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Dosimetric Comparison of Tangential Volumetric Arc Therapy and Half Beam Volumetric Modulated Arc Therapy Planning Technique for Carcinoma of the Breast

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ABSTRACT

Introduction: This study aims to compare tangential volumetric modulated arc therapy with half beam volumetric modulated arc therapy in the treatment of cancer in the left and right breasts.
Material and Methods: Twenty patients (10 with left and 10 with right breast cancer) were planned with Tangential Volumetric Modulated Arc Therapy (tVMAT) and Half Beam Volumetric Modulated Arc Therapy (HVMAT) techniques for prescribed dose of 42.56Gy over 16 fractions with 6MV photon. The tVMAT technique limit the radiation to non-target areas. Dosimetric evaluations were performed for planning target volume (PTV), ipsilateral lung, heart, and contralateral breast with analysis via Repeated Measures ANOVA with a significance level of 5%.
Results: tVMAT achieved superior target coverage and dose homogeneity compared to HVMAT. For left breast cancer, HVMAT reduced ipsilateral lung doses but increased contralateral breast doses. Heart doses remained similar in both techniques. For right breast cancer, tVMAT provided higher target coverage and reduced doses across critical parameters.
Conclusion: tVMAT demonstrates strong potential as an advanced radiotherapy technique for breast cancer, improving dose control to the ipsilateral lung and heart while minimizing dose spread to the contralateral side, making it a promising alternative to conventional VMAT for enhanced precision in breast cancer treatment.

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Introduction

Women are the ones who get diagnosed with breast cancer the most. The growing use of mammography screening is mostly to blame for this. After lung cancer, it is the second leading cause of cancer death among women. Breast cancer is a type of cancer that develops in the tissues of the breast, most commonly in the inner lining of milk ducts or the lobules that supply milk to the ducts [1,2]. It can be done by a biopsy of nodules detected by mammogram or by palpitation. Other modes are self-breast examination, magnetic resonance imaging, mammography, ultrasound, and molecular breast imaging. To kill cancer cells, high-energy X-rays, protons, or other particles are used in radiation therapy for breast cancer. Rapidly developing cells, such as cancer cells, are more vulnerable to radiation therapy's effects than normal cells. Radiation therapy has been used for nearly a century for the treatment of breast cancer. Radiation therapy is used to treat all stages of breast cancer. After breast-conserving surgery (BCS), radiation therapy is used to reduce the risk of cancer recurring in the same breast or near the lymph nodes, or after a mastectomy, if the tumor was greater than 5cm (2 inches) and cancer was identified in any lymph nodes [3,4]. If the patient had a mastectomy or has no lymph nodes that have cancer cells then the radiation is focused on the chest wall, the mastectomy scar, and the places where any drains from the body that occur after surgery. If the patient had done BCS the radiation should be given to the entire breast which is known as whole breast radiation and an extra boost is given to the breast where the cancer was removed to prevent the re-occurrence [5]. Intraoperative Radiation Therapy (IORT), Three-Dimensional Conformal Radiation Therapy (3DCRT), Intensity Modulated Radiation Therapy (IMRT), which includes Volumetric Arc

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Therapy (VMAT), and Brachytherapy are the most regularly used radiation therapy modalities.

The delivery of cone beam in a circular motion with varying shape and intensity is commonly known as volumetric-modulated arc therapy (VMAT). The gantry moves constantly with MLC leaves and also with a changing dose rate throughout the arc with VMAT treatment. By sampling, the TPS will calculate the dose at the number of discrete angles [6,7]. To develop a perfect single arc dosage plan, a significant number of gantry angles must be optimized to optimize field shapes and beam intensities. If Planning is harder for both left and right-sided breast cancer, considering the risk of ischemic heart disease after radiotherapy for breast cancer increases linearly with the mean dose to the heart by 7. 4% per gray (Gy) with no apparent threshold [8].In breast cancer treatment using 3D-CRT, beam divergence and photon scatter can expose nearby organs, such as the contralateral breast, heart, thyroid, ipsilateral lung, and liver, to significant radiation, increasing the risk of secondary cancers [9]. VMAT allows for a reduction of the maximum doses to OAR, especially to the heart, while retaining target homogeneity and coverage. The VMAT is a novel form of IMRT in which generally partial arc beams and Tangential Volumetric Modulated Arc Therapy (tVMAT) are used to improve the homogeneity and conformity in planning target volume (PTV), reduce the dose to normal tissues, and with fewer monitor units(MU) [10,11]. tVMAT is a specialized approach within volumetric modulated arc therapy that uses carefully controlled, tangentially focused arcs. These arcs are positioned at angles that specifically target the breast, reducing radiation exposure to surrounding organs at risk (OARs) such as the heart, lungs, and contralateral breast, which are critical in breast cancer treatments. By focusing radiation in narrower, tangential arcs, tVMAT enhances dose homogeneity within the tumor while sparing healthy tissues. This precision minimizes the low-dose radiation “bath” that typically affects non-target tissues in traditional VMAT techniques, allowing for high therapeutic efficacy with improved safety. The optimization process involves inverse planning in which beam weights or intensities are adjusted to acquire the predefined dose criteria for a composite plan [12].

Materials and Methods

Monaco Version 5. 11 Treatment planning system

Monaco 5. 11 is a software for treatment planning that offers users up to four times faster calculation rates than previous models [13,14]. For high- quality dependable treatment planning outcomes, Monaco continues to use multicriteria optimization and Monte Carlo dose calculations. Monaco templates also boost productivity by allowing users to quickly import and export treatment plans, making it easier to share best practices across departments and organizations. The ability to create multiple prescription plans simultaneously decreases the overall planning time. Improved data sharing creates opportunities to optimize individual treatment plans.

Treatment preparation systems should be more precise, more automated, more responsive to patient biology, and integrated with the treatment machine as radiation therapy procedures become quicker and more complex day by day with a rise in doses, shorter fraction schemes, and smaller target margins [13]. To meet these problems Monaco combines the calculation accuracy of the Monte Carlo algorithm with a variety of tools to simulate the actual delivered dose to the patient. Monaco also supports a wide variety of radiation therapy modalities, including 3-dimensional (3D)forward planning and field in-field (FiF); dynamic and step-and-shoot intensity-modulated radiotherapy (IMRT); arc therapy techniques, including volumetric modulated arc therapy (VMAT) and dynamic conformal arc therapy (DCAT); cone and multileaf collimator (MLC)- based Stereotaxy; and magnetic resonance(MR)- based treatment planning

Monaco algorithms

Monaco provides a variety of dose calculation algorithms. The current algorithm used in Monaco treatment planning systems are:

Monte Carlo algorithm

It is a technique of radiation transport using a well-established probability distribution governing the interaction of electrons and photons through matter. This algorithm is important for model-based computation. It is also used to produce convolution kernels and to characterize clinical beams [15,16]. Some people use the Monaco algorithm to compute photon dose distribution directly. This method will reduce the uncertainty from systematic errors or random uncertainties. The greater the number of histories, the smaller the uncertainty. One of the main advantages of the Monte Carlo method is it does not matter whether the photons are directed at the target from one direction or many, the same number of histories can be used. The distribution of fluence and energy emerging from the accelerator can be obtained with this simulation.

Pencil beam algorithm

The dosage is calculated using a modified Batho method to adjust for heterogeneities along fan lines as a convolution of the radiation field fluence with the dose deposition kernel of a narrow photon pencil beam in water. The integration of all point-spread kernels along an infinite ray of photons in the medium yields a pencil-beam kernel [16]. The main application of this algorithm is the reduction of time used for calculation that is, the dosage calculation can be simplified to a few 2D convolutions with a simple single value decomposition of the kernel, allowing a 3D dosage calculation for a conventional treatment plan to be completed in seconds. It is a method that is built on corrections [17]. Pencil beam algorithms are not used for the heterogeneous medium as there is a lot of secondary electron distribution.

Collapsed cone algorithm

Stopping power ratios and attenuation coefficients are explicitly implemented in this algorithm using relative electron density values. Modeling the energy fluence distribution is the first step in the collapsed cone algorithm's dose calculation. This model assumes a 2-dimensional Gaussian defined elliptical primary photon source at the linear accelerator's target [14,15]. From the flattening filter, secondary photon scatters occur or from the primary collimator for flattening filter-free machines, with additional scatter arising from the collimators and wedges, if used. Dose deposition calculation in collapsed cone algorithm is volume-based and constructed from 3D kernels which are already calculated. Dose deposition from primary photons and scattered photons are considered with separate calculation kernels. The primary and scattered energy distributions are corrected for off-axis and beam hardening effects and are transported through the patient model leaving energy as absorbed dose [14]. The dose arising from contamination-charged particles is calculated separately and added to the dose arising from photon interactions [18]. The dose is calculated within each voxel of the patient model. Dose for the user-defined points within the patient model is determined by interpolation between the center points of dose voxels.

Procedure

Patient selection

Total twenty patients with carcinoma in the breast were selected retrospectively (10 left-sided breasts and 10 right-sided breasts) chosen from Kasturba medical college over the period of the year 2019 to 2021. Summary of patients is given in table 1.

Table 1. summary of patients

Total number of patients	20
Diagnosis	Ca breast
Sex	Female
Number of left- sided breast	10
Number of right-sided breast	10
Radiation dose prescription	42. 56Gy in 16 fractions

The patient was positioned head supine, with their back on a flat table couch with an appropriate immobilization device called thermoplastic mould (ORFIT) with four clamps clipped to the couch. The arm of the tumor side was kept perpendicular to the body also their face was turned little upward towards the other side of the tumor. CT images were acquired with a slice thickness of 5mm using a Philips Brilliance Big Bore sixteen slice computed tomography. After the acquisition of CT, images were transferred to the Monaco treatment planning system for the delineation of the tumor as well OARs within the CT images.

Image registration and contouring

The gross tumor volume (GTV) is the total size and location of a tumor, which includes both main and secondary tumors. GTV can be identified through imaging. The actual tumor plus the tissue with suspected tumor make up the clinical target volume (CTV). Because the exact extent and location of the tumor can only be seen in CTV, we add extra margin to the GTV, which is then depicted as CTV. Planning target volume (PTV) was created over CTV with an additional internal margin as well as a setup margin of 3mm in every direction [6,19]. Delineation of OARs such as ipsilateral lung, contralateral breast, heart, the spinal cord was contoured on the CT slices based on the standard guidelines recommended by the radiation therapy oncology group (RTOG). The external contours were also drawn that is the body. Any errors or uncertainties should not occur in the structures, for that no external margins have been given.

Treatment Planning

Treatment planning was done in Monaco planning system version 5. 11. The prescribed dose to the PTV was 42. 56Gy in 16 fractions which is 2. 66Gy per fraction. All the 20 cases were done in the Monte- Carlo algorithm in the Monaco treatment planning system. Coverage of 95% of dose and doses to OARs was checked Constraints for target volume and OARs are given in Table 2 and 3.

VMAT

All the 20 patients with left-sided breasts, as well as right-sided breasts, were planned with two tVMAT and half beam VMAT. In tVMAT for the left-sided breast, the gantry start angle was kept at 300 degrees and 90 degrees with an arc rotation of 60 degrees. For half beam, VMAT the gantry start angle was 300degree with 180-degree rotation.

tVMAT for right-sided breast gantry start angle was kept 300 degrees and 215 degrees with arc rotation 60 degrees and for half beam VMAT the gantry angle; starts from 215 degrees with an arc rotation of 180 degrees. All these were planned with a photon energy of 6 MV and delivered by Elekta Versa HD Linear Accelerator. All the fields were made to conform to PTV by giving a 7mm margin for the account for penumbra. Planning optimization is done without affecting the PTV and also by keeping the constraints that need to be achieved. All the plans were optimized to achieve low dose to the OARs such as contralateral breast, ipsilateral lung, and heart with a significant increase in the dose coverage and homogeneity using tangential VMAT.

Table 2. Constraints for target volume

Target dose in Gy	Target Penalty	No. of #	Dose per #
PTV 42. 56	TV 95% > 95% for PTV 42. 56Gy	16	2Gy
CTV 42. 56	TV 95% > 95% for CTV 42. 56Gy	16	2Gy

Table 3. Constraints for OARs

Organ At Risk (OAR)	Constraints
Ipsilateral lung	$V_{20} < 20\%$
heart	$V_{25} < 10\%$
Contralateral breast	Mean dose < 2Gy
Spine	Max < 45Gy

Plan Evaluation

The dosimetric comparison and quantitative analysis of tVMAT and half beam VMAT were carried out by the standard Dose Volume Histogram(DVH).

Outcome Measures

Homogeneity Index

Homogeneity index analyses the uniformity of doses in the target volume. One is the ideal value for homogeneity index and if the value comes more than 1 then the plan becomes less homogeneous and if the value is less than or near to 1 then the plan is considered to be homogeneous [20]. The homogeneity index is an important quality indicator for a plan.

The equation for homogeneity index is given by :

$$HI = \frac{D5\%}{D95\%}$$

Homogeneity Index is simply defined as the ratio between dose at 95% of PTV volume and the dose at 5% of the PTV volume.

HI = homogeneity Index

D5% = minimum dose in 5% of PTV indicating the maximum dose

D95% = minimum dose in 95% of PTV indicating the minimum dose

Conformity Index

The Radiation Therapy Oncology community identified the conformity index as a treatment plan assessment index (RTOG). Dosimetric analysis and dose-volume histograms were used to create this. It's defined as an absolute value derived from the relationship between tumor volume (or a fraction of it) and the volume delineated by an isodose (or a fraction of it). It can also be defined as the ratio between the volume covered by reference isodose and the target volume which is the planning target volume [20]. The ideal value for conformity is 1and any variation in this ideal value will not be a perfect conformation.

The equation for conformity index is given by :

$$CI = \frac{V_{RI}}{TV}$$

CI = conformity Index

VRI = volume at reference isodose

TV = planning target volume

Statistical Analysis

All the comparisons of PTV and other OARs were analyzed using repeated measures of ANOVA technique. Here since we are comparing two dependent data we use the paired t-test. This method helps us to evaluate the difference between related means. To find the statistical significance of the study p-value should be used and it is set to be less than 0. 05 to compare the two plans. That is there is a 5% chance of getting a result like the one that was observed if the null hypothesis was true. If the p-value is greater than 0. 05 we can tell that there is no statistical significance between the two plans and if the p-value is less than 0. 05 then there is a significant difference between both the plans. We have also calculated mean and standard deviation.

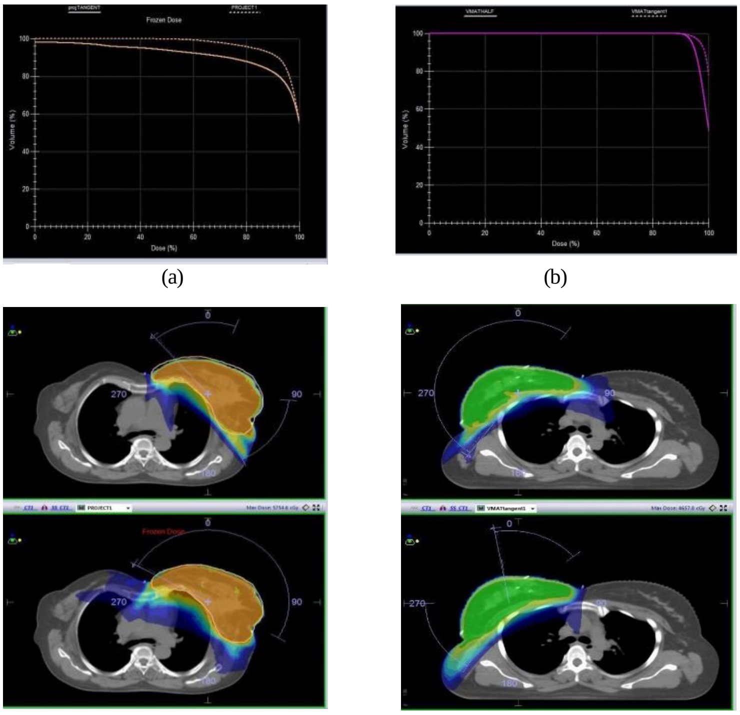
Results

PTV dose evaluation

In both the plans, a prescribed dose of 42. 56Gy was achieved, and proper dosimetric comparison in terms of coverage of target and corresponding OARs sparing were calculated. In left-sided breast, with tVMAT planning target coverage that is the PTV which was V95% were 93. 678 ± 3. 123 and 88. 673 ± 5. 363 for HALF-ARC VMAT planning (Figure 1a. In right-sided breast, target coverage is 95. 667 ± 2. 765 for tVMAT and 91. 977 ± 4. 576 for HALF-ARC VMAT. PTV showed a p-value less than 0. 05, that is 0. 0387 for right-sided breast and 0. 00983 for left-sided breast (Figure 1b. As per the results obtained we can tell that in both left-sided and right-sided breast, tVMAT gives more coverage and homogeneity than HALF-ARC VMAT (Figure 1 c, d)). The CI and HI of whole PTV for both the plans showed high conformity and homogeneity index and their p values also showed significance which is less than 0. 05. The comparisons of both sided breasts plans are tabulated in table 4 and 6. The comparison between both the plans in terms of conformity index and homogeneity index are tabulated in table 5 and 7.

OAR dose evaluation

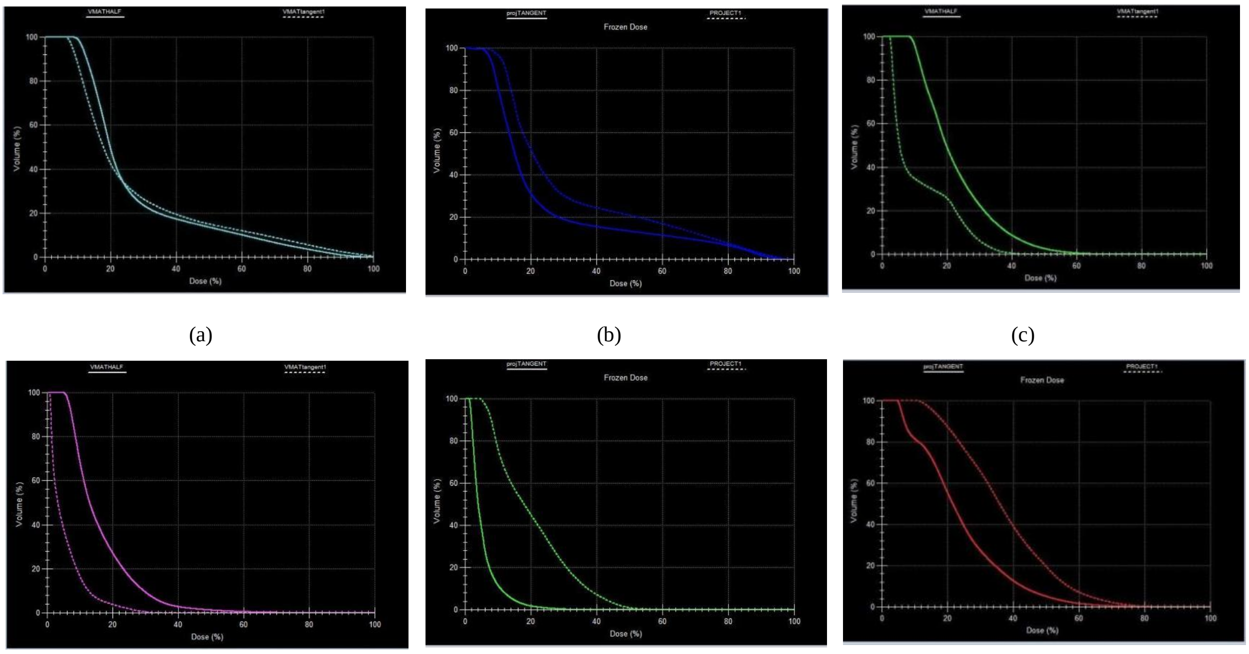
For left-sided breast cancer, the dose reduction of OAR in tVMAT is large for contralateral breast and HALF-ARC VMAT planning gives less dose to ipsilateral lung with their mean values 17. 443 ± 4. 893 and heart 5. 032 ± 4. 537 (Figure 2 a, b). But right-sided breast with tVMAT showed better results and low doses to all the parameters and much more target coverage with mean values coming around 16. 934 ± 2. 499 for ipsilateral lung and 0. 007 ± 0. 0221 for the heart with significant p values. When we compared dosimetric parameters for both cases it showed better coverage and better OAR sparring in tVMAT than Half beam VMAT except for ipsilateral lung receiving V20<20. The values are tabulated in table 4 and 6. (Figure 2, c,d,e and f) The DVH graphs of all the OARs and PTV are shown below:



(a) (b)

(c) (d)

Figure1. The PTV dose of a) left-sided breast, b) Right-sided breast, and isodose distributions of c)left-sided breast, d) right-sided breast



(a) (b) (c)

(d) (e) (f)

Figure 2. The dose to the critical organs a) the right lung, b) the left lung c) the heart in left side breast case, d) the heart in right side breast case, the contralateral breast in e) the right breast case, f) the left breast case

Table 4. For left-sided breast comparison between tVMAT and HALF-ARC

Parameter	tVMAT	Half beam VMAT	P- value
PTV	93. 67 ±3. 12	88. 67± 5. 36	0. 01
Ipsilateral lung	18. 08 ± 2. 44	17. 44 ± 4. 89	0. 73
Heart	5. 53 ±2. 98	5. 03 ± 4. 53	0. 76
Contralateral breast	295. 23 ± 169. 70	372. 55 ± 142. 54	0. 22

Table 5. Comparison between tVMAT and HALF-ARC VMAT in terms of conformity index and homogeneity

Parameter	tVMAT	Half- Arc VMAT	P- value
CI	1. 04 ± 0. 07	1. 01 ± 0. 12	0. 27
HI	1. 13 ± 0. 03	1. 16 ± 0. . 05	0. 01

Table 6. Right-sided breast plan comparison between tVMAT and HALF-ARC VMAT

Parameter	tVMAT	Half- Arc VMAT	P- value
PTV	95. 66 ± 2. 76	91. 97 ± 4. 57	0. 03
Ipsilateral Lung	16. 93 ± 2. 49	18. 47± 2. 94	0. 23
Heart	0. 007 ± 0. 02	0. 61 ± 0. 89	0. 05
Contralateral breast	324. 13 ± 176. 62	443. 07 ± 148. 42	0. 15

Table 7. Comparison between tVMAT and HALF-ARC VMAT in terms of conformity index and homogeneity

Parameter	tVMAT	Half- beam VMAT	P- value
CI	1. 10 ± 0. 09	1. 01 ± 0. 08	0. 02
HI	1. 13 ± 0. 02	1. 10 ± 0. 03	0. 04

Discussion

Generally, VMAT can be defined with larger volume with low doses to other critical organs or OARs which will eventually lead to secondary malignancy [8]. For a VMAT planning technique, deciding the placement of the start angle and end angle of the arc is very important. Wrong selection of these angles will lead to a significant increase in the doses to OARs and an increase in optimization time. The anatomy of the patient is also important in determining the best plan. For example, there are circumstances where the patient's anatomy is ideal for tVMAT, with a chest wall that is not too concave, a heart that is away from the chest, and limited healthy tissues in the fields.

In the present study, tVMAT gives more target coverage than HALF-ARC VMAT. HALF-ARC VMAT in the left-sided breast gives a reduction of doses in the ipsilateral lung. Contralateral breast dose is pretty much more in HALF-ARC VMAT. But heart doses are found to be almost the same in both the plans. For right-sided breasts, tVMAT planning gives high target coverage and homogeneity and decreases the dose in almost all the parameters. To reduce the doses in the ipsilateral lung and heart we can keep two tangent arcs with gantry start angle 350° and 210° with arc rotation of 60° in right-sided breast and for left-sided breast 320° and 95° with rotation of 60° are used. It should also be noted that we have used the monte Carlo algorithm for planning. The limitation of this study was, movement of the breast was not accounted for and also no SCF and MRM cases are taken. The minimization of the dose to the contralateral breast is highly prioritized.

Both plans achieved the prescribed dose of 42.56 Gy, and the study evaluated their efficacy in terms of target coverage and sparing of organs at risk (OARs). In the left-sided breast, tVMAT provided significantly higher target coverage (V95%: 93.678 ± 3.123) compared to HALF-ARC VMAT (V95%: 88.673 ± 5.363). Similarly, in the right-sided breast, tVMAT demonstrated superior target coverage (V95%: 95.667 ± 2.765) compared to HALF-ARC VMAT (V95%: 91.977 ± 4.5757), with both cases showing statistically significant differences ($p < 0.05$) favoring tVMAT. Moreover, both planning techniques exhibited high conformity and homogeneity indices for the whole PTV, with significant p-values (< 0.05). Regarding OAR dose evaluation, tVMAT showed notable reductions in doses to OARs, particularly for the contralateral breast in left-sided cases and for all OARs in right-sided cases.

When comparing our study to earlier research efforts in optimizing radiation therapy for breast cancer, several distinct approaches emerge. Fogliata et al. (21) implemented an avoidance sector technique aimed at reducing mean doses to critical structures during whole breast irradiation. While effective in minimizing doses to these structures, this technique incurred trade-offs such as increased high-dose spillage in healthy tissue and elevated skin doses. In contrast, Pasler et al. (22) explored the use of small tangential arc segments versus large-angle VMAT, prioritizing reduced low doses to the heart and contralateral structures, albeit with a slight compromise in target coverage and homogeneity. Similarly, Kuo et al. (23) introduced a modified VMAT technique employing partial arcs to spare the ipsilateral arm, particularly relevant for patients with expander or implant reconstructions. Our study, in contrast, directly compared two VMAT planning techniques, tVMAT and HALF-ARC VMAT, in terms of achieving the prescribed dose while optimizing target coverage and sparing of organs at risk (OARs). We found that tVMAT consistently outperformed HALF-ARC VMAT, providing superior target coverage and OAR sparing, particularly notable in the contralateral breast for left-sided cases and across all OARs for right-sided cases. While each study offers unique insights into improving radiation therapy outcomes for breast cancer, our focus on comparative evaluation underscores the significance of selecting the most effective planning technique to optimize treatment efficacy and minimize adverse effects on healthy tissues.

The possibility of generating unfavorable effects in breast tissue will be reduced if dosage uniformity is increased. This enables hypofractionation to be used even in patients with a significant PTV. However, due to the patient population, dosage prescription, delineation, and radiation procedures, comparing two studies will always be challenging. This could clarify the partially incongruent findings for HI, CI, MU, and OAR sparing.

Conclusion

In the present study compared two different treatment planning techniques, tVMAT and HALF-ARC VMAT, for the treatment of both left-sided and right-sided breast cancer patients. For advanced left breast cancer, tVMAT is a groundbreaking radiotherapy preparation technique. It overcomes the drawbacks of conventional VMAT in terms of less dose spreading and contralateral organ effects on treatment plan dosimetry while retaining target coverage and homogeneity. It establishes a model for the treatment of difficult cases requiring nodal irradiation.

In comparison to tVMAT, half beam vmat in left-sided breast irradiation dramatically and significantly decreased dose organs at risk, except the ipsilateral lung, thus providing high coverage. Almost all parameters receive less dose with high target coverage and homogeneity in right-sided breast irradiation. The risk of secondary tumor induction was significantly lower after tVMAT than after HALF-ARC VMAT, particularly in the contralateral lung and breast, but not in the ipsilateral lung. Based on index calculations, tVMAT plans achieved greater homogeneity and conformity. This may be essential in some cases where adequate coverage of the parasternal nodes is needed.

In conclusion the findings of this study highlight the superiority of tVMAT over HALF-ARC VMAT in terms of target coverage, conformity, and OAR sparing for both left-sided and right-sided breast cancer cases. These results contribute valuable insights for treatment planning decisions, emphasizing the importance of selecting optimal techniques to maximize treatment efficacy while minimizing potential side effects on surrounding healthy tissues. Limitations of the present study is the smaller sample size, this is because of the time constraint of the study. In the future the study can be conducted with more sample size.

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