Iranian Journal of Medical Physics

ijmp.mums.ac.ir

Dosimetric Effect of Setup Errors on Left Sided Breast Irradiation, For the Mono and Dual Isocenter Techniques

Yassine Oulhouq[1*], Abdeslem Rrhioua[1], Mustapha Zerfaoui[1], Dikra Bakari[2]

1. Laboratory of Physics of Matter and Radiation, Faculty of sciences, University Mohamed 1st, Oujda, Morocco
2. National School of Applied Sciences, University Mohamed 1st, Oujda, Morocco

ARTICLE INFO

Article type:
Original Paper

Article history:
Received: Jun 22, 2022
Accepted: Oct 22, 2022

Keywords:
Breast Cancer
Radiotherapy
Mono Isocenter
Dual Isocenter

ABSTRACT

Introduction: This study quantifies the dosimetric impact of lateral and longitudinal positioning errors on left-sided breast cancer during 3D conformal radiation therapy, employing both mono isocenter (MIT) and double isocenter technique (DIT) irradiations, and explores the frequency dependence of these errors.

Material and Methods: The study includes 10 left breast cancer patients, with two reference treatment plans created for each using both MIT and DIT techniques. Positioning errors of 2mm and 4mm in the right and inferior directions were simulated across varying error repetition scenarios (1 time, 5 times, 10 times, and 25 times) throughout the 25-fraction treatment period. Statistical analysis employed paired samples Student t-tests with a significance level of $\alpha<0.05$.

Results: Dosimetric impact was observed in MIT and DIT-TG (breast isocenter) plans for the heart, and in MIT and DIT-SC (supraclavicular isocenter) plans for the spinal cord. DIT-SC, being close to the spinal cord, demonstrated sensitivity to small lateral isocenter movements, impacting spinal cord dosimetry. Similarly, the heart and isocenter position in DIT-TG plans were susceptible to right-directional errors, affecting dosimetric parameters of these organs-at-risk.

Conclusion: Even minimal errors, measured in millimeters, can significantly influence heart and spinal cord dosimetry, potentially leading to heightened post-treatment toxicities, particularly when reference plan doses are close to recommended limits. The study advocates for vigilant repositioning accuracy control in DIT plans during each treatment session. Encouraging the use of MIT, when feasible, emerges as a crucial consideration to mitigate dosimetric variations and enhance treatment precision.

► *Please cite this article as:*
Oulhouq Y, Rrhioua A, Zerfaoui M Bakari, D. Dosimetric Effect of Setup Errors on Left Sided Breast Irradiation, For the Mono and Dual Isocenter Techniques. Iran J Med Phys 2023; 20: 290-297. 10.22038/IJMP.2022.66264.2138.

Introduction

Breast cancer is the most frequent malignancy in women worldwide [1]. Radiation therapy plays an indispensable role in the treatment of breast cancer, aiming to destroy malignant cells while preserving adjacent local healthy tissues. Breast cancer radiotherapy is one of the most common treatments in radiation oncology.

Damage caused by radiation to normal tissues can be both deterministic and stochastic. Major organs at risk of damage from breast cancer radiotherapy are heart, ipsilateral lung, spinal cord and skin.

Various modern radiation techniques, such as intensity-modulated radiotherapy (IMRT) and volumetric-arc modulated radiotherapy (VMAT), are currently used to obtain better dosimetric results than 3D conformational technique (3DCRT) in breast cancer radiotherapy by improving dose distribution. However, many studies reported that these modern techniques could have significant complication rate increase in some organs at risk, such as an excess of absolute risk for secondary ipsilateral lung cancer in multibeam IMRT and VMAT as compared to 3DCRT or tangential IMRT [2-4].

Furthermore, it's important to acknowledge that the accessibility to these advanced techniques is not uniformly available to all breast cancer patients globally. This disparity is primarily attributed to logistical and economic differences between regions. As a result, the 3DCRT technique remains the primary modality for the majority of breast cancer treatments [5].

The two commonly used techniques in 3DCRT, for the breast and supraclavicular irradiation, are the mono-isocenter technique (MIT) and the double isocenter technique (DIT) (Figure 1) [6].

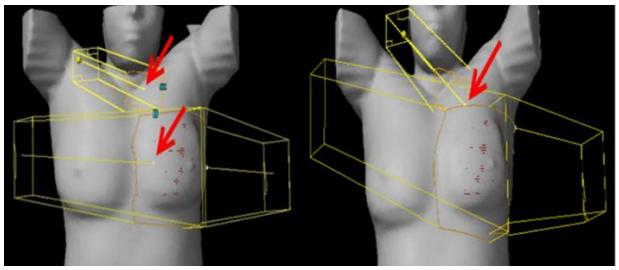

Figure. 1. An example of the treatment planning configuration used for the MIT (Right) and DIT (Left)

*Corresponding Author: Tel: +212 670 230 530; Fax: +212 536 500 603; Email: Oulhuq.y@gmail.com

The MIT use only one isocenter for all the irradiation fields. There is therefore only one positioning of the planned isocenter of treatment. Hence, it is necessary to establish an appropriate reference point for dose calculation, as the dose distribution cannot be normalized to the isocenter point, given its location below the jaw edge of the linear accelerator collimator.

On the other hand, in the DIT technique there is an isocenter for each treatment plan, the first used for supraclavicular area (DIT-SC) and the second used for the breast irradiation (DIT-TG), and it requires a relatively long implementation time. In addition, the manipulator must fix up each field independently, thus creating regions of over and/or under dosage at the junction of treatment fields.

In large breast size irradiation, radiotherapy planning becomes quite complex. Since mono-isocentric treatment approaches may have certain limitations as the half beam size. This requires choosing other treatment techniques like dual-isocentric that may be a solution for the treatment of such patients.

The precision of positioning of breast cancer patients during radiotherapy is vital for its success. At each course of the treatment, the patient positioning must be reproducible to ensure that target volumes receives the planned doses [6-7. Therefore, high precision in patient positioning is required, as even slight errors in the positioning affect not only the dose distribution in the target volume but also the dose exposure of organs at risk, leading to the increase of complication probability.

The aim of this study is to quantify the dosimetric effect of the lateral and longitudinal positioning errors on left sided breast cancer, for 3DCRT mono isocenter and double isocenter techniques irradiations, and its frequency dependence.

Materials and Methods

Patients and methods

A total of 10 patients with left breast cancer were included in this study. All patients performed a non-contrast computed tomography (CT) simulation with 3.0 mm slice thickness, in a supine position with arms abducted beside head and immobilized with a breast board, using General Electrical Medical Systems (OPTIMA CT 580). The data sets were transferred to the Eclipse Planning System version 13.6 (Varian Medical system). The physician contoured the planning target volumes comprised of two sections, chest wall and/or residual breast (PTVBreast), and supraclavicular lymph node area (PTVN). As well as organs at risk (heart, ipsilateral lung, contralateral lung and spinal cord) on each CT slice, according to Radiation Therapy Oncology Group guidelines [8-9].

Eclipse™ v. 13.6 TPS, was used to generate two different treatment plans for each patient described below. The algorithm used for dosimetry calculations was the Analytical Anisotropic Algorithm AAA.

The prescribed doses for all plans was 50 Gy, and treatment is usually given with a fractionation scheme of 5 days per week for 5 weeks (3–5) and by using 6 MV static photon beam energy only or mixed with 18 MV. For each patient two reference treatment plans were planned by two different techniques:

Double isocenter technique (DIT): One isocenter is assumed for the anterior supraclavicular field. Habitually, the reference isocenter was situated at the field's center and at a depth ranging from 2 cm to 3 cm beneath the patient's skin, aligned with the medial aspect of the humeral head at the midsternal line. By employing a gantry angle of 10–15 degrees, this setup effectively shielded critical structures like the esophagus, spinal cord, and larynx.

For both tangential fields, a separate isocenter was designated. Typically, it was positioned at an equidistant point between the upper and lower borders of the target tissue, with a depth of approximately 2 cm to 3 cm from the chest wall's surface. The adjustment of both fields' gantry angles was carried out to ensure comprehensive coverage of the defined clinical breast margins marked by radiopaque wires while minimizing the inclusion of ipsilateral lung volume within the treatment area.

Among the drawbacks of this technique, the radiation therapist needs to enter the treatment room and change the patient positioning to treat second part of the dosimetric plan.

In the Mono Isocenter Technique (MIT), also known as the single isocenter technique, a sole isocenter is employed to guide the three-photon field. This isocenter is strategically positioned along the axis that connects the supraclavicular and tangential fields, at a depth coinciding with the lower boundary of the supraclavicular and thoracic wall. All fields are configured using asymmetric collimation. During the definition of the tangential fields, the upper half of the beam is restricted, whereas in setting up the supraclavicular field, the collimator jaw limits the inferior half of the field.

For the tangential fields, the gantry angle is meticulously chosen to encompass breast tissue within the clinically delineated margin demarcated by radiopaque wires while minimizing the involvement of ipsilateral lung tissue within the treatment field.

For each treatment technique, we studied the influence of positioning errors in two different directions (lateral and longitudinal) on target volumes and OARs. For each patient, a reference plan without positioning error for each treatment technique (MIT / DIT-tangential / DIT-supraclavicular) was set. Then positioning errors of 2 mm and 4 mm in both directions (right and inferior) were applied to each reference plan, in different error repetition scenarios (error occurring 1 time, 5 times, 10 times, and 25 times) over the 25 fraction treatment planned. Quantitative evaluation of the 16 resulting error plans was performed for each

technique (as described in the statistical analysis section) using dose volume histogram analysis.

The mean doses of the PTVBreast and PTVN, as well as the heart mean and spinal cord max doses were checked as a function of error frequencies at each positioning error. The same for the ipsilateral lung mean dose. Each dosimetric parameter was analyzed for all patient plans.

Statistical analysis

Statistical analysis was done using SPSS software for Windows (Version 20). To test the distribution normality of variables, we used the Kolmogorov-Smirnov test, which did not reach the significance threshold of 0.05, confirming that we were allowed to use parametric tests in our statistical analysis.

« Student's test for paired samples » was used to compare variables between related groups. For each volume, we have calculated the mean ± standard deviation of the dose received by the hole sample of patients in the original dosimetric plan, then when the setup errors were applied to the simulation plan. Each setup error plan (x-2 mm, x-4 mm, z-2 mm, z-4 mm) was compared to the original dosimetric plan for several scenarios of error repetitions: 1 single error /25 fractions, 5 repetitions /25 fractions, 10 repetitions / 25 fractions, and 25 repetitions / 25 fractions (systematic error).

In total, 480 dosimetric plans were compared to their respective reference plans. The comparisons concerned the PTVBreast and the PTVN mean doses, the spinal cord maximum dose, the heart and the ipsilateral lung mean doses.

The error risk alpha of 0.05 was set to access the statistical significance of the comparison results.

Results

The comparison of the mean doses, of the target volumes PTVBreast and PTVN for all the patients studied, are summarized in Tables 1 and 2. This comparison concerns the reference plans and those perturbed for MIT and DIT techniques, for each positioning error as a function of its frequency.

For the mean doses of PTVBreast, there was a statistically significant differences for lateral positioning errors in the MIT, which is noticeable from a single error repetition. Regarding the longitudinal errors, there was a statistically significant difference in the DIT plans for the SC isocenter (DIT-SC), which are also remarkable from a single error repetition. However, there was no significant difference for DIT plans in the positioning errors along the tangential isocenter DIT-TG (Table 1).

For the PTVN mean dose, the most sensitive plan to positioning error was the DIT-TG in the inferior direction. DIT-SC was not altered by positioning errors in both directions, while the MIT plan was significantly different only in the 4 mm inferior error when repeated 25 times, as shown in Tables 2.

Table 1. Comparison of average PTVBreast mean doses, between the reference and perturbed plans as function of error frequencies at pitches of 2 mm and 4 mm, for MIT and DIT isocenters

			MIT		DIT-TG		DIT-SC	
Error		Frequency	Mean (Gy)	P-Value	Mean (Gy)	P-Value	Mean (Gy)	P-Value
		Ref Plan	49.53± 1.49	-	49.7± 1.21	-	49.7± 1.21	-
Right	2 mm	1	49.42± 1.49	0.023	49.72± 1.21	0.572	49.67± 1.23	0.698
		5	49.42± 1.5	0.012	49.75± 1.21	0.238	49.67± 1.23	0.616
		10	49.41± 1.5	0.007	49.77± 1.22	0.199	49.66± 1.23	0.513
		25	49.4± 1.51	0.006	49.86± 1.24	0.112	49.78± 1.08	0.548
	4 mm	1	49.38± 1.53	0.018	49.71± 1.2	0.651	49.66± 1.23	0.354
		5	49.37± 1.53	0.008	49.75± 1.2	0.302	49.65± 1.23	0.34
		10	49.37± 1.53	0.005	49.79± 1.22	0.244	49.65± 1.23	0.32
		25	49.38± 1.56	0.03	49.94± 1.27	0.141	49.77± 1.08	0.576
Inferior	2 mm	1	49.5± 1.46	0.366	49.7± 1.21	0.173	49.7± 1.21	0.015
		5	49.5± 1.46	0.414	49.69± 1.22	0.133	49.71± 1.21	0.015
		10	49.5± 1.45	0.477	49.68± 1.24	0.131	49.71± 1.21	0.017
		25	49.51±1.45	0.661	49.64±1.28	0.128	49.73±1.21	0.016
	4 mm	1	49.79± 1.92	0.428	49.7± 1.21	0.105	49.7± 1.21	0.021
		5	49.51± 1.46	0.543	49.67± 1.23	0.095	49.71± 1.21	0.033
		10	49.52± 1.46	0.763	49.64± 1.25	0.075	49.73± 1.21	0.035
		25	49.56± 1.47	0.682	49.55± 1.33	0.091	49.73± 1.22	0.034

Table 2. Comparison of average PTVN mean doses, between the reference and perturbed plans as function of error frequencies at pitches of 2 mm and 4 mm, for MIT and DIT isocenters

			MIT		DIT-TG		DIT-SC	
Error		Frequency	Mean(Gy)	P-Value	Mean(Gy)	P-Value	Mean(Gy)	P-Value
		Ref Plan	50.54±1.12	-	50.59±1.23	-	50.59±1.23	-
Right	2 mm	1	50.45±1.13	0.335	50.58±1.23	0.333	50.59±1.23	0.711
		5	50.49±1.13	0.608	50.58±1.23	0.548	50.47±1.08	0.412
		10	50.5± 1.11	0.632	50.59±1.22	0.938	50.48±1.09	0.458
		25	50.71±1.18	0.238	50.61±1.22	0.28	50.49±1.13	0.513
	4 mm	1	50.45±1.13	0.338	50.58±1.23	0.42	50.59±1.23	0.561
		5	50.53±1.15	0.92	50.59±1.22	0.835	50.59±1.26	0.867
		10	50.54±1.12	0.986	50.61±1.22	0.261	50.58±1.28	0.83
		25	50.94±1.31	0.103	50.65±1.22	0.042	50.56±1.37	0.707
Inferior	2 mm	1	50.51±1.12	0.296	50.59±1.23	0.015	50.59±1.23	0.722
		5	50.49±1.12	0.163	50.58±1.24	0.005	50.62±1.23	0.157
		10	50.43±1.13	0.138	50.57±1.24	0.005	50.64±1.23	0.16
		25	50.36±1.16	0.072	50.55±1.24	0.005	50.72±1.23	0.162
	4 mm	1	50.74±1.51	0.561	50.59±1.23	0.004	50.59±1.23	0.822
		5	50.41±1.14	0.201	50.58±1.24	0.004	50.62±1.23	0.282
		10	50.38±1.17	0.121	50.55±1.24	0.026	50.64±1.22	0.284
		25	50.26±1.25	0.042	50.51±1.24	0.004	50.71±1.23	0.284

Table 3. Comparison of average ipsilateral lung mean doses, between the reference and perturbed plans as function of error frequencies at pitches of 2 mm and 4 mm, for MIT and DIT isocenters

			MIT		DIT-TG		DIT-SC	
Error		Frequency	Mean (Gy)	P-Value	Mean (Gy)	P-Value	Mean (Gy)	P-Value
		Ref Plan	12.04± 3.2	–	12.22±3.14	–	12.22± 3.14	–
Right	2 mm	1	12.06± 3.21	0.001	12.24± 3.14	0.002	12.53± 2.74	0.359
		5	12.15± 3.23	<0.001	12.31± 3.16	0.003	12.56± 2.73	0.332
		10	12.26± 3.25	<0.001	12.4± 3.18	0.001	12.6± 2.73	0.303
		25	12.59± 3.31	<0.001	12.7± 3.24	0.001	12.7± 2.72	0.238
	4 mm	1	12.08± 3.21	<0.001	12.25± 3.15	0.027	12.22± 3.14	0.75
		5	12.26± 3.24	<0.001	12.4± 3.18	0.001	12.25± 3.16	0.015
		10	12.49± 3.28	<0.001	12.6± 3.22	0.001	12.29± 3.17	0.007
		25	13.16± 3.41	<0.001	13.19± 3.35	0.001	12.41± 3.22	0.005
Inferior	2 mm	1	12.05±3.2	<0.001	12.21±3.14	0.26	12.23±3.14	0.119
		5	12.12±3.19	<0.001	12.2±3.13	0.157	12.3±3.13	<0.001
		10	12.21±3.18	<0.001	12.19±3.12	0.153	12.39±3.12	<0.001
		25	12.46±3.15	<0.001	12.17±3.1	0.196	12.66±3.1	<0.001
	4 mm	1	12.12±3.11	0.138	12.21±3.13	0.209	12.24±3.13	0.005
		5	12.21±3.18	<0.001	12.19±3.12	0.147	12.39±3.12	<0.001
		10	12.39±3.15	<0.001	12.16±3.12	0.199	12.56±3.1	<0.001
		25	12.91±3.09	<0.001	12.14±3.07	0.224	13.09±3.05	<0.001

Dose parameters for OARs are summarized in tables 3 to 5. Table 3 compare the ipsilateral mean dose calculated with MIT and DIT techniques for the reference and perturbed plans for each positioning error depending on its repetition frequency.

As regard to the ipsilateral lung dosimetric parameters, the differences between the reference plan and the perturbed plans were statistically significant ($p < 0.05$) for all studied positioning errors, starting from a single repetition For the MIT plans. The differences increase significantly when the error change from 2 mm to 4 mm. Further, the mean dose can increase from 12.04 ± 3.2 in the reference plan up to 12.59 ± 3.31 and 13.16 ± 3.4 after introducing lateral errors of 2 mm and 4 mm respectively, in the whole treatment course (25 repetitions).

For the DIT plans after considering 2 mm and 4 mm position error, firstly at the TG isocenter (DIT-TG) plans, the difference between the reference plan and the disturbed plans is statistically significant only in the lateral direction. Regarding the DIT-SC plans there were no significant differences.

The mean and maximum doses of the heart and the spinal cord respectively, were compared for each positioning error presented in Tables 4 and 5.

Table 4. Comparison of average Spinal cord max doses, between the reference and perturbed plans as function of error frequencies at pitches of 2mm and 4mm, for MIT and DIT isocenters

			MIT		DIT-TG		DIT-SC	
Error		Frequency	D max (Gy)	P-Value	Dmax(Gy)	P-Value	Dmax(Gy)	P-Value
		Ref Plan	25.45±10.17	-	29.03±7.83	-	29.03±7.83	-
Right	2 mm	1	25.61±10.19	0.694	29.01±7.54	0.936	29.99±6.88	0.366
		5	26.98±10.16	0.001	29.01±7.54	0.939	31.3± 6.26	0.075
		10	28.69±10.15	<0.001	29.01±7.54	0.943	33.01±5.56	0.015
		25	34.31±10.55	<0.001	28.77± 7.6	0.466	39.01±3.31	0.003
	4 mm	1	26.03± 9.67	0.12	29.22±7.23	0.655	29.33±7.65	0.276
		5	28.33± 9.31	0.001	29.22±7.23	0.652	31.57±6.69	0.002
		10	31.21± 8.87	<0.001	29.22±7.23	0.648	34.53±5.61	0.001
		25	40.18± 7.89	<0.001	28.98± 7.3	0.922	44.11±2.22	0.001
Inferior	2 mm	1	25.42±10.13	0.127	29.03±7.83	0.667	28.92±7.75	0.102
		5	25.3± 10	0.125	29.03±7.83	0.772	28.63±7.58	0.071
		10	25.15± 9.83	0.125	29.03±7.83	0.368	28.37± 7.5	0.089
		25	24.69± 9.35	0.127	29.03±7.84	0.132	27.77±7.62	0.144
	4 mm	1	25.55± 10.2	0.598	29.03±7.83	0.356	28.78±7.63	0.097
		5	25.12± 9.88	0.086	29.03±7.83	0.911	28.33±7.42	0.093
		10	24.78± 9.6	0.086	29.03±7.83	1	27.95± 7.5	0.13
		25	24.02± 9.24	0.058	29.03±7.82	1	27.13±7.98	0.184

Table 5. Comparison of average Heart mean doses, between the reference and perturbed plans as function of error frequencies at pitches of 2mm and 4mm, for MIT and DIT isocenters

			MIT		DIT-TG		DIT-SC	
Error		Frequency	Mean (Gy)	P-Value	Mean (Gy)	P-Value	Mean (Gy)	P-Value
		Ref Plan	4.03± 1.4	–	4.64± 2.65	–	4.64± 2.65	–
Right	2 mm	1	4.04± 1.4	0.105	4.67± 2.66	0.038	4.77± 2.62	0.348
		5	4.1± 1.41	<0.001	4.73± 2.68	0.001	4.78± 2.62	0.348
		10	4.19± 1.43	<0.001	4.82± 2.72	0.001	4.79± 2.62	0.348
		25	4.44± 1.5	<0.001	5.09± 2.82	0.001	4.83± 2.62	0.354
	4 mm	1	4.06± 1.4	0.001	4.68± 2.67	<0.001	4.64± 2.65	0.298
		5	4.2± 1.43	<0.001	4.82± 2.71	<0.001	4.64± 2.65	0.13
		10	4.38± 1.48	<0.001	5.01± 2.78	<0.001	4.64 ± 2.65	0.089
		25	4.91± 1.61	<0.001	5.57± 2.98	<0.001	4.64± 2.65	0.032
Inferior	2 mm	1	4.02±1.39	0.491	4.64± 2.65	0.573	4.64± 2.65	0.172
		5	4.03± 1.4	0.672	4.64± 2.65	0.578	4.64± 2.65	0.003
		10	4.04± 1.4	0.18	4.64± 2.64	0.55	4.64± 2.65	0.003
		25	4.07± 1.42	0.039	4.65± 2.63	0.554	4.64± 2.65	0.002
	4 mm	1	4.05± 1.39	0.457	4.64± 2.65	0.549	4.64± 2.65	0.03
		5	4.04± 1.4	0.192	4.64± 2.64	0.525	4.64± 2.65	0.003
		10	4.06± 1.41	0.061	4.64± 2.61	0.977	4.64± 2.65	0.002
		25	4.13± 1.45	0.03	4.66± 2.59	0.252	4.65± 2.65	0.001

For the spinal cord, only MIT and DIT-SC plans are sensitive to positioning errors in the right directions. For the MIT plans, we noted that the differences between the reference plan and the error plans are statically significant from 5 repetitions. Whereas, for the DIT-SC plan, the differences has become significant from 10 repetitions in 2 mm and 5 repetitions in 4 mm. DIT-TG plans were not statically different despite positioning error application and repetition in both directions.

Particularly for the spinal cord, we noted that the maximum dose reached 34.31±10.55 Gy and 39.01±3.31 Gy for the MIT and DIT-SC plans respectively, when 2 mm error repeated 25 times, and it reached 40.18±7.89 Gy and 44.11±2.22 Gy for 4 mm error repeated 25 times. This was significantly higher than the planned maximum spinal cord dose in the reference MIT and DIT-SC plans (25.45±10.17 Gy and 29.03±7.83 Gy, respectively).

To better appreciate the impact of positioning errors as a function of the number of error repetitions, the DVH (Dose Volume Histogram) of the spinal cord is shown in figure 2, for 2 mm and 4 mm errors to the right of the patient.

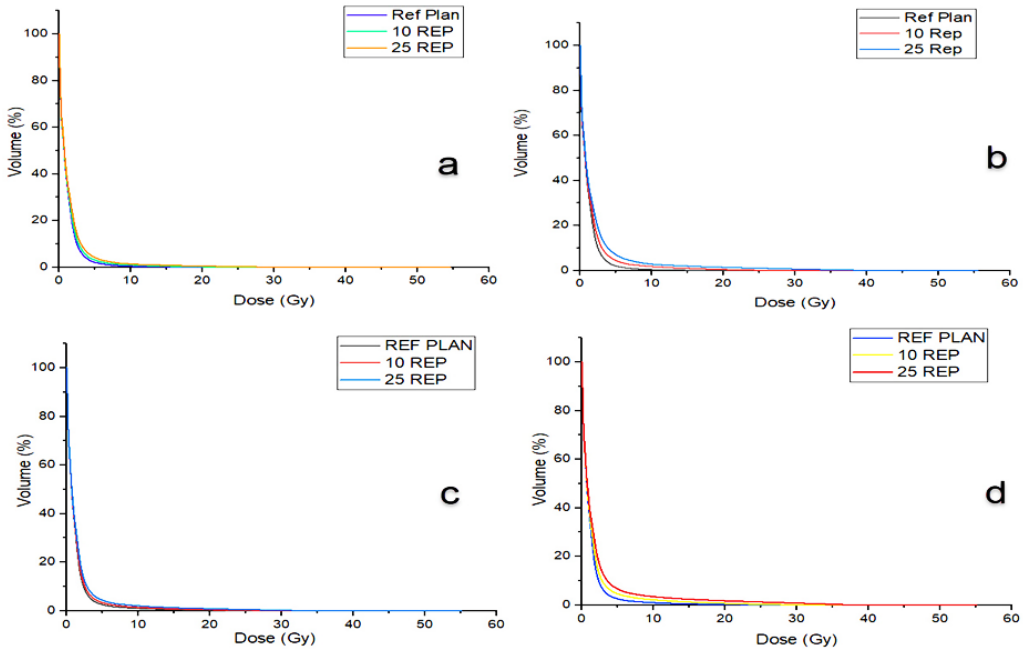

Figure 2. Comparison of the spinal cord dose-volume histograms for the reference without and with two lateral positioning error to the right of 2mm (subFigs a and c) and 4mm (subFigs b and d), for MIT isocenter (a and b) and DIT SC isocenter (c and d), according to 0, 10 and 25 error repetitions

Table 6. Comparison of average plans Hotspots, between the reference and perturbed plans as function of error frequencies at pitches of 2mm and 4mm, for DIT isocenters

Axis		DIT-Tg		DIT-sc		DIT	
Direction		Sup		Inf		Sup+Inf	
Error	Frequency	Mean (Gy)	P-value	Mean (Gy)	P-value	Mean (Gy)	P-value
	0 (reference)	55.2 ±0.312		55.2 ±0.312		55.2 ±0.312	
2mm	1	55.21±0,314	0.750	55.318±0,260	0.183	55.49±0,455	0.037
	5	55.87±1.056	0.118	56.067±1,004	0.063	57.56±1.97	0.026
	10	57.78±2.012	0.024	57.505±2,019	0.031	60.061±3.517	0.020
	25	64.184±7.22	0.029	63.416±4.8290	0.009	70.63±10.80	0.018
4mm	1	55.335±0.332	0.335	55.443±0.336	0.085	-	-
	5	56.733±1.364	0.028	57.040±1.798	0.045	-	-
	10	59.501±2,709	0.011	60.279±3.305	0.013	-	-
	25	69.534±8.90	0.011	70.65±9.085	0.009	-	-

The same finding was observed for the heart mean dose. Only the MIT, DIT SC in inferior direction, and DIT-TGplan positioning errors in the right direction reached statistical significance. We observed that the mean dose for the heart, can increase from 4.03 Gy to 4.44±1.5 Gy for an error of 2 mm, and from 4.03 Gy to 4.91±1.61 Gy for a pitch of 4 mm, for the MIT plans.

In order to illustrate the effect of longitudinal positioning errors at the junction between the supraclavicular field and the breast tangential fields for the DIT, a comparison of the hot spot dose of the 3 plans was done. Errors were applied firstly at the SC isocenter (DIT-SC), secondly at tangential isocenter DIT-TG and finally at both isocenter, depending on error repetition frequency (Table 6).

Discussion

The dosimetric effect of lateral and longitudinal positioning errors of 2 mm and 4 mm was studied in this work. Here two 3DCRT processing techniques have been studied in the lateral and longitudinal directions, the DIT technique with double isocenter and the MIT technique with one isocenter. For each positioning error, four error repetition frequencies (1, 5, 10 and 25) were analyzed. The results are used to draw conclusions that can be used to improve the quality of the left breast treatment.

Based on our study findings, positioning errors for both the DIT and the MIT techniques were shown to cause significant dosimetric impact on target volumes and OARs. This effect was increasing as the positioning error magnitude was higher (2 mm versus 4 mm) and as its repetition frequency increased.

Nevertheless, the mean doses of PTVBreast was slightly affected, and there was a statistically significant differences for lateral positioning errors in the MIT isocenter, and DIT SC in inferior direction, from a single repetition. However, there was no significant difference for DIT plans in the positioning errors along the TG isocenter DIT-TG as shown in Table 1.

For OARs, as shown in Tables 3 to 5, the left lung mean dose was statistically affected in all directions in the case of the MIT technique. This is true even for a single repetition error. Whereas for the DIT-TG and DIT-SC plans, the dose is affected in the lateral and lower directions respectively. Whereas for the heart (mean dose) and the spinal cord (maximum dose), significant dosimetric impact was noticed especially for errors occurring in the lateral (right) direction.

This dosimetric impact of positioning errors affects the MIT, and DIT SC in inferior direction, and the DIT-TG in right direction plans for the heart, and the MIT and DIT-SC plans for the spinal cord. This can be explained by the proximity of the spinal cord, the heart and the left lung to target volumes, and by the position of the isocenters in each technique. For the DIT-SC, the isocenter is near the spinal cord, so every small lateral movement of the isocenter would dosimetrically affect the spinal cord. The same goes for the heart and the isocenter position in the DIT-TG, and DIT SC in inferior direction plans. Thus, the right direction affected dosimetric parameters of these organs at risk, likely leading to increased post-treatment toxicities.

All these dosimetric effects increased when the right direction positioning error step increased from 2 to 4 mm.

For the DIT, the increase in hot spot doses is due to the impact of the overlap of the tangent fields over the supraclavicular field. We found that even a small longitudinal error of 2 mm from the SC beam to the inferior direction, could increase the hot Spot dose from 55.2 ± 0.312 Gy up to 63.416 ± 4.829 Gy, which represented 126.9 % of the prescribed dose. This increased hot spot dose was more important for 4 mm error where it reached 70.65 ± 9.085 Gy (141.3% of the prescribed dose).

Our findings are in agreement with recently published studies [10-11]. They have shown that shifts in isocenter position as large as 3 mm produce a modest effect on the quality of dosimetric planning.

The probability of a complicating cardiovascular event, or generally cardiotoxic effects, increases when the dose received by the heart is increased [12-13]. Then, the spinal cord will lose its function if one of its sub-volumes is damaged [14-15]. Therefore, in its DVH, the dose constraint to be respected is Dmax < 45 Gy [16-18]. To avoid complications, it is also recommended to respect a maximum dose of less than 50 Gy [19].

Thus, it is clear that even a few millimeters could have significant consequences for OARs, in particular the heart and spinal cord, when the reference doses in the reference DVH were already close to the constraint limit recommended.

The double isocenter technique requires additional work and time during treatment to change the isocenter, forcing the radiotherapist to enter the treatment room and manually perform the patient's new position, where he could unintentionally produce an error when shifting from the SC isocenter to the TG isocenter if the shift includes manual couch position calculation [10]. In most cases, imaging control of positioning is done after switching from the SC isocenter to TG isocenter only before treatment and weekly. No further additional imaging is done during each fraction, so the risk of millimetric positioning error is higher compared to the MIT. For these reasons, the MIT could be favorable to avoid positioning errors as compared to the DIT.

Conclusion

For MIT and DIT 3DCRT techniques, the dosimetric impact of positioning errors in the lateral and longitudinal directions of left-sided breast cancer was high for the OARs compared to the target volumes, particularly for the lateral errors in the MIT and DIT-SC plans. Even a millimeteric error could have consequences on the heart and spinal cord, especially if the reference plan doses of DVH were close to the limit recommended.

If DIT plan is used, it is necessary to control the repositioning accuracy of the patient at each treatment session. The MIT should be encouraged whenever possible.

References

1. Ferlay J, Colombet M, Soerjomataram I, Parkin DM, Piñeros M, Znaor A, et al. Cancer statistics for the year 2020: An overview. International journal of cancer. 2021 Aug 15;149(4):778-89.
2. Nissen HD, Appelt AL. Improved heart, lung and target dose with deep inspiration breath hold in a large clinical series of breast cancer patients. Radiotherapy and Oncology. 2013 Jan 1;106(1):28-32.
3. Abo-Madyan Y, Aziz MH, Aly MM, Schneider F, Sperk E, Clausen S, et al. Second cancer risk after 3D-CRT, IMRT and VMAT for breast cancer. Radiotherapy and Oncology. 2014;110(3): 471-6.
4. Lee B, Lee S, Sung J, Yoon M. Radiotherapy-induced secondary cancer risk for breast cancer: 3D conformal therapy versus IMRT versus VMAT. Journal of radiological protection. 2014;34(2):325.
5. Abdel-Wahab M, Bourque JM, Pynda Y, Iżewska J, Van der Merwe D, Zubizarreta E, et al. Status of radiotherapy resources in Africa: An International Atomic Energy Agency analysis. The lancet oncology. 2013;14(4):168-75.
6. Banaei A, Hashemi B, Bakhshandeh M. Comparing the monoisocentric and dual isocentric techniques in chest wall radiotherapy of mastectomy patients. Journal of applied clinical medical physics. 2015;16(1):130-8.
7. Takano S, Omura M, Suzuki R, Tayama Y, Matsui K, Hashimoto H, et al. Intensity-modulated radiation therapy using TomoDirect for postoperative

radiation of left-sided breast cancer including lymph node area: comparison with TomoHelical and three-dimensional conformal radiation therapy. Journal of radiation research. 2019;60(5): 694-704.
8. Stimato G, Ippolito E, Silipigni S, Venanzio CD, Rinaldi CG, Gaudino D, et al. A new three-dimensional conformal radiotherapy (3DCRT) technique for large breast and/or high body mass index patients: evaluation of a novel fields assessment aimed to reduce extra–target-tissue irradiation. The British journal of radiology. 2016;89(1065): 20160039.
9. Julia White AT, Douglas A, Thomas B, Shannon M, Lawrence M, Lori P, et al. Breast Cancer Atlas for Radiation Therapy Planning: Consensus Definitions. RTOG-Radiation Therapy Oncology Group. 2018.
10. Stroom J, Vieira S, Mateus D, Greco C, Fogliata A, Nicolini G, et al. On the robustness of VMAT-SABR treatment plans against isocentre positioning uncertainties. Radiat Oncol. 2014;9(1):1–9 .
11. Liao X, Wu F, Wu J, Peng Q, Yao X, Kang S, et al. Impact of positioning errors in the dosimetry of VMAT left-sided post mastectomy irradiation. Radiation Oncology. 2020; 15(1):1-7.
12. Farzin M, Garosi M, Rajabpour MV, Gholami S. Deep inspiration breath hold (DIBH) for cardiac sparing in breast cancer radiotherapy. International Journal of Radiation Research. 2022;20(1):91-5.
13. Hong JC, Gross CP, Shafman TD, Hu X, Yu JB, Ross R, et al. Modern radiation therapy for left-sided breast Cancer: an analysis of mean heart dose within diverse practice settings. Int J Radiat Oncol Biol Phys. 2016;96(2):S209.
14. Bahreyni Toossi MT, Rajab Bolookat E, Salek R, Layegh M. Dose measurements of parotid glands and spinal cord in conventional treatment of nasopharyngeal carcinoma using rando phantom and thermoluminescent dosimeters. Iranian J Med Phys. 2015;12(2):78-84.
15. Adamus-Górka M, Mavroidis P, Lind BK, Brahme A. Comparison of Dose Response Models for Predicting Normal Tis-sue Complications from Cancer Radiotherapy: Application in Rat Spinal Cord. Cancers. 2011; 3(2): 2421-43.
16. McKenzie A, van Herk M, Mijnheer B. Margins for geometric uncertainty around organs at risk in radiotherapy. Radio-therapy and Oncology. 2002;62(3):299-307.
17. Majumder D, Patra NB, Chatterjee D, Mallick SK, Kabasi AK, Majumder A. Prescribed dose versus calculated dose of spinal cord in standard head and neck irradiation assessed by 3.D plan. South Asian J. Cancer. 2014; 3(1): 22-7.
18. Oulhouq Y, Rrhioua A, Zerfaoui M, Bakari D. Dosimetric Effect Resulting From the Collimator Angle, the Isocenter Move, and the Gantry Angle Errors. Iran J Med Phys 2019; 16(5): 355-61.