TURKISH JOURNAL of ONCOLOGY

Turk J Oncol 2023;38(4):444–50
doi: 10.5505/tjo.2023.4152

ORIGINAL ARTICLE

Dosimetric Comparison of 3-dimensional Conformal Technique, Intensity-modulated, Volumetric Arc Modulation, and Helical Tomotherapy with Radixact in Patients with Breast Cancer

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OBJECTIVE

Adjuvant radiotherapy (RT) has been used often at breast cancer treatment. RT techniques differ from each other in terms of accessibility and applicability. We aimed to compare the dosimetric evaluations of four modern RT techniques through ten breast cancer patients that had been treated previously with intensity-modulated RT (IMRT) technique.

METHODS

A single-center dosimetric study was performed based on treatment plannings of left-sided breast cancer patients. The patient's images, simulated at computed tomography with deep inspiration breath hold technique between March and June 2023, were used. Four different techniques, field-in-field (FinF), dynamic IMRT (dIMRT), volumetric modulated arc treatment (VMAT), and helical therapy (HT) were created on each patient image. Conformal index (CI) and homogeneity index (HI) were calculated. Mean doses of heart, contralateral breast, volume of doses 5 Grey (Gy) (V5) and 10 Gy (V10) of left lung and total lungs were also calculated for each plan and the descripted and comparisons analysis was performed.

RESULTS

The better results of CI and HI were reported with dIMRT, VMAT, and HT techniques. However, these approaches were expected with increased percentage of lower doses at organs at risk (OAR). The lowest of V5 of left and total lungs, mean heart, and contralateral breast doses were achieved with FinF techniques, HT values were observed similar to FinF by these factors at OAR. Particularly, the lowest V20 value was demonstrated at HT techniques.

CONCLUSION

Adjuvant RT techniques at breast cancer still carry controversial subtitles. New technologic improvements might be indispensable and treatment plannings should be based on the individual properties of patients.

Keywords: Breast cancer; helical tomotherapy; intensity-modulated; radiotherapy.
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Received: August 22, 2023
Accepted: August 30, 2023
Online: September 09, 2023

Accessible online at:
www.onkder.org

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INTRODUCTION

Breast cancer is the most common malignant tumors among the women.[1] Adjuvant radiotherapy (RT) is one of the standard treatments in particular cases and decreases locoregional recurrence and disease-free survival.[2,3] Three-dimensional conformal radiotherapy (3D-CRT) is the most widely used method of treatment planning and delivery at breast cancer RT. With the improvements at RT planning systems and devices, more conformal treatment plans have been achieved and doses at organs at risk (OAR) have been avoided using intensity-modulated radiotherapy (IMRT). Deep inspiration breath hold (DIBH) technique is an essential modern improvement for IMRT to achieve lower mean heart doses and better protection of OAR.[4,5] In the current practice, RT plannings of left-sided breast cancer patients are performed with DIBH technique as long as the RT devices are eligible to do so.

In the era of dosimetric optimization, homogenous dose distribution and coverage at target volumes with decreased high doses at OAR have been obtained with these IMRT techniques.[6–11] Hence, similar local control rates and survivals were reported with a lower RT-related adverse effects.[12–16] Rotational IMRT has been developed more recently. Volumetric-modulated arc therapy (VMAT) or helical tomotherapy (HT) is the forms of rotational IMRT at RT departments. Better target volumes coverage and dose homogeneity have been observed not in all patients, but also at patients with complexity for RT planning.[17–21]

Although it is expected that new RT techniques would allow the increase of the efficacy/toxicity ratio, some unexpected dose distributions were encountered. The low doses could occur in any region inside treatment fields, even leading to higher OAR doses in some cases. Patient anatomy is an important determinant, so it would be the guide for the choice when comparing techniques.

This study aimed to present the results of comparison of RT techniques at left-sided breast cancer patients. Plans with field-in-field (FinF), dynamic-IMRT (dIMRT), VMAT, and HT were compared for each patient using the same planning contours to gather data about target and OAR.

MATERIALS AND METHODS

Data Selection

A single-institution, retrospective study was planned to analyze the comparison of treatment plans. Ten patients treated in the Department of Radiation Oncology between March 2023 and June 2023 were selected. The inclusion criteria were the early stage left-sided breast cancer, having breast-conserving surgery and no chemotherapy treatment. Patients allowed to receive hormonotherapy during RT. Median age of patients is 54.10 years (range 42–73). Patients with breast implants were excluded from the study.

Dosimetric Analysis

Patients were immobilized supine by C-Qual breast board (Civco Medical Instruments Co. Inc. Coralville, Iowa, USA) with the left arm above the patient's head. Real-time Position Management (RPM, Varian Medical Systems Inc., Palo Alto, USA) system was used for the breath-holding method. An RPM localizer box was placed on the skin between the chest and abdomen of the patients and was followed by the cameras. All cases were delineated by the same senior radiation oncologist based on the images obtained for each patient with a computed tomography (CT) simulator (Somatom Force, Siemens Healthineers, Germany).

The clinical target volume was consisted of breast tissue with the guidance of ESTRO and planning target volume (PTV) was created by adding 5 mm margins in all directions and cropped 3 mm under the skin. OAR was defined as heart, left lung, contralateral breast, and total lungs and delineated. Prescribed dose was 50 Gy in 25 fraction and optimization was based on the constraint that ensuring 95% isodose line encompasses 95% of PTV.

Eclipse planning system (version 13.6, Varian Medical Systems, Palo Alto, CA, USA) was used for FinF, dIMRT, and VMAT plans. HT plans were calculated at HT planning station (Radixact, Accuray Precision, version 3.3.1.2; Sunnyvale, CA, USA). The different treatment techniques have been applied to the patients' data set without any clinical application. This activity does not require an ethical approval according to our institution's rules.

The same criteria of biophysical dosimetric evaluation for each structure were used. Dose-volume histograms were calculated for each planning. The mean doses, D2 and D98 doses of PTV, were recorded. Conformal index (CI) and homogeneity index (HI) were calculated. CI was defined as the quality of target dose distribution, taking into account the dose inside versus outside the PTV and HI was obtained from the target D2, D50, and D98 doses.[22,23] The formulas were chosen in such a way that the optimal value for CI is 1 and for HI is 0. Mean doses of all OAR were recorded and other factors as values for the percentage of the left lung and total lungs that received 5 Gy (V5) and 20 Gy (V20) were obtained.

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Table 1 PTV coverage comparison

Variable (mean)	FinF	dIMRT	VMAT	HT
HI	0.1570	0.2140	0.0930	0.1220
CI	0.9980	1.0570	0.9070	1.0650

PTV: Planning target volume; FinF: Field-in-field; dIMRT: Dynamic-intensity-modulated radiotherapy; VMAT: Volumetric modulated arc treatment; HT: Helical therapy; HI: Homogeneity index; CI: Conformal index

Statistical Analysis

For descriptive statistics, mean±standard deviation was used to present continuous data with normal distribution. Median with minimum-maximum values was applied for continuous variables without normal distribution. Numbers and percentages were used for categorical variables. The Paired Samples t-test was used for comparison and analysis of the difference between any 2 of 4 plans. Data analysis and graphic presentations were performed using the SPSS program, version 23.0 (SPSS Inc.).

RESULTS

Average values of HI, CI, and mean doses OAR with four different treatment plannings were summarized at Tables 1 and 2. While Table 3 presents the comparison between each plan and allows the significance, Table 4 shows the indices comparison of quality of plans with HI and CI values.

On two main quality indices, there was better homogeneity for VMAT compared to FinF, but the comparison of HI between others showed no significance. All plannings were created with the aim for the good homogeneity. Greater conformity for all intensity-modulated techniques was reported compared to FinF. Thus, CI 95% was improved in both dIMRT, VMAT, and HT highly significantly, but non-significant difference between dIMRT and HT was observed.

For the dose to the heart, lower mean doses were achieved with the plans with FinF and HT techniques, significantly. The highest mean heart doses were observed with VMAT plans. HT plans showed the lowest V20 both to the left lung and total lung. Furthermore, FinF and dIMRT plans reported lower total lung V20 doses, but the left lung V20 doses were significantly lowest with HT plans. The lowest V5 doses to the left lung, total lung, and contralateral breast were observed with FinF plans as expected. On the other hand, HT plans showed no significant difference from FinF for left lung V5 doses and significant lower left lung V5 doses from dIMRT and VMAT plans.

Table 2 OAR sparing and statistic values

Variable (mean)	FinF	dIMRT	VMAT	HT
Heart D_{Mean} (Gy)	2.6390	4.2480	6.57	2.28
L Lung V20 (%)	25.00	23.40	44.50	11.710
L Lung V5 (%)	44.00	53.60	81.50	48.75
T Lung V20 (%)	12.2740	12.2390	20.700	10.620
T Lung V5 (%)	19.9280	23.00	54.00	37.75
Contralateral breast D_{Mean} (Gy)	0.7070	0.8830	2.6840	2.3180

OAR: Organs at risk; FinF: Field-in-field; dIMRT: Dynamic-intensity-modulated radiotherapy; VMAT: Volumetric modulated arc treatment; HT: Helical therapy; L: Left; T: Total

DISCUSSION

The use of RT for breast cancer has become widespread due to the high number of patients. For achieving optimal results, modern RT techniques are being used and have advantages from traditional RT techniques. However, some caveats to these advances were known and treatment planning has to be created individually for each patient. The knowledge of benefits of these modern RT techniques can help to determine preferences at planning process.

The milestone of modern RT technique was IMRT that has been used common at RT departments since 2000s. Afterward, arc treatments have been taken a great part with the time and provided dose coverage advantages at many cancer type. The results of this trial indicated the comparison of these current modern methods with FinF plannings, based on 3D-CRT technique, and each other at left-sided breast cancer simulated with DIBH technique.

In the left-sided breast irradiation, the aim is to minimize the dose to the heart to decrease any late cardiac toxicity.[24] Many techniques have been tried to achieve this low heart mean dose at RT departments, and today each center has its own preferred technique.[11,17,19] Respiratory control is one the most preferred and DIBH is easily adapted by patients. Not only the advantage of eliminating movement of respiratory for IMRT techniques, but also the advantage of increasing distances between target and OAR is concluded with DIBH. All the plans were created on images obtained with DIBH technique during CT simulation. Hence, both the anatomical regions were ensured to be the same and the effect of the advantage on each planning technique was observed.

Regarding dose conformity and homogeneity, there is a clear theoretical advantage for IMRT, VMAT, and HT

Table 3 FinF vs dIMRT vs VMAT vs HT at OAR comparison

OAR	Parameters	Estimate	CI 95%	p	S
Heart D_{mean} (Gy)	FinF				
	ΔdIMRT	−1.60	−2.26 – −0.95	0.000	S
	ΔVMAT	−3.93	−5.31 – −2.54	0.000	S
	ΔHT	0.35	−0.37–1.09	0.297	NS
	dIMRT				
	ΔVMAT	−2.32	−3.62 – −1.01	0.003	S
	ΔHT	1.96	0.86–3.06	0.003	S
	VMAT				
	ΔHT	4.28	2.88–5.68	0.000	S
L Lung V20 (%)	FinF				
	ΔdIMRT	1.60	−2.83–6.03	0.436	NS
	ΔVMAT	−19.50	−25.98 – −13.02	0.000	S
	ΔHT	13.29	8.88–17.69	0.000	S
	dIMRT				
	ΔVMAT	−21.20	−28.95 – −13.24	0.000	S
	ΔHT	11.69	6.29–17.08	0.001	S
	VMAT				
	ΔHT	32.79	24.96–40.61	0.000	S
L Lung V5 (%)	FinF				
	ΔdIMRT	−9.60	−15.28 – −0.91	0.004	S
	ΔVMAT	−37.50	−45.26 – −29.73	0.000	S
	ΔHT	−4.75	−10.65–1.15	0.102	NS
	dIMRT				
	ΔVMAT	−27.90	−37.73 – −18.06	0.000	S
	ΔHT	4.85	−1.9–11.60	0.142	NS
	VMAT				
	ΔHT	32.75	21.86–43.63	0.000	S
T Lung V20 (%)	FinF				
	ΔdIMRT	0.03	−2.00–2.07	0.970	NS
	ΔVMAT	−8.42	−12.40 – −4.45	0.001	S
	ΔHT	1.65	−8.15–11.46	0.712	NS
	dIMRT				
	ΔVMAT	−8.46	−13.17 – −3.75	0.003	S
	ΔHT	1.61	−8.70–11.94	0.731	NS
	VMAT				
	ΔHT	10.08	−0.72–20.88	0.64	NS
T Lung V5 (%)	FinF				
	ΔdIMRT	−3.07	−6.83–0.69	0.098	NS
	ΔVMAT	−34.07	−43.66 – −24.47	0.000	S
	ΔHT	−17.82	−27.59 – −8. 05	0.003	S
	dIMRT				
	ΔVMAT	−31.00	−40.56 – −21.43	0.000	S
	ΔHT	−14.75	−24.91 – −4.58	0.009	S
	VMAT				
	ΔHT	16.25	4.08–28.41	0.014	S
Contralateral breast D_{Mean} (Gy)	FinF				
	ΔdIMRT	−0.17	−0.47–0.12	0.214	NS
	ΔVMAT	−1.97	−2.55-−1.40	0.000	S
	ΔHT	−1.61	−2.14 – −1.08	0.000	S
	dIMRT				
	ΔVMAT	−1.80	−2.30 – −1.30	0.000	S
	ΔHT	−1.43	−1.79 – −1.07	0.000	S
	VMAT				
	ΔHT	0.36	−0.14–0.87	0.141	NS

Δ: Difference between the plans for the criterion; S: Statistically significative result; NS: Statistically non-significative result. FinF: Field-in-field; dIMRT: Dynamic-intensity-modulated radiotherapy; VMAT: Volumetric modulated arc treatment; HT: Helical therapy; OAR: Organs at risk; CI: Conformal index; L: Left; T: Total

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doi: 10.5505/tjo.2023.4152

Table 4 FinF vs dIMRT vs VMAT vs HT for quality parameters

Quality parameters	Parameters	Estimate	CI 95%	p	S
HI	FinF				
	ΔdIMRT	−0.05	−0.26–0.14	0.546	NS
	ΔVMAT	0.06	0.05–0.07	0.000	S
	ΔHT	0.03	−0.00–0.07	0.081	NS
	dIMRT				
	ΔVMAT	0.12	−0.09–0.33	0.232	NS
	ΔHT	0.09	−0.12–0.30	0.359	NS
	VMAT				
	ΔHT	−0.02	−0.06–0.01	0.131	NS
CI 95%	FinF				
	ΔdIMRT	−0.05	−0.10 – −0.01	0.020	S
	ΔVMAT	0.09	0.01–0.16	0.024	S
	ΔHT	−0.06	−0.10 – −0.02	0.004	S
	dIMRT				
	ΔVMAT	0.15	0.08–0.21	0.001	S
	ΔHT	−0.00	−0.04–0.03	0.674	NS
	VMAT				
	ΔHT	−0.15	−0.2 – −0.10	0.000	S

Δ: Difference between the plans for the criterion; S: Statistically significative result; NS: Statistically non-significative result. FinF: Field-in-field; dIMRT: Dynamic-intensity-modulated radiotherapy; VMAT: Volumetric modulated arc treatment; HT: Helical therapy; CI: Conformal index; HI: Homogeneity index

compared to 3D conformal techniques.[11,19,25–28] CI and HI are considered important indicators for irradiation plans quality and help to compare different irradiation plans. However, the effect of these parameters at clinically is inaccurately known. In the study, VMAT has been reported as better for dose homogeneity as expected, but the only significance was observed between VMAT and FinF techniques. CI was superior at HT treatments compared with 3DCRT and VMAT, but similar with dIMRT. Hence, FinF technique as having the least appropriately was concerned and HT was the confluence of results.

Modern techniques usually consist great number of beams to have better conformity and homogeneity often at the expense of increased low-dose exposure for the tissue surrounding the tumor. Increased percentage of low dose bath may result in a higher risk of second malignancies for long mean life expected patients.[29,30] Comparison of techniques is having importance in terms of both understanding the superior homogeneity and conformity and minimized lower doses at OAR and longer follow-ups will give us the result of this low dose irradiation with advanced RT techniques.

In the analysis, lower doses at OAR had been observed with FinF techniques as expected. However, also HT plans provided low percentages, even more than FinF plans at V20 values of lung. While HT was reported as only significantly lower V20 for the left lung, total lung V20 values were not significant between HT, FinF, and dIMRT plans. In regard to V5 values, HT was seemed to lose advantage and FinF plans were having lower V5 values for the left lung and total lungs, but only significant for total lung V5 value. The difference between FinF, dIMRT from HT, and VMAT has been observed particularly at the contralateral breast and contralateral lung, both receiving relatively low dose.

In left-sided breast cancer irradiation, heart is considered the most important OAR in terms of deterministic late effects and risk of subsequent ischemic events.[25,30,31] Significant lower dose for mean heart dose was observed with FinF and HT techniques compared to dIMRT and VMAT. Whereas the lowest mean heart dose would be expected with the FinF technique, HT also had similar mean heart doses. This may be a result of the new Radixact system, because of new property of Radixact planning system with definitive blockages descriptions. With appropriate definitions and limitations of OAR, more precise plans can be achieved at this rotational therapy device. Likewise, significant lowest mean doses of left lung V20, total lung V20, and left lung V5 were reported with HT. The left lung also had the new described advantage of this rotational treatment, but naturally, this was concluded with further spread of the low dose to surrounding organs. VMAT and HT techniques both had significantly higher V5 doses at contralateral breast and contralateral lung.

CONCLUSION

Comparison of four techniques at breast cancer radiotherapy and the different advantages of treatment plans were analyzed. As result, RT technique should be based on the individual properties of the patient. Anatomic complexities, age, disease factors, etc. are all that a radiation oncologist takes into to give a decision.

Peer-review: Externally peer-reviewed.

Conflict of Interest: All authors declared no conflict of interest.

Financial Support: None declared.

Authorship contributions: Concept – S.Y., D.P.; Design – S.Y.; Supervision – E.D., F.A.; Funding – F.A.; Materials – Z.G.; Data collection and/or processing – S.Y., D.P.; Data analysis and/or interpretation – S.Y.; Literature search – S.Y., D.P.; Writing – S.Y.; Critical review – F.A.

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