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Dosimetric Evaluation of Volumetric Modulated Arc Therapy (VMAT) for Left-Sided Breast Cancer Assessment of Plan Quality Using Conformity and Homogeneity Indices Using Monaco Treatment

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Abstract
Introduction: Radiotherapy serves as the main treatment approach for breast cancer on the left side. The challenge lies in ensuring sufficient coverage of the target while reducing radiation exposure to nearby organs at risk. Volumetric modulated arc therapy (VMAT) has been introduced to enhance dose conformity and better protect normal tissues.
Objective: This research aimed to assess the dosimetric properties of VMAT plans for patients with left-sided breast cancer by examining dose–volume histogram (DVH) parameters.
Methods: A retrospective analysis was conducted on fifty VMAT treatment plans. The dosimetric assessment focused on target coverage metrics (V95%, conformity index, and homogeneity index) and the radiation doses received by organs at risk, such as the heart, ipsilateral lung, contralateral lung, contralateral breast, esophagus, and spinal cord.
Results: VMAT planning provided consistent and clinically satisfactory dosimetric outcomes for both the target volumes and surrounding normal tissues. The chest wall PTV had an average V95 of 97.2%, while the lymph node PTV reached 98.7%, demonstrating sufficient target coverage with satisfactory conformity and dose uniformity. In terms of organs at risk, cardiac exposure was kept low, with the heart receiving an average dose of 5.0 Gy. The ipsilateral lung experienced mean V5, V20, and V30 values of 56.6%, 25.0%, and 21.0%, respectively. In contrast, the contralateral lung was subjected to minimal high-dose exposure, as indicated by mean V20 and V30 values of 0.3% and 0.06%. The contralateral breast received an average dose of 3.5 Gy, and the esophagus had a mean dose of 13.1 Gy, with a mean maximum dose of 33.6 Gy. Additionally, the spinal cord's mean maximum dose was 13.6 Gy. These dosimetric results suggest that VMAT effectively targeted irradiation while keeping radiation exposure to nearby critical structures within acceptable clinical thresholds.
Conclusion: VMAT achieved efficient target coverage, demonstrating good dose conformity and uniformity, all while keeping radiation exposure to nearby organs at risk within acceptable limits. These results endorse the clinical practicality of using VMAT for treating left-sided breast cancer.

1. Introduction

Radiation therapy (RT) is a central part of the management of breast cancer with Post-Mastectomy Radiotherapy (PMRT) being a standard adjuvant treatment after breast-conserving surgery, especially in early stage disease. Because of the complex breast anatomy, and the fact that the lungs and heart are organs at risk (OAR), a strict dosimetric control is warranted by hypofractionated regimens that are increasingly being adopted. One of the main challenges in postmastectomy radiotherapy (PMRT) [1], To ensure the best possible target coverage with minimal radiation exposure to healthy tissues in the vicinity. Patients with left sided breast cancer are at increased risk for radiation induced cardiac toxicity because the radiation is close to the heart. Also, over-radiation of the lung may lead to radiation pneumonitis and chronic disease of the lung [2]. Thus, careful treatment planning is essential to achieve optimal tumour control and to minimise the radiation dose to surrounding normal tissues. Volumetric Modulated Arc Therapy (VMAT) is an advanced form of external beam radiotherapy, which delivers radiation using continuously rotating, adjusting arcs in the machine's gantry, as well as changing the location of the multileaf collimator (MLC), the beam delivery rate and the gantry rotation speed. In suitable patients, this method results in very uniform dose distribution, a high degree of target coverage and sparing of organs at risk, which are better outcomes than those of conventional radiotherapy. Dosimetric analysis is often used in the evaluation of VMAT treatment plans, especially for the use of dose–volume histogram (DVH) parameters and quality indices such as the Conformity Index (CI) and Homogeneity Index (HI) [3]. These metrics provide quantitative information on the degree of target dose coverage, and the amount of exposure to organs at risk, which can be used to optimize treatment plans and to assess the clinical efficacy of radiation therapy [4].

2. Patient and methods

2.1 Patient selection

This prospective dosimetry study will be conducted in the Wasit Oncology Center between November 2025 and May 2026. The study was approved by the Institutional Review Board (IRB) of the College of Medicine at Al-Nahrain University as a research requirement for a Master of Science degree in medical physics. The study included fifty female patients diagnosed with left-sided breast cancer who underwent surgical removal of the tumor from the breast, which was being treated with adjuvant radiotherapy in our study.

2. 2 Computed Tomography (CT) Simulator

The CT simulator was equipped with a dedicated breast board used for patient positioning and immobilization during CT simulation for breast radiotherapy planning, as shown in Figure (1). For those with breast cancer on the left side, the head was turned to the right during CT simulation to aid in positioning and enhance the consistency of the treatment setup. CT images were captured with a 2.5 mm slice thickness, as this thickness allows for more precise visualization of the target volume and adjacent organs at risk. These CT images were then transferred to the MONACO Treatment Planning System (TPS) for contouring and planning the treatment. The delineation of target volumes and organs at risk (OARs) followed the guidelines set by the Radiation Therapy Oncology Group (RTOG) and the European Society for Radiotherapy and Oncology (ESTRO). The Clinical Target Volume (CTV) encompassed the chest wall for all patients, as well as the regional lymph nodes. To ensure consistency in treatment planning comparison, a uniform 5 mm margin was added around the CTV to generate the Planning Target Volume (PTV).

Figure (1): CT Simulation Scanner with Breast Immobilization Board for Breast Cancer Radiotherapy.

2.3 Treatment Planning Techniques

Fifty female patients diagnosed with left breast cancer based on clinical examination by imaging US, MRI, and biopsy to have left breast Cancer, patients underwent surgery, whether partial (lumpectomy) or total resection (mastectomy), with regional lymph nodes, and all patients received adjuvant radiotherapy treatment in our study. The patients were prepared for the GE CT (GE revolution EVO, GE health care, JAPAN Corporation) was used with a slice thickness of 2.5 mm.Linear Accelerator (Synergy Agilty), Elekta 2015.Monaco Elekta HP, vesion

6.2.1. They were treated with an X-ray photon beam 10 MV for VMAT The prescribed dose to the PTV is 40.05 Gy delivered in 15 fractions energy using ELEKTA's Agility linear accelerator.

2.4 VMAT

PTV total was contoured (PTVCW+ PTVLN) and the isocenter where placed at the isocenter, where placed at the center of (PTV total). Two beam (with 2 arc per beam) were used in the planning, the two beams were counter clock wise started from 190º and with arc length (225º and 205º). The grid spacing was (0.3) which is recommended for VMAT. The segment width was 0.5 cm and beamlet width was 0.5 cm auto flash 2 cm that, as illustrated in figure (2).

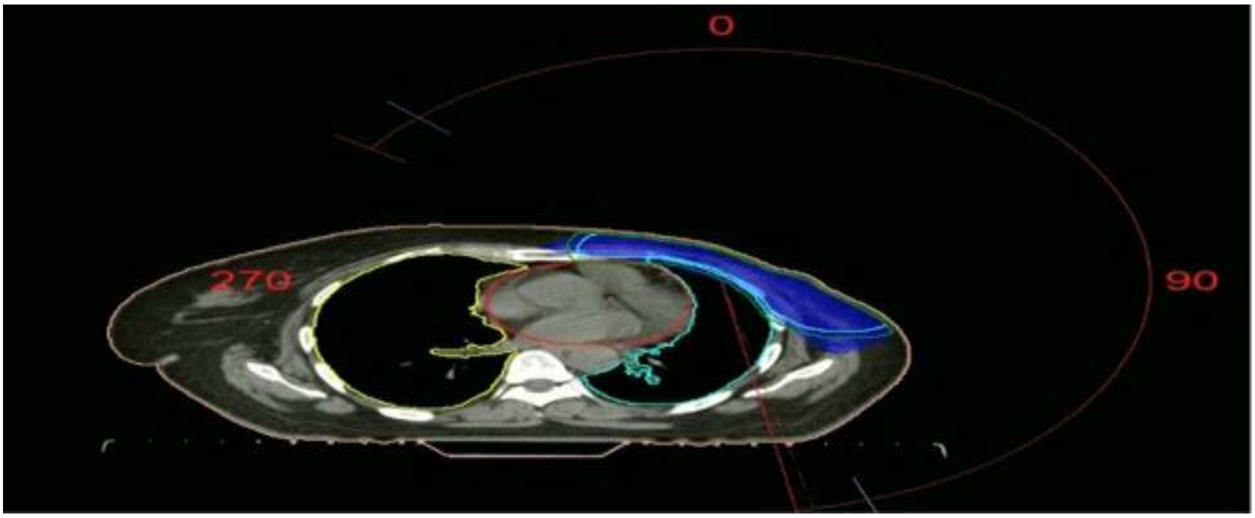

Figure (2): Left breast radiotherapy planning using VMAT technique.

2.6 Plan Evaluation

As per the planning objectives, the Dose Volume Histogram (DVH) parameters were analyzed to find the dose received by PTV and OARs. The dose-volume histogram is a valuable tool to explain and evaluate a treatment plan statistically, so we can find how much (numerically) dosage is received for targets and organs, the dose-volume histogram is a useful tool for describing and evaluating a treatment plan statistically. However, DVH was unable to provide us with a comprehensive picture of the dose distribution, the homogeneity of the dosage, and how the radiation dose is (geometrically) dispersed around the target. The dose conformation on the target and the surrounding tissue volume covered by the reference dose are measured by the conformance index (CI). Several equations have been proposed to describe the Conformity Index (CI) and, homogeneity Index however, in this study, the following equation was used [5], Lomax and Scheib had another definition of conformity index, which took into account the tissue covered with reference radiation dose. They called it the healthy tissue conformity index and could be expressed as follows equation (1):

Healthy tissue conformity index= TV_{RI}/ V_{RI} --------(1

Where:

TV_{RI} is the target volume that is covered with reference radiation dose.

V_{RI} is the volume of reference radiation dose [6].

$HI=D_{5\%}/D_{95\%}$

Where:

$D_{5\%}$ is the maximum In general, the dose homogeneity is a characterization of the absorbed- dose distribution within the target volume. A perfectly homogeneous dose to the PTV would be characterized by a spike in the differential DVH or a vertical drop of the cumulative DVH line for the PTV at that absorbed dose, as proposed by the RTOG target volume, shadowed; volume of reference isodose, enclosed in black dashes, as demonstrated in figure (3) [7] .

$D_{95\%}$ is the minimum dose in 95% of the target volume [11].

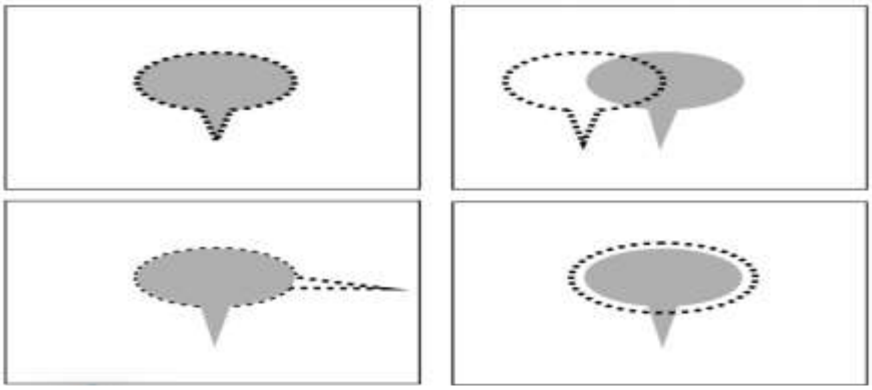

Figure 3: Four possibilities for which the VRI /TV ratio is equal to 1(index proposed by the RTOG) (1) (target volume, shaded; volumeof reference isodose, enclosed in black dashes) [39].
also, the defined homogeneity index was used in the following equation
dose for 5% of the target volume.
$D_{95\%}$ is the minimum dose in 95% of the target volume [8].

3. Statistical analysis

The statistical analysis achieved using SPSS v24 (IBM Inc., Chicago, IL, USA). Descriptive statistical analysis was used to summarize the dosimetric parameters of the VMAT treatment plans. The results were presented as mean ± standard deviation (SD).

4. Results

The results obtained from the Volumetric Modulated Arc Therapy (VMAT) treatment plans. The evaluated dosimetric parameters included the planning target volume (PTV) and organs at risk (OARs) for minimum and maximum doses, as illustrated in table (1).

Table (1): Dose received by organs and target using VMAT planning technique.

Endpoints		min	max	mean	SD	median
Contralateral lung	V5 Gy (%)	13.00	44.00	23.30	6.30	23.40
	V20 Gy (%)	0.00	1.40	0.30	0.10	0.00
	V30 Gy (%)	0.00	0.25	0.06	0.10	0.00
	Mean dose (Gy)	2.90	6.10	3.80	0.60	3.80
Ipsilateral lung	V5 Gy (%)	42.30	68.00	56.60	5.10	56.00
	V20 Gy (%)	19.00	31.00	25.00	2.50	25.40
	V30 Gy (%)	10.10	27.90	21.00	3.50	21.30
	mean dose (Gy)	3.20	10.10	3.50	2.30	3.60
Heart	V5 Gy (%)	10.00	25.70	19.70	3.60	20.20
	V10 Gy (%)	5.20	13.90	8.90	2.40	8.50
	V25 Gy (%)	0.20	4.10	1.08	1.04	1.60
	mean dose (Gy)	3.60	5.90	5.00	0.50	5.10
Contralateral breast	mean dose (Gy)	2.50	4.30	3.50	0.40	3.60
Esophagus	max dose (Gy)	29.20	38.90	33.60	2.20	33.40
	mean dose (Gy)	3.80	15.60	13.10	1.30	12.70
Spinal cord	max dose (Gy)	4.80	28.40	13.60	3.50	13.30
PTV (chest wall)	V95 (%)	94.00	99.90	97.20	1.50	97.40
	CI	0.65	0.90	0.79	0.05	0.80
	HI	1.02	1.11	1.07	0.02	1.07
PTV (lymph nodes)	V95 (%)	96.10	99.90	98.70	1.40	98.40
	CI	0.68	0.90	0.84	0.03	0.85
	HI	1.03	1.09	1.06	0.03	1.06

5. Discussion

Table (1) presents the radiation doses delivered to the organs at risk (OARs) and target volumes using the VMAT planning technique, both lungs showed the dose-volume analysis showed that the VMAT technique effectively spared both the ipsilateral and contralateral lungs. As expected, the ipsilateral lung received higher radiation doses because of its proximity to the target volume, whereas the contralateral lung received minimal exposure, particularly for V20 and V30. These results show that the VMAT technique yields good target coverage with minimal radiation dose to healthy lung tissue, which can help limit the risk of radiation-induced lung toxicity [9] and demonstrates relatively low radiation doses for the heart. The mean values of V5, V10, and V25 were 19.70%, 8.90%, and 1.08%, respectively, with a mean heart dose of 5.00 Gy. These findings illustrated that VMAT effectively reduced the radiation dose to the heart while maintaining adequate target coverage, which may help decrease the risk of radiation-induced cardiac toxicity. The contralateral breast showed low radiation doses with the VMAT technique, recording a mean does of 3.50±0.40 Gy. These Findings demonstrated effective sparing of the contralateral breast, with only a small volume receiving higher radiation doses. This may help reduce unnecessary radiation exposure and the risk of radiation-induced secondary breast cancer. The esophagus received low radiation doses with the VMAT technique. The maximum and mean doses delivered to the esophagus were 33.60 ± 2.20 Gy and 13.10 ± 1.30 Gy, respectively. These findings indicate effective sparing of the esophagus. These findings indicate effective sparing of the esophagus, with only a small volume receiving moderate and high radiation doses, which may reduce the risk of radiation-induced esophageal toxicity [10], the maximum dose delivered to the spinal cord was 13.60 ± 3.50 Gy. This relatively low maximum dose indicates effective protection of the spinal cord during VMAT treatment while maintaining adequate target coverage. Keeping the maximum dose low is important to minimize the risk of radiation-induced spinal cord injury. The results demonstrated excellent target coverage for both the chest wall and lymph node PTVs. The mean V95 values were 97.20 ± 1.50% and 98.70 ± 1.40%, respectively, which were satisfactory. The mean CI was 0.79 ± 0.05 for chest wall and 0.84 ± 0.03 for the lymph nodes, indicating good dose conformity. Furthermore, the mean HI values were 1.07 ± 0.02 and 1.06 ± 0.03, which means a homogeneous distribution of the dose in both target volumes[11].

The results in Table (1) show that the VMAT technique was able to cover the target with a high precision while avoiding the organs at risk. Chest wall and lymph node target doses were accurately delivered and homogenous, as evidenced by high V95s and acceptable conformity and homogeneity indices. In addition, low doses of radiation are given to the heart, contralateral breast, esophagus, spinal cord and contralateral lung are indications of VMAT's ability to reduce unnecessary radiation exposure to healthy tissues. The doses for the ipsilateral lung were relatively higher due to its close proximity to the target volume, but all the dose parameters were within the clinically acceptable limits. All these results indicate that VMAT delivers the best trade-off between target coverage and organ-at-risk sparing and, therefore, may offer a better treatment quality while minimizing radiation-induced toxicities.

The similarity between the mean and median values in our finding implies that there were no extreme values that significantly affected the data and that the data were not strongly skewed. This indicates that the dosimetric values obtained are likely to be believable and representative of the population studied. Based on their clinical importance and their connection with radiation-induced toxicity, the dosimetric parameters were chosen. The parameter V20 was selected as the most important parameter for the ipsilateral lung since it is highly correlated with the risk of radiation pneumonitis. From a clinical point of view, a V20 of less than 30% is a protective factor to minimize the risk of radiation pneumonitis and a risk factor for the development of radiation pneumonitis-related symptoms like cough and dyspnea. V25 and mean dose were highlighted for the heart, where keeping V25 less than 10% will reduce the incidence of late cardiac side-effects. Moreover, the mean dose to the heart is associated with a relative risk increase of ~7% per 1 Gy. Unnecessary radiation exposure was estimated for the contralateral breast by using the mean dose, as doses exceeding 5 Gy can lead to an increased risk of secondary breast cancer in the future. Lastly, V95%, CI and HI were chosen to assess the target coverage, dose conformity and dose homogeneity for a thorough representation of the treatment plan quality.

6. Conclusion

The dosimetric measures have shown that VMAT can deliver a good dose distribution for left-sided breast cancer patients. The treatment plans included good coverage of the target areas with high V95 values, and satisfactory conformity and homogeneity indices, which indicated excellent coverage of the target areas including the chest wall and regional lymph nodes. It implies that the doses prescribed was accurately and regularly applied in the targeted areas. VMAT significantly reduced radiation dose to the heart, opposite lung, opposite breast, esophagus and spinal cord, while maintaining clinically acceptable dose levels for these organs at risk. The higher doses were received by the ipsilateral lung, but all of the dosimetric parameters evaluated remained within acceptable limits. This study's findings suggest that VMAT is an effective approach to treating left breast cancer patients, with good target coverage and protection of the surrounding healthy tissues. These dosimetric characteristics may reduce the risk of radiation induced side effects, but remain accurate and high-quality radiotherapy treatment.

Ethical Permissions: The College of Medicine/ Al-Nahrain University has approved the ethical permission for this research (IRB-).

Conflicts of Interest: The authors declared no conflicts of interest.

Authors' Contribution: Aya Khalied (First Author), Introduction Writer/Methodologist/Main Researcher/Discussion Writer (60%); Jenan Hussien Taha (Second Author), Introduction Writer/Statistical Analyst (20%); Ahmed Jasim (Third Author), Discussion Writer (20%)

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