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Research Article

A retrospective study for the dosimetric comparison of parallel opposed wedged tangent fields radiotherapy treatment planning and tangential dual-mini-arcs planning (VMAT technique) for left-sided post lumpectomy ca breast

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Abstract

Aim: In our study, we have dosimetrically compared two radiotherapy planning techniques (parallel opposed wedged tangents and volumetric modulated arc therapy using dual-mini–arcs) for intact lt breast (post lumpectomy for ca breast).
Method: For the study, 10 ca lt breast patients were re-planned with volumetric modulated arc therapy using dual-mini-arcs; these patients already underwent radiotherapy with parallel opposed 3DCRT technique. Target coverage, conformality and homogeneity of radiation dose in these two techniques were compared. Doses to critical structures and normal tissue were also compared including low dose volumes.
Result: Our study demonstrate superiority of VMAT using dual-mini-arcs over conventional 3DCRT for better dose sculpting to the target and reducing high dose volumes for critical structures specially heart and ipsilateral lung but at the cost of increased low dose volumes in ipsilateral as well as contralateral critical structures and normal tissue.
Conclusion: Compared to tangential 3D planning, volumetric modulated arc therapy using dual-mini-arcs provide improved target dose conformality and provide uniform dose distribution inside the target along with better tissue sparing for radiation toxicities but there is an overall increase in low dose volume which leads to increased probability of secondary malignancy in the patients.

Keywords: Volumetric modulated arc therapy (VMAT), 3DCRT, Radiotherapy, Ca lt Breast, ICRP 103 (2007).

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1. Introduction

Incidence of breast cancer is on the rise among young women in India and as per the National Cancer Registry Programme data the highest rate of increase is observed in females of 30-40-year age group [1]. Lumpectomy (breast conservative surgery) plus radiation therapy (RT) provides results comparable with mastectomy (removal of complete breast tissues of the diseased side) in early-stage breast cancer [2]. Various studies have shown the necessity of RT for improved local control as well as overall survival of the patient [3].

However, RT of lt breast has its side effects as well in terms of risk of cardiac and lung toxicity and also there is a risk of radiation-induced secondary cancers.[4] Therefore, Target volume needs to be irradiated adequately to achieve the local control on the same time we need to keep the doses to critical structures below the tolerance level to keep the toxicity in the acceptable level.[5] young patients undergoing RT for the left-sided breast may have a long period of survival, so reducing the low dose region can reduce the risk of radiation-induced secondary carcinogenesis. Low doses delivered to the contralateral breast and bilateral lungs are of more concern for the risk of development of secondary cancer because of the higher tissue weighting factor (W_R) [6].

Three-dimensional conformal radiation therapy (3DCRT) of the lt sided breast is done using parallel opposed (sometimes not exactly opposite) tangential wedged fields with half beam block (to reduce the beam divergence to the lung and heart). Optimal gantry angle can be selected with the help of Beam's Eye View (BEV) and beam shaping is done using multileaf collimator (MLC) [7]. The field in field techniques is sometimes adopted to create the wedge effect and/or to reduce the hotspot [8]. In volumetric modulated arc therapy (VMAT), we try to simulate the same parallel opposed orientation like 3DCRT plan using the parallel opposed mini-arcs to reduce low doses to the patient volume.

In this study, we have investigated the efficacy of dual-mini-arcs (VMAT) over the 3DCRT for coverage and dose conformality to the target and sparing of normal tissues for hypofractionated radiotherapy regimen. Various studies have shown that hypofractionated Radiotherapy of the breast is equally effective as conventional fractional without increasing toxicity to normal structures [9]. This study further investigates the volume of low doses to contralateral breast, lungs, heart and remaining volume at risk.

2. Materials and Method

For this study 10 anonymized patients of early-stage carcinoma of the left-sided breast having undergone breast conservative surgery (lumpectomy), previously treated with tangential 3DCRT were selected. The mean age of these patients was 37.6 ± 6.7 years at the time of planning. These patients were earlier simulated in Philips Brilliance Big Bore CT with 3 mm slice thickness for radiotherapy planning. CTV was contoured on CT and adequate CTV and PTV margins were given to the target as per our Institute protocol. For 3DCRT planning, PTV was extended to air outside the body (external contour) by 1.5 cm for the flash margin and PTV evaluation was drawn by subtracting the PTV form the external contour by 5.0 mm. Critical structures Lt Lung, Rt Lung, Heart, Liver, trachea, esophagus, and spinal cord were delineated in Monaco Treatment Planning System (version V5.11.03). Spinal cord PRV was by giving 5.0 mm to the spinal cord. These patients were planned by using differentially weighted tangential parallel opposed wedged fields and calculated with the collapsed cone algorithm with 0.3 mm grid size. Sometimes, beam orientation which was not exactly parallel was also used. These patients were treated in Versa HD linear accelerator with image guidance (XVI).

For our study, all these patients were again planned with dual-mini-arcs in Monaco TPS with hybrid optimization (using radiobiological as well as physical constraints) with 6 MV flattened partial mini-arcs. Partial mini-arcs are placed in a manner, minimizing entry or exit from the critical structures. It tries to mimic a conventional parallel opposed plan and supposed to provide better normal organ sparing [10]. Target objectives were defined as Target penalty and quadratic overdose and for critical structures with serial and parallel radiobiological constraints, physical constraints such as quadratic overdose, conformity, and maximum dose were also used to control maximum dose outside the target and to reduce dose sharply outside the target volumes in IMRT constrained module [11, 12].

For all plans minimum segment width was taken as 10 mm, a maximum number of control points were restricted to 50 and 3 numbers of subarcs were used for each plan. Grid spacing was kept as 3.0 mm and a statistical uncertainty of 1% per calculation was used for Monte Carlo (XVMC) dose calculations of the plans.

Target objectives and dose constraints for all the plans are listed in table 1.

Table 1: Plan objectives and critical structures constraints for 3DCRT and mini dual arc VMAT plans

Target/ Critical Structure	Target Objective or Dose Volume Constraint
PTV	Dose (40 Gy in 15 fractions), Minimum 95 % of PTV should be covered with 95 % of Prescribed Dose V107 < 10 %, V110 < 1%
Lt Lung (Ipsilateral lung)	Less than 30% volume of the lung should receive more than 20 Gy dose (V20 < 30%)
RT Lung (Contralateral lung)	Not Specified
Spinal Cord PRV	Max dose < 44 Gy
Heart	Less than 15% volume of heart should receive more than 20 Gy Dose V20 < 15% (Soft Constraint) Less than 10% volume of heart should receive more than 20 Gy Dose V20 < 10% (Hard Constraint)
Spinal Cord	Max dose < 44 Gy
Contralateral Breast	Mean Dose < 2.0 Gy

For plan comparison, Paddick Conformity Index, which is a measure of target coverage and prescription isodose spillage outside the planning target volume was used which and can be calculated using the equation

$$CI = = (TV\ covered\ by\ PIV)^2 / TV \times PIV$$

Where PIV= Prescription Isodose volume and TV= Target Volume,

And Homogeneity Index that is the measure of dose homogeneity inside the target was calculated with the equation

$$HI = (D_{max} - D_{min}) / Mean\ Dose$$

Perfect values of CI and HI are 1[13].

V95, V100, V107, and V110 were compared to PTV in both the plans, doses to different volumes of critical structures and Low dose volumes in RVR V2 Gy, V5 Gy and V10 Gy were evaluated and compared. The Number of monitor units for both the plans were also compared.

3. Results

While performing VMAT planning for left-sided Ca breast selecting proper start angle and the arc length is crucial for getting a clinically acceptable PTV coverage along with low doses to the critical structures; it takes more than 40-50 minutes to create an acceptable plan for one patient with dual mini-arc VMAT. For a clinically acceptable quality 3DCRT plan, it takes around 30-40 minutes to plan a noncomplex case.

Table 2 lists various plan quality parameters for PTV evaluation for both the planning techniques. For the statistical analysis of the data, Microsoft Excel was used and analysis was done using *paired sample t-test (small sample and same subject*). P value ≤ 0.05 was considered statistically significant.

Table 2: Comparison of PTV Doses

Plan Parameters	Tangential parallel opposed 3DCRT	Dual mini arc VMAT	*p Value*
Conformity Index (CI) for PTV Evaluation	0.39 ± 0.07	0.62 ± 0.05	0.001
Homogeneity Index (HI) for PTV Evaluation	1.114 ± 0.763	1.118 ± 0.038	0.26
V95% for PTV Evaluation	95.33 ± 0.80	97.17 ± 1.32	0.02
V 100% for PTV Evaluation	51.34 ± 5.90	84.50 ± 2.49	0.00007
V107% for PTV Evaluation	2.40 ± 1.43	3.76 ± 2.12	0.36
V110% for PTV Evaluation	0.07 ± 0.05	0.05 ± 0.46	0.46
Total number of MUs	710.55 ± 268.70	994.61 ± 136.43	0.05

The comparison of various PTV parameters shows that dual-mini-arc technique provides better target coverage compared to parallel opposed 3DCRT (V95 is *97.17 ± 1.32* in VMAT compared to *95.33 ± 0.80* in 3DCRT and V100 *51.34 ± 5.90* in 3DCRT vs *84.50 ± 2.49* in VMAT) which is statistically significant ($p \le 0.02$ and $p \le 0.00007$). VMAT plans are more conformal compared to 3DCRT and both the techniques provide equivalent plans in terms of plan homogeneity. VMAT plans are able to provide better dose sculpting than 3DCRT with statistical significance. Table 3 shows lists the comparison of doses to critical structures in both the plan techniques.

Table 3: Dose Volumes for critical/normal structures

Critical Structure		Parallel opposed tangential 3DCRT	Dual mini Arc VMAT	p Value
Lt Lung (Ipsilateral Lung)	V2	43.75 ± 10.27	54.93 ± 12.27	0.014
	V5	28.82 ± 7.98	30.80 ± 12.83	0.540
	V10	23.32 ± 7.51	20.63 ± 8.19	0.110
	V20	18.48 ± 7.18	13.91 ± 5.83	0.015
Rt Lung (Contralateral Lung)	V2	0.70 ± 1.14	3.04 ± 2.29	0.047
	Mean Dose (cGy)	47.98 ± 9.39	110.36 ± 14.62	0.0001
Heart	V2	42.90 ± 7.40	54.80 ± 9.70	0.04
	V5	19.75 ± 5.91	21.21 ± 7.18	0.84
	V10	15.82 ± 5.42	12.73 ± 4.98	0.07
	V20	12.08 ± 4.89	8.63 ± 3.56	0.02
Spinal Cord PRV (Max Dose)	cGy	49.98 ± 17.89	112.5 ± 37.48	0.005
Rt (Contralateral) Breast	V2	7.70 ± 3.87	18.14 ± 5.70	0.02
	V5	3.20 ± 2.58	4.90 ± 2.67	0.38
	V10	0.38 ± 1.50	2.35 ± 1.63	0.40

Use of dual-mini-arc technique is beneficial for reducing high dose volumes in the ipsilateral lung as well as heart significantly, but on the same time, there is an increase of low dose volumes V2 (statistically significant) and V5 (Statistically non-significant) for these structures.

Low doses to the contralateral lung and contralateral breast are also higher in dual mini partial arc VMAT.

V2 Gy, V5 Gy and V10 Gy (Volume receiving 2 Gy, 5 Gy and 10 Gy of radiation dose) for RVR (RVR is unspecified tissue and it is created by subtracting PTVs Volumes and other structures volumes from the total patient volume as defined in IURU 83) is tabulated in percentage in table 4.

Table 4: Doses to Remaining Volume at risk

Remaining Volume at Risk (RVR)	3DCRT Plan	Dual arc VMAT plan	P Value
V2	10.32 ± 9.27	18.40 ± 6.56	0.05
V5	5.62 ± 3.0	8.52 ± 2.70	0.05
V10	7.83 ± 4.23	6.15 ± 2.07	0.16

In IMRT and VMAT planning, there is an increase in low dose volume compared to 3DCRT which is a matter of concern as it increases the probability of radiation-induced secondary malignancy. In our study, there is an increase in low dose volume (V2 and V5) in RVR which is statistically significant. However, V10 is slightly lesser (without statistical significance).

Therefore, dual- mini-arcs planning provides superior coverage to the target volume as well as better organ sparing (heart and ipsilateral lung) but on the same time there are more low doses volumes of critical structures (both Lungs, contralateral breast and RVR) compared to parallel opposed 3dcrt planning for the left-sided ca breast but at the cost of increased low doses to the critical and normal tissues.

4. Discussion

Our study demonstrates that volumetric modulated arc therapy, with dual-mini-arcs can provide better target coverage along with better conformality of prescription dose to the target, thereby, reducing the high dose to the non-target area compared to tangential 3DCRT. The same technique shows its dosimetric benefits for ipsilateral lung and heart, where the application of the VMAT technique can significantly reduce high dose volumes. In their study comparing three different techniques (conventional, forward IMRT and VMAT) of treatment planning, Giri *et al* had also shown similar results [14] in favor of VMAT technique.

Our study further investigates very low and low dose volumes V2 and V5 respectively to normal structures and RVR, which are significantly more compared to 3d tangent technique. Figure1 and Figure 2 below shows tangent field placement and mini-arcs placement for 3D and VMAT techniques.

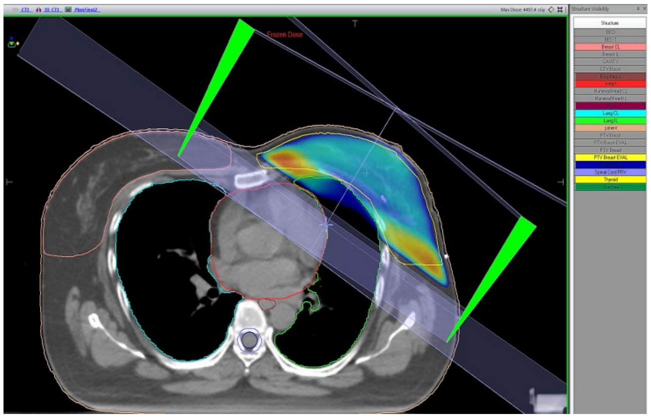

Figure 1: The arrangement of tangents for parallel opposed 3d planning

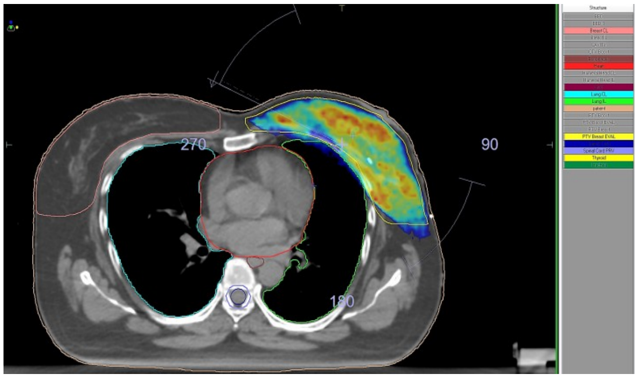

Figure 2: The arrangement of mini-arcs for VMAT planning

Dose-volume histograms below show the comparison of dose-volume for normal structures and RVR along with PTV coverage (same in both the histograms, representing a comparison of dose volumes of different organs in same plans. For clarity the histogram is represented two times).

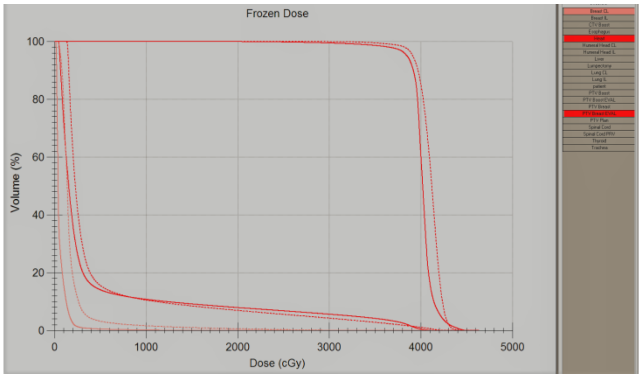

Figure 3: Comparison of contralateral breast and heart doses in two techniques

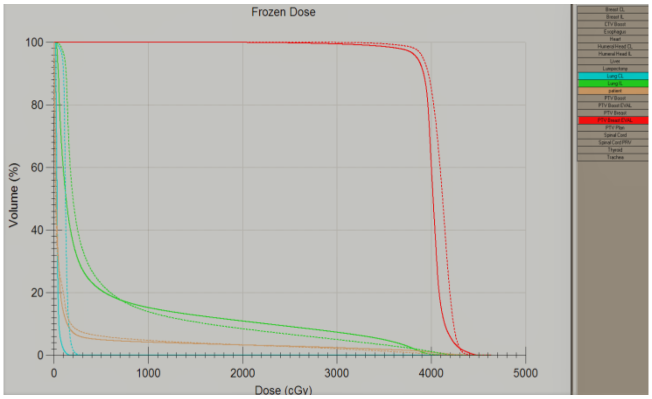

Figure 4: Comparison of Ipsilateral and contralateral lung doses and RVR doses in two techniques

(**Note:** The solid line represents parallel opposed 3D plan while dashed line represent split dual mini partial arc VMAT in DVH)

In the study titled "Risk of secondary malignancies after radiation therapy for breast cancer: Comprehensive results." Burt LM *et al* have shown that there is an increased risk secondary malignancy in ca breast patients compared to normal population and the increased risk of secondary malignancies in breast cancer patients treated with radiation therapy compared to those without was significant regardless of age at breast cancer diagnosis and more pronounced with longer latency [15].

Reduction to cardiac and ipsilateral lung doses by using VMAT may help to achieve lower toxicity; however, low dose volume is significantly more.

5. Conclusion

Our study concludes that the use of dual-mini- arcs (VMAT) provides better PTV coverage and conformality. There is a significant reduction of the volume of heart receiving 20 Gy dose (V20), reduction of V20 of the ipsilateral lung is also significant. This may lead to a higher probability of local control of disease and a lesser probability of cardiac and pulmonary toxicity. But low dose region in the contralateral lung is significantly higher with an almost threefold increase in mean dose. There is also an almost threefold increase of V2 of the contralateral breast. Low doses to the Ipsilateral lung, heart, and RVR also increases as compared to tangential 3d planning. The increased low dose volume leads to higher probability of radiation-induced secondary malignancy and a matter of concern. Favouring any technique for the treatment shall be based on benefits to the patients and with caution.

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