Review Article

Planning System-dependent Recommendations of Intensity-modulated Technique for Breast Radiotherapy: A Literature Review-based Adaptation and Institutional Dosimetric Experience from a Large-volume Tertiary Cancer Care Hospital

Biplab Sarkar[1,2], Anirudh Pradhan[3]

[1]Department of Radiation Oncology, Apollo Multispeciality Hospitals, Kolkata, West Bengal, [2]Department of Physics, GLA University, [3]Director, Centre for Cosmology, Astrophysics and Space Science (CCASS), GLA University, Mathura, Uttar Pradesh, India

Abstract

This article aims to identify, through a literature review, the best intensity-modulated technique (IMRT)/volumetric-modulated arc therapy (VMAT) for the breast/chest wall (Br/CW) as a function of the treatment planning system (TPS) and present the institutional dosimetric data for the same. A PubMed search was conducted following intensity-modulated irradiation techniques (IMRT) presented in the study: field-in-field (FiF), tangential IMRT (t-IMRT), multi-field IMRT, tangential VMAT (t-VMAT), half-arc VMAT (HA-VMAT), and large arc VMAT (LA-VMAT). The literature with at least one arm VMAT is included in this study. A total of 370 articles were identified between 2010 and 2022, out of which 19 articles were found to be unique. These articles were classified in terms of the TPS used: Eclipse (9), Monaco (6), RayStation (2), Pinnacle (1), and one unidentified TPS. Based on the literature review, dosimetric attributes, and second cancer risk analysis (SCRA), t-IMRT was found to be the most preferable technique in Eclipse, Pinnacle, and RayStation TPS. However, for Monaco TPS, t-VMAT (approximately 30° tangential arc) offers better dose coverage with lower organ-at-risk (OAR) doses. In terms of OAR doses and SCRA, LA-VMAT (≥210°) and HA-VMAT (180°) are avoidable techniques in any TPS, and FiF should be preferred over these two techniques. In our present institution, which uses the Eclipse TPS, data for 300 patients treated with t-IMRT were collected. The data included beam angle, monitor unit [MU], target coverage (D95% and V105% [cc]), and analysis of the maximum (%), and mean dose (%) of the OAR. t-IMRT utilizes two medial and three lateral tangential beams placed at a spread of approximately 10° and 20°, respectively. The results showed a D95% of 96.3 ± 1.2% and a V105% of 4.9 ± 7.0 cc. The mean doses to the heart and ipsilateral lung were 10.1 ± 20.9% and 11.4 ± 10.2%, respectively. The mean MU was 1282.7 ± 453.4. Based on the findings, the most preferred intensity-modulated technique for Eclipse, Pinnacle, and RayStation is t-IMRT, while for Monaco, it is t-VMAT. The data from the Eclipse planning system demonstrate a satisfactory dosimetric outcome for t-IMRT. However, the use of VMAT techniques employing an arc angle between 180° and 210° or higher is strongly discouraged.

Keywords: Breast, intensity-modulated technique, radiotherapy, volumetric-modulated arc therapy

Received on: 20-04-2023 **Review completed on:** 27-06-2023 **Accepted on:** 08-08-2023 **Published on:** 18-09-2023

Introduction

Tangential beam three-dimensional conformal radiotherapy (3D-CRT) or field-in-field (FiF) technique is still the most commonly used technique in breast (Br) radiotherapy.[1] Volumetric-modulated arc therapy (VMAT) for the breast radiotherapy was first described by Popescu *et al*. in 2010 using Otto's algorithm, which was later adopted in the

Access this article online

Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_51_23

Address for correspondence: Dr. Biplab Sarkar, Department of Radiation Oncology, Apollo Multispeciality Hospitals, Kolkata, West Bengal, India. Department of Physics, GLA University, Mathura, Uttar Pradesh, India. E-mail: biplabphy@gmail.com

How to cite this article: Sarkar B, Pradhan A. Planning system-dependent recommendations of intensity-modulated technique for breast radiotherapy: A literature review-based adaptation and institutional dosimetric experience from a large-volume tertiary cancer care hospital. J Med Phys 2023;48:221-9.

Eclipse planning system.[2] Giorgia *et al*. then described an elaborate technical guideline for the Eclipse planning system.[3] Currently, users are shifting toward intensity-modulated plans that employ both IMRT and VMAT techniques. A wise choice of beam/arc angle for intensity-modulated techniques may result in lower ipsilateral lung and cardiac doses and a more conformal dose distribution. The dosimetric superiority of IMRT over 3DCRT is well documented in the literature.[4]

Nonetheless, as reflected in the published literature, a nonuniform, planning system-dependent adaptation of IMRT/VMAT has been observed among users.[1-3,5-16] The classical tangential beam wedged 3DCRT (W3DCRT) or FiF technique has been replaced by the following different intensity-modulated techniques: large arc (≥210°) VMAT (LA-VMAT), half-arc VMAT (HA-VMAT) (≈180°), tangential arc (30° ×2) VMAT (t-VMAT), multiple IMRT beams distributed over a large arc (multi-field IMRT [m-IMRT]), and tangential field IMRT (t-IMRT). Two primary changes have occurred for Eclipse (Varian Medical Systems, Palo Alto, CA, USA) and RayStation (RaySearch Laboratories, Stockholm, Sweden) where w3DCRT/FiF was replaced by LA-VMAT, HA-VMAT, or m-IMRT and the complex generation of the flash margins.[3-9,10,12,13,16] However, studies show that a small tangential arc VMAT and automatic flash margin are possible with a planning system like Monaco (Elekta CMS, Palo Alto, CA, USA).[7,8,14,15] With a wide variety of planning systems, the varied adaptation of the breast radiotherapy arc/beam angles yields a difference in organ doses, low-dose bath, and predictive second cancer risk.[1,17-19] Therefore, the question is, while adopting VMAT from a W3DCRT/FiF technique, why has the arc angle increased so much? The large arc angle adaptation violates the fundamental solid geometrical equivalence between 3DCRT and VMAT/IMRT. There is not much justification to replace a half-blocked tangential (wedged/FiF) beam with an arc of ≥180°. This is due to the inability of planning systems such as Eclipse/RayStation to generate a good dose distribution with short arcs.[5,9,10-13,16] Furthermore, these treatment planning systems do not provide an automatic flash margin for VMAT.[2,9,13]

Presently, all radical treatments have shifted to intensity-modulated techniques. Therefore, it is essential to find the best intensity-modulated technique for breast/chest wall (Br/CW) radiotherapy and establish it through a literature review.

The primary objective of this article is, through a literature review, to find the best intensity-modulated technique for Br/CW radiotherapy as a function of the planning system. The secondary objective is to report the dosimetric results from institutional practice for the most suitable intensity-modulated radiotherapy technique (t-IMRT) for the Eclipse planning system for a large population of patients.

This article identifies patients after Br conservation surgery and intact breast irradiation as "Br" and radiotherapy after modified radical mastectomy irradiation as "CW."

This study has two parts. In the first part (Part 1), we build up the literature-based recommendation of different IMRT techniques as a function of different commercially available planning systems. In the second part (Part 2), based on the recommendation of Part 1, we present the dosimetric results of the most preferred intensity-modulated technique for our present institutional planning system.

Part 1: Literature Review-based Recommendation of Intensity-modulated Technique for Different Treatment Planning Systems

Part 1: Materials and methods: Literature review

An extensive PubMed search using the keywords "breast radiotherapy," "dosimetric comparison," "VMAT," and "IMRT" yielded 2565 articles between January 1, 2010, and December 31, 2022. Article inclusion criteria were "full text" and "at least one arm VMAT." Article exclusion criteria were "prone," "hybrid techniques," "arc angle ≥180° or IMRT beams spread over ≥180°," "partial breast irradiation," "proton," "cost-effectiveness," and studies limited only to "IMRT versus 3D-CRT," leading to 370 articles in total. These articles were individually read by one of the authors to include or exclude in this research the combination of the study protocols "VMAT versus IMRT" or "VMAT versus 3DCRT" or "VMAT versus IMRT versus 3D-CRT." We identified a total of 19 representative articles, grouped as Eclipse (9), Monaco (6), RayStation (2), Pinnacle (1), and one unidentified TPS. The remainder of this article is a subset of these articles. One of these articles was eliminated because of the extra-large VMAT arc angles, which are not used in the other articles or are not practiced in general clinical situations.[20] Fifteen of the 19 articles were dosimetric results, with two describing breath hold or active breathing coordinator-based techniques and four analyzing second cancer risk.[14-18]

Part 1: Results

Table 1 summarizes the chronological analysis and conclusions of the reviewed literature. We have included authors' remarks (AR), which we consider to represent the final merit or demerit of the study's endpoint.

Popescu *et al*. (Eclipse) conducted a dosimetric comparison of nine-field IMRT (9F-IMRT) and LA-VMAT for the Eclipse planning system and concluded that the two techniques were dosimetrically equivalent.[2] AR: 9F-IMRT was required to treat the internal mammary chain (IMC) along with breast tissue and the supraclavicular fossa (SCF). Prophylactic IMC chain treatment is no longer given to all patients and is limited to those with node-positive disease, reducing the volume of the target and eliminating the need for 9F-IMRT. Nonetheless, several authors described t-IMRT prior to Popescu *et al*.[2,21]

Nicolini *et al*. (Eclipse) described the breast VMAT technique using a 243° ±6° arc and generated the flash margin using virtual bolus.[3] AR: A large arc is required to treat the IMC

Table 1: Reviewing the Literature on Radiotherapy for Breast and Chest Wall: Focusing on Unique Techniques and Results. All selected articles incorporate at least one arm as VMAT

Investigators	Treatment planning systems	Arc angle	Flash margin	Conclusion
Popescu, 2010[2]	Otto's algorithm; which will be further adopted by Eclipse	m-IMRT: 9 static IMRT fields over 190° spread VMAT=190×2	Could not generate flash	VMAT is comparable to 9F IMRT in target coverage and dose to normal tissue at the V5Gy level AR: IMRT field spread used was too large and probably not required in modern practice. Because of the incorporation of IMC chains, the heart and lung dose is excessively high in comparison to modern studies
Nicolini, 2011[3]	Eclipse	243±6°	Virtual bolus	Describe the breast VMAT planning technique in Eclipse and introduce a virtual bolus-based flash margin. AR: This is not a dose comparison study
Badakhshi, 2013[5]	Eclipse	t-3DCRT, m-IMRT (5 beams over 180° arc), and large arc VMAT (degree not specified)	Not specified	VMAT was found to be inferior to IMRT and 3D-CRT in terms of dose distribution to organs at risk, particularly at low-dose levels, so it was not recommended. AR: This is caused by a large VMAT angle
Jin, 2013[34]	Pinnacle, Elekta Synergy	W3DCRT, FiF, t-IMRT, 7FIMRT, 1/2 arc VMAT	Not specified	Considered t-IMRT is superior to all other techniques. AR: The outcome is consistent with our observations
Zhao, (2015)[7]	Monaco	t-IMRT (2 F and 4F), t-VMAT and 210° VMAT	Not specified	All competing arms have comparable target dose coverage and OAR doses. The conclusion is that 2F IMRT is superior in terms of PTV coverage and normal tissue dose AR: Our results partially match the observation, as double arcs were required for a better dosimetric result in Monaco, and investigators used less effective single arc VMAT
Virén, 2015[8]	Monaco	t-FiF, t-IMRT, t-VMAT (50°), 240° arc VMAT	Automatic	t-VMAT provides better target dose coverage and overall OAR doses. The t-VMAT technique does not increase low-dose volumes in the contralateral breast or lung while increasing dose coverage and homogeneity significantly
Boman *et al*., 2016[9]	Eclipse	Two 190° arc VMAT, two 240° arc VMAT, FiF	Virtual bolus	Split arc VMAT outperformed large arc and FiF, but it was unable to control the dose to the contralateral breast and lung AR: Inconclusive result due to excessively long VMAT arc length, which is unacceptable for clinical practice
Jing Yu *et al*., 2016[10]	Monaco	4 Field t-IMRT, 40° t-VMAT	Automatic	In Monaco, t-VMAT superior than t-IMRT. When compared to t-IMRT, t-VMAT methodology provided superior target-volume coverage, dose conformity, and normal tissue protection, as well as reduced treatment time and the number of MU
Jensen, 2018[11]	RayStation/Versa HD	Two 240° arc and 3DCRT	Flash compensated by plan robustness	The authors published two articles on the plan robustness for the difference technique. In article 2, they used a tangential 3DCRT field only to reduce the number of breath holds, whereas in article 1, they stated that VMAT plans were more robust on average than conventional 3DCRT plans for DIBH when localization errors were considered. AR: The study's findings are contradictory
Jensen, 2017[12]	Elekta Synergy or Elekta Precise: TPS not specified	t-3DCRT	Not specified	
Tyran, 2018[13]	Eclipse	300–170 and return=230° VMAT and t-FiF technique	Virtual bolus	Established the necessity of a virtual bolus for generation of flash margin in the Eclipse environment. Target volume coverage for virtual-bolus-based VMAT is not worse than for FiF
Rossi, 2018[14]	Eclipse	Two 190° arcs, two 240° arcs plan, FiF	Virtual bolus	It is not a multi-arm dose comparison study, but rather an assessment of the influence of anatomical deformation between VMAT and FiF. Dosimetry varies slightly due to anatomical deformation. In VMAT cases, a virtual bolus-based flash margin takes care of anatomical deformation
Munshi *et al*., 2017[15]	Monaco	30°+30° tangential=60°	Automatic	Not a multi-arm dose comparison study. Presented the dose volume parameters for a large group of patients who received t-VMAT treatment with an average arc length of 33–35 in medial and lateral directions AR: The authors argue that an arc angle of≈30° offers the best trade-off between target dose coverage and OAR dose deposition

Contd...

Table 1: Contd...

Investigators	Treatment planning systems	Arc angle	Flash margin	Conclusion
Giri, (2017)[16]	Monaco	W-3DCRT, FiF, and t-VMAT	Automatic	Dosimetric comparison of w3DCRT, FiF, and t-VMAT plans with limited arc lengths will result in the lowest possible heart doses and should be used for left breast irradiation
Byrne, 2018[17]	RayStation	3DCRT and 50° VMAT (t-VMAT) arc for breast/CW+240° arc VMAT SCF±AX	Physical bolus if required	w3DCRT, FiF, and t-VMAT dosimetric comparison t-VMAT plans with short arc lengths result in the lowest possible heart doses and should be used for left breast irradiation
Risk of second cancer				
Yasser Abo-Madyan, (2014)[18]	Monaco	W3DCRT, t-IMRT, m-IMRT, VMAT-gantry/arc angle detail not provided; however, dose distribution [Figure-1d] showed it's a large angle VMAT		The second cancer risk offered by 3D-CRT or t-IMRT is lower than that offered by m-IMRT or VMAT by about 34% (linear model) and 50% (linear-exponential and plateau models) AR: The VMAT arc angle used is incorrect for Monaco, t-VMAT should have been used to compare the second cancer risk
Boram Lee, (2014)[19]	Eclipse: Anthropomorphic phantom measurement	t-3DCRT, 5F IMRT, and half-arc VMAT		Researchers used an anthropomorphic phantom to compare dose deposition in the contralateral breast and ipsilateral lung and found that IMRT and VMAT had a higher secondary cancer risk than 3D-CRT. AR: The preferred technique is 3DCRT
Haciislamoglu, (2019)[20]	Eclipse	t-3DCRT, 9F IMRT, and partial arc (angle not specified probably large arc) VMAT		In all dose-response models, FiF has a significant reduction in the EARs of the contralateral breast, contralateral lung, and ipsilateral lung compared to IMRT and VMAT. AR: FiF is the preferred technique
Racka, (2022)[1]	Eclipse: DIBH	t-3DCRT and partial arc VMAT (140–305°) ×3 arcs		VMAT reduces OAR volume receiving a high dose for left-sided breast cancer, the large low-dose bath (≤5 Gy) is still a concern because it may paradoxically lead to an increase in mean heart and contralateral organ doses AR: 3D-CRT (DIBH) significant reduction of projected secondary cancer risk compared to VMAT

AR: Author's remark, IMRT: Intensity-modulated irradiation techniques, IMC: Internal mammary chain, VMAT: Volumetric-modulated arc therapy, EAR: Excessive absolute risk, OAR: Organ at risk, DIBH: Deep inspiration breath hold, FiF: Field in field, w-3DCRT: Wedged-3DCRT, CW: Chest wall, SCF: Supraclavicular fossa, PTV: Planning target volume, Ax: Axilla. t-3DCRT: tangential 3DCRT, 7F IMRT: IMRT technique using seven fields. 9F IMRT: IMRT teachinique using nine fields. m-IMRT: multiple IMRT beams distributed over a large arc

along with the breast tissue and SCF. As mentioned earlier, prophylactic irradiation of the IMC chain is no longer a standard practice. This change in practice guidelines affects the target volume and eliminates the use of large arcs in Br/CW radiotherapy. A large arc angle results in high doses to the ipsilateral lung and heart (in the case of left-sided treatments). While this article may have historical relevance, the practice it describes is outdated and no longer in clinical use.

Badakhshi *et al*. (Eclipse) compared 3DCRT, multiple IMRT beams distributed over a large arc (m-IMRT), where five beams were spread over a 180° arc, and LA-VMAT (undisclosed angle) and concluded that VMAT was inferior to IMRT and 3D-CRT due to high organ-at-risk (OAR) doses, particularly at the low-dose level.[5] AR: We conclude that both IMRT and VMAT had a wide beam spread, resulting in a large low-dose region.

Yu *et al*. (2016: Pinnacle) conducted a five-arm study involving W3DCRT, FiF, t-IMRT, 7-F IMRT, and HA-VMAT and found that t-IMRT was dosimetrically superior to the other techniques.[6] AR: Expected outcome.

Zhao *et al*. (Monaco) compared the dosimetric results between t-IMRT (2F and 4F), t-VMAT, and LA-VMAT (210°) and found that all competing techniques had comparable target dose coverage and OAR doses. They concluded that 2F IMRT is superior in terms of planning target volume (PTV) coverage and normal tissue doses.[7] AR: This result partially matches our observations, as investigators in Monaco used a less effective single-arc technique; for a better dosimetric result, a double arc was required.[14,15,22] The data for Monaco TPS were presented by Virén *et al*., Yu *et al*., Munshi *et al*., and Giri *et al*.[6,8,14,15] Except for Munshi *et al*., all are multi-arm comparative dosimetric studies.[14]

All Monaco articles have at least one arm as t-VMAT, which was compared to a permutation of W3DCRT, FiF, t-IMRT, and large arc (210°–240°) VMAT.[6-8,14,15] We could identify only one article for Monaco, which has used large arc VMAT and m-IMRT, yielding a high secondary cancer risk compared to W3DCRT and t-IMRT.[17] Within the group of remaining authors, Boman et al., Tyran et al., and Rossi et al. conducted dosimetric comparisons of various Breast/Chest Wall (Br/CW) techniques using the Eclipse planning system. Additionally, Byrne et al. conducted a comparative study using RayStation, where they assessed LA-VMAT/HA-VMAT techniques in comparison to FiF or 3DCRT, excluding the t-VMAT.approach.[9,12,13,16]

Three of the reviewed articles on second cancer risk are based on Eclipse TPS, while the remaining one is based on Monaco.[1,17-19] All three articles about Eclipse, including the recently published article by Racka *et al.* (2022),[1] categorically indicated that LA-VMAT and m-IMRT were inferior to 3DCRT.[1,18,19] The lone article in Monaco TPS calculated secondary cancer risk by comparing LA-VMAT and m-IMRT with W3DCRT and t-IMRT to establish.[17] As t-IMRT is an established technique in Monaco, Abo-Madyan *et al*. should have compared t-VMAT with other arms to obtain a more universal result.[17]

In conclusion, the most recommended approach for the Eclipse, RayStation, and Pinnacle workstations is t-IMRT, and t-VMAT for Monaco. We are going to provide extensive dosimetric data for Br/CW patients treated with t-IMRT because our current institution's planning system is Eclipse.

Part 2: Dosimetric Result for t-IMRT in Eclipse Planning System: Institutional Practice

Part 2: Materials and methods

Simulation and target volume delineation

The patient was suitably aligned on a breast board in the computed tomography simulator using the moving LASER system. A set of fiducials were placed in the anterior and two lateral positions (approximately in the plane passing through the craniocaudal center of the Br/CW). Suitable wires or markers were placed over mastectomy scars and breast to aid in contouring. Axial scans with a thickness of 3 mm were taken from the hyoid to 8 cm below the ipsilateral (in the case of conservation) or contralateral (in the case of mastectomy) inframammary fold. Each patient's chest wall or breast clinical target volume (CTV) was contoured by a registrar and verified by an experienced radiation oncologist. The contours were done in the SomaVision contouring station (Varian Medical Systems, Palo Alto, CA, USA). All OARs were identified, including the contralateral breast, heart, both lungs, and liver.

Part 2: Clinical practice: Dosimetry of t-IMRT

Although the present article does not entail a multi-arm dose comparative analysis, we have included visual dosimetric results of two patients (one with chest wall and the other for intact breast radiotherapy) for three techniques: t-IMRT, t-VMAT, and HA-VMAT. For t-IMRT, five beams were employed, consisting of three lateral tangential beams and two medial tangential beams. This technique was adapted from the t-VMAT technique described by Munshi *et al*., wherein the short arcs of 30° were replaced with static IMRT beams.[14] For t-VMAT, two tangential 30° arcs were used, adopted from the same group.[14] The HA-VMAT technique was adopted from Boman *et al*. in 2016.[9] These visual dosimetric results are included to enhance the general understanding of the reader.

Figures 1a-d and f present the typical dose distributions of t-IMRT, t-VMAT, and HA-VMAT for CW and Br radiotherapy, respectively. Figure 2 is the comparative dose–volume histogram (DVH) for the three techniques. This study included 300 patients who received five-field t-IMRT radiotherapy for Br/CW ± SCF between April 2021 and September 2022. Table 2 shows the patient distribution as a function of disease direction (left or right), histopathology, and dose fractionation regimen. If SCF irradiation is required, tangential IMRT fields were placed with a 0° collimator rotation; otherwise, a suitable collimation (≈±20°) was used to reduce exposure to the ipsilateral lung. The SCF nodal target was not included in the tangential IMRT beam portal as per institutional practice and was planned using direct open multileaf collimator (MLC)-shaped field(s) at a 90° collimator angle, sharing the same isocenter as the IMRT beams. The gantry of the SCF field was slightly tilted (±3° to ±8°) to avoid direct radiation to the esophagus. The junction between IMRT fields and SCF fields was neutralized by manually adjusting the MLC position. All plans were created on the Novalis Tx (Varian Medical Systems, Palo Alto, CA, USA), which utilizes a 6 MV flattened photon beam with 60 pairs of 2.5 mm wide MLCs at the isocenter, no backup jaws, and a maximum MLC-shaped field of 40 cm × 22 cm. Dose calculation was performed using Eclipse V15.6 with the AAA algorithm.

All patients were analyzed for target volume, maximum dose (%), mean dose (%), D95% (dose received by 95% of target volume), and V105% (cc) (volume in cc receiving ≥105% dose). The volume maximum (%) and mean dose (%) of the OARs were also calculated. Other parameters included the monitor units (MUs) for tangential and SCF fields and the gantry angle for tangential and SCF fields as a function of the direction of the target.

Part 2: Results

Institutional practice: Dosimetric result of t-IMRT

The average age of patients was 42.3 ± 17.6 years, with a range of 67 years to 26.3 years. Table 1 indicates patient categorization and histopathology. Patients undergoing IMC irradiation were not included in this study.

Tables 3 and 4 present the dose–volume parameters for the target and OARs, respectively. The liver dose was only presented for the right-side treatment. Table 5 presents the MUs, 50% and 20% isodose volumes representative of low-dose spillage for the two medial tangential and three lateral tangential beam angles, in terms of mean ± standard deviation and median angle. In only 2% of the breast cases, who had large target volumes, a third beam was added in the medial tangential direction. The mean (medial) angle for the left side was 313.5° ±2.1° (313.5°), and for the right side, it was 11° ±1.4° (11°). The supraclavicular nodal station dose was deemed adequate, with a mean dose of around 80%–85%, and the SCF contour was primarily used for beam port shaping.

Discussion: Part 1 + Part 2: Literature Review-based Adaptation of Institutional Practice: Beam Angle Standardization and Dosimetric Outcome of t-IMRT

In 2013, we transitioned from the classical tangential w3DCRT technique to t-VMAT for Br treatment on Elekta/

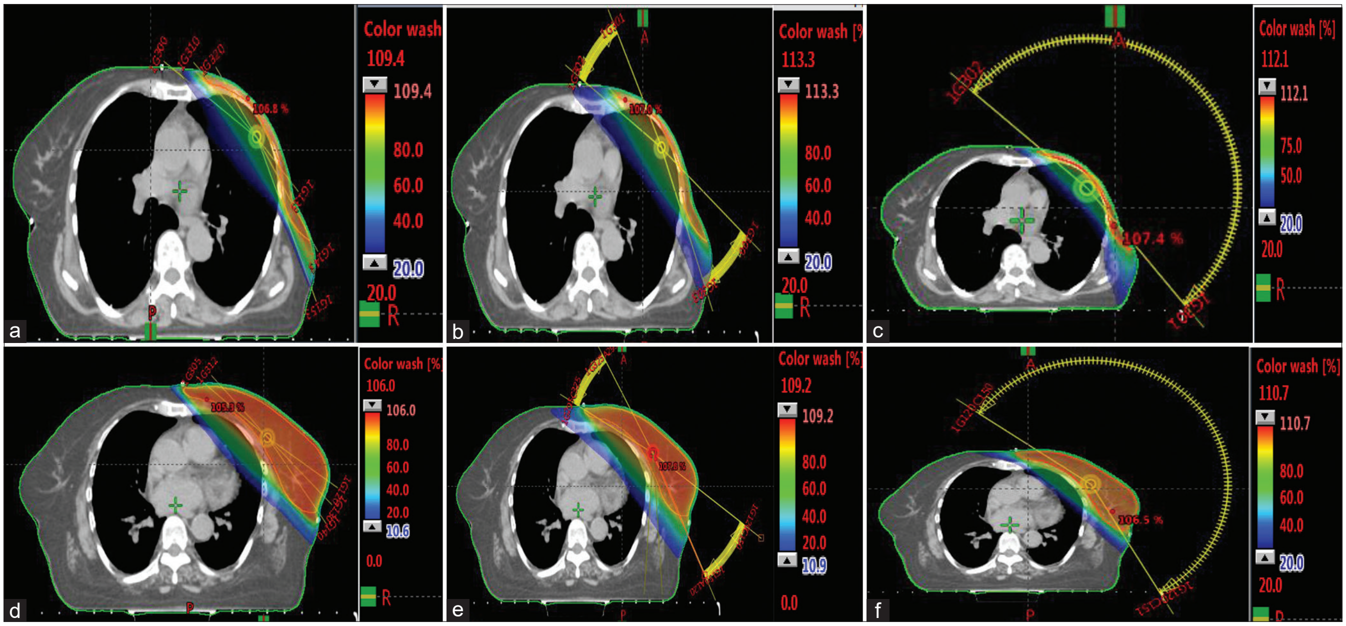

Figure 1: Beam angle and dose distribution for tangential intensity modulated radiotherapy (t-IMRT), tangential volumetric-modulated arc therapy (VMAT), and half-arc VMAT for chest wall and breast radiotherapy in Eclipse planning system, (a) Left chest wall: tangential intensity modulated radiotherapy (t-IMRT)-5beam arrangement, (b) Left chest wall: t-VMAT: 30° double arc, (c) Left chest wall: Half-arc VMAT: 180° double arc, (d) Left breast: t-IMRT-5beam arrangement, (e) Left breast: t-VMAT: 30° double arc, (f) Left breast: Half-arc VMAT: 200° double arc

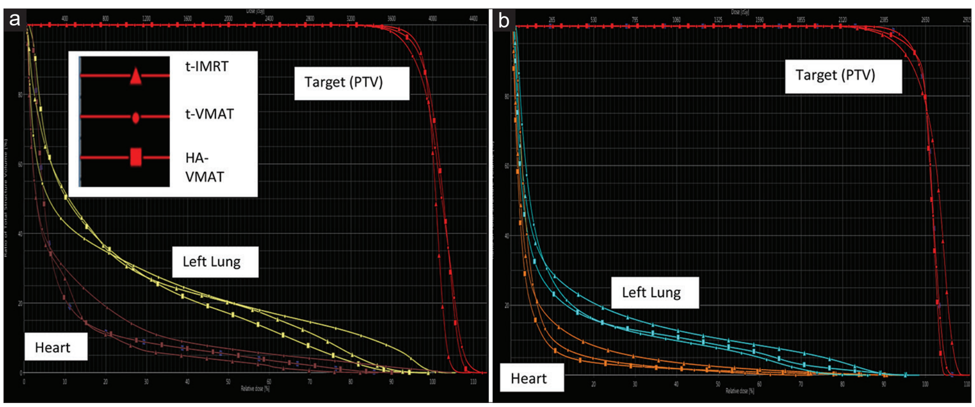

Figure 2: Dose-volume histogram comparison between tangential intensity modulated radiotherapy (t-IMRT), tangential volumetric-modulated arc therapy (t-VAMT), and half-arc VMAT for chest wall and breast radiotherapy in Eclipse planning system, (a) Dose–volume histogram (DVH) for left chest wall, (b) DVH for left breast. PTV: Planning target volume, HA-VMAT: Half-arc VMAT

Table 2: Patient characteristics, histopathology, and prescription dose as a function of number of patients

	Number of patients	Histopathology	50 Gy/25 F	40 Gy/15 F	26 Gy/5 F
Total	300	IDC=221	76	221	3
Left breast	67	ILC=48	23	60	1
Left chest wall	73	Phyllodes=19	18	74	
Right breast	79	Lymphoma=12	20	46	2
Right chest wall	81		15	41	

IDC: Infiltrating ductal carcinoma, ILC: Infiltrating lobular carcinoma

Monaco systems. Subsequently, in 2018, we further adopted t-IMRT on Varian/Eclipse systems. This decision was based on various factors, including the equivalence in solid angles between 3DCRT and VMAT/IMRT. In addition, we considered factors such as optimizing the beam angle, minimizing OAR doses (such as the heart, lung, and contralateral breast), reducing low-dose spillage, and improving treatment time for both the normal and deep inspiration breath hold (DIBH) techniques. The primary reason for t-IMRT adaptation in the Eclipse environment is

Table 3: Dose-volume parameters for breast/chest wall target as a function of direction (left and right) and combined

PTV	Volume (cc)	Maximum dose (%)	Mean dose (%)	Percentage dose received by 95% PTV volume (D95%)	Volume receiving ≥105% dose (V105%) (cc)
Left breast/CW	835.1±487.5	99.5±17.1	101.6±2.3	95.9±1.3	5.1±5.8
Right breast/CW	711.1±553.8	106.5±1.6	100.8±1.4	96.8±0.9	4.7±8.9
Left + right breast/CW	779.6±508.6	102.7±12.9	101.3±1.9	96.3±1.2	4.9±7.0
Supraclavicular node left	31.7±7.2	104.7±1.2	96.4±3.4	84.8±9.9	3.2±7.4
Supraclavicular node _right	26.1±3.9	103.1±3.7	94.3±4.5	82.0±8.1	0.9±1.1
Supraclavicular node_right + left	28.7±6.1	96.7±2.8	92±6.4	83.4±8.3	2.0±5.2

Dose to SCF fossa presented independently as per the institution protocol. SCF: Supraclavicular fossa, PTV: Planning target volume, CW: Chest wall

Table 4: Dose-volume parameters for different organs at risk as a function of direction (left and right) and combined with left and right

OAR	Left breast/CW			Right breast/CW			Right + left breast/CW		
	Volume (cc)	Maximum dose (%)	Mean dose (%)	Volume (cc)	Maximum dose (%)	Mean dose (%)	Volume (cc)	Maximum dose (%)	Mean dose (%)
Esophagus	25.1±2.9	25.1±2.9	9.5±9.9	26.7±6.3	75.3±14.3	4.4±3.2	25.8±3.4	62.1±37.8	7.3±8.0
Heart	573.7±147.1	68.5±37.3	14.6±26.7	567.3±93.8	17.6±11.2	3.8±5.5	571±124.3	47.1±38.6	10.1±20.9
Contralateral breast	873.9±535.1	17.2±28.4	0.9±0.9	697±373.7	27.9±34.0	13.2±35.3	799.4±470.6	21.7±30.5	6.1±23.0
Spinal cord	28.6±12.0	42.4±41.7	10.3±12.6	16.8±2.3	43.5±28.4	2.9±1.0	23.5±10.8	42.9±35.3	7.4±10.3
Lung left (ipsilateral lung)	1017.2±365.3	88.6±29.3	19.4±4.9	875±235.1	4.2±2.7	0.5±0.1	957.3±317.6	53.1±48.1	11.4±10.2
Lung right_left	1258.8±399.6	21.9±28.8	1.6±3.4	1087.4±232.9	98±4.9	20±3.8	1186.6±342.6	53.9±44.3	9.3±9.9
Liver_right				1132.9±200.5	96.8±3.4	8.7±3.0			

CW: Chest wall, OAR: Organ at risk

Table 5: Tangential and supraclavicular fossa monitor unit, low-dose spillage, and beam angels for tangential and supraclavicular fossa beams for the institutional practice

	MU (tangential)	MU (SCF)	50% isodose volume (cc)	20% isodose volume (cc)	Beam angles	Med tan 1 (°)	Med tan 2 (°)	Lat tan 1 (°)	Lat tan 2 (°)	Lat tan 3 (°)	SCF (°)
Left	1302.9±580.2	388.4±349.6	1946.1±767.2	2606.7±945.9	Mean±SD (left)	303.6±3.6	314.4±5.5	126.8±6.0	136.5±6.3	146.5±6.3	341.8±15.5
Right	1254.6±214.7	292.7±129.5	1597.8±449.3	2329.0±524.0	Median (left)	305	315	130	137.5	147.5	346
Right + left	1282.7±453.4	332.6±236.7	1799.5±660.8	2489.8±789.7	Mean±SD (right)	56.5±6.1	45.9±6.5	227.9±9.8	224.8±4.1	219.6±10.1	10.7±3.6
					Median (right)	55	45	230	225	215	10

SCF: Supraclavicular fossa, MU: Monitor unit, SD: Standard deviation

the solid angle equivalence of t-IMRT with the 3DCRT/FiF technique. Other influencing factors were as follows: (1) to achieve a good dose distribution, HA-VMAT is required for Br/CW radiotherapy, which was not adopted based on our previous practice. (2) A review of the literature suggested t-IMRT, FiF, or 3DCRT over HA-VMAT based on the excess secondary cancer risk. (3) t-IMRT dose distribution was superior to t-VMAT [Figure 1a-f and 2], and (4) IMRT generated the flash margin more easily than VMAT.[22] In our clinical practice, it is mandatory to write the tumor's quadrant (a permutation of upper-lower-inner-outer). When the treatment plan is complete, the treatment planner and clinicians double-check that the noted tumor quadrant and surgical clip, if any, are adequately covered. To achieve adequate coverage of the tumor quadrant, treatment plans are modified by changing the beam angle.

Neither in our clinical practice with the Eclipse planning system could we generate the best dose distribution using a short tangential arc (≈30°–40°) VMAT (compared with t-IMRT), nor did an extensive literature review identify a single article that advocated short arc VMAT for the Eclipse/RayStation planning system.[2,3,5-19,23,24] Although it is possible to generate a clinically acceptable dose distribution for Br/CW using t-VMAT in Eclipse TPS, as shown in Figure 1, the t-IMRT dose distribution is always superior, as shown in the DVH comparison [Figure 2]. Furthermore, IMRT takes less time to optimize than VMAT. More importantly, in IMRT, generating the flash margin is very simple, whereas in VMAT, it requires the addition of an additional virtual target volume.[22] It is difficult for us to burden the treatment planner with additional contouring to generate the flash margin in a tertiary cancer care hospital with high patient footfall. If breast cancer cases are excluded, we have a 95% VMAT compliance rate for any other planning, including palliative treatments.

Secondary cancer risk assessment analysis between different techniques, as a function of the planning system's majority contribution from the Eclipse planning system, allowed us to identify a single study in Monaco and none for other planning systems.[17] All articles categorically discourage half arc (180°) or excesses of half arc (≥210°) VMAT. Three of the four secondary cancer risk assessment articles used Schneider's concept of organ equivalent dose based on the LQ model, while the fourth, Lee *et al*., used BEIR VII models.[1,17-19,25] All of these secondary cancer risk assessment techniques are based on the LQ model and differ only slightly from one another.[26] Although the relative risk of secondary cancer is very high (34%–50%) for multi beam IMRT spread over >180 degree arc angle, HA-VMAT or LA-VMAT, the absolute risk is low. As a result, the large relative differences obtained have a low absolute risk.[17] Although the absolute risk of secondary cancer is low, if m-IMRT or large-angle VMAT is used in regular clinical practice, it might lead to an elevated risk of second cancer for young adult breast cancer patients, for whom the life expectancy is relatively higher.[27]

Adaptation of the large arc angle indicates an increase in the total solid angle at the target center, thereby affecting the low-dose region. This adaptation is not limited to Br radiotherapy alone but is also observed in VMAT-based craniospinal irradiation (CSI) in the Eclipse environment.[28] When transitioning from 3DCRT to VMAT in CSI planning, planners and investigators have utilized a 360° arc to replace a single direct 3DCRT field for the spinal target volume. While it is possible to achieve equivalent target coverage and reduce doses to OARs and spillage using shorter arcs (approximately 140° for Eclipse/100° for Monaco), this is not a common clinical practice as reflected in the published literature.[29]

Before implementing any new technique like VMAT in clinical practice, it is important for end-users to respect the techniques that have been practiced for many years. For breast/CW irradiation, the long-standing technique is 3DCRT/FiF and it is still more commonly used than IMRT/VMAT.[1] Various characteristics of the technique, such as beam angles, total solid angle generated at the target center, typical dose distribution, low-dose falloff, and MUs, should be considered. Just adopting HA-VMAT or multiple-field IMRT for better conformity cannot be done without considering other factors and their clinical consequences, such as the low-dose region that directly contributes to pneumonitis as an immediate effect, and the long-term risk of ischemic heart disease.[30-32] Therefore, it is crucial to remain as close as possible to 3D-CRT, especially in the case of Br/CW radiotherapy, which is not difficult after discontinuing prophylactic irradiation of the IMC.

The Eclipse planning system is one of the most widely used planning systems worldwide, with Varian holding over half of the radiotherapy linear accelerator market share. Although the Eclipse planning system is highly efficient, certain adaptations from 3DCRT to VMAT have not followed the general principle of solid angle equivalence between the techniques. CSI and Br/CW radiotherapy are two common examples. Even though the Eclipse planning system can produce a better dose distribution with a 3DCRT-equivalent (or slightly increased) solid angle, this has not been thoroughly explored by investigators.[33] Whatever has been presented by one or two early investigators has been followed by others after a decade of practice (Popescu *et al.* Racka *et al*., 2022,[1] for breast radiotherapy and Foglieta *et al*. for CSI).[1,3,28] It is important to rationalize the total solid angle and not accept abrupt changes solely because they offer improved dose conformity.

Conclusion

Based on the literature search and institutional practice, we recommend the following techniques for breast and chest wall radiotherapy for different commercially available treatment planning systems.

- Eclipse: t-IMRT (5 Fields) with two medial tangential fields (separated not more than 15°, preferably around 10°) and three lateral tangential fields (separated not more than 30°, preferably around 20°). For patients with a very thin chest wall and large breast, one medial beam may be added if the dose distribution is unsatisfactory. A 2 cm flash margin should be applied using fluence painting for each field. Supracalvicular area can be treated with single direct field with no intensity modulation.
- Monaco: Adopted from Munshi *et al*.: t-VMAT using double arcs medially and tangentially at approximately of 30° arc length. No other technique is recommended. The flash margin is set automatically.[14] For supraclavicular, same strategy as that of Eclipse planning system can be adapted.
- Pinnacle and RayStation: Limited studies on these planning systems suggest the superiority of t-IMRT over other techniques.
- General recommendation: Techniques involving large arc VMAT (≥180°) or multiple fields (>5) in IMRT, or 5-beam IMRT spread over 180° (Eclipse), are strongly discouraged.[5] When using the intensity-modulated technique, planners should ensure solid angle equivalence between 3DCRT and FiF.

Search Mesh in PubMed

[((“breast”[MeSH Terms] OR “breast”[All Fields]) AND (“radiotherapy”[Subheading] OR “radiotherapy”[All Fields] OR “radiotherapy”[MeSH Terms]) AND dosimetric[All Fields] AND comparison[All Fields] AND (“radiotherapy, intensity-modulated”[MeSH Terms] OR (“radiotherapy”[All Fields] AND “intensity-modulated”[All Fields]) OR “intensity-modulated radiotherapy”[All Fields] OR “vmat”[All Fields]) AND imrt[All Fields]) AND (“2010/01/01”[PubDate]: “2022/12/31”[PubDate]).

Acknowledgment

We would like to thank Apollo Multispeciality Hospital, Kolkata, India: Sandipan Ray Chaowdhary, Sourav Mondal, and Prasenjit Soren.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Racka I, Majewska K, Winiecki J. Three-dimensional conformal radiotherapy (3D-CRT) versus volumetric modulated arc therapy (VMAT) in deep inspiration breath-hold (DIBH) technique in left-sided breast cancer patients-comparative analysis of dose distribution and estimation of projected secondary cancer risk. Strahlenther Onkol 2023;199:90-101.
2. Popescu CC, Olivotto IA, Beckham WA, Ansbacher W, Zavgorodni S, Shaffer R, *et al*. Volumetric modulated arc therapy improves dosimetry and reduces treatment time compared to conventional intensity-modulated radiotherapy for locoregional radiotherapy of left-sided breast cancer and internal mammary nodes. Int J Radiat Oncol Biol Phys 2010;76:287-95.
3. Nicolini G, Fogliata A, Clivio A, Vanetti E, Cozzi L. Planning strategies in volumetric modulated arc therapy for breast. Med Phys 2011;38:4025-31.
4. Beckham WA, Popescu CC, Patenaude VV, Wai ES, Olivotto IA. Is multibeam IMRT better than standard treatment for patients with left-sided breast cancer? Int J Radiat Oncol Biol Phys 2007;69:918-24.
5. Badakhshi H, Kaul D, Nadobny J, Wille B, Sehouli J, Budach V. Image-guided volumetric modulated arc therapy for breast cancer: a feasibility study and plan comparison with three-dimensional conformal and intensity-modulated radiotherapy. The British journal of radiology. 2013;86:20130515.
6. Yu J, Hu T, Chen Y. Small-arc volumetric-modulated arc therapy: A new approach that is superior to fixed-field IMRT in optimizing dosimetric and treatment-relevant parameters for patients undergoing whole-breast irradiation following breast-conserving surgery. Medicine (Baltimore) 2016;95:e4609.
7. Zhao H, He M, Cheng G, Han D, Wu N, Shi D, *et al*. A comparative dosimetric study of left sided breast cancer after breast-conserving surgery treated with VMAT and IMRT. Radiat Oncol 2015;10:231.
8. Virén T, Heikkilä J, Myllyoja K, Koskela K, Lahtinen T, Seppälä J. Tangential volumetric modulated arc therapy technique for left-sided breast cancer radiotherapy. Radiat Oncol 2015;10:79.
9. Boman E, Rossi M, Haltamo M, Skyttä T, Kapanen M. A new split arc VMAT technique for lymph node positive breast cancer. Physica Medica. 2016;32:1428-36.
10. Jensen CA, Roa AM, Johansen M, Lund JÅ, Frengen J. Robustness of VMAT and 3DCRT plans toward setup errors in radiation therapy of locally advanced left-sided breast cancer with DIBH. Phys Med 2018;45:12-8.
11. Jensen CA, Abramova T, Frengen J, Lund JÅ. Monitoring deep inspiration breath hold for left-sided localized breast cancer radiotherapy with an in-house developed laser distance meter system. J Appl Clin Med Phys 2017;18:117-23.
12. Tyran M, Tallet A, Resbeut M, Ferre M, Favrel V, Fau P, *et al*. Safety and benefit of using a virtual bolus during treatment planning for breast cancer treated with arc therapy. J Appl Clin Med Phys 2018;19:463-72.
13. Rossi M, Boman E, Skyttä T, Haltamo M, Laaksomaa M, Kapanen M. Dosimetric effects of anatomical deformations and positioning errors in VMAT breast radiotherapy. J Appl Clin Med Phys 2018;19:506-16.
14. Munshi A, Sarkar B, Anbazhagan S, Giri UK, Kaur H, Jassal K, *et al*. Short tangential arcs in VMAT based breast and chest wall radiotherapy lead to conformity of the breast dose with lesser cardiac and lung doses: A prospective study of breast conservation and mastectomy patients. Australas Phys Eng Sci Med 2017;40:729-36.
15. Giri UK, Sarkar B, Jassal K, Munshi A, Ganesh T, Mohanti B, *et al*. Left-sided breast radiotherapy after conservative surgery: Comparison of techniques between volumetric modulated arc therapy, forward-planning intensity-modulated radiotherapy and conventional technique. J Radiother Pract 2017;16:101-8.
16. Byrne M, Archibald-Heeren B, Hu Y, Fong A, Chong L, Teh A. Comparison of semiautomated tangential VMAT with 3DCRT for breast or chest wall and regional nodes. J Appl Clin Med Phys 2018;19:684-93.
17. 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. Radiother Oncol 2014;110:471-6.
18. Lee B, Lee S, Sung J, Yoon M. Radiotherapy-induced secondary cancer risk for breast cancer: 3D conformal therapy versus IMRT versus VMAT. J Radiol Prot 2014;34:325-31.
19. Haciislamoglu E, Cinar Y, Gurcan F, Canyilmaz E, Gungor G, Yoney A. Secondary cancer risk after whole-breast radiation therapy: field-in-field versus intensity modulated radiation therapy versus volumetric modulated arc therapy. The British journal of radiology. 2019;92(1102):20190317.
20. Karpf D, Sakka M, Metzger M, Grabenbauer GG. Left breast irradiation with tangential intensity modulated radiotherapy (t-IMRT) versus tangential volumetric modulated arc therapy (t-VMAT): Trade-offs between secondary cancer induction risk and optimal target coverage. Radiat Oncol 2019;14:156.
21. Donovan EM, Yarnold JR, Adams EJ, Morgan A, Warrington AP, Evans PM. An investigation into methods of IMRT planning applied to breast radiotherapy. Br J Radiol 2008;81:311-22.
22. Sarkar B, Ganesh T, Munshi A, Bansal K, Rastogi K, Tiwari S, *et al.* In regards to Bogue J, Wan J, Lavey RS, Parsai EI. Dosimetric comparison of VMAT with integrated skin flash to 3D field-in-field tangents for left breast irradiation. Journal of applied clinical medical physics. 2019 Feb; 20(2):24-9. J Appl Clin Med Phys 2019;20:202-3.
23. Munshi A, Sarkar B, Roy S, Ganesh T, Mohanti BK. PV-0135: Short tangential arcs in VMAT based breast and chest wall radiotherapy planning. Radiother Oncol 2017;123:S64.
24. Schneider U. Mechanistic model of radiation-induced cancer after fractionated radiotherapy using the linear-quadratic formula. Med Phys 2009;36:1138-43.
25. Donovan EM, James H, Bonora M, Yarnold JR, Evans PM. Second cancer incidence risk estimates using BEIR VII models for standard and complex external beam radiotherapy for early breast cancer. Med Phys 2012;39:5814-24.
26. Kutcher GJ, Burman C. Calculation of complication probability factors for non-uniform normal tissue irradiation: The effective volume method. Int J Radiat Oncol Biol Phys 1989;16:1623-30.
27. Miller KD, Fidler-Benaoudia M, Keegan TH, Hipp HS, Jemal A, Siegel RL. Cancer statistics for adolescents and young adults, 2020. CA Cancer J Clin 2020;70:443-59.
28. Fogliata A, Bergström S, Cafaro I, Clivio A, Cozzi L, Dipasquale G, Hållström P, Mancosu P, Navarria P, Nicolini G, Parietti E. Cranio-spinal irradiation with volumetric modulated arc therapy: a multi-institutional treatment experience. Radiotherapy and Oncology. 2011;99:79-85.
29. Sarkar B, Munshi A, Ganesh T, Manikandan A, Mohanti BK. Dosimetric comparison of short and full arc in spinal PTV in volumetric-modulated arc therapy-based craniospinal irradiation. Med Dosim 2020;45:1-6.
30. Cottin V, Frognier R, Monnot H, Levy A, DeVuyst P, Cordier JF, *et al*. Chronic eosinophilic pneumonia after radiation therapy for breast cancer. Eur Respir J 2004;23:9-13.
31. Darby SC, Ewertz M, McGale P, Bennet AM, Blom-Goldman U, Brønnum D, *et al*. Risk of ischemic heart disease in women after radiotherapy for breast cancer. N Engl J Med 2013;368:987-98.
32. Sarkar B. An incorrect impression of dose versus the ischemic cardiac toxicity risk profile for breast and chest wall radiation therapy. Int J Radiat Oncol Biol Phys 2020;106:451-2.
33. Sarkar B, Biswal SS, Shahid T, Ghosh T, Bhattacharya J, De A, *et al*. Comparative dosimetric analysis of volumetric modulated arc therapy based craniospinal irradiation plans between halcyon ring gantry and TrueBeam C-arm linear accelerator. Sci Rep 2023;13:3430.
34. Jin GH, Chen LX, Deng XW, Liu XW, Huang Y, Huang XB. A comparative dosimetric study for treating left-sided breast cancer for small breast size using five different radiotherapy techniques: conventional tangential field, filed-in-filed, tangential-IMRT, multi-beam IMRT and VMAT. Radiation oncology. 2013;8:1-8.