25 Gy (V25%), 30 Gy V30%), and 40 Gy (V40%). The Maximum Heart Distances (MHD) within the radiation field for left breast cancer patient sand the Minimum Distance of Heart from the Posterior Border of the Radiation Field (MDHF) for right breast cancer patients were measured. Through TPS, the mean dose to the 5% and 10% heart volumes, the lowest dose (D_{min}), the maximum dose (D_{max}), and the average dose (D_{avg}) of the heart for all patients with left and right breast cancer were also calculated. For patients with left breast cancer, higher mean values of V20 (%), V25 (%), V30 (%), and V40 (%) were estimated and a direct correlation between MHD and D_{avg} was observed. The relationship between MDHF and D_{avg} in patients with right breast cancer was observed to be linear but with a negative slope. Patients undergoing radiotherapy for left breast cancer receive higher doses and are therefore recommended for assessment of cardiac complications during follow-ups.

Keywords: Cardiac dose, TPS, Dose-Volume Histogram (DVH), Radiotherapy

INTRODUCTION

Breast cancer is the most common cancer among women worldwide, with over 1.4 million cases of non-cutaneous malignancies diagnosed each year [1]. The three treatments (surgery, chemotherapy, and radiotherapy) used to treat breast cancer have been effectively enhanced over the past few decades, which has significantly raised the survival rate of breast cancer patients [2,3]. Radiation-induced malignancy, pulmonary fibrosis, glandular atrophy, pleural effusion, cardiomyopathy, fat necrosis, pericardial disease, and skin thickening with breast edema are the post-radio therapy consequences of breast cancer [4].

Cardiac complications have been reported after radiotherapy of breast cancer, especially in cases of individuals with left breast cancer [5-9]. A significant portion of the heart is directly exposed to the radiation beam during left breast cancer radiotherapy, resulting in a larger cardiac absorbed dose than during right breast cancer irradiation [8-11]. Radiation exposure to the heart raises the risk of coronary artery disease and is correlated with the average absorbed dose received by the heart. It starts a few years after treatment and can last up to 20 years. Patients with a history of cardiac disease are at a higher risk of having additional cardiac complications from radiotherapy treatment than other patients [12]. Therefore, it is essential to assess the cardiac doses received during breast cancer radiotherapy [13]. The cardiac tolerance dose can be calculated using data from studies on cardiovascular mortality and radiation-induced pericarditis [14,15]. Several studies have proposed various threshold levels for cardiac doses. According to the Danish Breast Cancer Cooperative Group's (DBCCG) recommendations, the threshold levels for cardiac doses are denoted as D10% (mean dose received by 10% of the heart volume) and D5%(mean dose received by 5% of the heart volume), and their respective values are 20 Gy and 40 Gy [14-16]. The radiobiological model predicts that heart fatalities will be less than 1% within 15 years of radiotherapy for V25(%) (The percentage volume of the heart receiving 25 Gy or larger doses) received by less than 10% of the heart volume. Conducted a study on Danish and Swedish women with breast cancer from 1958 to 2001, estimating cardiac doses for each patient and exploring that the probability of major coronary post-irradiation effects increased linearly with the mean dose to heart by 7.4% per Gy, with no apparent threshold below which there was no risk [12].

The Norwegian Breast Cancer Group (NBCG) and the Auckland (New Zealand) national breast cancer guidelines recommend that V25(%) received by the heart should be ≤ 5% of total heart volume [15]. The mean cardiac doses were estimated in the literature during various studies [17-19]. The mean cardiac dose for patients with left and right breast cancer is 3.2 Gy and 1.3 Gy, respectively. Heart doses ranging from 7.5 Gy to 12.0 Gy for left breast cancer patients and 3.2 Gy to 3.6 Gy for right breast cancer patients in Sweden [20]. In addition, the average cardiac doses of 358 women between 1970 and 1990 and reported that values ranged from 0.1 Gy to 46.3 Gy. Determined that the average dose to the entire heart is 4.9 Gy (range, 0.03 to 27.72). Found a linear relationship between the Maximum Heart Distance (MHD) within the radiation field for left breast cancer patients and an average cardiac dose [21].

The goal of this study is to calculate the cardiac dose of breast cancer patients receiving conventional radiotherapy. The Maximum Heart Distance (MHD) within the radiation field for the left breast and MDHF for right breast cancer patients were used to estimate the mean cardiac doses. Due to the possibility that the exposed volume of the heart is related to the risk of cardiac illnesses and mortality, D5% and D10% are computed in this study for all patients. A total absorbed dose of V20(%) V40(%) Gy may have significant adverse effects on vascular morbidity and mortality, especially in left breast cancer patients. Therefore, we also calculated the V20(%), V25(%), V30(%), and V40(%) for these patients during the conventional radiotherapy course of breast cancer. To the best of our knowledge, no other cancer hospital in Pakistan has conducted such an assessment of female breast cancer patients. This type of research is useful for assessing cardiac complications in post-breast radiotherapy follow-ups [22].

METHOD

At the Institute of Nuclear Medicine, Oncology and Radiotherapy (INOR) cancer hospital in Abbottabad, Pakistan, a total of 83 female breast cancer patients were chosen for this study from various rural and urban areas; of these, fifty-two had left breast cancer and thirty-one had right breast cancer. After mastectomy, the patients received conventional radiotherapy (25 fractions, opposed tangential fields, 5 fractions per week) [23,24].

The Siemens CT simulator (Soma tom model, sensation open bore size: 82 cm, and 24 slice/rotation) was used to acquire patient anatomical data. The CT scanner's positioning laser was used to align the patient on the breast board while the ipsilateral arm was abducted 90° to 120° androtated externally. The CT scans for volumetric planning were captured on film. Theraplan Plus 2000 Treatment Planning System (TPS), which uses the pencil beam algorithm for dose calculation, was used to transfer the CT images from the films into the scanner using the Vidar Dosimetry Pro Advantage. The radiation oncologist outlined the anatomical structures and areas of interest, i.e., planning target volume (PTV), on CT images in TPS, including organs at risk such as the heart and lungs, as shown in Figure 1. To cover the PTV as depicted in Figure 2, a virtual linear accelerator of 6 MV photon beams (Varian

CLINAC 2100°C) was used in the TPS. Two tangential beams were used to irradiate the chest wall, and one supraclavicular field was used to irradiate axillary lymph nodes.

Figure 1 Anatomy modelling and contouring of externals, planning treatment volumes, and organs at risk (lungs, heart, and spine)

The beam modifiers, such as wedges (15^{o} and 30^{o}), were employed to correct the patients' asymmetrical contouring and tissue inhomogeneity (Figure 2). In a supraclavicular field, the femur head was shielded using multi-leaf collimators (MLCs). To evaluate the treatment plans, a variety of tools including beam eye view, dose distribution, 3D views, digitally reconstructed radiographs, and Dose-Volume Histograms (DVHs) were used. The radiation was concentrated on the tumor while sparing the surrounding healthy tissues. Only for left breast cancer patients, the DVH and PTV of the heart were used to calculate V20(%), V25(%), V30(%), and V40(%). Additionally, the TPS was used to obtain the D5%, D10%, D_{min}, D_{max}, and D_{avg} of the heart for each patient. The side from that, MHD and MDHF were calculated from TPS for patients with left and right breast cancer, respectively.

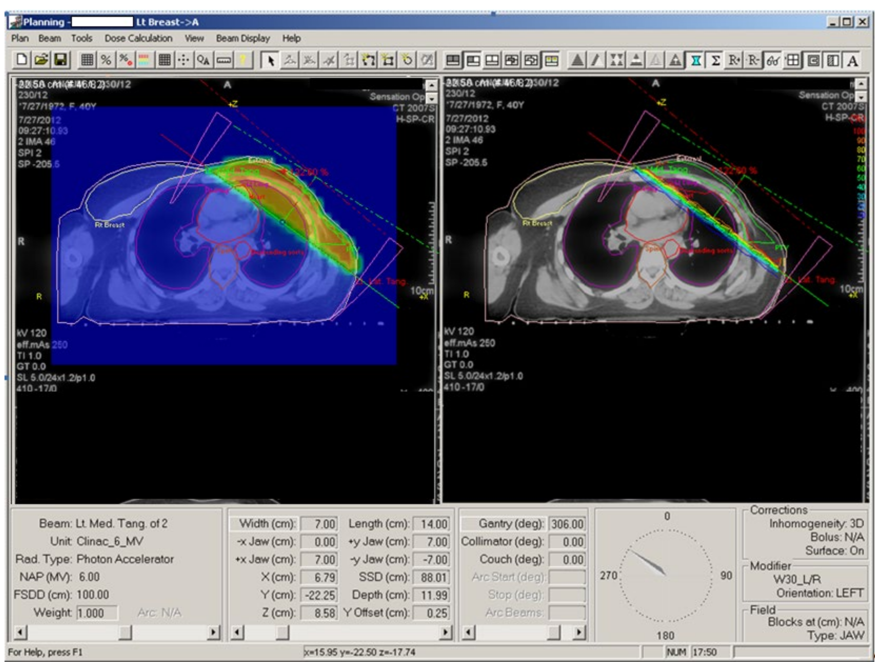

Figure 2 Radiation beam and wedges application to PTV and 2D dose distribution with iso-dose lines

RESULTS AND DISCUSSION

The minimum heart distances from the posterior radiation field border for right breast cancer patients and the Maximum Heart Distance (MDH) within the radiation field for left breast cancer patients are enlisted in Table 1. The average total volume of the heart in breast cancer patients was found to be 536.17 cm^3, with an SD of 101.96 and a range of (348-845) which is equivalent to the heart volume determined in the German population. As shown in Table 1, mean values of V20 (%), V25(%), V30(%), and V40(%) were found to be 15.96% (10.1-26), 12.70% (5.68-19.59), 10.05% (3.98-18.51) and 7.92% (3.22-16.85), for left breast patients, respectively [25]. However, these values are significantly higher than those measured and thus may result in cardiac complications and require follow-up. However, the maximum point dose of heart for right breast cancer patients was found to be 4.17 Gy, therefore, V20 (%)-V40 (%) values would be virtually zero for these patients because no volume of heart would be receiving 20 Gy or higher dose. In left breast cancer patients, mean values of D5% and D10% measured from DVHs were 41.67(25.76, 54.66) Gy with SD of 8.53 and 21.00 (5.20, 49.96) Gy with SD of 11.78, respectively, as shown in Figure 3 and 4(a).

Table 1 In patients with breast cancer, the mean heart volume, MHD, MDHF, D5%, D10%, V20 (%), V25 (%), V30 (%), V40 (%), as well as the mean of Dmax (Gy), Dmin (Gy) and Davg (Gy)to the heart

Characteristics	Left breast cancer patients	Right breast cancer patients
No of patients	52	31
Mean heart volume (cm^3)	546.65 (384.5-845)	518.60 (348-732)
Mean MDH (cm)	2.82 (1.54-4.65)	0
Mean MDHF (cm)	0	0.47 (0.1-1)
Mean V20 (%)	15.96 (10.1-26)	0
Mean V25 (%)	12.7 (5.68-19.59)	0
Mean V30 (%)	10.05 (3.98-18.51)	0
Mean V40 (%)	7.92 (3.22-16.85)	0
Mean D5% (Gy)	41.67 (25.76-54.66)	3.49 (2.56-4.56)
Mean D10% (Gy)	21.00 (5.20-49.96)	3.08 (2.57-4.22)
Mean Davg (Gy)	7.07 (3.69-11.79)	1.88 (1.54-2.31)
Mean Dmin (Gy)	1.34 (1.17-1.68)	1.20 (1.02-1.42)
Mean Dmax (Gy)	53.37 (51.10-55.89)	3.41 (2.33-4.17)

However, the mean value of D5% in right breast cancer patients was 3.49 (2.56, 4.56) Gy with an SD of 0.63 and D10% was 3.08 (2.57, 4.22) Gy with an SD of 0.47, as shown in Figure 4(b). These values for left breast cancer patients were found to be higher than the DBCCG's suggested criteria of 40 Gy and 20 Gy for D5% and D10%, respectively. As a result, post-radiotherapy cardiac complications may arise [12,14-16].

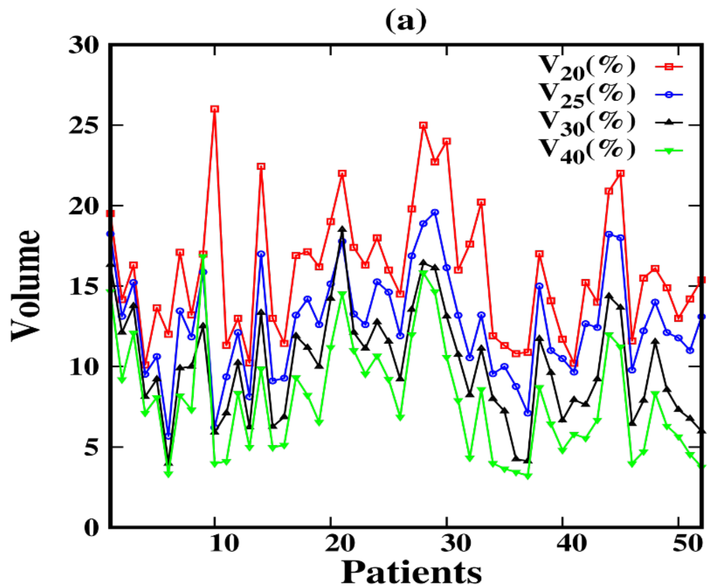

Figure 3 Mean volumes for left-sided breast cancer patients. Where red, blue, black, and green colors represent V20 (%), V25 (%), V30 (%), and V40 (%) respectively

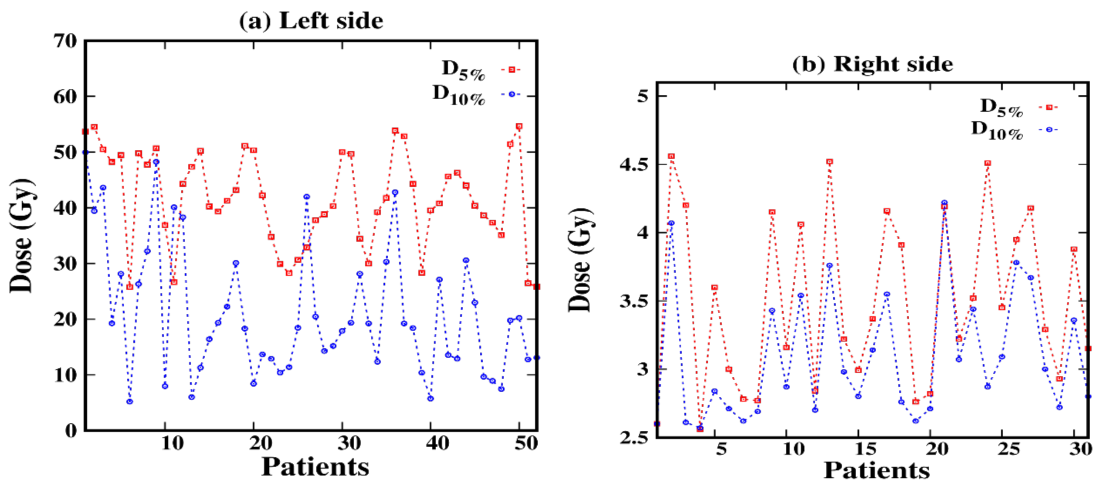

Figure 4 Mean doses D5% and D10% in Gy for a) left sided-breast cancer patients and b) right-sided breast cancer patients. Where red and blue colors represent D5% and D10% respectively

Figure 5(a) illustrates the mean values of Dmax ± SD, Dmin ± SD, and Davg ± SD of the heart for patients with left breast cancer were 53.37 Gy ± 1.48 Gy, 1.34 Gy ± 0.1 Gy, and 7.07 Gy ± 2.46 Gy, respectively. These values are quite larger because a portion of the heart is situated within tangential radiation fields of the chest wall. These values are greater than those who determined the average heart's D_{max} and D_{avg} values to be 49.3 Gy and 3.6 Gy, respectively [25]. Although the heart was not included in the radiation fields for right breast cancer patients, it still received a dose greater than 1 Gy due to scattered radiation from internal organs, which may increase cardiac damage and thus result in cardiac mortality [26]. In patients with right breast cancer, the mean values of SD_{max} ± SD, D_{min} ± SD, and D_{avg} ± SD of the heart were 3.41 Gy ± 0.59 Gy, 1.20 Gy ± 0.13 Gy, and 1.88 Gy ± 0.23 Gy, respectively, as shown in Figure 5(b). The mean heart dose for patients with left breast cancer in this study was 7.07 Gy, which was higher than the 3.2 Gy reported [15].

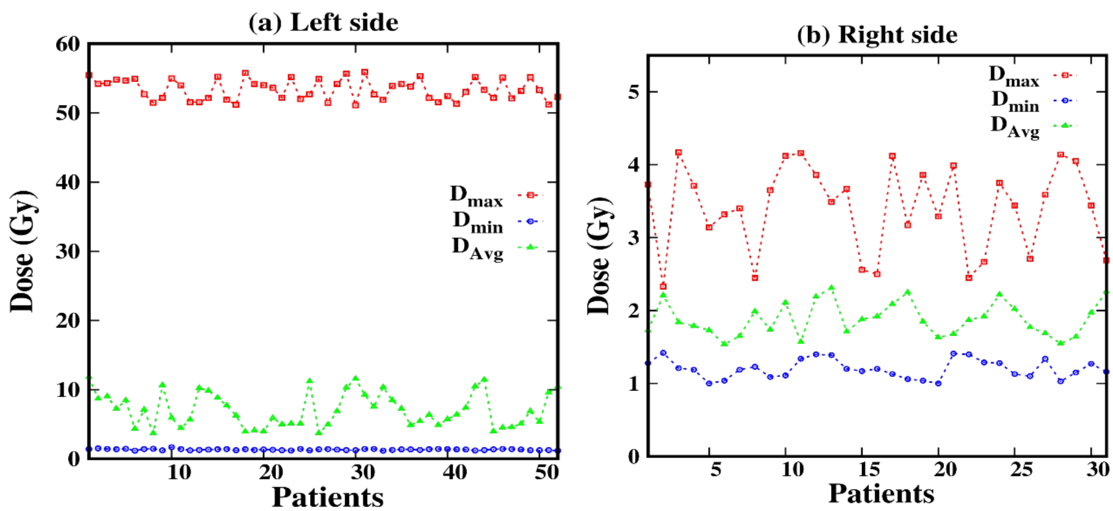

Figure 5 D_{max}, D_{min}, and D_{avg} in unit of Gray (Gy) for a) left-sided breast cancer patients b) right-sidedbreast cancer patients. Where red, blue, and green colors represent D_{max}, D_{min}, and D_{avg}, respectively

The mean heart dose for patients with left breast cancer in this study was 7.07 Gy, which was higher than the 3.2 Gy reported. The mean heart dose for right breast patients was 1.88 Gy, which is comparable to the 1.3 Gy reported. The calculated cardiac doses were in good agreement with findings [10,20]. The total mean of the average absorbed doses to the heart was 5.13 Gy, which is comparable to the number 4.9 Gy found [12,15].

Tangential fields irradiate a portion of the heart in patients with left breast cancer, so MHD in the radiation field was measured in these patients. The mean MHD value was 2.82 cm, with a standard deviation of 0.92 cm and a range of (1.54 to 4.65).

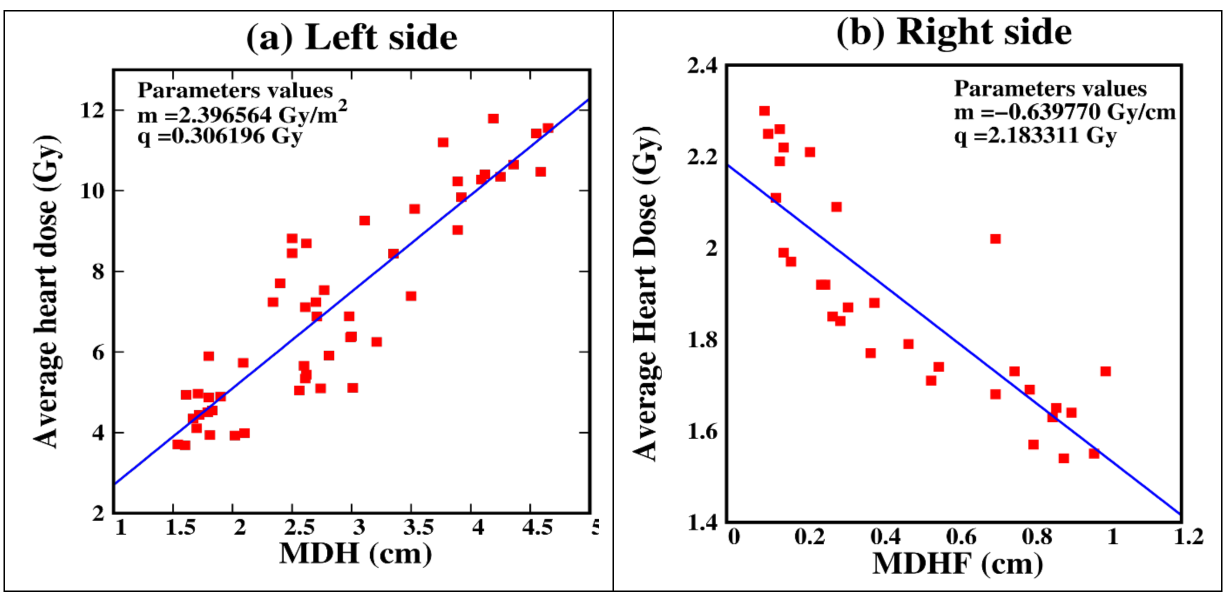

Figure 6 a) Relation between MHD (cm) and average cardiac dose (Gy) for patients with left-sided breast cancer, b) Graph between MDHF (cm) and average heart dose (Gy) for patients with right-sided breast cancer

$$Mean\ Heart\ Dose\ (Gy) = 2.4 \times MHD(cm) + 0.31,\ for\ R^2 = 0.80 \qquad (1)$$

This demonstrates that for every 1 cm increase in MHD, the average cardiac dose is increased by 2.4%, with R^2 equal to 80%. Figure 6(a) depicts the aforementioned relationship. MDHF was computed for patients with right breast cancer. As shown in Figure 6(b) radiation doses to the heart in these patients are affected by MDHF. Figure

6(b) depicts an inverse relationship between MDHF and average heart dose, which was also demonstrated in equation (2).

$$Mean\ Heart\ Dose\ (Gy) = -2.4 \times MHD(cm) + 2.18,\ for\ R^2 = 0.72 \quad (2)$$

This means that for every 1 cm increase in MDHF, the average heart dose is reduced by 0.64%, while R^2 is reduced by 72%.

CONCLUSION

This study demonstrates that for radiotherapy treatment of breast cancer, there is a direct dependence of average heart dose with MHD for left-sided breast cancer, and inverse relation with MDHF for right-sided breast cancer. Furthermore, patients undergoing left breast cancer radiotherapy should be monitored for cardiac complications because their doses exceed the threshold for various cardiac complications. This study will help in the formulation of guidelines on cardiac threshold doses for the local population.

DECLARATIONS

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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