Frontiers in Biomedical Technologies Vol. 12, No. 2 (Spring 2025) 365-375

ORIGINAL ARTICLE

Comparing the Absorbed Dose of the Contralateral Breast between Physical Stationary and Motorized Wedged Fields Radiotherapy Techniques

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Received: 29 October 2023 / Accepted: 02 December 2023

Abstract

Purpose: The breast is a radiosensitive organ and it is important to prevent the Contralateral Breast (CLB) from irradiation in radiotherapy. In this study, the received dose of CLB was calculated and compared between two breast radiotherapy techniques, including physical stationary and motorized wedged fields.

Materials and Methods: Forty female patients undergoing breast radiotherapy with supraclavicular involvement were randomly selected. Twenty were treated with the tangential fields using physical wedges and twenty patients were treated with the tangential fields using motorized wedges. Three thermo-luminescent dosimeters (TLD GR-200) were placed on the CLB skin to estimate the breast dose. Dosimetric parameters for target tissue and Organs At Risk (OARs) were obtained from the plans of the evaluated techniques and compared to find the differences. CLB doses were compared between the radiotherapy techniques using an independent T-test.

Results: There were no significant differences in the target tissue and OARs dosimetric parameters between the evaluated radiotherapy techniques. The results showed that the measured CLB skin doses in patients treated with the motorized wedges were significantly higher than the physical wedge radiotherapy technique, 201.5±20.4 mGy vs. 159.8 ±14.2 mGy ($P<0.05$).

Conclusion: The physical wedged fields technique had lower doses for CLB compared to the fields using motorized wedges. Therefore, it can be proposed to use tangential physical wedged fields for patients with high concern about the CLB. Furthermore, more research considering radiotherapy techniques without using wedges in medial tangent fields and other relevant parameters can be performed to obtain a better evaluation of the CLB dose.

Keywords: Absorbed Dose; Contralateral Breast; Radiotherapy; Thermoluminescent Dosimeters.

DOI: https://doi.org/10.18502/fbt.v12i2.18281

1. Introduction

Breast cancer is the most common cancer in women and one of the most curable worldwide [1–3]. There are various methods for the treatment and control of breast cancer, including chemotherapy, radiation therapy, surgery, etc. [4, 5]. At most institutions, radiotherapy is considered the main treatment option for breast cancer, due to its long-term advantages such as reduced locoregional recurrence and improved survival [6, 7]. During the radiation treatment, it is important to deliver prescribed doses to the tumoral area accurately, besides preventing healthy organs as much as possible.

It was reported that scatter radiation produced in Linac head, unavoidable neutrons, and internal patient scatter radiation led to increasing radiation dose for the out-of-field regions [8–10]. Although the out-of-field region doses are low, they can induce secondary malignancies with a long latency period, depending on several factors, such as delivered dose, size of the irradiated volume, dose rate, dose distribution, and patient-specific factors [11–14].

The International Commission of Radiation Protection (ICRP) reported that the breast is a sensitive organ to radiation [15]. Therefore, the Contralateral Breast (CLB) must spare as much as possible in breast radiotherapy. CLB usually receives a low amount of radiation doses due to scattered radiation of the patient's body, leakage, and scattering of the machine head [16], which can cause second malignancies [9]. Several studies assessed the doses of CLBs or out-of-field regions during breast cancer radiotherapy [9,17–20]. For instance, Bagheri *et al.* [9] measured the received photon and thermal neutron doses to CLB. They stated that dose values of CLB were remarkable during breast cancer radiotherapy with high-energy photon beams using both physical and dynamic wedges. Bouzarjomehri and Rezaie Yazdi [17], measured the radiation dose of CLB in 50 breast cancer patients. The CLB dose due to breast cancer radiotherapy was significant (7.84% of the prescribed dose).

Based on our literature search, previous studies have not evaluated the CLB doses using 3D-conformal radiotherapy on patients using physical and motorized wedged fields. In this regard, we assessed and compared the absorbed dose of the CLB in breast cancer radiotherapy for two radiotherapy techniques including physical stationary and motorized wedged fields using Thermoluminescent Dosimeter (TLD) measurements. To obtain the CLB doses, the measurements were calculated in two steps (first and last sessions) using 3D-conformal radiotherapy of breast cancer for each patient.

2. Materials and Methods

This experimental study was conducted under the recommendations and regulations of National Ethical Committee. The consent forms were obtained from the patients and they were aware of the whole procedure of TLD dosimetry during radiotherapy.

2.1. Patients and Treatment Planning

In this study, 40 female patients aged 41-78 years with conserving breast surgery (without breast mastectomy) were randomly chosen from two different radiotherapy centers (20 patients from each center). All the selected patients had left breast cancer and schedules for left whole breast+regional lymph nodes radiotherapy. The patients in the first center (center A) were treated with the motorized wedged tangential fields, while patients in the second center (center B) were treated with tangential physical wedged fields.

In the radiotherapy center A, an Elekta linear accelerator (Elekta compact, Sweden) with the irradiation of 6 MV photon beams was used for breast cancer treatment. Elekta is equipped with a motorized wedge which produces wedge angles of less than 60° continuously by the combination of a wedged field and an open field with appropriate proportions. In the radiotherapy center B, breast radiotherapy treatments were performed by the tangential fields with physical wedges (15-30° angles) and 6 MV photon beams produced by a Varian linear accelerator (Varian, Clinac 2100 C/D, USA). We chose two different machines because the motorized wedge was defined on one available machine and the physical wedge was defined on another machine (a machine working with both defined physical and motorized wedges was not available). Both of the machines were calibrated and their output was similar in a way that 1 MU of exposure from each machine delivered 1 cGy dose in the depth of maximum dose (1.5 cm) of water at a source-to-isocenter distance of 100cm-dmax and 10×10 cm^2 field size.

In both centers, the patients were placed supine while their ipsilateral arms were elevated on a breast board. Computed Tomography (CT) images with 3 mm resolution were acquired and exported to the computer Treatment Planning System (TPS). The prescribed dose for the target tissue was 50 Gy, 25 fractions (2 Gy per session). The whole breast as marked in primary simulation imaging with the inferior margin of 2 cm, axillary nodal groups level 1-3, internal mammary lymph in the first three intercostal spaces, and whole supraclavicular lymph nodes were considered as target tissue. The heart and lungs were contorted as Organs At Risk (OARs).

Treatment plans were designed with two wedges (physical or motorized based on the radiotherapy center) using two tangential fields to the breast and portions of lymph nodes levels 1 and 2 located inside the breast fields. The thickness of the wedge was placed in the nipple region. One or two supraclavicular fields were considered for delivering 50 Gy to the remaining part of axillary and supraclavicular lymph nodes. The field size and other radiation field parameters may be different from a patient to another patient. However, the anatomical borders and field arrangements were relatively similar. In brief, the gantry angles of tangential beams were 300-310 degrees for the left medial tangent and 120-130 degrees for the left lateral tangents' fields. The whole chest walls, breast tissues, and regional lymph nodes were considered target tissue.

For both of the radiotherapy techniques, all the treatment planning procedures and dose calculations were performed in Isogray ITPS (Ver. 4.3.1, DOSIsoft Company, Cachan, France). In addition, all of the dose distributions were calculated by the collapse cone convolution algorithm in Isogray TPS. Figure 1 shows an example of the left breast radiotherapy plans for a patient in radiotherapy center A (stage T2, with breast-conserving surgery, and surgical axillary staging showing 2 positive axillary nodes. ER, PR, and HER2 status for the patient was positive, and planned adjuvant chemotherapy and hormone therapy).

2.2. Evaluation and Comparison of Breast Radiotherapy Treatment Plans

Several dosimetric parameters were extracted from the radiotherapy plans and compared to assess the differences between the physical and motorized wedge techniques. Homogeneity and conformity Indices (HI, and CI) were calculated for Planning Target Volume (PTV) based on the equations recommended by the International Commission of Radiation Units (ICRU) 83 report [21]. Furthermore, mean doses of lung and heart, V_{20Gy} and V_{30Gy} of ipsilateral lung, and V_{10Gy} and V_{40Gy} of the heart were obtained from the planning dose distribution and used for dosimetric comparison of the radiotherapy techniques. It must be mentioned that V_{xGy} represents

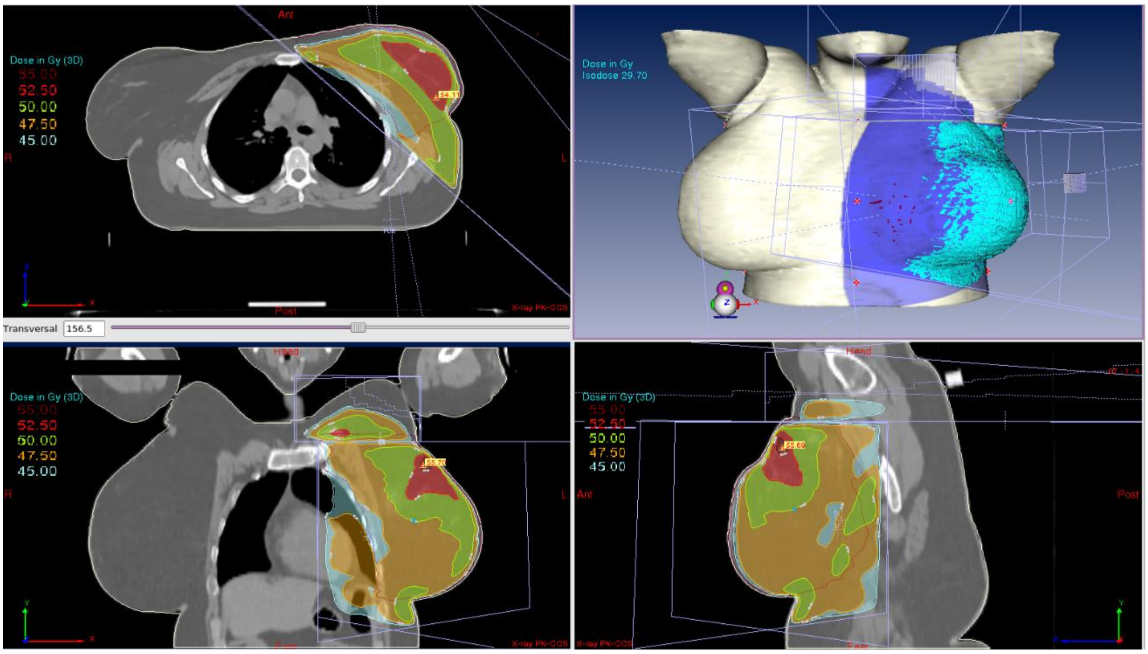

Figure 1. An example of the left breast radiotherapy for a patient in center A

the percentage volume of an organ receiving at least xGy radiation dose.

2.3. TLD Calibration

TLD chips (model: GR-200, material: LiF, Mg, Cu, P, disks of 4.5 mm diameter, and 0.8 mm thickness) produced by Solid Dosimetric Detector & Method Laboratory (Beijing, China) were used to measure the entrance skin dose of CLB. All the TLDs were heated at 240°C for 10 min and then cooled to 35°C for annealing. The TLDs were irradiated with an equal dose from a 10×10 cm^2 irradiation field produced by a linear accelerator with an X-ray energy of 6 MV at a depth of 2 cm below the slabs (RW3 slabs, PTW, Germany). The responses of these TLDs were read out using the Harshaw-4500 TLD reader device. The ECC (element correction coefficient) values were obtained for each TLD using Equation 1. Readouts were performed at 240°C for 34 seconds and pre-heating at 135°C for 5 seconds in the TLD reader after 48 h of exposure [22].

$$ECC_i = TLD_i \,/\, TLD_{(average)} \qquad (1)$$

For the TLD calibration and obtaining the TLD calibration curve, a calibrated farmer type 30013 ionization chamber dosimeter (0.6 cc effective volume, PTW, Germany) was used as the reference dosimeter at the same depth and setup for measuring the delivered dose based on IAEA TRS-398 protocol [23]. In this regard, nine TLD chips in three plastic packs were exposed to doses of 0.1, 0.2, 0.5, and 1 Gy. Three TLD chips were also used for background radiation measurements. All of the exposed TLDs corrected readings (based on the ECC values) were used to calculate the calibration curve [24].

2.4. TLD Uncertainty

Standard error values obtained from repeated measurements were used for the evaluation of TLD calibration uncertainty. The standard uncertainty (Uc) of TLDs can be calculated using Equation 2:

$$U_c = \sqrt{(N)^2 + (F_{fad})^2 + (F_{hot})^2 + (F_{energy})^2 + (F_{lin})^2} \qquad (2)$$

Where N and F_{fad} are the calibration coefficient, and the fading correction factor, respectively. F_{fad} is equal to 0.05% for GR-200 according to the Izewska *et al.*'s study [25]. F_{hol} is the TLD holder correction factor, estimated at 1% for GR-200 [25]. F_{energy} is the energy correction factor measured as the standard error of the actual corrections used for all patients. Six TLD chips were irradiated (as a group) for each dose, and the dose-response non-linearity correction factor (F_{lin}) was obtained by making a linear fit to the experimental data.

2.5. TLD Dosimetry of CLB Dose

In this project, the TLD dosimetry of the breast was performed at the first and last session of the radiotherapy procedure for each patient. Three locations (points) of the CLB, including the inner fold (between the upper and lower inner quadrants and 3 cm away from the nipple), center (2 cm above the nipple), and outer fold (between the upper and lower outer quadrants and 3 cm away from the nipple) were chosen for attaching the TLD chips (Figure 2). Three TLDs were placed as close as possible in each point to improve the statistical fluctuation of dosimetry results. The breast skin dose using TLD was calculated by Equation 3:

$$D\,(TLD) = R \times N \times G \times k \qquad (3)$$

In the above equation, R is the TLD reading (in nC) corrected by the ECC values, and N is the calibration coefficient (in Gy/nC). We did not consider the energy correction factor, because the calibration process was performed in the radiotherapy setup. G is the geometry correction factor and accounts for the inverse square relationship between the dose at the point of interest and the point of measurement. The point of interest was the basal skin layer (for all measurements), defined at a depth of skin surface (0.07 mm depth) in accordance with the ICRP recommendations [26]. Since the point of interest in the skin had a slightly higher distance to the source than the measured point, the dose will be slightly lower at basal skin than the TLD dose. However, it is negligible in external radiotherapy due to high distances between the source and skin (G can be assumed equal to 1 [27]). The k factor accounts for the correction factor relates to the lack of electronic equilibrium for skin measurement. In a previous study [28], the k factor was obtained by the Monte Carlo simulation with an average value of 0.98.

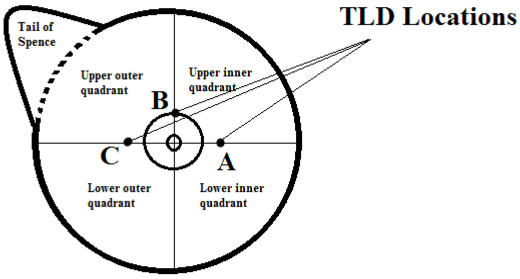

Figure 2. Schematic locations of the TLDs on the CLB

2.6. Analysis

The plan dosimetric parameters were compared between the physical and motorized wedged fields of radiotherapy techniques using an independent T-test to find any dosimetric differences. Furthermore, the measured dose of CLB was compared between the wedges using an independent T-test. It must be mentioned that the Kolmogorov-Smirnov test was used to check the compatibility of data distribution with normal distribution. The level of statistical significance was considered at $P < 0.05$. The statistical tests were carried out using the SPSS software package (V18, SPSS Inc., Chicago, USA).

Table 1. Uncertainty of TLD GR-200

Factor	N	F_{fad}	F_{hol}	F_{energy}	F_{lin}	U(D)
Uncertainties(%)	0.6	0.05	1.0	1.5	1.0	**2.15**

3. Results

3.1. TLD Calibration and Uncertainty

The obtained calibration curve of GR-200 is shown in Figure 3. The calibration coefficient of TLD dosimeters and reader system is 0.2013 cGy/μc at the dose range of 10-100 cGy. Furthermore, the R2 value of the fitting line was obtained at 0.999.

The uncertainty of TLD GR-200 was estimated from repetitive measurements at different distances. It was about 2.15% (Table 1) which is in agreement with the uncertainty values reported in previous studies [6, 27].

3.2. Dosimetric Comparison of Treatment Techniques

The mean and standard deviation of dosimetric parameters calculated from breast radiotherapy treatment plans with physical and motorized wedge fields are presented in Table 2. The results of the statistical T-test analysis showed that there were no significant differences in dosimetric parameters between the breast radiotherapy techniques. The dosimetric parameters related to both the target volume (including HI, and CI) and OARs (heart and lung) were statistically similar.

A sample of DVH curves obtained from motorized and physical wedge breast radiotherapy techniques performed on the same patient is illustrated in Figure 4. As can be observed, the differences between the treatment plan DVHs obtained from the radiotherapy techniques are small, supporting the statistical results that show no significant differences between the techniques in all the assessed dosimetric parameters.

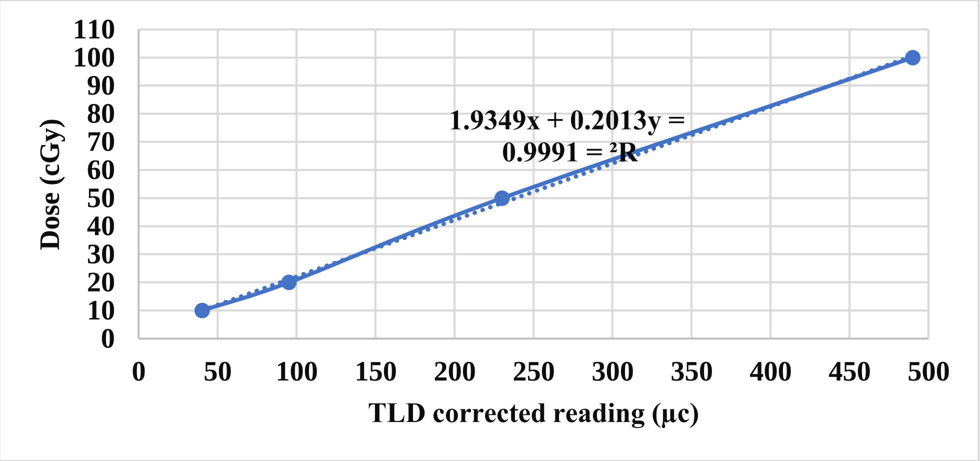

Figure 3. TLD calibration curves and the values of calibration coefficient and R^2 linear fitting

Table 2. Mean ± standard deviation values of dosimetric parameters calculated from physical and motorized wedge fields for breast radiotherapy

Treatment technique	PTV-HI	PTV-CI	$D_{0.1cc}$ (Gy)	MU		V_{20Gy}-lung (%)	V_{30Gy}-lung (%)	Mean dose (Gy) lung	V_{10Gy}-heart (%)	V_{40Gy}-heart (%)
				SC	Breast					
Motorized wedge	0.15±0.07	0.72±0.11	56.7±3.14	208±11.08	225±17.83	25.72±2.91	22.47±4.06	13.56±2.17	11.47±1.81	5.52±0.88
Physical wedge	0.24±0.05	0.79±0.09	58.1±3.44	215±13.21	231±15.29	27.14±3.05	23.83±3.51	14.25±2.21	9.21±2.42	4.36±1.12
P-value	0.074	0.451	0.377	0.754	0.446	0.205	0.691	0.774	0.345	0.408

HI: Homogeneity Index; CI: Conformity Index; $D_{0.1cc}$: Maximum average dose delivered to a 0.1-cc volume; MU: Monitor Unit; SC: Supraclavicular lymph nodes region; V_{xGy}: The percentage volume of an organ receiving at least xGy radiation

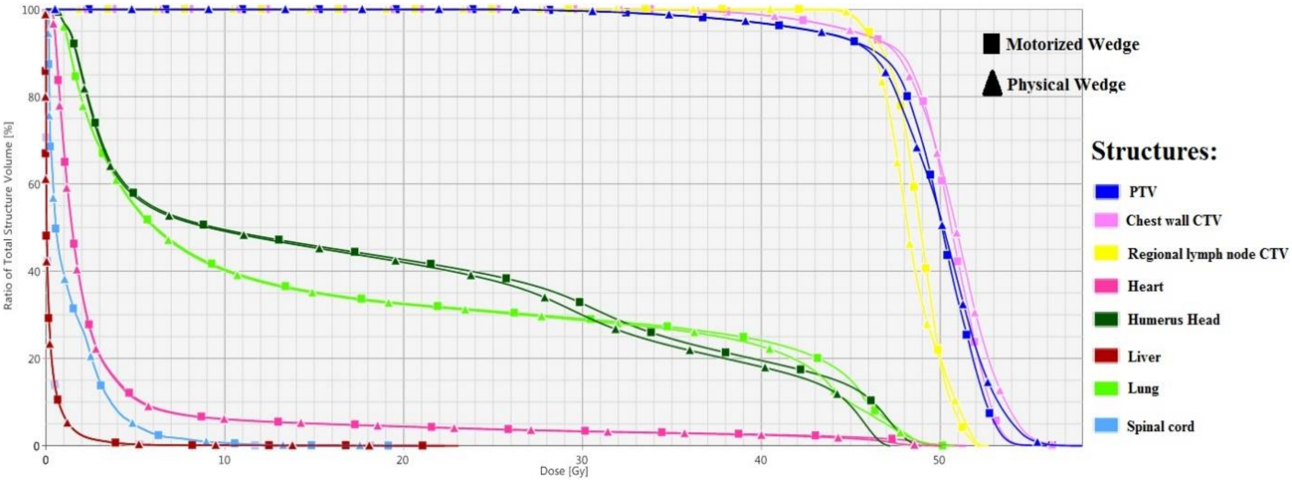

Figure 4. A sample of DVH curves obtained from motorized and physical wedge breast radiotherapy techniques performed on the same patient

3.3. CLB Dose Estimation

The CLB doses (breast skin doses at three different points) were measured for each patient. Figure 5a illustrates the mean and standard deviation values of the measured dose in the mentioned points at the first and last session of the radiotherapy treatment procedure for all patients. As expected, there were not any significant differences in measured doses between the first and final radiotherapy sessions (P>0.3). However, the measured doses at different points had great differences from each other. For example, the average (±standard deviation) measured doses in points A, B, and C were 367.5±55.2, 134.4±16.7, and 24.5±4.1 mGy, respectively.

Figure 5b illustrates the measured dose for the first session of the radiotherapy treatment, and Figure 5c shows the CLB skin doses measured at the last session. The statistical analysis revealed that the CLB skin dose in the first session did not differ significantly between the physical and motorized wedge techniques in all the evaluated points (P>0.09). However, the skin dose of point A showed a significant difference in the last treatment session, with the motorized wedge technique having higher doses (P=0.044).

Figure 5d shows the mean and standard deviation values of the average CLB kin dose (average value of points A, B, and C). The statistical analysis revealed that the average CLB dose measured at the last treatment session is significantly higher in the motorized wedge technique (P=0.039). However, the measured breast doses did not show any significant difference between the motorized and physical wedge techniques at the first session of treatment (P=0.84).

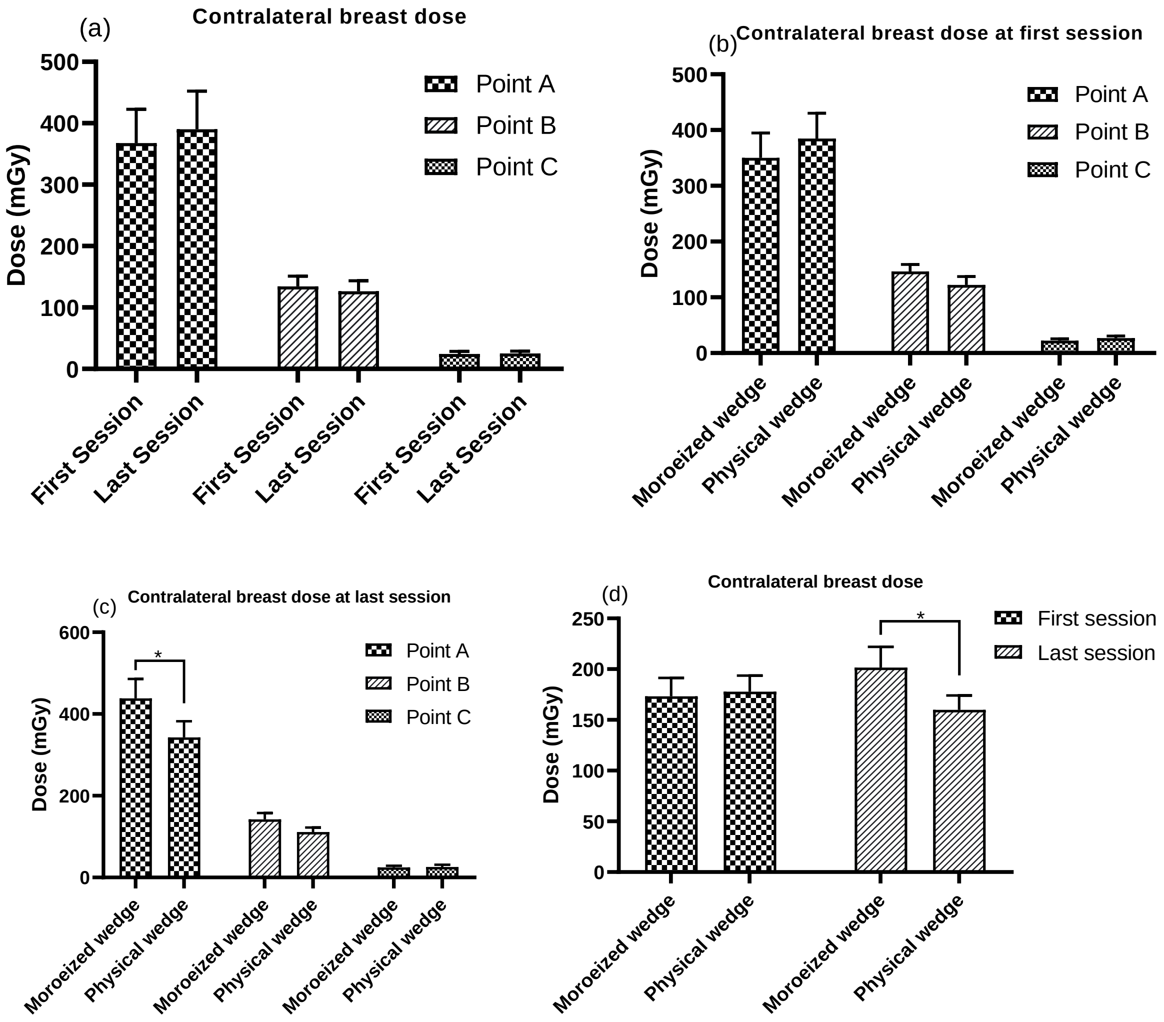

Figure 5. a): Mean and standard deviation values of CLB doses in the three points at the first and last session, b and c): CLB doses at different points for motorized and physical wedge fields, and d): Average value of CLB doses (mean value of points A, B, and C) of the radiotherapy treatment procedure

4. Discussion

The CLB skin dose was measured and compared between the physical and motorized wedge techniques in this study. We showed that the plan dosimetric parameters of these techniques had no significant differences. However, the motorized wedge technique delivered significantly higher doses to CLB. The CLB dose measurements were performed in the first and last session of the radiotherapy procedure.

Although the exposure to radiation outside the treatment area is lower compared to treatment field inside regions, research has demonstrated that even at low radiation doses, damage can occur to critical organs located outside the treatment region, resulting in the development of secondary cancers [10]. Consequently, the accurate calculation of out-of-field doses is crucial for evaluating the risk of secondary cancers and is integral to clinical decision-making. It was reported that a majority of secondary cancers arise within a range of 2.5 cm inside to 5 cm outside the PTV, where the received dose is less than 6 Gy [29]. The American Association of Physicists in Medicine Task Group 158 (AAPM-TG158) emphasizes caution when using TPSs for dose calculations in out-of-field regions [30]. Numerous studies have indicated that various TPSs employing different dose calculation algorithms lack efficacy in accurately calculating out-of-field doses [8, 10, 31]. For instance, Sanchez-Nieto *et al.* [31] demonstrated significant dose calculation errors in conformal and Intensity-Modulated

Radiation Therapy (IMRT) treatment plans using the Monaco TPS with different dose calculation algorithms. Additionally, Huang *et al.* [8] found that the Pinnacle TPS underestimated doses by more than 30% within 3–4 cm from the treatment field edge. They reported that the underestimation error increased with distance from the field edges and could potentially reach 100%. In relation to the accuracy of dose calculations with the Monaco TPS, Mahmoudi *et al.* [10] found mean errors of 37%, 48%, and 36% for water, lung, and bone equivalent media, respectively. Furthermore, all calculations consistently underestimated doses by an average of 40% across various distances and dose rates. The error rate was particularly elevated at a distance of 13 cm from the field edge.

Secondary breast cancer, especially in women younger than 45 years, due to breast radiotherapy is an important concern. In this regard, several studies assessed the CLB doses followed by changes in various factors [9, 17–19]. Our results showed that the motorized wedge technique had higher doses than the physical wedge method. Of course, there are other parameters such as field and block size, and gantry angle can be effective in the results.

In Heydari and Sardari's study [18], 32 female patients with breast cancer underwent breast radiation therapy (3-dimensional using Eclipse software). Two medial and lateral tangential fields plus an anterior supraclavicular field were determined for each patient. They used three TLD dosimeters (similar to our study), one of which was placed in the nipple of the CLB and the other two 3 cm above and below this point, and the CLB doses in each patient were measured. The results showed that the average dose measured by the TLD dosimeter in the inner part of the breast on the CLB had a significant increase compared to the upper and center of the nipple. The TLD locations of the Heydari and Sardari's study were different from our setup. However, we also found that the point closest to the involved breast receives the highest amount of dose. Another important finding of their study was the higher amount of CLB absorbed dose in patients treated with the wedge in the medial tangential field compared to patients treated without the wedge. Although we did not evaluate the open medial tangents fields, the reason for the higher CLB doses could be due to the scattering radiations resulting from the wedge. There are also several reports recommending not to use wedges with medial tangent fields if there are considerable concerns about the CLB dose [32]. Generally, when the wedges are used, some of the primary beams will attenuate, and also scatter radiations will increase; hence, excessive monitor units (MUs) should be delivered; as a result, head leakage and scattering will increase which causes higher CLB doses [21].

Williams *et al.* [20] measured the dose of the CLB after whole breast irradiation. An anthropomorphic phantom was imaged with a CT scanner and various treatment planning methods, including open tangents, tangents with an external wedge on the lateral beam, and tangential fields with external wedges, were performed to calculate dose distributions. They found that the treatment method with a single and double wedge increased the CLB doses compared to the treatment method without a wedge. In order to obtain the desired uniformity in the treatment of the breast while minimizing the absorption dose of the CLB, IMRT, and segmental methods were more effective than the treatment methods using physical compensators. To obtain a more general and accurate conclusion, it is recommended that in addition to the wedge, other parameters such as the effect of the field and block size should also be assessed [20].

In Bagheri *et al.*'s study [9], the received photon and thermal neutron doses to CLB ranged from 92.94-335.47 mSv and 90.62-332.56 mSv, respectively. The CLB doses were related to the use of physical and dynamic wedges at different field sizes, in which the average doses in the physical wedge were higher (197.09 mSv) than in the dynamic wedge. Our study obtained contrary results, showing that physical wedged tangential fields had lower CLB doses compared to motorized wedged fields. This may be related to a higher amount of scatter radiations produced by a motorized wedge (used in Elekta Compact linear accelerator) which must be assessed in future studies. Bouzarjomehri and Rezaie Yazdi [17] measured the radiation dose of CLB in 50 breast cancer patients treated with Oncor (Siemens, Germany) and Compact (Elekta, Sweden) linear accelerators. The CLB dose due to breast cancer radiotherapy by Oncor machine (physical wedge) was lower than the Compact (motorized wedge); the CLB doses (7.84% prescribed dose) in Compact linac were significantly higher. Their result is in agreement with our findings; the conclusion of the previous studies as well as the current study emphasizes again the need for future studies about the measurement and comparing the scatter radiations from different wedges such as motorized, virtual, and physical wedges.

Several other studies evaluated the CLB dose in breast radiotherapy. Bhatnagar *et al.* [33], evaluated the CLB dose for the patients treated by the conventional tangential field techniques and they showed that the CLB dose was 5.61 Gy (11.22% of the prescribed dose) on average. Faaruq *et al.* [19] compared the CLB doses in a Co-60 machine and 6 MV photons from a linear accelerator with three fields (two tangential and one supraclavicular field). The results showed that the CLB dose for patients treated with Co-60 was in the range of 3.2-10 Gy (6.4-20% of the prescribed dose), while the doses with Linac treatments were in the range of 2.6-7.5 Gy (5.2-15% of the prescribed dose). In the current study, the average CLB dose was 187.1 mGy (9.3% of the prescribed dose) and 168.8 mGy (8.4% of the prescribed dose) in each session for the patients treated with tangential field utilizing motorized and physical wedges, respectively.

Several suggestions can be considered in future research, including a) considering breast radiotherapy without using wedges in the medial tangential field and comparing the result of CLB dose with wedged fields techniques, b) measuring the amount of scatter radiations produced by various wedges such as physical, virtual, and motorized wedges with direct measurements or Monte Carlo simulations, and c) carrying out the project with a higher population of patients with breast cancer to perform calculations and analyze information more accurately.

5. Conclusion

Although the breast radiotherapy techniques using physical and motorized wedges are similar regarding the dosimetric parameters of PTV and OARs (heart and lung), the physical wedged fields technique had lower doses for CLB compared to the fields using motorized wedges. Therefore, it can be proposed to use tangential physical wedged fields for patients with high concern about the CLB dose. Furthermore, more research considering radiotherapy techniques without using a wedge in the medial tangent field or other relevant parameters such as using blocks, gantry angle, and collimator/multi-leaf collimator positions can be performed to obtain a better evaluation of the CLB dose.

Acknowledgments

We would like to express our appreciation to the SRBIAU (Science and Research Branch, Islamic Azad University) for their cooperation in our study.

This study was approved by the Science and Research Branch, Islamic Azad University, Tehran, Iran. The patients were enrolled in the study after obtaining the patients’ informed written.

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