Impact of Seroma Volume Reduction on Dosimetry in Whole Breast Radiation Therapy: A Case Study and Adaptive Planning Considerations

ABSTRACT

Aims: To explore the impact of seroma volume reduction on dosimetry during whole breast radiation therapy (WBRT) and evaluate the significance of adaptive planning.

Presentation of Case: A 71-year-old female with left breast invasive carcinoma underwent lumpectomy and radiotherapy. An initial CT (CT1) six weeks taken post-opshowed a seroma cavity, and a second CT (CT2) five weeks later documented a 65% seroma volume reduction (from 217 c.c. to 75 c.c.). Five radiotherapy techniques were evaluated: two-field conventional, three-field conventional, forward IMRT, inverse IMRT, and VMAT.Inverse IMRT and VMAT achieved better high-dose coverage and reproducibility but had larger dose variations (hot spot volume). They also showed higher maximum doses and increased hot spot volumes, indicating potential overdosage risks. Conventional techniques provided stable lower-dose coverage but less uniform high-dose distribution compared to IMRT and VMAT.

Discussion: The significant reduction in seroma volume affected dosimetry, highlighting the importance of adaptive planning. In this case, daily KV and weekly MV imaging were used for alignment, but CBCT may better monitor seroma changes. Adaptive radiotherapy, repeated CT simulations, and CBCT are essential for effective treatment. Further research should focus on improving treatment precision through advanced imaging and radiotherapy technologies.

Conclusion: This single WBRT case highlights the dosimetric impact of seroma reduction and the importance of imaging and adaptive strategies. Advanced techniques like inverse IMRT and VMAT improve precision but need careful IGRT monitoring. These findings emphasize the need for individualized treatment and further research to optimize protocols for managing seroma volume changes during WBRT.

Keywords:Breast cancer, radiation therapy, seroma, dosimetry, breast-conserving treatment, adaptive planning, IGRT

1. INTRODUCTION

Breast-conserving treatment, which involves tumor excision followed by post-operative adjuvant radiation therapy, aims to preserve the breast while ensuring the remaining tissue is free of cancerous cells. However, the formation of seromas—fluid-filled cavities at the tumor bed—complicates radiation treatmentplanning. Seromas can significantly alter the breast's shape and volume, posing a challenge in radiation therapy by shifting the target area, potentially leading to underdosing of the tumor bed or overdosing surrounding healthy tissue.[1] [2] A significant 65% volume reduction of seroma was found in this case. This study aims to explore the impact of seroma volume changes on dosimetry during WBRT and evaluate how different treatment techniques can accommodate these changes.

2. CASE REPORT

A 71-year-old female diagnosed with left breast invasive carcinoma underwent lumpectomy as part of her breast-conserving treatment. At six weeks after surgery, a computed tomography CT scan (CT1) noted a large seroma cavity remained at the breast tumor bed. The planned radiotherapy regimen included conformal radiotherapy using bilateral tangential photon beams and an anterior photon beam, delivering 46 Gy to the whole breast, followed by a 14 Gy electron beam boost targeting the tumor bed.Electron beam treatment was applied with block shielding to boost the tumor bed, shaped by manual clinical marking.Notable reduction in palpable breast dimensions,as observed by the radiation oncologist, prompted a second CT scan (CT2) before the electron beam boost, allowing for a direct comparison between initial and subsequent seroma volumes and dosimetry impact. A 65% reduction in seroma volume was observed, decreasing from 217 c.c. in CT1 to 75 c.c. in CT2, a difference of 142 c.c.[Fig. 1].With CT2 implemented, the treatment plan can reflect the anatomical changes and verify any potential overdosage or underdosage of the target area and surrounding tissues during treatment.

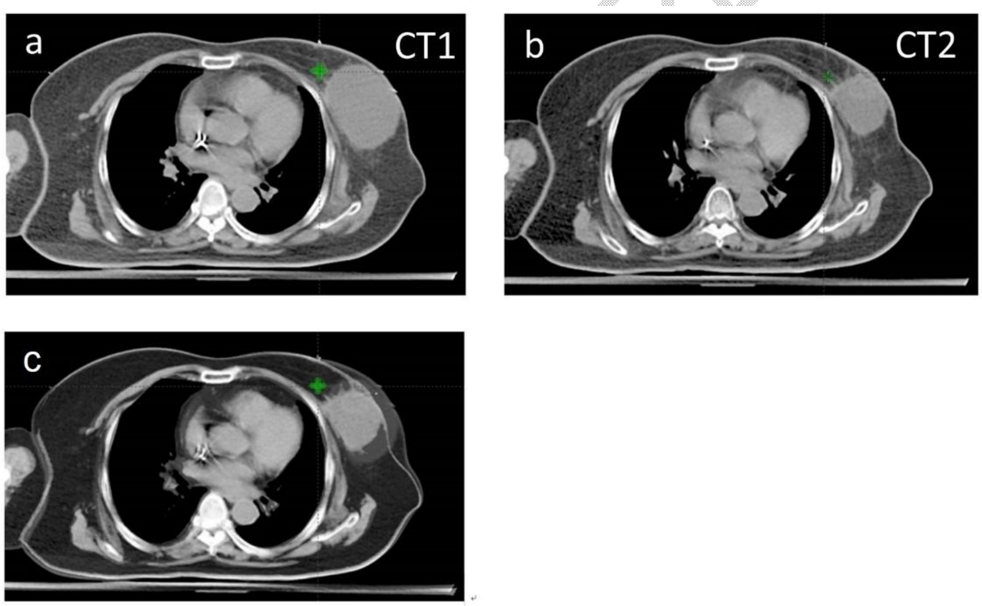

Fig. 1.(a) Initial CT (b) Second CT scan after five weeks (c) Image registration of CT1 and CT2 showing the reduction of seroma

Five different techniques were developed and optimized to ensure the clinical target volume (CTV) received 95% of the prescribed dose for comparison purpose [Fig. 2] [Fig. 3]. These included:

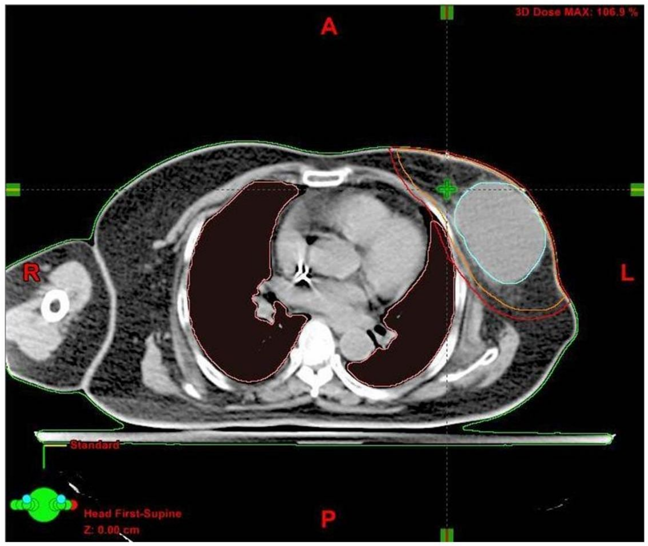

Fig.2.Contouring of seroma(cyan), CTV(orange), and PTV(red)

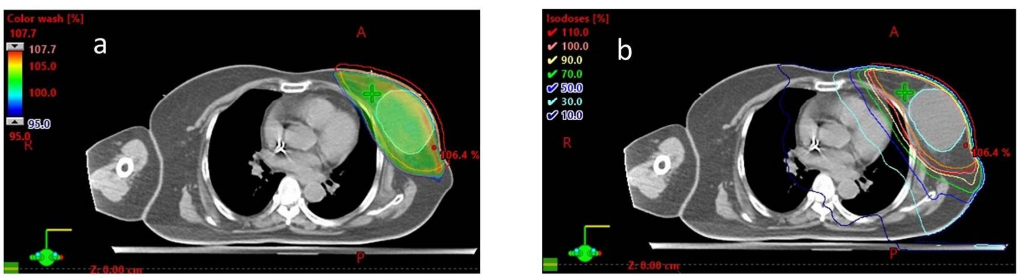

Fig.3.Example of dose distribution using VMAT (a) Color wash (b) Isodose line

1. Two-field Conventional Plan: Adjusted bilateral opposed tangent fields with a multileaf collimator (MLC) to shape the target and shield the lung and heart with physical wedge applied [Fig. 4a].

2. Three-field Conventional Plan: Added an anterior oblique field to mitigate unnecessary dose in the lateral axillary area [Fig. 4b].

3. Forward Intensity-Modulated Radiation Therapy (Forward IMRT): Utilized MLC to conform to the target shape without wedge modulation [Fig. 4c].

4. Inverse Intensity-Modulated Radiation Therapy (Inverse IMRT): Complex plans optimized using planning systems with numerous small segments/fields [Fig. 4d].

5. Volumetric-Modulated Arc Therapy (VMAT): Modulated gantry speed, dose rate, and MLC during treatment delivery using an inverse planning method with a four-arc plan [Fig. 4e].

Registration was performed between CT1 and CT2, and the CT1 plan was subsequently applied to the CT2 images for dose calculation. Comparisons were then conducted between the two plans/images. The quality of each treatment plan was assessed through various dosimetric parameters, including maximum point dose (Dmax), CTV coverage, and the volume of irradiated normal tissue. The Reproducibility Index (RI) was used to evaluate consistency across different scans. A higher RI value approaching one indicates better reproducibility across different CT images.

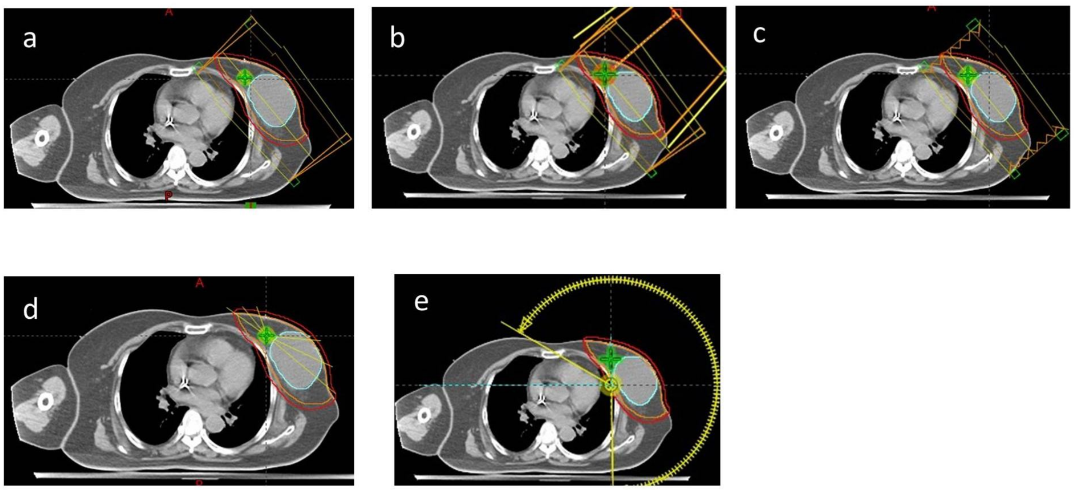

Fig.4.Different techniques of whole breast radiation therapy (WBRT) plans (a) Two-field plan (b) Three-field plan (c) Forward IMRT (d) Inverse IMRT(e) VMAT

Table 1 provides a detailed comparison of various radiotherapy techniques based on parameters assessed on two CT scans (CT1 and CT2). Inverse IMRT and VMAT provided better high-dose coverage (CTV100) and high-dose reproducibility (CTV100 RI) but showed larger dose variability (hot spot volume). Inverse IMRT exhibited a higher D_{max} (from 107.4% to 124.0%) and a significant increase in hot spots volume V_{105} (from 0.0 cm^3 to 17.5 cm^3) between CT1 and CT2. Similarly, VMAT showed an increase in D_{max} (from 107.7% to 115.9%) and hot spots volume V_{105} (from 1.6 cm^3 to 2.7 cm^3), indicating potential risks for overdosage. Conversely, the conventional two-field and three-field techniques demonstrated more stable CTV_{95}coverage but lower CTV_{100}RI which indicated less favorable high-dose uniformity compared to inverse IMRT(CTV_{100} RI =0.815) and VMAT(CTV_{100} RI =0.825).

Table 1. Comparison of dose metrics and reproducibility indices across different radiotherapy techniques

Technique	Image	Dmax (%)	CTV V_{95} (%)	CTV V_{100} (%)	Hot spots V_{105} (cm^3)	Hot spots V_{100} (cm^3)	CTV_{95} RI	CTV_{100} RI
	CT1	107.0	94.2	56.9	11.8	156.5		
Two-field	CT2	110.6	94.9	49.0	11.7	142.5	0.812	0.677
	CT2-CT1	3.6	0.7	-7.9	-0.1	-14.0		

	CT1	107.0	94.3	69.1	2.5	79.2		
Three-field	CT2	108.3	95.0	62.0	3.2	77.2	0.812	0.677
	CT2-CT1	1.3	0.7	-7.1	0.7	-2.0		
	CT1	107.1	93.1	50.7	10.5	104.3		
Forward IMRT	CT2	109.8	92.9	47.5	6.8	94.9	0.809	0.663
	CT2-CT1	2.7	-0.2	-3.2	-3.7	-9.4		
	CT1	107.4	96.5	93.4	0.0	265.9		
Inverse IMRT	CT2	124.0	93.1	87.9	17.5	229.5	0.822	0.815
	CT2-CT1	16.6	-3.4	-5.5	17.5	-36.4		
	CT1	107.7	95.1	92.0	1.6	181.3		
VMAT	CT2	115.9	92.7	87.4	2.7	125.5	0.844	0.820
	CT2-CT1	8.2	-2.4	-4.6	1.1	-55.8		

**CTV V95: percentage volume of CTV covered by 95% prescribed dose*

**CTV V100: percentage volume of CTV covered by 100% prescribed dose*

**Hot spots V105: volume covered by 105% prescribed dose and located outside CTV*

**Hot spots V100: volume covered by 100% prescribed dose and located outside CTV*

**RI (Reproducibility index) = (overlapping volume of CTV' and CTV")^2 / (CTV' x CTV")*

**CTV' represents the overlapping volume of the prescribed 95% dose in CT1*

**CTV" represents the overlapping volume of the prescribed 95% dose in CT2*

3. DISCUSSION

The findings from this study emphasize the dynamic nature of seroma cavities following breast-conserving surgery and the impact of these changes on radiation therapy planning. Seroma volume changes can significantly impact dose delivery accuracy in WBRT.[3] The study documented a 65% reduction in seroma cavity volume over five weeks, emphasizing the evolving nature of post-surgical breast anatomy. Techniques like inverse IMRT and VMAT, while providing better high-dose coverage uniformity, exhibited higher dose variability, i.e., higher CTV_{100} coverage and larger hot spot volume.

The optimal timing for the initiation of radiation therapy post-surgery remains a balance between allowing seroma stabilization and minimizing the delay to reduce the risk of local recurrence.[4] [5] This studydemonstrated a single WBRT case starting radiation therapy six weeks aftersurgerywith large seroma.Theresults offer a practical perspective on how to implement different radiotherapy techniques and suggested the importance of adapting to anatomical change. Adaptive radiotherapy techniques that can account for these anatomical shifts.[6] [7]Accounting for seroma volume changes through treatment, repeated CT simulations and adaptive planning can be considered for ensuring accurate dosimetry and effective treatment.

Image-guided radiation therapy (IGRT) can help address changes in seroma volume. Techniques such as cone-beam CT (CBCT) during treatment can enable timely adjustments to the treatment plan, ensuring accurate dose delivery and minimizing the risk to surrounding healthy tissue.In this case, daily KV imaging was used for aligning bony structures, and weekly MV imaging was used for checking alignment of the breast outline. While those two IGRT techniques cannot monitor changes in seroma volume, they ensure the target remains within the radiation field. Post-treatment analysis and review suggest that CBCT might be a better option for monitoring seroma changes and alignment during treatment.

The reduction in seroma volume during radiotherapy is influenced by several factors, including the timing of treatment initiation. Prendergast et al. [8] and Cho et al. [9] found no significant statistical relationship between the initial volume of the cavity and the rate of reduction, indicating that other factors may play a role in seroma dynamics.However, Cho et al. observed that as the time from surgery to the start of WBRT increased, the volume reduction in the lumpectomy cavity during WBRT decreased, suggesting that earlier initiation of WBRT might lead to more pronounced volume changes.

Advanced Radiotherapy Techniques: Inverse IMRT and VMAT are recommended due to better consistency and reliability in high-dose coverage compared to conventional techniques. These advanced methodscombined with adaptive planning can reduce hot spots resulting from anatomical changes andenhance treatment precision, particularly in the context of WBRT post-surgery.

Huh et al. [10] reported that seroma reduction resulted in increased dose inhomogeneity, with up to 13.9% for conventional treatment and 20.7% for IMRT, similar to the inverse IMRT result in our case. According to Alderliesten et al. [11],seroma volume decreased by an average of 62% from the start of radiotherapy to the third week, with a less significant reduction from the third to the fifth week. They evaluated the hybrid IMRT dosimetric effect of seroma reduction with both WBRT and simultaneous integrated boost (SIB). An increase in hot spot areas and slightly worse target coverage was found, especially for SIB with larger initial seroma volumes. These studies, along with our case, highlight the significant impact of seroma reduction on dosimetry during radiotherapy.

The case report's findings are based on a single patient's experience, and future research should focus on evaluating the long-term outcomes of patient with significant seroma volume changes and leveraging technological advancements in imaging and radiotherapy to enhance the treatment precision.

4. CONCLUSION

This report focuses on a single patient case of WBRT, providing detailed insights into five different techniques and the dosimetric effects of seroma reduction. Predicting the reduction volume is challenging. This case demonstrates preliminaryevidence for considering imaging monitoring and adaptive strategies in radiotherapy to address dynamic changes. Advanced techniques like inverse IMRT and VMATcombined with adaptive strategies, can improve dosimetric precision and patient outcomes but require careful IGRT monitoring due to increased dose variability.The findings underscore the need for individualized treatment approaches and further research is warranted to establish optimal protocols for managing significant seroma volume changes during WBRT.

ETHICAL APPROVAL

This study was reviewed and approved by the CGMH Institutional Review Boards (number: 201801223B0). The IRB determined that the study met all ethical guidelines, and that patient consent was not required due to the retrospective nature of the research.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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