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Impact of Patient Arm Positioning on Ddose Distribution in Target and Organs at Risk in Rright Bbreast Cancer Radiotherapy

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ABSTRACT

Introduction: Breast cancer (BC) ranks as the second most frequently diagnosed cancer among women globally. The aim of this study was to evaluate the effect of the patient's arm positioning on dose distribution in the organs at risk (OARs) and target in BC radiotherapy for mastectomy patients.

Material and Methods: Computed tomography (CT) scans of images of 30 right BC patients were collected. The patients were divided into two groups, each with 15 patients. The first group was with right arm-up positioning, and the second was with both arms-up positioning. The Monaco treatment planning system (TPS) was used for treatment planning. Radiotherapy included a prescribed dose of 50 Gy/25 fractions. For the planning target volume (PTV), the minimum dose (D_{min}), mean dose (D_{mean}), maximum dose (D_{max}), homogeneity index (HI), conformity index (CI), and tumor control probability (TCP) were calculated. For the OARs D_{min}, D_{mean}, D_{max}, and $V_{20\ Gy}$ (%) for the lung and normal tissue complication probability (NTCP) were assessed. We compared the two groups based on PTV and OAR levels.

Results: There was no statistical difference between quantities for PTV and OARs for the lung, heart, and spinal cord, but a statistical difference was only found in D_{mean} and D_{max} for the thyroid gland.

Conclusion: Although a statistically significant difference in thyroid dose was found, the absolute difference is small and within tolerance limits. Both positioning techniques provide comparable coverage of the target volume and sparing of the critical organs. With regard to patient comfort and ease of reproducibility during radiotherapy treatments, positioning with both arms up is generally favored, while positions with the right arm up may be an alternative if thyroid dose minimization is an issue.

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Introduction

Breast cancer (BC) is the most common malignancy diagnosed in women worldwide. Since radiotherapy (RT) is an essential tool for BC treatment, an increased number of new patients for external beam RT can be anticipated in the near future [1]. Breast-conserving surgery and RT have evolved as the preferred method for successful BC treatment [2]. Recent population-based retrospective reports suggest that breast-conserving therapy can provide satisfactory results compared with more traditional treatment modalities [3]. Adjuvant RT following mastectomy has also been found to provide remarkable results in the prevention of locoregional recurrence and mortality among patients with BC [2]. Nonetheless, RT following mastectomy tends to necessitate the irradiation of regional lymphatic stations such as the internal mammary and supraclavicular nodes. Targeting these areas typically leads to the treatment with larger fields and larger irradiated volumes. As a result, nearby organs at risk (OARs) receive elevated doses of radiation, thereby raising the risk of both early and late toxicities, particularly ischemic heart disease [3, 4].

Optimization of the radiotherapy (RT) modality choice is required to maximize target volume dose coverage while minimizing short- and long-term treatment-related toxicities [5]. The advances seen with new RT modalities such as intensity-modulated radiotherapy (IMRT), volumetric modulated arc therapy (VMAT), and tomotherapy have brought more emphasis towards minimizing patient positioning inaccuracies to provide higher accuracy in the delivery of the dose [6, 7]. The primary function of RT is not only to achieve effective irradiation of the tumor field but also to decrease doses of radiation to adjacent healthy organs and tissues [8, 9].

From the treatment positioning viewpoint, the arms-up treatment position is the standard for supine

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breast RT, but it poses challenges for some women, and they could not maintain a satisfactory arms-up, supine position [1, 2]. However, in the supine position, no dosimetric impact of arm position upon target coverage and normal tissue sparing in RT with photon beams has ever been evaluated [10]. Likewise, arms-down reproducibility for daily treatments has never been validated. In radiotherapy, position of the arm is considered to be important because the position can change the distance between the organs and the radiation field and even change the geometry of the organs [11, 12]. Therefore, the aim of this study is to evaluate the effect of a patient's arm positioning on dose distribution in planning target volume (PTV) and OARs in BC radiotherapy for mastectomy patients.

Moreover, some previous studies [13-17] for right BC, evaluated the treatment planning and patient positioning and compared the different types of linear accelerators by radiotherapy technique. These studies summarize that changing the patient's arm position would reduce the PTV dose or the dose to the OARs in some cases. There is also a clear discrepancy for some results on changing the type of radiotherapy technique, such as 3DCRT or IMRT or VMAT, and these studies do not evaluate the arm's positioning.

Materials and Methods

Patient selection

The characteristics of the patients in this study for right arm up and both arms up positioning groups, for radiotherapy of right breast cancer are presented in Table 1. CT scans were obtained by a Neusoft CT simulation machine (NeuViz 16, Neusoft Medical System Co. China), and images of 30 right BC patients were divided into two groups, each group with 15 patients. For the patients in the first group, the patients had their arms up and grabbed the handle, and the other arm was straight along the body, and the head rotated (almost 20 degrees) opposite of the tumor side (right). 6 radiopaque markers were put on the patient's body in order for us to be able to ensure that the patient's position during the radiotherapy was identical to the image on which the treatment plan was established, and these marks are placed in the same place in the radiological image, and then a radiopaque marker was placed on it during the radiotherapy sessions.

Table 1. Patient characteristics, stratified by arm positioning cohort for right arm-up and both arms-up positioning groups, for radiotherapy of right breast cancer

Characteristics	Patient positioning	
	Right arm up	Both arms up
Number of patients	15	15
Age (in years)	34-60 (average 47)	36-60 (average 48)
Prescription dose (Gy)	50.00	50.00
Mean PTV volume (cc)	1354.62	1506.71
Heart volume (cc)	592.80	595.70
Spinal cord volume (cc)	35.36	35.44
Right lung volume (cc)	1013.35	1022.54
Thyroid volume (cc)	22.79	22.60

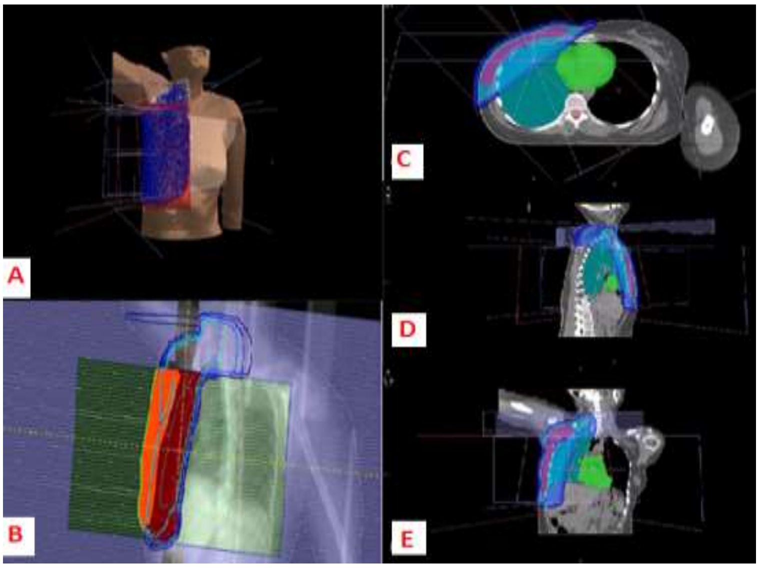

Figure 1. Images from TPS for a sample patient with right arm positioning: 3-dimensional (A), multileaf collimator (B), axial (C), sagittal (D), and coronal (E) views.

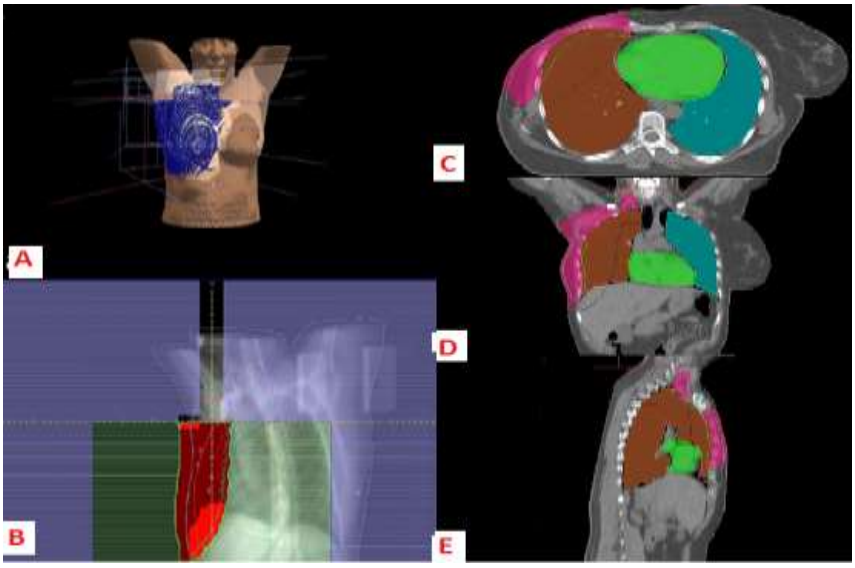

Figure 2. Images from TPS for a sample patient with both arm positioning: 3-dimensional (A), multileaf collimator (B), axial (C), sagittal (D), and coronal (E) views.

In the second group, both patients' arms were up and comfortably grabbed the side handles of the breast board, the patient's head was straight upward, and 9 radiopaque markers were put on the patient's body (3 sagittal markers on the midline of the patient body, upper markers were placed on the suprasternal notch, the middle one was placed between the other two markers in a fixed place, and a lower marker was placed 2 cm below the breast; 3 coronal markers were placed on the axilla of the right side and 3 coronal markers were placed on the right side axilla of the patient body in line. Images from different views for a sample patient with right arm positioning are illustrated in Figure 1. Furthermore, images from different views for a sample patient with both arm positioning are illustrated in Figure 2.

The reason for applying two different techniques in two patient groups was that our main objective was to evaluate and compare the dosimetric outcomes of these methods in right breast cancer radiotherapy patients. By analyzing both techniques, we aimed to determine which approach provides a more suitable dose distribution to the target while minimizing radiation exposure to the OARs. Comparing two techniques on the same patient group would provide the most direct evidence. However, performing two full CT simulations and treatment plans with different arm positioning for the same patient group would expose them to unnecessary additional radiation. From an ethical standpoint, we could not justify this extra radiation exposure. Therefore, two separate patient groups, each treated with one technique, were compared to minimize patient risk while still allowing a meaningful evaluation of the impact of arm positioning on dose distribution.

The CT number curve was calibrated in the Monaco TPS (version 5.11.03, Elekta, Sweden). It is important to highlight that this study exclusively included patients who received post-mastectomy radiotherapy.

After the treatment planning, plan evaluation was performed, and dose-volume histogram (DVH) curves were obtained. One experienced oncologist evaluated the plans, and different parameters for the PTV and OARs, such as D_{min}, D_{mean}, D_{max}, HI, and CI, were obtained from DVH curves. For the treatment planning of the patients, a 50 Gy dose was prescribed to the PTV throughout 25 fractions. The two arm positioning groups were compared in terms of these quantities.

Sample size

This study used a retrospective convenience sample of 30 right-breast mastectomy patients whose CT simulation data and treatment plans were available in our department during the study period. We divided these patients into two groups of 15 (right-arm-up and both-arms-up) to avoid exposing patients to additional CT radiation that would have been necessary if we had imaged the same patient in two different arm positions. Because the study was exploratory and retrospective in nature, no a priori power calculation was used to set the sample size; instead the sample size reflects the number of eligible and complete datasets available within the ethical constraints of the study.

Treatment planning and dosimetric parameters

In this study, the plans were designed by a medical physicist with highly experience in treatment planning to ensure optimal dosimetric coverage of the PTV and adequate OAR sparing. Experience and knowledge of physicists play an important role in more efficient treatment planning and differentiating between two arms up positioning groups in terms of treatment plans and comparing the dosimetric coverage of the radiation dose in PTV and dose to OARs.

Table 2. Parameters used to calculate TCP and NTCP for breast cancer based on Niemierko's EUD model [18].

Organ	Fraction	α/β	a	γ_{50}	TCD_{50} (%)	TD_{50} (%)
Breast	25	4	-7.2	2	28	-
Heart	25	2.5	3	3	-	50
Lung	25	4	1	2	-	24.50
Spinal cord	25	2	13	4	-	66.50

After collecting CT images of the patients in the two groups with the right arm up positioning and both arms up positioning from the radiotherapy centers, all structures, including the PTV and OARs were contoured by a radiation oncologist. These contours were imported to the Monaco TPS, where treatment plans were generated and compared for both patient groups.

The target structures, including the chest wall and regional lymph nodes, were considered to be included in the clinical target volume (CTV) and PTV were segmented. In addition, the heart, lung, and spinal cord were delineated as OARs; also, we used the thyroid as a sensitive organ. In Monaco TPS, the Monte Carlo dose calculation algorithm was used for dose distribution optimization based on the CT images. The tolerance dose level was according to the values found in the study by Emami [19].

From a dosimetric viewpoint, the following parameters were used to compare the two plans together: D_{min}, D_{mean}, D_{max}, HI, CI, and TCP for PTV. For the OARs, D_{min}, D_{mean}, D_{max}, and NTCP were used. TCP and NTCP can be calculated by the equivalent uniform dose (EUD) model in Microsoft Excel software. The parameters which were used to calculate TCP and NTCP, based on Niemierko's EUD model, are presented in Table 2 [18]. There is a need to import differential DVHs for PTV and OARs to calculate TCP and NTCP. The information provided by the CI reflects how well the shape and size of the prescribed isodose volume match those of the intended volumes [19].

Homogeneity index (HI) is defined by the following formula [20]:

$$\mathrm{HI}=\frac{\text{Dose that covers high dose reference percentage of tissue}}{\text{Dose that covers minimum dose reference percentage of tissue}} \quad (1)$$

The homogeneity index was obtained from the Monaco TPS.

The conformity index (CI) is also described as the ratio between the volume enclosed by the reference isodose-commonly set at 95% as per ICRU recommendations-and the target volume delineated by the treatment planner. It can be calculated using the following formula [20]:

$$\mathrm{CI}= V_{RI}/\mathrm{TV} \quad (2)$$

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

Equivalent Uniform Dose (EUD):

The EUD for each structure was calculated according to Niemierko's model using the following equation:

$$\mathrm{EUD} = \left(\sum_{i=1}(V_i \mathrm{EQD}_i^{\alpha})\right)^{\frac{1}{\alpha}} \quad (3)$$

Where:

- V_i= fractional volume receiving dose
- D_i= dose in dose-volume
- a = tissue-specific model parameter (negative for tumors; positive for normal tissues)

Tumor Control Probability (TCP):

TCP was calculated using the EUD-based Niemierko model as:

$$\mathrm{TCP} = \frac{1}{1+\left(\frac{\mathrm{TCD}_{50}}{\mathrm{EUD}}\right)^{4\times\gamma_{50}}} \quad (4)$$

Where:

- TCD_{50}= dose yielding 50% control probability
- γ50 = normalized dose-response gradient
- EUD = equivalent uniform dose of the target volume

Normal tissue complication probability (NTCP)

NTCP for each organ-at-risk (OAR) was calculated using the following Niemierko formula**:**

$$\mathrm{NTCP} = \frac{1}{1+\left(\frac{\mathrm{TD}_{50}}{\mathrm{EUD}}\right)^{4\times\gamma_{50}}} \quad (5)$$

Where:

- TD_{50}= tolerance dose producing 50% complication probability
- γ50= dose-response slope for each organ
- EUD = equivalent uniform dose of the organ

Statistical analysis

Statistical analysis was carried out using the Statistical Package for the Social Sciences (SPSS) version 16 (SPSS Inc., Chicago, USA). The normality of data distribution was ascertained using the Shapiro-Wilk test. p < 0.05 was considered to be a statistically significant difference between both groups (right arm-up positioning and both arms-up positioning) in terms of dosimetric parameters in PTV and OARs.

An independent t-test was applied to variables with a normal distribution, while the Mann-Whitney *U* test was used for variables that did not follow a normal distribution.

Results

Sample DVH curves for a mastectomy breast cancer patient with right arm up positioning and both arms up positioning are presented in Figure 3 and Figure 4, respectively.

In Table 3, the results for D_{min}, D_{mean}, D_{max}, HI, CI, and TCP for PTV for the right arm up positioning and both arms up positioning groups are presented. Table 4 also shows the results of the comparison between D_{min}, D_{mean}, D_{max}, and NTCP for OARs between the right-arm-up positioning and both-arms-up positioning groups.

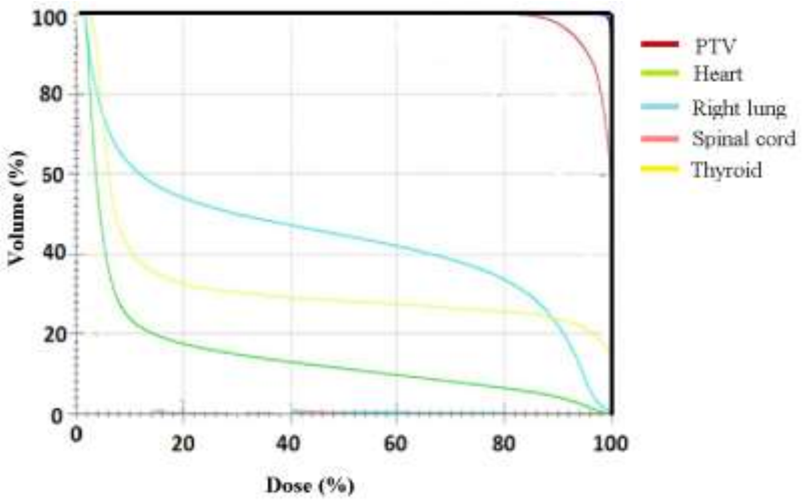

Figure 3. Sample DVH curves for a mastectomy right breast cancer patient with right arm-up positioning.

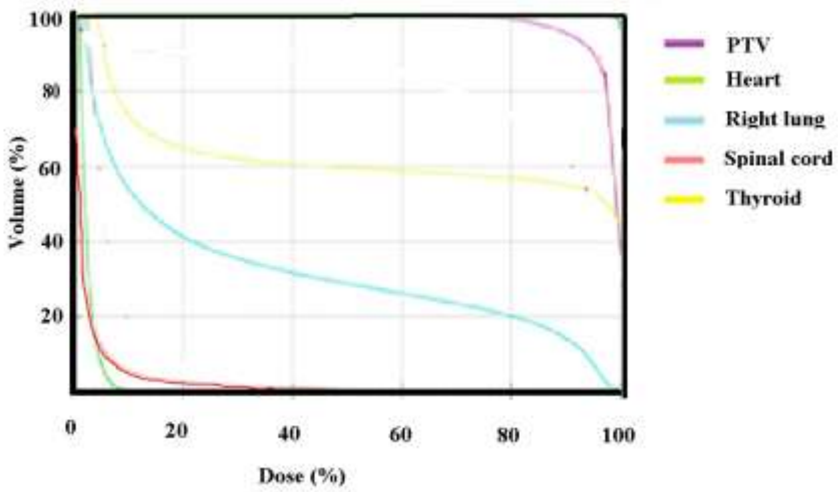

Figure 4. Sample DVH curves for a mastectomy right breast cancer patient with both arms up positioning.

Table 3. Comparison of dose distribution parameters for PTV between right arms-up and both arms-up positioning groups after radiotherapy for right breast cancer where HI is homogeneity index

Parameter	Right arm up	Both arms up	*p*-value
	Mean± SD	Mean± SD	
D_{min} (Gy)	31.17 ±3.96	30.25 ±5.16	0.52
D_{mean} (Gy)	49.28±2.70	50.38±3.32	0.44
D_{max} (Gy)	54.23±2.06	54.79±3.50	0.26
HI	1.15 ±0.06	1.15±0.03	0.90
CI	0.59±0.12	0.61±0.08	0.92
TCP (%)	96.86±1.93	97.13±2.06	0.71

Table 4. Comparison of dose distribution and NTCP for organs at risk (OARs) between right-arm-up and both-arms-up positioning groups.. * *p*-value is less than 0.05

OAR	Parameter	Right arm up (Mean ± SD)	Both arms up (Mean ± SD)	*p*-value
Heart	D_{mean} (Gy)	4.53 ± 3.97	3.84 ± 3.32	0.84
	NTCP (%)	0.00 ± 0.00	0.00 ± 0.00	0.24
Lung	$V_{20\ Gy}$ (%)	38.79 ± 3.19	38.55 ± 4.61	0.76
	NTCP (%)	0.03 ± 0.01	0.03 ± 0.09	0.79
Spinal cord	D_{max} (Gy)	29.60 ± 10.65	28.09 ± 7.67	0.52
	NTCP (%)	0.30 ± 0.21	0.23 ± 0.15	0.11
Thyroid	D_{min} (Gy)	2.51 ± 0.68	2.58 ± 0.52	0.79
	D_{mean} (Gy)	26.42 ± 2.28	31.21 ± 3.62	<0.01*
	D_{max} (Gy)	51.76 ± 1.58	53.36 ± 1.56	0.01*

Discussion

In this study, the effect of patient's arm positioning on dose distribution in PTV and OARs in right breast cancer radiotherapy for mastectomy patients was evaluated. Based on the presented data in Figure 5, the values of D_{mean} (Gy) for the right arm up positioning and both arms up positioning are 49.28 Gy and 50.37 Gy, respectively. 50 Gy was applied for both groups as the prescribed dose. For the two groups, the D_{mean} in PTV ranged from 95 (%) to 107 (%) which is normally considered to be the range for dose coverage of the PTV compared to the prescribed dose.

The D_{mean} for PTV values in the right arm up positioning and both arms up positioning groups were 50.38 Gy and 49.28 Gy, respectively. Statistical analysis revealed no significant difference between the two groups. ($p > 0.05$). This meant that the arm's positioning doesn't significantly change the dose distribution or geometry, shape, or distance of the organs affecting the dose to PTV.

HI for PTV is almost the same in both groups (Table 3), and there is no meaningful difference between the two groups in terms of HI ($p > 0.05$). Regarding CI for PTV, the nearest value of CI to 1.00 indicates that PTV has high conformity coverage. There is no significant difference between the two groups in terms of CI ($p > 0.05$); (Table 3). In terms of TCP for PTV, there is no statistically significant difference between the two groups ($p > 0.05$), this is because changing the position of the arms and head position almost does not affect the dose or geometry or change the distance from the radiotherapy source for PTV.

By knowing the *p*-values for dose distribution in PTV in terms of D_{min}, D_{mean}, D_{max}, HI, CI and TCP, there is no statistically significant difference between the first group (right arm up positioning) and the second group (both arms up positioning) ($p > 0.05$). This indicates that the right arm-up positioning is not different from both arms-up positioning in terms of dose distribution in PTV.

Regarding Table 4 and Figure 6 on the comparison of $V_{20\ Gy}$ (%) for the right lung in patients versus the tolerance level in the study by Emami [19], for two groups, the average $V_{20\ Gy}$ (%) in patients for the right arm up positioning was 38.79 %, and for both arm up positioning, it was 38.55 %. There is less than a 1% difference between them, but the $V_{20\ Gy}$ (%) for both groups is about 9% higher than the tolerance level. The reason for this effect is clinical consideration because while the physicist was trying to have 95% to 107% dose coverage for the PTV compared to the prescribed dose, the lung dose high in some patients. In other words, between covering PTV with good dose coverage and having the $V_{20\ Gy}$ (%) high for the lung, the good dose coverage for PTV is the choice that is selected.

Based on the data in Table 4, the comparison of D_{max} (Gy) for the spinal cord and D_{mean} (Gy) for the heart in patients versus tolerance dose for the right arm-up positioning and for both arms-up positioning shows that there is no significant difference ($p > 0.05$) between the two groups. The average D_{max} (Gy) for the spinal cord is 29.6 for right arm up positioning and 28.09 Gy for both arms up positioning; these are much less than 45 Gy, which is the tolerance dose based on the study by Emami [19].

Based on the data in Table 4, D_{mean} (Gy) for the heart is 4.52 Gy for the right arm-up positioning and 3.84 Gy for both arms-up positioning groups; these results are much less than the 26 Gy tolerance dose based on the study by Emami [19]. The results of NTCP in Table 4 can approve this because the NTCP for the heart for both groups is almost 0.00 (%), for the lung is about 0.25 (%), and for the spinal cord is about 0.23 (%). These values are good percentages for the heart, lung, and spinal cord, and it should be noted that there is no statistical significant difference ($p > 0.05$) in terms of NTCP for heart, lung and spinal cord. Concerning the results in Table 4, dose distribution parameters and radiobiological parameters for OARs are very close together for both groups ($p > 0.05$), except for the D_{mean} and D_{max} for thyroid; the p-value was 0.01and 0.01, respectively ($p < 0.05$).

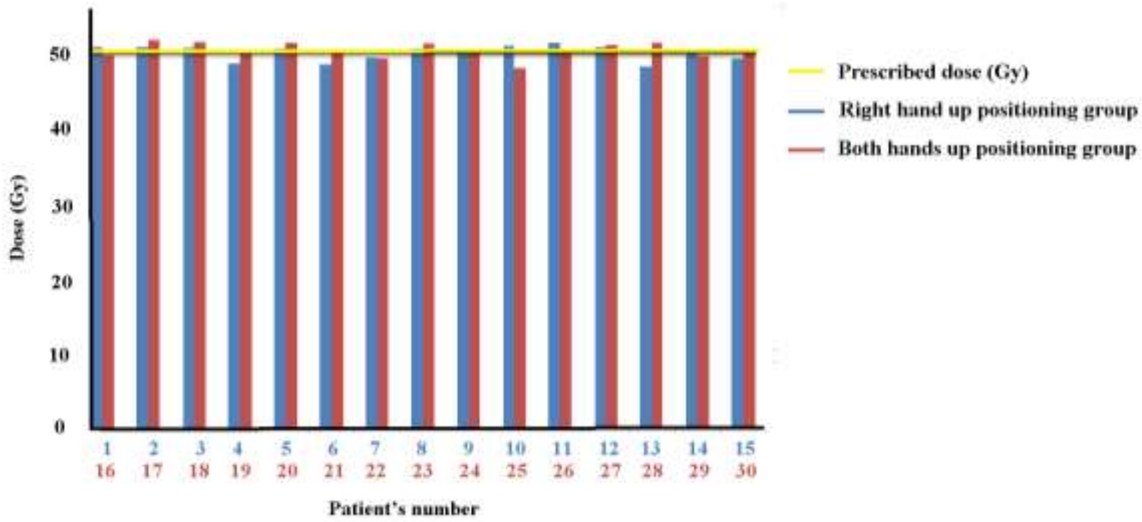

Figure 5. D_{mean} (Gy) for PTV versus prescribed dose (50 Gy) for the patients, for the right arm up positioning and both arms up positioning.

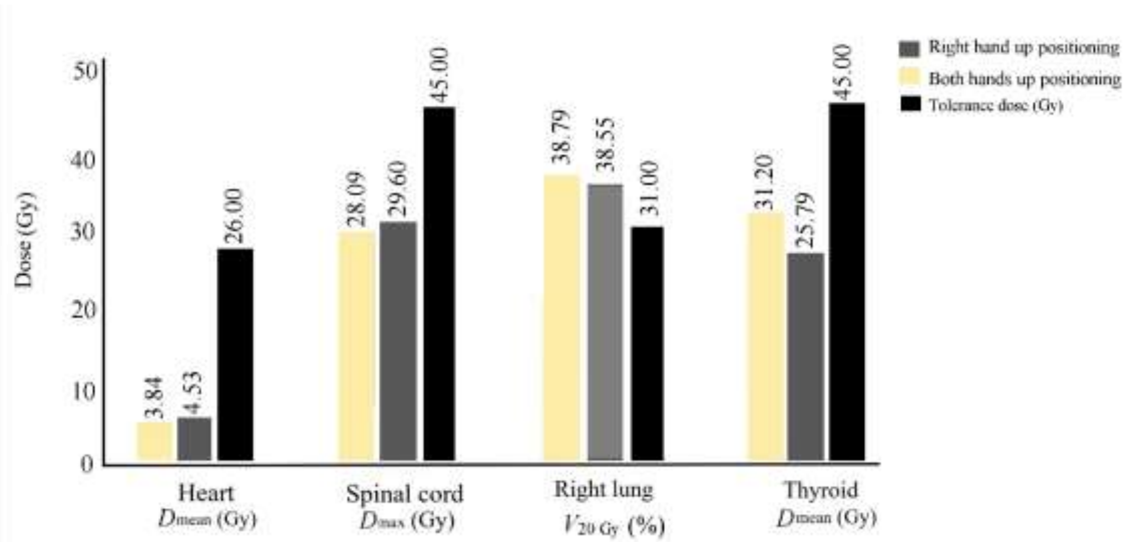

Figure 6. D_{mean} (Gy) for heart and right lung; D_{max} (Gy) for spinal cord; D_{mean} (Gy) for thyroid; and tolerance dose for a right arm up positioning and both arms up positioning.

All doses are lower than the tolerance dose for OARs such as heart, right lung, spinal cord and thyroid, as they can be seen in Figure 6. The tolerance dose for heart is 26 Gy, for lung is 20 Gy and for spinal cord is 45 Gy, based on the study by Emami [19]. There was a statistically significant difference between the two groups in thyroid dose ($p < 0.05$). As shown in Table 4, the D_{mean} was 26.42 ± 2.28 Gy in the right-arm-up group and 31.21 ± 3.62 Gy in the both-arms-up group, and the D_{max} was 51.76 ± 1.58 Gy and 53.36 ± 1.56 Gy, respectively.

In our study, the impact of arm positioning on the dose received by target and OARs was evaluated. However, other studies [21-24] have investigated this issue from different perspectives, employing various methods such as respiratory management techniques, treatment planning techniques, or patient setup variations. These studies, although different in methodology, also provide valuable dosimetric insights into how both the target volume and surrounding healthy tissues are affected by different factors. Taken together, these findings highlight the crucial importance of minimizing radiation exposure to healthy organs while maintaining adequate coverage of the tumor. The results of this study, alongside those from other approaches, emphasize the continuous effort within the field of radiotherapy to optimize treatment techniques. The ultimate goal is to improve tumor control while simultaneously reducing the risk of the radiation related side effects and preserving patient quality of life.

Conclusion

In post-mastectomy right-breast radiotherapy, arm positioning has little effect on the dose distribution to the PTV and most OARs, including the heart, right lung, and spinal cord. Though statistically significant, the differences in D_{mean} and D_{max} of the thyroid between the right-arm-up and both-arms-up groups were small in absolute amplitude and remained below clinical tolerance levels, suggesting that this effect is clinically negligible. Both positioning methods yield comparable target coverage and organ sparing. Considering aspects of patient comfort and reproducibility throughout radiotherapy, the both-arms-up position is generally favored, while the right-arm-up position may be preferred when it is desirable to minimize thyroid exposure. Patient comfort was considered in terms of how well the patients tolerated the prescribed position during their CT simulation and throughout treatment sessions. The both-arms-up position was felt to be much better tolerated by most patients.

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