Advances in Radiation Oncology (2024) 9, 101476

advances in radiation oncology

www.advancesradonc.org

Critical Review

Master Breast Radiation Planning: Simple Guide for Radiation Oncology Residents

Mona Arbab, MD, MEd,* Romona Frame, MS, Prasanna Alluri, MD, PhD, David Parsons, PhD, Mu-Han Lin, PhD, Jennifer Cleaton, MS, and Asal Rahimi, MD

Department of Radiation Oncology, UT Southwestern Medical Center, Dallas, Texas

Received 16 July 2023; accepted 4 February 2024

Abstract

This article focuses on various aspects of breast radiation treatment planning, from simulation to field design. It covers the most common techniques including tangents, mono isocentric, dual isocentric, electron-photon match, and VMAT. This can serve as a guide for radiation oncology residents and medical students to advance their understanding of key aspects of breast radiation treatment and planning processes.

Introduction

This article focuses on various aspects of breast radiation treatment planning, from simulation to field design. This can serve as a guide for radiation oncology residents and medical students to advance their understanding of key aspects of breast radiation treatment and planning processes. It is important to know that radiation techniques can vary between institutions. Therefore, checking with your program for specific details and your institute's guidelines is recommended.

Computed tomography (CT) simulation

The first step in radiation planning is simulating the patient in the treatment position. It is important to wire the scar and breast borders with radiopaque wires. The superior border is the inferior part of the clavicular head. The inferior border is 2 cm below the inframammary fold. The medial and lateral borders are the midsternum and midaxillary lines. In a patient with unilateral mastectomy, the inferior border is determined based on the position of the contralateral breast. In the case of bilateral mastectomies, the inferior border is determined based on the impression of the tissue expander or implant, which is usually around the seventh rib.

Patients can be simulated in either a supine or prone position depending on body habitus and planning goals.

Supine

The patient is placed in a supine position with arms abducted and externally rotated. The head is turned to the contralateral side. A breast board (5-15 degrees) is used for immobilization. Knee support can also be used to provide a more comfortable position for the patient and prevent them from sliding down the board. An upper vacuum bag is used in certain cases in patients with a limited range of motion in the ipsilateral arm. CT simulation can be done using free breathing (FB) or deep inspiration breath hold (DIBH) techniques.

Sources of support: None

*Corresponding author: Mona Arbab, MD, MEd; Email: Mona.Arbab@utsouthwestern.edu

https://doi.org/10.1016/j.adro.2024.101476

Prone

The patient is placed in a prone position with ipsilateral arm or both arms above the head using a prone breast board with the head turned away from the treatment side. This position helps move the breast away from the chest wall. This is an ideal setup for patients with large and pendulous breasts. The contralateral breast should be moved laterally and away from the treatment area.[1] In certain cases, the patient must be resimulated in supine position. In general, if the axilla must be covered with high tangents or if a supraclavicular field is needed, prone breast radiation may not be the best technique, although some experienced centers have done this successfully.[1,2]

Deep inspiration breath hold techniques

At our institution, we use DIBH for left-sided treatments to achieve superior cardiac sparing. We currently use VisionRT,[3] a surface-guided radiation therapy technique, which uses infrared mapping of the external surface of the patient's body surface in the treatment area. Coordinates in superior, inferior, anterior, posterior, medial, lateral, pitch, yaw, and roll are established in the treatment position. We set a 3 mm threshold in each direction (and determine the degree of yaw and roll), and therapists use that as guidance to maintain the same external position during DIBH at the time of treatment. Depending on the machine, the beam can be turned off automatically in the case of being outside the prespecified parameters, rather than manually by the therapist. Other available techniques include the spirometry-based active breathing coordinator (ABC) and video-based real-time position management (RPM) systems.[4] ABC is a mouthpiece attached to a spirometer, and when the patient reaches the threshold for inspiration, the spirometer valves close, preventing more inhalation or exhalation by the patient. RPM uses a marker box with reflective dots on the patient's xiphoid process or umbilicus; an infrared camera mounted on the wall detects the marker box and calculates the position and movement of the thorax. Both techniques allow for control of the degree of breath hold.

In patients with left sided breast cancer, who are not able to do the breath hold, heart blocks using multileaf collimators (MLCs) can be used to reduce the dose to the heart. It is important to remember that these blocks can cause a reduction in dose to the medial and lateral portions of the breast. Therefore, it is important to ensure adequate coverage of the breast and minimize blockage of the tumor bed. In certain cases, an electron field can help cover the medial portion of the breast.[5]

How to place the isocenter

For breast-only treatments with tangential fields in the supine position, the isocenter is placed halfway between the superior and inferior border of the breast, and in the middle of a line drawn between the medial and lateral borders of the breast.

For prone position, marks are drawn on the patient's back around the spine and close to the midplane. This helps with setup reproducibility and leveling. The isocenter is placed similarly to that used in the supine position, halfway between the superior and inferior portion of the breast and in the middle of the line drawn between the medial and lateral borders. However, it is adjusted anteriorly, to overcome jaw limits, and medially, to overcome beam angle clearance. The sagittal laser position and the intersection of the lateral room lasers with the longitudinal scale on the breast board are used to set up the patient (Fig. 1). Different techniques are used to solve clearance

Figure 1 Isocenter (yellow) in prone setup.

issues in the prone position. One technique is to use a source to skin distance of 100 cm to provide sufficient clearance. However, this can increase setup time.[6]

For breast/chest wall treatments that include regional lymph nodes, including supraclavicular (SCLV), axillary, and internal mammary nodes (IMN), the isocenter is placed 2 cm below the inferior aspect of the humeral head, midway between the medial and lateral borders of the breast/chest wall and within 24 cm from the top of the couch to allow for any posterior beam clearance. This tends to be approximately around the clavicular head. The isocenter is placed at the bottom of the clavicular head for the mono-isocentric technique.

It is important to remember that reference points are needed to align patients for daily setup. The internal reference point is located inside the body and used for beam setup on the simulator. The external reference points are visible on the surface of the body and the fixation devices.[7]

Breast Tangents

Medial and lateral tangents should encompass the breast. This beam arrangement is known as posterior nondivergent beam. The posterior edges of both beams are nondiverging and match each other (Fig. 2). This prevents divergence of the beam into the lung. This is achieved by rotating the gantry such that the edges are along the same plane while ensuring that the contralateral breast is not in the field.

The collimator is rotated to decrease the amount of lung in the field to around 2 cm. The anterior portion of the beam is opened around 2 cm (skin flash) to account for setup uncertainty, possible breathing motion, and possible swelling of the breast during radiation treatments.

To ensure homogeneity of the dose, dosimetrists use various approaches, including dynamic wedges, electronic tissue compensators with dynamic multileaf collimator (MLC) delivery, or a field-in-field technique.

MLCs are adjusted to reduce the dose to the heart and lungs. However, the MLCs should not block the area of the lumpectomy bed or the scar.

In cases with pN1mic, modified tangents including level I-II lymph nodes are used.[8] These are known as high tangents because the superior border of the field covers up to the humeral head to provide adequate coverage to level I-II lymph nodes.

Tumor bed boost

A margin of 1.5-2 cm around the lumpectomy bed is needed in patients with clear microscopic margins to design the tumor bed boost.[9] Coronal en-face electrons, 6-12 MeV, are commonly used to boost the tumor bed. The most common prescription isodose line is 90% to 95%.[10] The major benefits of electron boosts are the minimal dose to underlying structures and the defining field on skin. However, electrons have limited use in large breasts, deep tumors, or tumors located in regions with sudden depth change such as inframammary or axillary folds. In these cases, different positioning such as a decubitus position might reduce the maximum distance of the tumor bed to the skin and lower maximal dose to the target volume.[11] Additionally, photon boosts are used. There are different techniques including mini tangents, the 3-field technique, and reduced tangents with conformal arc.[12] The 3-field technique reduces the integral dose to the uninvolved breast. The addition of arc can also increase conformity. However, it can

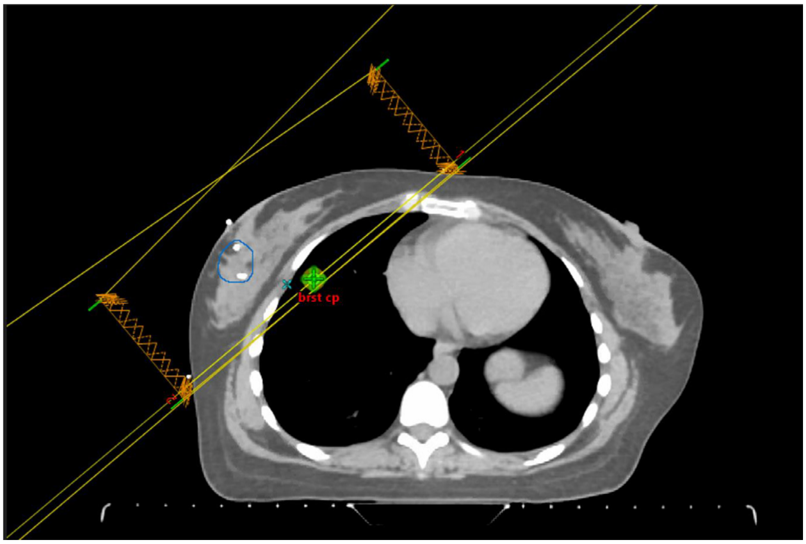

Figure 2 Non-divergent tangential beams in the supine setup.

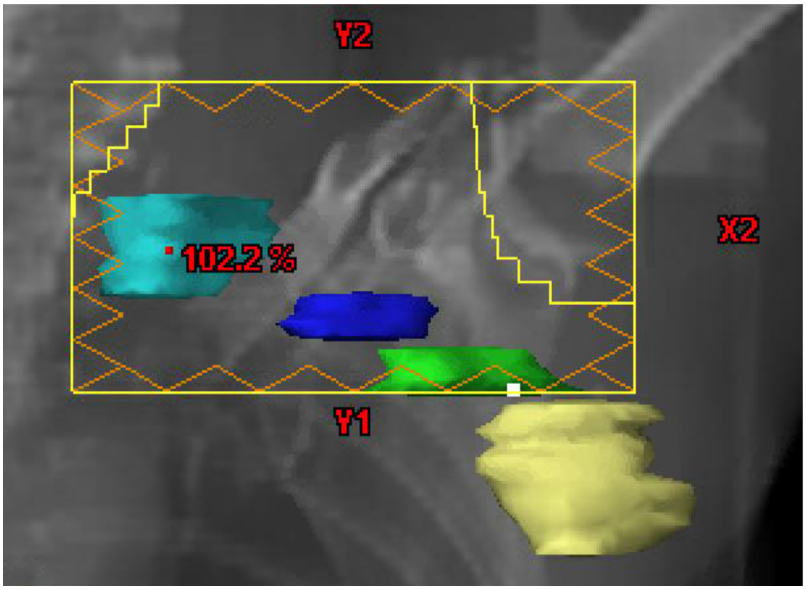

Figure 3 Supraclavicular field in the monoisocentric technique. SCLV lymph nodes (cyan), axillary level III (blue), and axillary level II (green) are covered by the SCLV field. The pedicles and humeral head are blocked by the MLCs.

increase the maximal dose to critical structures including the heart.[12]

3-field mono-isocentric technique

This technique is used when regional lymph nodes including SCLV and axillary nodes are treated in addition to the chest wall/breast. The isocenter is placed as discussed earlier. The supraclavicular field is half beam blocked inferiorly, and the tangents are half beam blocked superiorly. This prevents divergence of both fields and hot spots in the areas of overlap.

The tangents are placed as described earlier. However, because this is a mono-isocentric technique, no collimator rotation is needed.

The supraclavicular gantry is rotated approximately 10-15° away from the spine. The MLCs are appropriately positioned to block the humeral head laterally and the pedicles medially. In certain cases where there is concern about axillary nodal coverage, the humeral head might not be blocked completely per the radiation oncologist's decision. The superior border of the field is set around the level of the cricoid, and the lateral border is placed lateral to the humeral head if the axillary nodes must be treated. It has been shown that if dissected level I and II lymph nodes are excluded from the radiation field by placing the lateral border of the field along the medial aspect of the humeral head, there will be less lymphedema (Fig. 3).[13] However, this technique cannot be used if there is a high burden of disease in the axilla, for example, in cases with more than 3 positive nodes and nodal metastasis ≥2 cm.

Posterior axillary boost (PAB)

In cases where adequate axillary coverage is not achieved with the approach outlined above, a posterior axillary boost (PAB) field can be used (10-20 cGy per day) to supplement the SCLV field. This field is designed by opposing the SCLV field and blocking the lung, humeral head, and the area above the clavicle (Fig. 4).

Historically, SCLV fields were used to treat to 3 cm depth. However, lateral level I and II lymph nodes have a deeper location. Therefore, PAB was used to supplement the dose to this region in the pre-CT-based planning era.[14] This technique might result in higher rates of lymphedema. As a result, with advances in technology, we can provide better coverage of nodes by using different beam weighting techniques, multiple energies, and even intensity modulation.

Dual isocentric technique

There are 2 major indications for a dual isocentric technique. The first one is for patients with a long torso, where the tangents do not cover the whole region of interest (more than 20 cm, which is the jaw limit). The second one is in cases where the ipsilateral lung dose exceeds tolerance. In such a case, a dual isocentric technique allows the dosimetrists to reduce the lung dose in the supraclavicular field. Therefore, a second isocenter center is placed 3-5 cm below the SCLV isocenter.

It is important to remember that this technique results in divergence of the tangents to the SCLV field. To overcome this limitation, a couch kick away from the gantry is employed to eliminate divergence of the superior

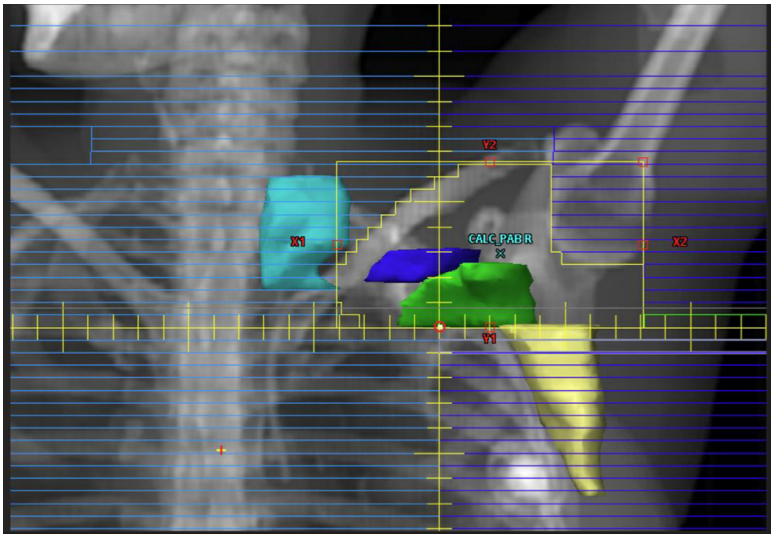

Figure 4 PAB field with blocks for the lung, humeral head, and above the clavicle.

tangential field into the SCLV field. In this technique, there is also a collimator rotation for the tangents (Fig. 5). The amount of rotation for the couch and collimator can be calculated using the following formulas:

$\text{Couch} : \text{Arc tan} = \text{Y}/\text{SAD};$

$\text{Collimator} : \text{Arc tan} = \text{Y}/\text{SSD};$

$\text{Y is } 1/2 \text{ length of the tangent.}$

$\text{SAD} = \text{Source Axis Distance;}$

$\text{SSD} = \text{Source to Skin Distance.}$

In clinic, sometimes the mono-isocentric technique is used instead of the dual isocentric technique.[15] To overcome the field size limitation, the isocenter is shifted below the match line of tangents and SCLV by 2-3 cm with minimal divergence of the jaws at the match line.

Covering internal mammary nodes (IMNs)

Common techniques for covering IMNs include partially wide tangents, electron/photon match, and intensity modulated radiation therapy (IMRT).

Partially wide tangents are used to cover the first 3 intercostal spaces where the IMNs are located. The gantries are rotated to cover the intercostal spaces, and this will include part of the contralateral side. Below the IMNs, the remaining heart and lung are blocked by the MLCs (Fig. 6)

In the electron/photon match technique, a shallow medial tangent is placed roughly 5 cm from the sternum into the ipsilateral chest, and the electron field is created with the same superior and inferior border as the tangent to cover the IMN. The field borders may vary based on the location of the heart borders or the presurgical tumor location. The medial border will go at least 2-4 cm into the contralateral chest from midsternum to ensure proper IMN coverage. There will be gantry rotation, and the electron gantry rotation is usually 5° less compared with the tangent to minimize hot and cold spots. The lateral border will be matched on the skin with the medial border of the tangential field (Fig. 7).

The electron field can be divided into 2 fields with different energy levels corresponding to the depth difference around IMNs and the chest wall. The superior part is covered by higher energy electrons, and the lower part is covered with a lower energy to minimize heart dose (Fig. 8).

Because of the possibility of cold and hot spots in the electron/photon match area, feathering can be used. Every 5 days, the field is moved approximately 1 cm so that cold and hotspots will not occur in the same area. This is more of a concern if using a breath hold technique, as normal respiration allows for auto-feathering.

IMRT is another technique that is used in patients with unfavorable anatomy when constraints cannot be met using 3D techniques. IMRT also has the benefit of reducing the acute toxicities of radiation treatment including moist desquamation and moderate-severe pain.[16] IMRT plans can be forward planned (FP-IMRT) or inverse planned (IP-IMRT). FP-IMRT uses open 6 and 15 MV fields normalized to a weight point. IP-IMRT uses a basic template and optimizes beams and completes segmentation of the beams to provide adequate coverage of the targets.[17] Different IMRT techniques have been described in literature including hybrid IMRT (2 tangential open fields and 4 sequentially optimized IMRT fields), full IMRT (7 coplanar sliding-window IMRT fields with gantry angles 140-300°), 2 arc VMAT (volumetric modulated arc therapy) (2 partial arcs with gantry angles 160-290-305°), and 6 arc VMAT (6 short partial arcs, irradiating between

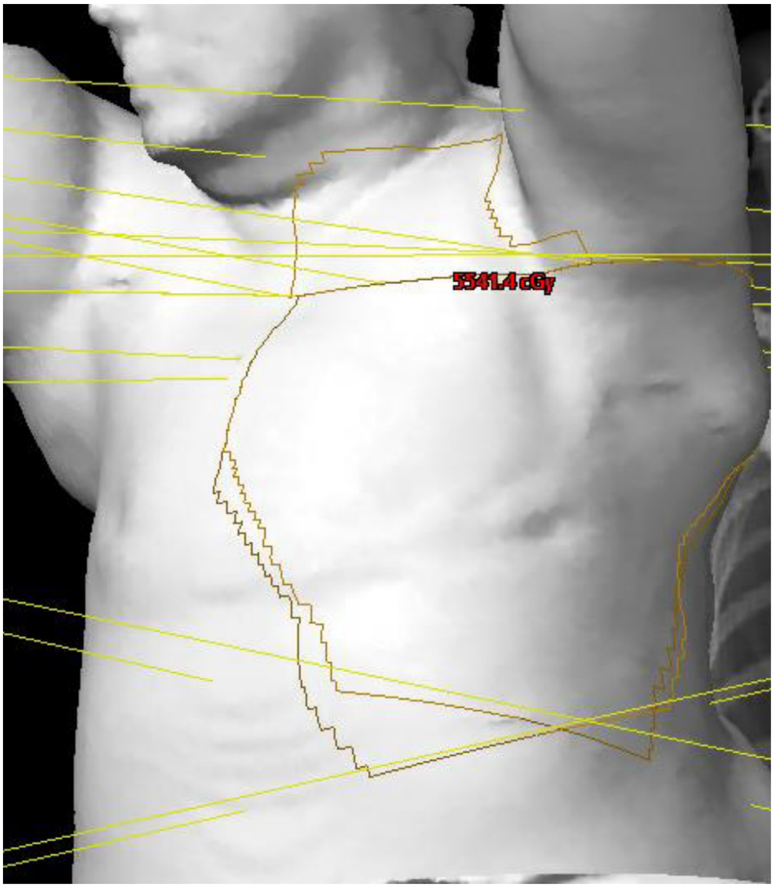

Figure 5 Dual isocentric technique. There is no overlap between the SCLV and tangents as there has been gantry, couch, and collimator rotation for the tangents in addition to gantry rotation for the SCLV field.

gantry angles 305-355, 355-45, 80-130, 130-80, 80-30, and 355-305°).[18]

There have been dosimetric studies comparing these techniques together.[19,20] VMAT can improve PTV coverage and dose homogeneity in addition to a possible decrease of dose to the left coronary artery compared with isocentric techniques. However, this can lead to an increase in low dose exposure, which might possibly increase secondary malignancies.[20] Another retrospective study has shown a decrease in acute toxicity (moderate-

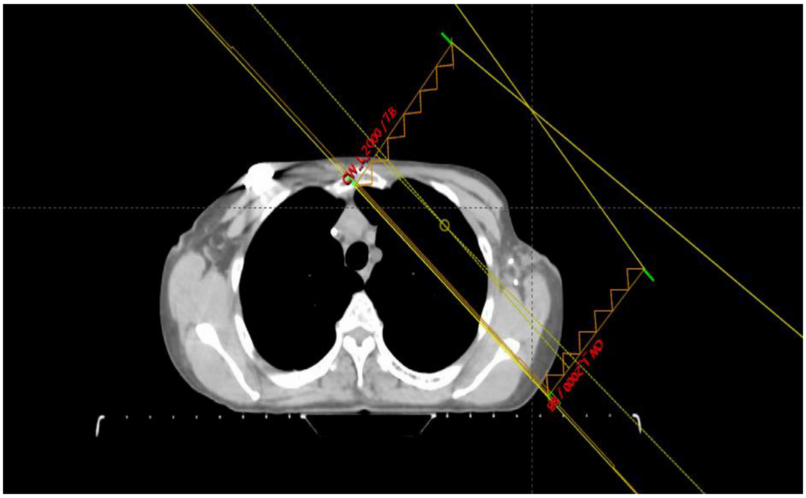

Figure 6 Partially wide tangents for IMN coverage.

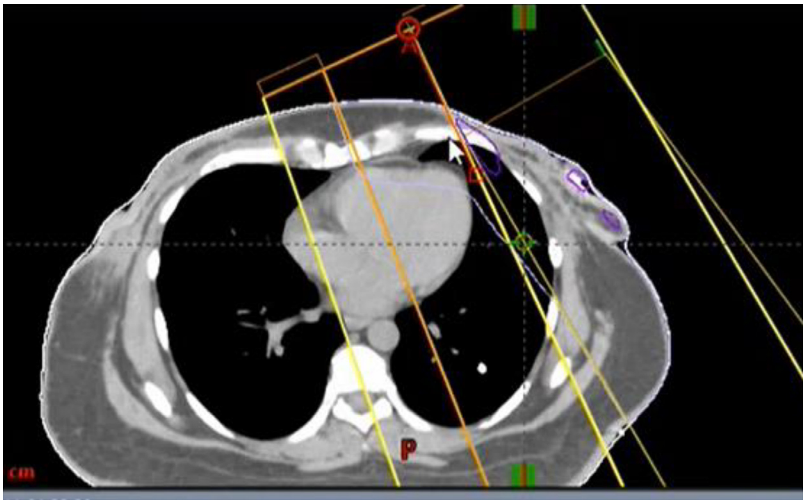

Figure 7 Electron/photon match.

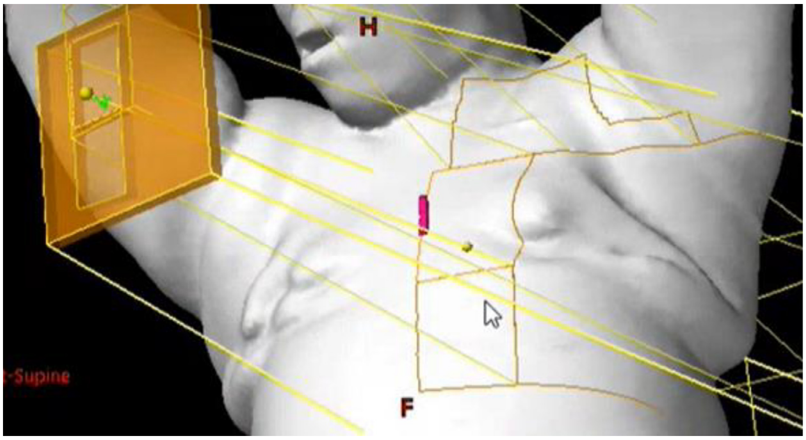

Figure 8 Electron/photon match at skin. The electron field is divided into two fields with different energies.

severe pain and moist desquamation) in patients treated with IMRT compared with patients receiving the 3D technique.[16] In a study by Jalbout et al,[21] the electron-photon match was compared with wide tangents. The wide tangent technique resulted in better dose homogeneity and lower dose to the left anterior descending coronary artery (LAD) if the LAD was located outside the wide tangents. However, this technique resulted in higher contralateral breast dose and also increased LAD dose if LAD was inside the wide tangents.

Bolus use in chest wall irradiation

Bolus is a tissue equivalent material that is used to overcome the skin-sparing effects of radiation. Per Delphi study and international consensus,[22] bolus use is recommended in postmastectomy cases with skin involvement, inflammatory breast cancer, positive anterior margin without removal of overlying skin, chest wall recurrences, and fungating or inoperable breast masses. A randomized trial compared the use of different bolus regimens based on skin involvement.[23] The group without skin involvement was randomized to no bolus or 5 mm bolus every other day, and the group with skin involvement was randomized to 5 mm bolus daily versus every other day. This study did not show a significant difference in 5-year local control between bolus regimens. However, daily bolus increased the risk of grade 2 and 3 radiodermatitis.

Partial breast irradiation (PBI)

Different radiation techniques can be used for PBI. One of the most common techniques was described in the Florence trial.[24] In this technique, a 5 6-MV step-and-shoot IMRT coplanar field was used. However, to reduce treatment delivery time and improve dose distributions, partial arc VMAT was used. The start and stop of the gantry was adjusted for each patient to spare the heart and lung. 3D conformal techniques can also be used. Noncoplanar 3, 4, or 5-field beams with mixed photon energy can be used. Field arrangements are similar to breast tangents with steeper medial angles to spare more of the breast tissue in addition to couch kicks.[25]

Proton therapy for breast cancer

The use of proton therapy has been increasing in breast cancer treatment due to an increase in access in addition to possible benefits in tumor coverage and reducing late toxicities due to the Bragg Peak. This can be beneficial, especially in bilateral breast cancer and reirradiation cases.[26] Target localization is very important in proton treatment as the areas outside the target may receive minimal radiation. For example, the posterolateral supraclavicular fossa (posterior triangle) can be contoured per the RADCOMP consortium to provide adequate coverage.[27]

Inter and intrafraction setup errors can affect target coverage. Therefore, changes in breast/chest wall shape due to inflammation or seroma should be accounted for. The Mayo Clinic considers setup uncertainty simulating worst-case scenarios of 5-mm shifts in isocenter along each translation axis and a 3% beam range uncertainty for the clinical target volume (CTV) and Organs at Risk (OARs). In addition, after each verification CT scan, the proton plan is cast onto this CT scan to ensure adequate coverage. Two multifield optimized antero-oblique beams arranged at 45°are usually used in these cases.[28] At Massachusetts General Hospital, 3.5% is added to the beam range to avoid under shootings. Patients with implants require additional measurements to ensure adequate coverage and skin dose calculation.[29]

Reirradiation for breast cancer recurrences or new primaries

There are different reirradiation techniques for patients who develop breast cancer after previous radiation of the breast. RTOG 1014 included patients who had undergone breast conserving surgery followed by whole breast irradiation with a breast cancer recurrence a year after initial treatment.[30] These patients were treated using 45 Gy delivered in 1.5 Gy fractions twice a day using the 3D technique. The lumpectomy cavity was delineated, and 15 mm uniformal expansion, excluding chest wall structures, pectoralis muscles, and 5 mm from the skin formed the CTV. PTV was generated by 10 mm expansion of the CTV. Several institutes use other PBI regimens including 45 Gy in 15 fractions daily and 30 Gy in 5 fractions.[31] Balloon brachytherapy or intraoperative radiation therapy (IORT) are among acceptable regimens.[32]

In patients who undergo mastectomy after breast cancer recurrence, reirradiation to the chest wall and nodes can be done. It is important to evaluate the dose to OARs to minimize toxicities.[33] In addition, other techniques including hyperthermia[34] or proton treatment[35] can be used.

Conclusion

This article summarizes current techniques used in radiation treatment planning and can serve as a guide to help learners.

Disclosures

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Shin SM, No HS, Vega RM, et al. Breast, chest wall, and nodal irradiation with prone set-up: Results of a hypofractionated trial with a median follow-up of 35 months. *Pract Radiat Oncol*. 2016;6:e81-e88.
2. Sethi RA, No HS, Jozsef G, et al. Comparison of three-dimensional versus intensity-modulated radiotherapy techniques to treat breast and axillary level III and supraclavicular nodes in a prone versus supine position. *Radiother Oncol*. 2012;102:74-81.
3. *Vision RT's Breast*, *Deep*. Inspiration Deep Hold (BDIDH); https://www.visionrt.com/applications/dibh/.
4. Latty D, Stuart KE, Wang W, et al. Review of deep inspiration breath-hold techniques for the treatment of breast cancer. *J Med Radiat Sci*. 2015;62:74-81.
5. Kang HJ, Kim SW, Son SH. The feasibility of a heart block with an electron compensation as an alternative whole breast radiotherapy technique in patients with underlying cardiac or pulmonary disease. *PLoS One*. 2017;12: e0184137.
6. Lakosi F, Gulyban A, Ben-Mustapha Simoni S, et al. Feasibility evaluation of prone breast irradiation with the Sagittilt© system including residual-intrafractional error assessment. *Cancer Radiother*. 2016;20:776-782.
7. Aaltonen P. *Definition of treatment geometry in radiation therapy*. IAEA; 1996.
8. Gebhardt BJ, Thomas J, Horne ZD, et al. Standardization of nodal radiation therapy through changes to a breast cancer clinical pathway throughout a large, integrated cancer center network. *Pract Radiat Oncol*. 2018;8:4-12.
9. Harrington KJ, Harrison M, Bayle P, et al. Surgical clips in planning the electron boost in breast cancer: a qualitative and quantitative evaluation. *Int J Radiat Oncol Biol Phys*. 1996;34:579-584.
10. Jalali R, Singh S, Budrukkar A. Techniques of tumour bed boost irradiation in breast conserving therapy: current evidence and suggested guidelines. *Acta Oncol*. 2007;46:879-892.
11. Kannan N, Kabolizadeh P, Kim H, et al. Is there an advantage to delivering breast boost in the lateral decubitus position? *Radiat Oncol*. 2012;7:163.
12. Pearson D, Wan J, Bogue J. A novel technique for treating deep seated breast cavity boosts. *Med Dosim*. 2020;45:149-152.
13. Gross JP, Sachdev S, Helenowski IB, et al. Radiation therapy field design and lymphedema risk after regional nodal irradiation for breast cancer. *Int J Radiat Oncol Biol Phys*. 2018;102:71-78.
14. Wang X, Yu TK, Salehpour M, et al. Breast cancer regional radiation fields for supraclavicular and axillary lymph node treatment: is a

posterior axillary boost field technique optimal? *Int J Radiat Oncol Biol Phys*. 2009;74:86-91.

15. Chui CS, Hong L, McCormick B. Intensity-modulated radiotherapy technique for three-field breast treatment. *Int J Radiat Oncol Biol Phys*. 2005;62:1217-1223.
16. Jagsi R, Griffith KA, Moran JM, et al. Comparative effectiveness analysis of 3D-conformal radiation therapy versus intensity modulated radiation therapy (IMRT) in a prospective multicenter cohort of patients with breast cancer. *Int J Radiat Oncol Biol Phys*. 2022;112:643-653.
17. Dean J, Hansen CJ, Westhuyzen J, et al. Tangential intensity modulated radiation therapy (IMRT) to the intact breast. *J Med Radiat Sci*. 2016;63:217-223.
18. Jeulink M, Dahele M, Meijnen P, et al. Is there a preferred IMRT technique for left-breast irradiation? *J Appl Clin Med Phys*. 2015;16:5266.
19. Ko H, Chang JS, Moon JY, et al. Dosimetric comparison of radiation techniques for comprehensive regional nodal radiation therapy for left-sided breast cancer: a treatment planning study. *Front Oncol*. 2021;11: 645328.
20. Tyran M, Mailleux H, Tallet A, et al. Volumetric-modulated arc therapy for left-sided breast cancer and all regional nodes improves target volumes coverage and reduces treatment time and doses to the heart and left coronary artery, compared with a field-in-field technique. *J Radiat Res*. 2015;56:927-937.
21. Jalbout W, Youssef B, Chahrour Z. Wide tangent photon field versus electron field in the treatment of internal mammary lymph nodes in patients with left breast cancer: a decision-making flowchart. *Adv Radiat Oncol*. 2023;8: 101282.
22. Kaidar-Person O, Dahn HM, Nichol AM, et al. A Delphi study and international consensus recommendations: the use of bolus in the setting of postmastectomy radiation therapy for early breast cancer. *Radiother Oncol*. 2021;164:115-121.
23. Sapienza LG, Maia MAC, Gomes MJL, et al. Randomized clinical trial of tissue equivalent bolus prescription in postmastectomy radiotherapy stratified by skin involvement status. *Clin Transl Radiat Oncol*. 2022;39: 100570.
24. Marrazzo L, Meattini I, Simontacchi G, et al. Updates on the APBI-IMRT-Florence Trial (NCT02104895) technique: from the intensity modulated radiation therapy trial to the volumetric modulated arc therapy clinical practice. *Pract Radiat Oncol*. 2023;13:e28-e34.
25. Vicini FA, Remouchamps V, Wallace M, et al. Ongoing clinical experience utilizing 3D conformal external beam radiotherapy to deliver partial-breast irradiation in patients with early-stage breast cancer treated with breast-conserving therapy. *Int J Radiat Oncol Biol Phys*. 2003;57:1247-1253.
26. Corbin KS, Mutter RW. Proton therapy for breast cancer: progress & pitfalls. *Breast Cancer Management*. 2018;7:BMT06.
27. Bekelman JE, Lu H, Pugh S, et al. Pragmatic randomised clinical trial of proton versus photon therapy for patients with non-metastatic breast cancer: the Radiotherapy Comparative Effectiveness (RadComp) Consortium trial protocol. *BMJ Open*. 2019;9: e025556.
28. Mutter RW, Remmes NB, Kahila MM, et al. Initial clinical experience of postmastectomy intensity modulated proton therapy in patients with breast expanders with metallic ports. *Pract Radiat Oncol*. 2017;7:e243-e252.
29. MacDonald SM, Patel SA, Hickey S, et al. Proton therapy for breast cancer after mastectomy: early outcomes of a prospective clinical trial. *Int J Radiat Oncol Biol Phys*. 2013;86:484-490.
30. Arthur DW, Winter KA, Kuerer HM, et al. Effectiveness of breast-conserving surgery and 3-dimensional conformal partial breast reirradiation for recurrence of breast cancer in the ipsilateral breast: the NRG Oncology/RTOG 1014 Phase 2 Clinical Trial. *JAMA Oncol*. 2020;6:75-82.
31. Abeloos CH, Purswani JM, Galavis P, et al. Different re-irradiation techniques after breast-conserving surgery for recurrent or new primary breast cancer. *Curr Oncol*. 2023;30:1151-1163.
32. Montagne L, Hannoun A, Hannoun-Levi JM. Second conservative treatment for second ipsilateral breast tumor event: a systematic review of the different re-irradiation techniques. *Breast*. 2020;49:274-280.
33. Fattahi S, Ahmed SK, Park SS, et al. Reirradiation for locoregional recurrent breast cancer. *Adv Radiat Oncol*. 2020;6: 100640.
34. Linthorst M, van Geel AN, Baaijens M, et al. Re-irradiation and hyperthermia after surgery for recurrent breast cancer. *Radiother Oncol*. 2013;109:188-193.
35. Choi JI, Khan AJ, Powell SN, et al. Proton reirradiation for recurrent or new primary breast cancer in the setting of prior breast irradiation. *Radiother Oncol*. 2021;165:142-151.