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Dose-volume Analysis of Heart and Lung during 3D planning of Tangential Breast Cancer Irradiation

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Abstract

Background: Breast cancer is becoming more frequently diagnosed at early stages with improved long term outcomes. Radiation-related heart disease and lung cancer can occur following radiotherapy for breast cancer. The aim of this study was to evaluate some dosimetric parameters of heart and lung during whole breast radiotherapy.

Methods: Twenty five consecutive patients with breast cancer who underwent radiotherapy were included in this study. Plans that employed the 3D conventional radiotherapy technique (Tangential Technique) were generated for each patient. Dose-volume histograms (DVHs) were calculated and dosimetric parameters such as, mean dose/volume receiving a dose 30 Gy (V30), mean dose/ volume receiving a dose 20 Gy (V20) for heart and lung were assessed, respectively.

Results: The average of mean dose of heart on left and right side irradiation was 9.68±5.10 Gy and 1.23±1.51 Gy, respectively. The average of mean dose of ipsilateral lung on left and right side irradiation was 14.49±4.07 Gy and 11.69±3.37 Gy, respectively. The percentage of heart volume that received at least 30 Gy was 16.32±9.56% for the left-sided treatment. The percentage of lung volume that received at least 20 Gy was 23.47±11.05% and 24.12±7.77% respectively on the left and right-sided breast irradiation.

Conclusion: Tangential beam conventional radiotherapy of the chest wall of postmastectomy breast cancer patients provides the potential to significantly keep the DVH parameters of heart and lung as low as the QUANTEC constrains.

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Introduction

One of the most common cancers in women is Breast Cancer (BC). The breast cancer incidence has increased during the past decades and patients suffering from the breast cancer are becoming much younger (1).

In order to manage the breast cancer, Radiotherapy (RT) plays an essential role (2). Better survival of patients after mastectomy followed by radiotherapy has been shown in many studies (3, 4). Breast-conserving surgery as well as supraclavicular region irradiation for patients with regional lymph node involvement are regular radiotherapy techniques (5). In modern radiotherapy technique, in order to avoid normal tissue damage, advanced radiation therapy techniques such as, Three-Dimensional Conformal Radiation Therapy (3DCRT), Intensity Modulated Radiation Therapy (IMRT) and recently, Volumetric Modulated Arc Therapy (VMAT) have been used (6, 7).

Given the fact that radiotherapy reduces the risk of death resulted from breast cancer, but it involves some incidental irradiation of some parts of heart and lung which can increase the subsequent risks of heart and lung diseases (8, 9). A study conducted over a period of 15 years showed an increase in cardiac mortality rate to 6.8% among patients who received adjuvant radiotherapy (10). It was demonstrated that breast or chest wall radiotherapy resulted in heart doses of 0.9 to 14.0 Gy and 0.4 to 6.0 Gy on left-sided and right-sided irradiation, respectively. Moreover, in nearly one-half of the patients, doses higher than 20 Gy are received to some parts of the heart with tangential breast or chest wall radiotherapy on left-sided cancer (11, 12). Also, the lung is sensitive to ionizing radiation and side effects may arise as acute pneumonitis and late lung fibrosis (9-12).

The risk for acute and chronic RT-induced lung morbidity is influenced by irradiated lung volume, total dose and dose per fraction (13). Clinically, significant symptomatic radiation pneumonitis (RP) occurs in 1–10% of patients irradiated for BC with modern RT techniques (14).

Many studies have been conducted on quantifying the heart and lung doses during breast cancer radiotherapy (8, 9, 15-18). To the best of our knowledge, no comprehensive local programs have been implemented to quantify the heart and lung doses during conventional breast radiotherapy technique on the ISOgray (Dosisoft, Cachan, France) commercial treatment planning systems (TPSs).

In this study, some dosimetric parameters from dose-volume histograms (DVHs) of (ipsilateral/contralateral) lung and ipsilateral heart during 3D conventional technique in breast cancer radiotherapy have been assessed.

Materials & Methods

In this study, twenty five consecutive patients with breast cancer who underwent adjuvant breast or chest-wall radiotherapy at the department of radiotherapy and oncology were analyzed in early 2015 from the CT planning database. The summary of patients' medical data is presented in table 1.

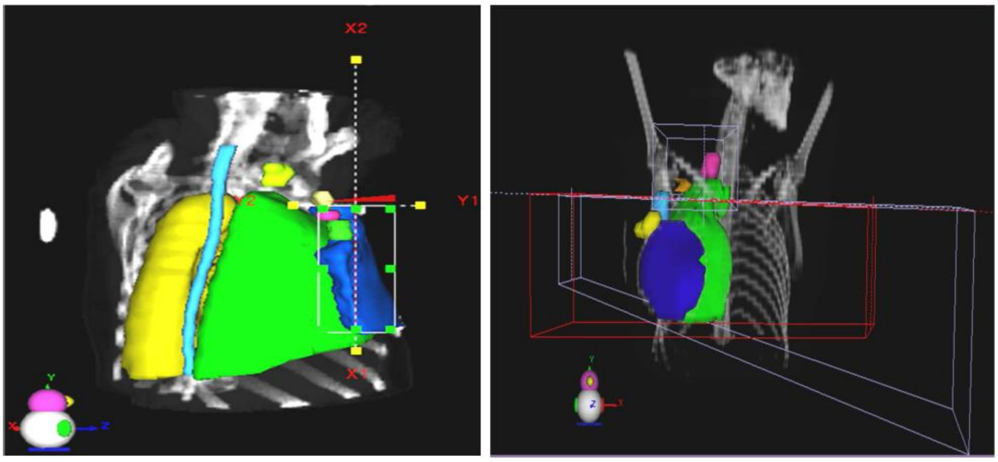
Table 1. Clinical characteristics of participants

	Left-Sided	Right-Sided	Conservative Surgery	Mastectomy	Clinical Staging		Nodal Involvement
					T_1 or T_2 Lesions	T_3 or T_4 Lesions	
Patients (%)	44	56	45	55	69	31	73
Breast Volume (cm^3)	572.78	584.03	----	----	----	----	----
Average Age (years)	45	49	45	48	47	47	46

CT Acquisition and Treatment Planning Design

All patients were positioned supine on a breast board, with the sternum horizontal to the treatment couch and both arms were extended above the head. The tangential field borders were determined clinically based on routine breast cancer radiotherapy criteria (11) and field borders were marked with radio-opaque wires. The three-dimensional computed tomography (CT) scans with 5 mm thickness slices were acquired by Toshiba CT scanner without contrast in free-breathing. Then, the CT data were imported to ISOgray TPS version 4.2. (Dosisoft, Cachan, France). ISOgray offers three different doses of calculation algorithms for photon beams such as 2D primary-scatter decomposition, with or without inhomogeneity correction, collapsed cone point kernel superposition and Monte Carlo, based on the Penelope code. For electron beams, pencil beam and Monte Carlo calculations are available algorithms (19).

Two-tangential fields with one isolated anterior-posterior supraclavicular field were designed for all of the patients. Treated volumes (levels I, II and III axillary and supraclavicular nodes, breast or chest wall) were delineated. Mono-isocenter and half beam techniques were used to align tangential fields with supraclavicular field. The upper margin of tangential field was placed at the head of clavicle and the medial margin was placed at midline. The lateral margin was defined in mid-axillary line and inferior margin was drawn 2 to 3 cm below the ipsilateral or contralateral inframammary fold. The inferior border of the supraclavicular field was matched to the tangential field. The medial border was in the medial border of sternocleidomastoid muscle and superior border was at the level of thyrocricoid groove and the lateral border was medial to humeral head (Figure 1). Then, each patient was planned so that the dose distribution, beam weights and wedge angles were optimized on the central of each slice and normalized to the International Commission on Radiation Units & Measurements (ICRU) reference point (20) of breast. The dose distributions were calculated with full CT density information including lung correction, using the pencil beam algorithm. All patients were planned and treated on an Elekta Compact^{TM}linear accelerator (Crawely, United Kingdom), without MLC, which has been designed and marketed as a relatively simple device, producing only 6 MV photons with an internal wedge of 60°. Bolus was used for some plans only if there was skin involvement. In order not to reduce or avoid cardiac irradiation, field borders were not modified and cardiac shielding was not used commonly at many radiotherapy centers in Iran at the time. All patients were treated with a tumor dose of 50 Gy to the isocenter in 25 fractions (2 Gy per fraction), five days per week (21).



(a) (b)

Figure 1. (a): 3-field design for intact breast irradiation. Regional nodes were delineated (Thin yellow: level I, Thin blue: Level II, Yellow: level III, Red: supraclavicular. (b): Beam eye view of lateral tangential field. Level I (green) and II (red) were included.

Dose-Volume Histogram (DVH) Calculations

For each plan, the ipsilateral/contralateral heart and ipsilateral lung DVHs were calculated from TPS. The normal tissues (heart and lung) dosimetric parameters such as percentage of heart volume (the proportion volume in 60% of isodose line) received 30 Gy or greater (V30), and ipsilateral left and right lung mean doses and percentage of lung volumes that received 20 Gy or greater (V20) were compared. Then, the averages were calculated for the whole set of patients and on right and left-sided treatments, separately (22). Since, there was evidence to prove that doses beyond some values could cause acute or late clinical symptoms, the dosimetric parameters to compare heart (V30) and ipsilateral lung (V20) were chosen (23).

Results

In this study, 11 consecutive patients with left-sided breast cancer and 14 consecutive patients with right-sided breast cancer treated at Shafa Kerman Radiotherapy center in early 2015 were selected. Figure 2 presents the results of mean heart dose for both sided treatments. The mean dose values for heart ranged from 0.20 to 5.82 Gy and 0.05 to 17.9 Gy for right and left-sided patients, respectively. Furthermore, all patients received a heart dose within the tolerance limit as recommended in the literature (<26.0 Gy) (22). Among twenty five patients, P23 received the lowest heart dose (0.05 Gy) which was on the left-sided breast radiotherapy. The data presented in figure 2 indicates that no patient treated with tangential-field technique and heart received a dose of 26 Gy or more.

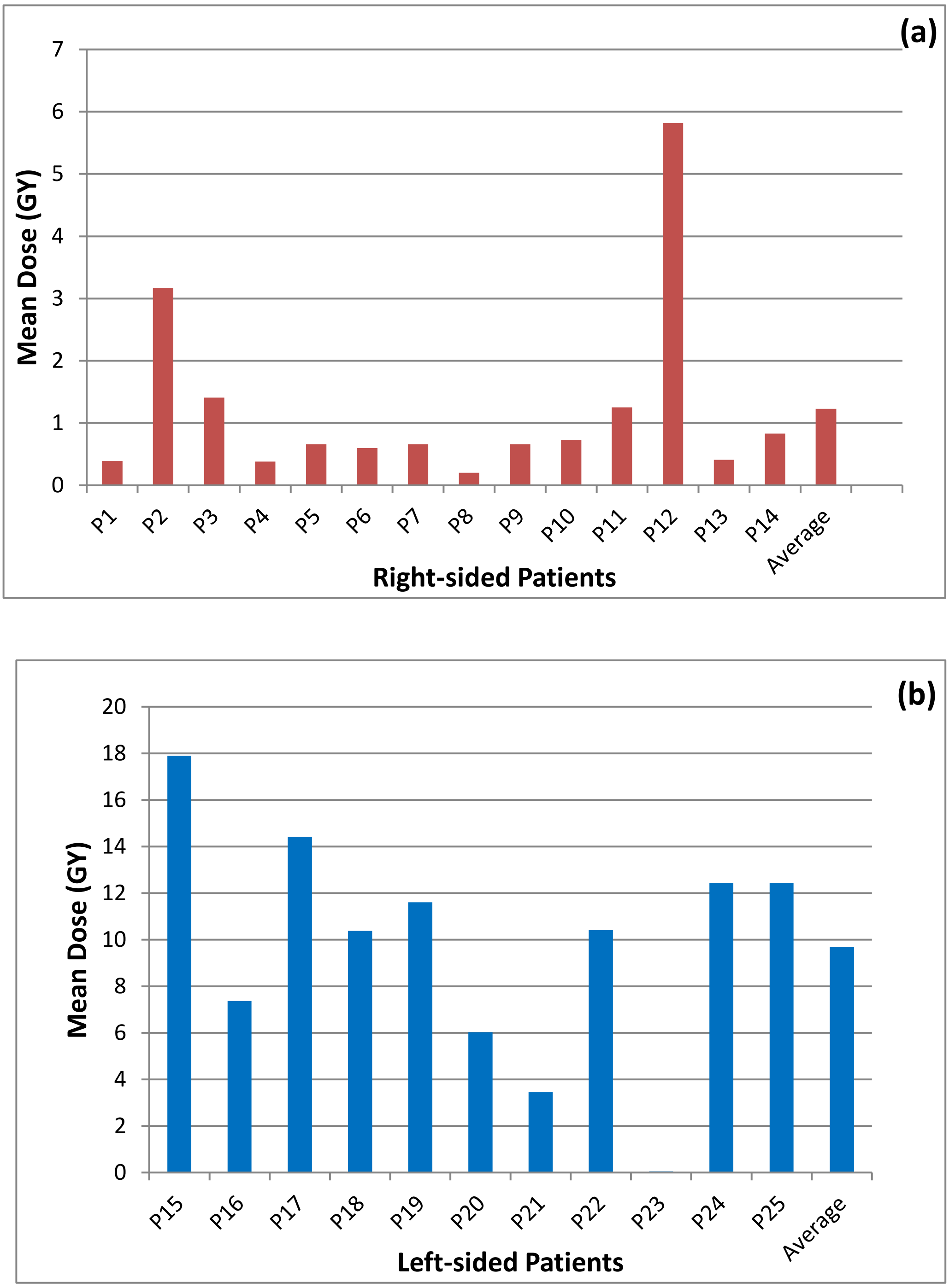


Figure 2. The mean heart dose values (a): Right-sided (b): Left-sided

The results related to the mean ipsilateral lung dose on both sided treatments are presented in figure 3. The mean dose values were 11.69±3.37 Gy and 14.49±4.07 Gy on the right and left lung-sided, respectively. Also, there was no risk of pneumonitis (with a rate of 30%) in both groups (right and left lung-sided).

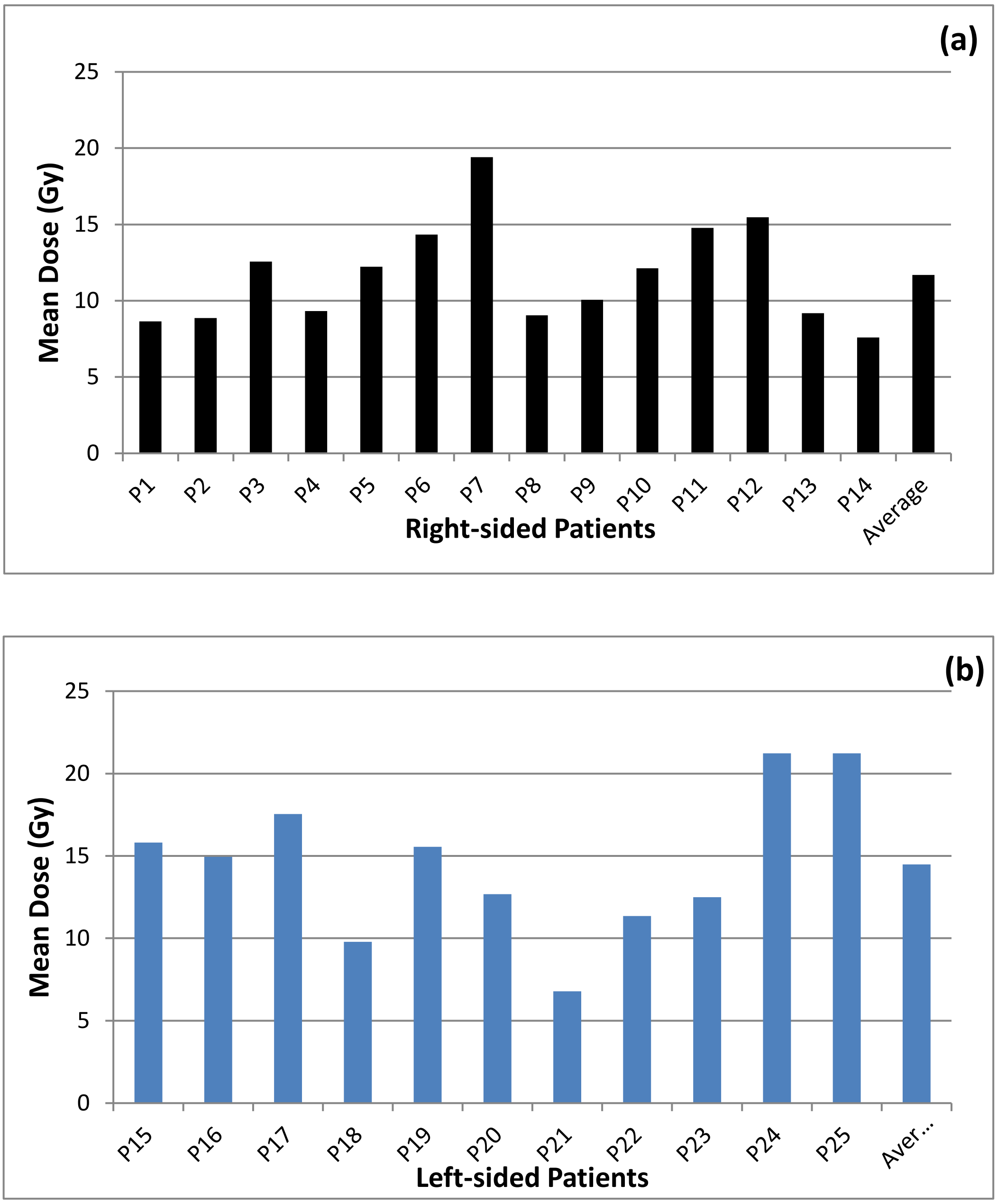


Figure 3. The mean lung dose values (a): Right-sided (b): Left-sided

Table 2 shows the V30 and V20 (two DVH-based parameters) for heart and lung organs at risks, respectively. It was illustrated that there were only minor differences between V30 values on right-sided breast cases, whereas the V30 values on left sided ranged from 0.00% to 33.75% with an average of 15.21%. Also, the V30 heart values on right sided were significantly lower than the left sided. The average relative right and left lung volumes irradiated to 20 Gy were 24.12% and 22.38%, respectively. Moreover, the V30s of all patients were within the tolerance level as recommended in the literature (V30<46%)(23). The mean values of V20 on the left side of lung were somewhat lower than those on the right side. The V20s of 76% of patients were lower than recommendations (V20<30%)(22).

Table 2. V30 and V20 values of OARs

Right-Sided Breast Cases	V30 (Heart)	V20 (Right Lung)	Left-Sided Breast Cases	V30 (Heart)	V20 (Left Lung)
[*]P1	0.00	17.15	P15	33.75	33.90
P2	0.00	18.95	P16	10.68	32.01
P3	0.00	25.29	P17	23.66	38.64
P4	0.00	18.34	P18	17.73	18.49
P5	0.00	25.04	P19	20.19	32.36
P6	0.00	30.34	P20	9.22	26.16
P7	0.00	42.75	P21	4.44	13.23
P8	0.00	17.37	P22	17.42	23.87
P9	0.00	21.42	P23	0.00	25.43
P10	0.00	23.68	P24	21.21	2.04
P11	0.00	29.70	P25	9.05	12.04
P12	2.09	33.83	-----	-----	-----
P13	0.00	18.62	-----	-----	-----
P14	0.00	15.18	-----	-----	-----

* Px means patient No. x.

Discussion

Radiation-induced cardiac and symptomatic pneumonitis complications have different significance and implications depending on the clinical scenario. Also, the mean heart dose is used as a common reference dose constraint given in the reports of studies related to clinical outcomes.

As illustrated in figure 2, generally, the average mean heart dose on the left treatment site was significantly much higher than the right side which may be due to the fact that the Breast RT as practiced in our department resulted significant myocardial exposure and this was higher when the left breast was treated. The reason that the mean heart dose of P12 patient was much higher than the other right-sided patients may be due to much higher extent of heart volume covered in the treatment fields and the impact of maximal heart distance (MHD) in CT. It can be difficult to determine the actual dose received. However, some studies provide insight into means of limiting the variability between these doses. It has been shown that patient setup errors of greater than 3mm in the posterior direction result in significant increased dose to the heart (24). In addition, the maximum anterior/posterior distance of heart in the treatment field has shown a strong linear correlation with the mean heart dose (25). Moreover, the average mean heart dose on the left sided was only (9.68±5.10 Gy); so, based on the recommendations (22), no incidence of pricartisis was appeared in both groups. However, a clear quantitative dose dependence for most cardiac toxicity has not yet been shown, that is primarily due to the scarcity of the data and several clinical factors such as age, comorbidities and doxorubicin use appear to increase the risk of injury. A review of 358 women treated for several decades in Sweden found that even though a number of different treatment techniques were used, but the overall mean heart dose on left-sided breast cancer patients was 5.1 Gy in the 1950s compared with 3.0Gy for women treated in the 1990s which they used a Theraphlan Plus TPS (Nucletron UK, Tattenhall, Chester, UK)(26). However, it is difficult to directly compare the calculated mean values with the data from the literature, because most studies do not include brief technical notes, and there is great variability in the definitions of the planned targets. But the average mean value dose to the heart in our study was 82% higher than in Gursel et al study which in their study they used Eclipse TPS (version 8.0, Varian Medical Systems, Palo Alto, CA, USA) (27). This difference may be related to the prescribed dose, margin, disease stage and not using multi leaf collimator (MLC) in our study in comparison with their work which affected the mean dose to the heart.

Moreover, radiation pneumonitis is a rare complication of breast RT and affects ~1% of patients receiving breast irradiation (28). The mean lung dose evaluation is not absolutely a compatible dosimetric parameter to the incidence of radiation pneumonitis. However, in our study, the total ipsilateral lung dose was 23.80 Gy (Figure. 3) which central lung distance (CLD) could be as a significant indicator of ipsilateral irradiated lung volume. According to the literature, the incidence of lung complications was reported in cases where >40% of lung tissues received at least 10 Gy and >20% of lung received at least 20 Gy (29). When we applied the ipsilateral lung volume constraint of V20≤30% in our 3D planning in BC, symptomatic RP was rare.

In our study, with the technique we used, the percentage of left lung volume that received a dose ≥20 Gy was 23.47±11.05% which was under limits (V20≤30%) of the incidence of symptomatic pneumonitis (Table 2). Our results are not significantly different from Xie *et al* results in which they used Varian Eclipse TPS (version 6.7; Varian Medical Systems, Palo Alto, CA, USA) (30). Our intent was to adhere to the V20 lung-dose constraint of 30%, but in a few cases we had to accept a somewhat higher lung dose because of the nature of the patient’s anatomy. The V20 in our study was about 10% higher than in Gursel *et al* study (27).

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