Radiation Physics and Chemistry 243 (2026) 113464

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Enhancing jawless VMAT plan quality for hypofractionated left breast cancer with the avoidance structure tool

J.H.M. Castelo [a,b,*], D.C.T. Menezes [a,b], G.R. Bittencourt [b], L.A.R. da Rosa [a], D.A.B. Bonifacio [a,c]

[a] ANSN / Instituto de Radioproteção e Dosimetria, Av. Salvador Allende 3773, Rio de Janeiro, Brazil
[b] Grupo Oncoclínicas, Rio de Janeiro, Rua Mal Niemeyer 16, Rio de Janeiro, Brazil
[c] Instituto de Pesquisas Energéticas e Nucleares, São Paulo, Av. Prof. Lineu Prestes, 2242, Sao Paulo, Brazil

ARTICLE INFO

Keywords:
Rapidplan
Avoidance structure
Knowledge-based planning
Left breast cancer

ABSTRACT

Introduction: The Avoidance Structure (AvS) tool shields a structure by maintaining the multileaf collimator leaves over the structure's projection in the beam's eye view. In this work, we tested the dosimetric impact of using part of the outlines of the heart and lungs as avoidance structure when creating knowledge-based left breast volumetric modulated arc therapy treatment plans.
Methods: Dose-volume histogram estimates were calculated using a RapidPlan model for 30 patients who received whole breast radiation therapy in five fractions. Then, two sets of plans were generated for a Halcyon v2 linear accelerator by alternating the use of the AvS tool. Dose metrics for both procedures were compared.
Results: Coverage on the target volume remained similar regardless of the use of AvS. The mean absorbed dose received by the heart, as well as the relative volumes receiving 1.5, 3.5 and 7.8 Gy, decreased with effect sizes (ESZ) 0.98, 1.43, and 0.63 respectively. Homolateral lung volumes receiving 1.5 and 3.5 Gy were also lowered using AvS. However, the dose received by 0.03 cc of the contralateral breast increased with an ESZ of 0.52.
Conclusions: Except for the contralateral breast, the AvS tool improved DVH metrics for organs at risk without compromising target coverage or worsening hotspots.

1. Introduction

Breast cancer is the most prevalent form of cancer among women and a significant cause of mortality (Brunt et al., 2020). Radiotherapy plays an important role in breast cancer treatment. The introduction of Volumetric Modulated Arc Therapy (VMAT) for breast cancer treatment is still debated in literature (Brunt et al., 2021; Ahmad et al., 2022; Fogliata et al., 2017). The concerns revolve around the increased integral dose to the patient and the challenges involved in treatment planning compared to conformal techniques. However, VMAT has been shown to improve target coverage with the prescribed dose while sparing organs at risk of lower doses as effectively as conformal therapy (Brunt et al., 2020, 2021; Ahmad et al., 2022; Fogliata et al., 2017).

Some modern linear accelerators (LINACs), such as Halcyon and Ethos (Varian Medical Systems, Palo Alto, USA), are not built with jaws. Instead, a dual layer multi-leaf collimator (MLC), capable of blocking up to 0.01 % of the beam's intensity, is responsible for shaping the radiation field (Costa et al., 2021; Pan, 2025; Seok et al., 2024). When a VMAT plan is created for a LINAC with jaws, the planner can pre-shape the beam. Hence, for any starting point, the optimization algorithm will not plan direct radiation to some regions. This is not true for a jawless LINAC. This key difference can influence plan quality metrics, making inter-planner variation a larger factor in jawless LINACs VMAT (Pan, 2025; Petroccia et al., 2019; Scaggion et al., 2018).

RapidPlan is a knowledge-based planning (KBP) software developed by Varian Medical Systems (Palo Alto, USA) (Costa et al., 2021). It incorporates machine learning algorithms to streamline and improve the quality of treatment plans in radiation oncology. The algorithm can predict organs at risk (OAR) and target structure's dose-volume histogram (DVH) based on the geometric features using metrics such as target-organ distance and retrospective planning data. RapidPlan has proven to be highly effective in treatment planning without human intervention, reducing inter-planner variation (Costa et al., 2021; Scaggion et al., 2018; Kubo et al., 2019).

When VMAT plans are optimized within Eclipse, Varian's treatment planning system (TPS), the Photon Optimizer (PO) algorithm attempts

* Corresponding author. ANSN / Instituto de Radioproteção e Dosimetria, Av. Salvador Allende 3773, Rio de Janeiro, Brazil.
E-mail address: jhmcastelo@gmail.com (J.H.M. Castelo).

https://doi.org/10.1016/j.radphyschem.2025.113464
Received 19 July 2025; Received in revised form 20 October 2025; Accepted 13 November 2025
Available online 19 December 2025
0969-806X/

to cover targets with the prescribed dose and spare OAR based on dose objective inputs. Rapidplan can create realistic dose objectives using the DVH predictions, also known as DVH estimates. Nonetheless it still relies on PO's control point generation, which has its limitations (Fogliata et al., 2022; Park et al., 2024; Son and Park, 2023; Zhang et al., 2024).

Plan quality metrics could be increased by blocking the beam's entry and exit on parts of the heart, homolateral lung and gastrointestinal regions using the Avoidance Structure (AvS) tool (Fogliata et al., 2022; Bowhall, 2022). AvS can decrease OAR absorbed doses by locking MLC leaves over the projection of any region of interest on the beam's eye view, effectively blocking beam's entry and exit through specific regions.

The aim of this study was to investigate the dosimetric impact of using AvS tool for left breast VMAT treatments on a Varian Halcyon v2 LINAC. It is important to distinguish AvS from Avoidance Sectors, which can also be used to spare organs at risk in breast cancer VMAT, as highlighted in a previous work (Fogliata et al., 2022). A key difference regarding the scope of our work is that Avoidance Sectors interfere with DVH estimates while AvS does not. The AvS tool will not change the effective arc length, resulting in similar DVH prediction than a plan without the AvS tool.

2. Experimental

2.1. Selection Criteria

Thirty whole left breast treatment plans were retrospectively selected from patients treated with the free-breathing tangential VMAT technique in our Halcyon v2 LINAC using a 6 MV flattening filter-free photon beam in five fractions (ultra-hypofractionation regimen, 5 fractions of 520 cGy each) (Brunt et al., 2020, 2021). Data collection was performed according to the study design requirements of the Instituto Oncoclınicas ethical board (CAE 67190423.1.0000.0227).

2.2. Technique

Patients were positioned using a wing-board and ankle support. A free-breathing treatment planning CT image was acquired using a 3 mm slice in a 16-channel Somatom Emotion CT scanner (Siemens, USA). The CT image was then exported to the Eclipse v15.6 planning system (Varian, Palo Alto, USA). All clinical target volumes (CTV) were contoured by experienced radiation oncologists following the RTOG guidelines (White et al., 2009). OAR were contoured by experienced dosimetrists. Planning target volume (PTV) was defined as a 5 mm isotropic margin from the CTV. A structure named PTV –3 mm from the skin was created for DVH evaluation. This structure was defined by subtracting the PTV from the body surface using a 3 mm isotropic margin.

The VMAT breast planning technique setup consisted of 6 partial arcs: 3 medial arcs ranging from 285 to 15° and 3 posterior arcs ranging from 80 to 179°. The collimator angles were 0, 45 and 90° for each gantry turn (2 partial arcs) (Pan, 2025; Seok et al., 2024; Fogliata et al., 2022; Zhang et al., 2024). There were no constraints on beam entry on

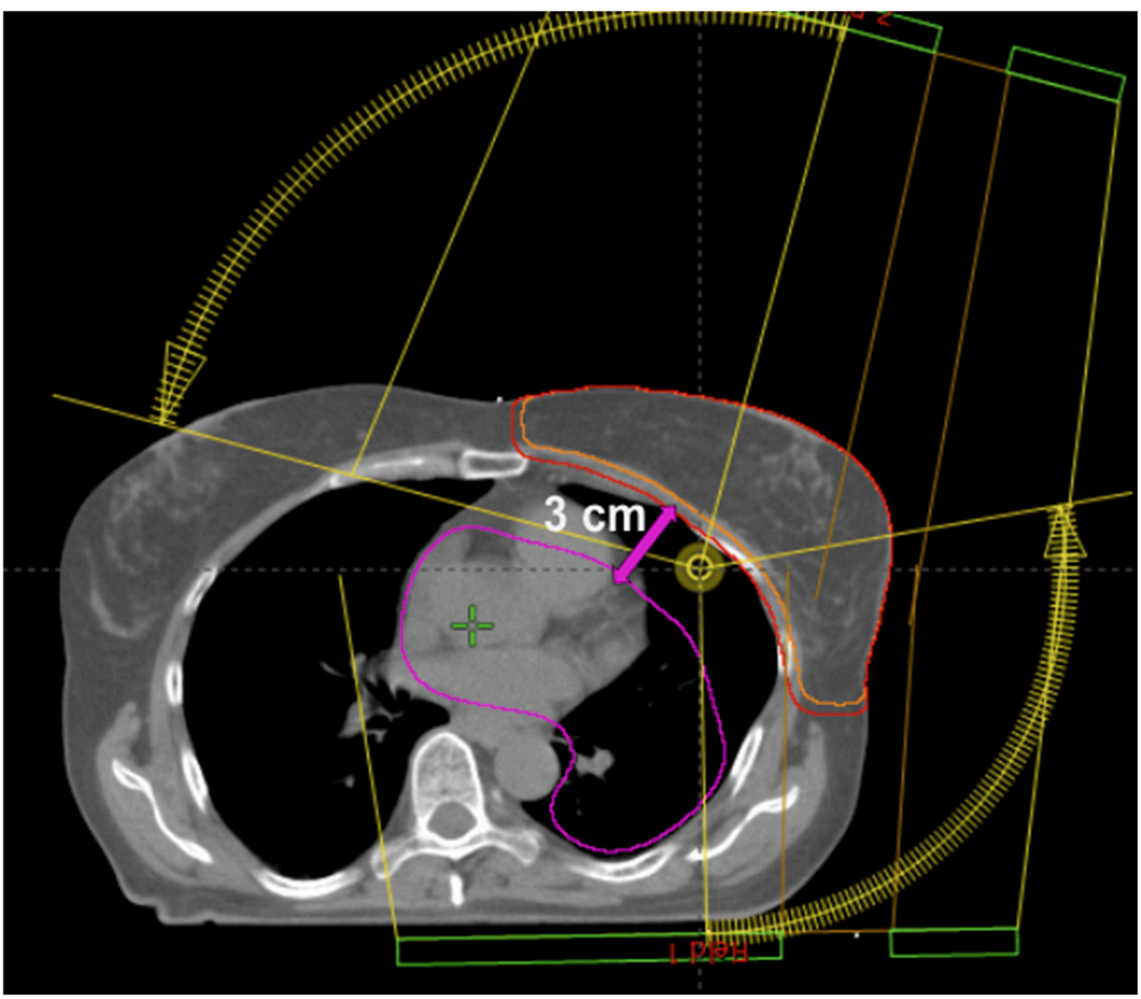

Fig. 1. Example of the trajectory of the partial arcs and the positioning of the isocenter relative to CTV (segmented in orange), PTV (segmented in red) and Avoid structure (segmented in magenta). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the contralateral breast.

For the plans using the AvS tool, the structure to be blocked was defined as the union of the CT segmented regions of the heart, homolateral lung and gastrointestinal (GI) organs subtracted 3 cm away from the PTV. The auxiliary structure chosen for this work is based on clinical experience. Its design was refined to reproduce dosimetric results from retrospective data planned on a Trilogy linac (Varian Medical Systems, Palo Alto, USA).

The isocenter was placed on the mid-point of the breast projection near the chest wall and lung interface, as shown in Fig. 1.

DVH estimates were performed by a RapidPlan model, trained with 112 tangential VMAT plans from patients with early-diagnosed left breast cancer, of which 18 % were treated with the 1-week regimen and 75 % with the 3-week regimen. The training dataset had a similar beam geometry as described above. The AvS tool was enabled in 36 % of the training dataset. Besides automatic line objectives, other optimization objectives based on the FAST Forward constraints were added to the model (Brunt et al., 2020). Since the DVH estimates did not change when using the AvS tool, we chose to use our clinical validated RapidPlan model for this work.

To ensure the skin flash margin, a virtual bolus of 1 cm was outlined and attributed −150 HU during optimization within the PO 15.6 algorithm (Gleeson, 2022; Lizondo et al., 2019). The HU and bolus thickness were selected to reduce differences between optimization and final calculation without the virtual bolus for the Halcyon 6X–FFF beam.

The optimization target was the PTV, which overlaps with the virtual bolus due to the isotropic margin from the CTV. The same objectives and beam geometry were replicated for plans with and without AvS, including line objectives for the avoidance structure. Final calculation, using the Anisotropic Analytical Algorithm 15.6 (AAA), was performed without the virtual bolus. Plans were normalized so that 95 % of prescribed dose covered 95 % of PTV –3 mm from skin volume. Plan creation was carried out without human interaction.

2.3. Plan comparison

DVH metrics were compared for PTV (D98 %, V105-110 %) and the OAR heart (Dmean, V1.5–7.8Gy), left lung (V1.5-V12Gy), right breast (Dmean, D0.03 cc, V3.5Gy), right lung (Dmean) and left anterior descending artery (LAD) (Dmean), as shown in Table 1. Monitor units (MU) were also accounted for.

2.4. Statistical analysis

DVH metrics were extracted from the plans via Eclipse Scripting Application Programming Interface (Zhou et al., 2023). Statistical analyses were performed using the Python programming language (Pedregosa et al., 2011; Chaikh et al., 2014). The plans using AvS were compared to the ones not using the tool via the Wilcoxon signed-rank test or paired *t*-test depending on the null hypothesis rejection of the Shapiro-Wilk normality test. Statistical significance was considered as p-value lower than 0.05. Effect sizes (ESZ) were calculated and reported as the absolute values of Cohen's d, such that only the magnitude of the effect was considered, regardless of direction (CHAIKH et al., 2014).

Table 1
DVH analysis for each region of interest, constraints are derived from a mix of metrics from our clinical goals and the FAST Forward protocol.

Region of interest (ROI)	Metrics
PTV – 3 mm from skin	D98 %; V105 %; V107 %; V110 %
LAD	Dmean
Heart	Dmean; V1.5Gy; V3.5Gy; V7.8Gy
Left Lung	V1.5Gy; V3.5Gy; V7.8Gy; V12Gy
Right Lung	Dmean
Right Breast	Dmean; D0.03 cc; V3.5Gy

2.5. Results

2.5.1. Monitor units

The AvS tool led to increased monitor units (MU). AvS plans had 2145 ± 112 MU (mean ± sample standard deviation) in comparison to plans not using it, which had 1600 ± 70 MU.

2.5.2. PTV

There was no statistical difference among the plans. Results are summarized in Table 2.

2.5.3. organs at risk

2.5.3.1. Avoidance structure effect. For the heart, the mean absorbed dose was significantly lower for the AvS group for an ESZ of 0.98. Additionally, the volumes receiving 1.5 Gy and 3.5 Gy were also significantly lower for the AvS plans, with ESZ of 1.43 and 0.63, respectively. For the LAD, although Dmean was lower for the AvS group, the ESZ was 0.18. The left lung showed significant differences in V1.5Gy and V3.5Gy between the two groups, with ESZ of 1.86 and 1.21, respectively. For the right breast, there were no significant differences in Dmean or V3.5Gy, but there was significance in D0.03 cc ($p = 0.04$), with an ESZ of 0.52. The results are summarized in Table 3.

2.5.4. DVH estimates

The AvS had no impact on DVH estimates. Hence, the DVH estimation algorithm yielded the same objectives for plans with and without AvS. Since the plans had no human interaction, line objectives based on the estimates and fixed objectives were the main drivers for dosimetric results. The DVH estimates were systematically lower than the achieved DVH for all OAR except the LAD. AvS plans had the best match to the estimates for all OAR except the right breast, favoring RP plans.

The greatest difference between estimates and AvS plans was seen for the right breast. There were significant differences between estimates and the results from V1.5Gy, V3.5Gy and D0.03 cc. The reported ESZ were 1.15, 1.19 and 1.61, respectively. For the left lung, V1.5Gy, V3.5Gy, V7.8Gy, V12Gy and V16Gy had ESZ of 0.99, 0.54, 0.67, 0.96, 1.02, respectively. Lastly, there were significant differences in V7.8Gy, V12Gy and D0.03 cc, with ESZ of 0.63, 0.75 and 1.39, respectively. The results are summarized in Fig. 2.

3. Discussion

Several studies present the partial arcs technique or the use of Avoidance Sectors as effective in reducing doses in OARs (Fogliata et al., 2017). The use of auxiliary structures and partial arcs was highlighted by Zhang et al. (2021).

The results for left breast VMAT plans treated in 1-week courses align with other works such as those by Piras et al. (2022) and Ahmad et al. (2022). Both authors reported a 10 mm margin compared to the 5 mm margin for our sample.

In this work, we seek to evaluate the importance of using the AvS for early left breast cancer with the VMAT technique in a Halcyon v2 LINAC. The dual-layer MLC blocked the beam entry and exit whenever an

Table 2
Dosimetric variables for PTV. The t/w value column refers to t as the Student's *t*-test statistic, and the Wilcoxon signed rank test statistic as w.

ROI	Metric	Test	t/w value	p value	RP (Mean ± SD)	AvS (Mean ± SD)
PTV	D98 % (Gy)	w	177	0.26	24.2 ± 0.2	24.1 ± 0.2
PTV	V105 %	w	226	0.9	8.8 ± 11.8	8.3 ± 11.1
PTV	V107 %	w	186	0.94	3.5 ± 6.5	3.5 ± 6.5
PTV	V110 %	w	69	0.29	0.9 ± 2.2	1.0 ± 2.3

Table 3
Dosimetric variables for organs at risk (OAR). The t/w value column refers to t as the Student's *t*-test statistic, and the Wilcoxon signed rank test statistic as w. LLung stands for left lung, RLung stands for right lung, Breast CL stands for breast contralateral. ** refers to p-values less than 0.01.

OAR	Metric	Test	t/w value	p-value	RP (Mean ± SD)	AvS (Mean ± SD)
Heart	Dmean (Gy)	t	3.9	**	1.7 ± 0.7	1.1 ± 0.4
Heart	V1.5Gy	t	5.7	**	38.3 ± 20.2	15.2 ± 9.0
Heart	V3.5Gy	w	13.0	**	7.7 ± 6.6	4.2 ± 3.2
Heart	V7.8Gy	w	104	0.07	1.9 ± 2.0	1.6 ± 1.6
LAD	Dmean (Gy)	w	39.0	**	3.4 ± 2.1	3.0 ± 2.1
LLung	V1.5Gy	t	7.4	**	62.6 ± 12.7	41.9 ± 8.3
LLung	V3.5Gy	w	1.0	**	28.1 ± 9.4	19.1 ± 4.2
LLung	V7.8Gy	t	1.5	0.13	12.6 ± 4.0	11.2 ± 3.0
LLung	V12Gy	t	0.4	0.68	7.5 ± 2.8	7.2 ± 2.4
Breast CL	Dmean (Gy)	t	−0.6	0.55	1.2 ± 0.5	1.3 ± 0.6
Breast CL	D0.03 cc (Gy)	t	−2.1	0.04	8.5 ± 1.9	9.7 ± 2.5
Breast CL	V3.5Gy	t	−1.0	0.32	8.3 ± 5.5	9.9 ± 6.7
RLung	Dmean (Gy)	w	6.0	**	0.4 ± 0.2	0.3 ± 0.2

auxiliary structure consisting of the sum of the heart, left lung and GI structures cropped 3 cm from the PTV was projected in the beam's eye view. A future study could address if different crop margins or different auxiliary structures could further increase plan quality.

Since AvS tool does not change DVH estimates, the differences between the AvS and RP plans are solely due to the PO algorithm and model limitations. Despite that, plans with AvS were closer to the estimates than plans without it. The right breast was an exception, possibly explained by the higher degrees of freedom for the arc and MLC arrangement.

Although higher near maximum doses were observed in AvS plans for the right breast, it is important to address that toxicity in contralateral breast is usually correlated with mean doses to a subregion of the breast on women younger than 40 years old, which are not eligible for the FAST Forward protocol (Brunt et al., 2021; Stovall et al., 2008). Nonetheless, as described in Table 3, there were no significant differences between RP and AvS plans for mean doses and V3.5Gy for the right breast.

Fogliata et al. (2022) addressed the dosimetric differences from the KBP to the estimates due to the PO algorithm being unable to decrease the dose rate at certain control points for the arc without Avoidance Sector.

Therefore, using the AvS tool leads to a significant dosimetric improvement in the left lung and heart. However, the improvement in the OAR absorbed dose resulted in an increase in the monitor units. This could be impactful for patient management during deep inspiration breath-hold treatments, as dose and MU trade-offs might differ in that scenario (Gleeson, 2022).

Differences in the contralateral lung are negligible, still favoring the AvS plans. The absorbed dose of the contralateral lung is primarily controlled by the length of the partial arcs. One limitation of the automatic planning used in this work is related to the change in the dose distribution on the target once the virtual bolus is removed. This effect can be mitigated using optimized values for virtual bolus size and HU (Lizondo et al., 2019).

4. Conclusion

In this work, the use of the AvS tool had a significant effect on reducing the absorbed dose to the OARs, mainly the left lung and heart. RapidPlan DVH estimates do not change when using the AvS tool. Hence, when the same objectives are set, AvS plans yielded better dosimetric results according to institutional protocols. The increase in the volume of isodoses greater than 105 % was noted in both plans in relation to the treated plans.

Despite the small sample and the 5 mm margin instead of 1 cm as prescribed by Brunt et al. (2020), the results presented were similar or superior to the others (Ahmad et al., 2022; Piras et al., 2022). The use of the AvS tool resulted in plans closer to the DVH estimates than those not using it. Hence, the tangential VMAT technique can benefit from the MLC blocking promoted by the AvS tool.

CRediT authorship contribution statement

J.H.M. Castelo: Writing – original draft, Methodology,

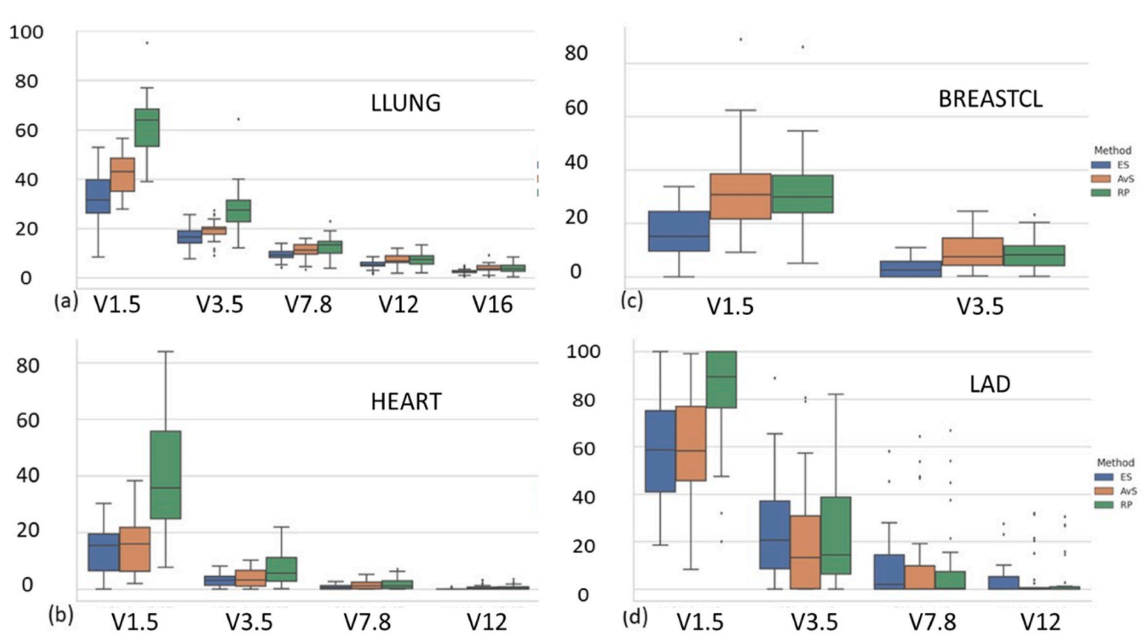

Fig. 2. Relative cumulative DVH values for (a) left lung, (b) heart, (c) LAD, (d) right breast. DVH estimates are displayed as method ES, results from the plans without Avoidance Structure as RP (RapidPlan) and results from the plans with AvS as AvS.

Investigation, Formal analysis, Data curation, Conceptualization. **D.C.T. Menezes:** Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **G.R. Bittencourt:** Visualization, Methodology, Conceptualization. **L.A.R. da Rosa:** Writing – review & editing, Supervision, Resources, Project administration. **D.A. B. Bonifacio:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition.

Ethics approval

Data collection was performed according to the study design requirements of the Instituto Oncoclınicas ethical board (CAE 67190423.1.0000.0227).

Funding

This research was funded by the ANSN/Instituto de Radioproteção e Dosimetria./ Instituto de Radioproteção e Dosimetria.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgements

The author would like to thank the Radioterapia Botafogo, ANSN / Instituto de Radioproteção e Dosimetria and Instituto Oncoclínicas for allowing the development of this research work.

Data availability

Anonymized summary data and selected plan evaluation metrics generated during this study are available from the corresponding author upon reasonable request.

References

Ahmad, A., Das, S., Kharade, V., Gupta, M., Pandey, V., Anju, K., Balasubramanian, I., Pasricha, R.K., 2022. Dosimetric study comparing 3d conformal radiotherapy (3d-crt), intensity modulated radiotherapy (imrt) and volumetric modulated arc therapy (vmat) in hypofractionated one-week radiotherapy regimen in breast cancer. Cureus 14 (11).

Bowhall, Grace E., 2022. A Dosimetric Comparison Using Avoidance Sectors vs Avoidance Structures for Hip Prostheses in Cancer Patients Receiving Pelvic Irradiation, 165. Culminating Experience Projects. https://scholarworks.gvsu.edu/gradprojects/165.

Brunt, A.M., Haviland, J.S., Sydenham, M., Agrawal, R.K., Algurafi, H., Alhasso, A., Barrett-Lee, P., Bliss, P., Bloomfield, D., Bowen, J., et al., 2020. Ten-year results of fast: a randomized controlled trial of 5-fraction wholebreast radiotherapy for early breast cancer. J. Clin. Oncol. 38 (28), 3261.

Brunt, A., Haviland, J., Kirby, A., Somaiah, N., Wheatley, D., Bliss, J., Yarnold, J., 2021. Five-fraction radiotherapy for breast cancer: Fast-forward to implementation. Clin. Oncol. 33 (7), 430–439.

Chaikh, A., et al., 2014. The choice of statistical methods for comparisons of dosimetric data in radiotherapy. Radiat. Oncol. 9 (1), 1–11. Springer.

Costa, E., Richir, T., Robilliard, M., Bragard, C., Logerot, C., Kirova, Y., Fourquet, A., De Marzi, L., 2021. Assessment of a conventional volumetricmodulated arc therapy knowledge-based planning model applied to the new halcyon© o-ring linac in locoregional breast cancer radiotherapy. Phys. Med. 86, 32–43.

Fogliata, A., Seppala, J., Reggiori, G., Lobefalo, F., Palumbo, V., De Rose, F., Franceschini, D., Scorsetti, M., Cozzi, L., 2017. Dosimetric trade-offs in breast treatment with vmat technique. Br. J. Radiol. 90 (1070), 20160701.

Fogliata, A., Parabicoli, S., Paganini, L., Reggiori, G., Lobefalo, F., Cozzi, L., Franzese, C., Franceschini, D., Spoto, R., Scorsetti, M., 2022. Knowledge based dvh estimation and optimization for breast vmat plans with and without avoidance sectors. Radiat. Oncol. 17 (1), 1–11.

Gleeson, I., 2022. Comparing the robustness of different skin flash approaches using wide tangents, manual flash vmat, and simulated organ motion robust optimization vmat in breast and nodal radiotherapy. Med Dosim. 2022 Autumn; 47 (3), 264–272. https://doi.org/10.1016/j.meddos.2022.04.004. Epub 2022 May 23. PMID: 35618563; PMCID: PMC7613212.

Kubo, Kazuki, Monzen, Hajime, Ishii, Kentaro, Tamura, Mikoto, Nakasaka, Yuta, Kusawake, Masayuki, Kishimoto, Shun, Nakahara, Ryuta, Matsuda, Shogo, Nakajima, Toshifumi, Ryu, Kawamorita, 2019. Inter-planner variation in treatment-plan quality of plans created with a knowledge-based treatment planning system. Phys. Med. 67, 132–140. https://doi.org/10.1016/j.ejmp.2019.10.032. ISSN 1120-1797.

Lizondo, M., Latorre-Musoll, A., Ribas, M., Carrasco, P., Espinosa, N., Coral, A., Jornet, N., 2019. Pseudo skin flash on vmat in breast radiotherapy: optimization of virtual bolus thickness and hu values. Phys. Med. 63, 56–62.

Pan, H., 2025. Plan comparison of left breast postmastectomy radiotherapy: Halcyon IMRT and VMAT plan vs. truebeam fixed-jaws plan. Int. J. Radiat. Oncol. Biol. Phys. 117 (2), e703.

Park, S.H., Ko, H., Choi, J., 2024. Effect of jaw tracking during Volumetric modulated arc therapy for facial non-melanoma skin cancer. In Vivo 38 (2), 849–854. https://doi.org/10.21873/invivo.13510. PMID: 38418154; PMCID: PMC10905431.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M., Duchesnay, E., 2011. Scikit-learn: machine learning in Python. J. Mach. Learn. Res. 12, 2825–2830.

Petroccia, H.M., Malajovich, I., Barsky, A.R., Ghiam, A.F., Jones, J., Wang, C., Zou, W., Teo, B.K., Dong, L., Metz, J.M., Li, T., 2019. Spine SBRT with halcyon™: plan quality, modulation complexity, delivery accuracy, and speed. Front. Oncol. 9, 319. https://doi.org/10.3389/fonc.2019.00319. PMID: 31106151; PMCID: PMC6498946.

Piras, A., Menna, S., D'Aviero, A., Marazzi, F., Mazzini, A., Cusumano, D., Massaccesi, M., Mattiucci, G.C., Daidone, A., Valentini, V., et al., 2022. New fractionations in breast cancer: a dosimetric study of 3d-crt versus vmat. J. Med. Radiat. Sci. 69 (2), 227–235.

Scaggion, A., Fusella, M., Roggio, A., Bacco, S., Pivato, N., Rossato, M.A., Peña, L.M.A., Paiusco, M., 2018. Reducing inter- and intra-planner variability in radiotherapy plan output with a commercial knowledge-based planning solution. Phys. Med. 53, 86–93. https://doi.org/10.1016/j.ejmp.2018.08.016. Epub 2018 Aug 23. PMID: 30241759.

Seok, J.H., Ahn, S.H., Ahn, W.S., et al., 2024. Comparison of skin dose in IMRT and VMAT with TrueBeam and Halcyon linear accelerator for whole breast irradiation. Phys. Eng. Sci. Med. 47, 443–451. https://doi.org/10.1007/s13246-023-01373-x.

Son, S., Park, S.Y., 2023. Progressive resolution optimizer (PRO) predominates over photon optimizer (PO) in sparing of spinal cord for spine SABR VMAT plans. BMC Cancer 23, 445. https://doi.org/10.1186/s12885-023-10925-z.

Stovall, M., Smith, S.A., Langholz, B.M., Boice Jr., J.D., Shore, R.E., Andersson, M., Buchholz, T.A., Capanu, M., Bernstein, L., Lynch, C.F., Malone, K.E., Anton-Culver, H., Haile, R.W., Rosenstein, B.S., Reiner, A.S., Thomas, D.C., Bernstein, J.L., Women's Environmental, Cancer, and Radiation Epidemiology Study Collaborative Group, 2008. Dose to the contralateral breast from radiotherapy and risk of second primary breast cancer in the WECARE study. Int. J. Radiat. Oncol. Biol. Phys. 72 (4), 1021–1030.

White, J., Tai, A., Arthur, D., Buchholz, T., Macdonald, S., Marks, L., et al., 2009. Breast cancer Atlas for radiation therapy planning: consensus definitions collaborators. Breast Cancer Atlas Radiat. Therapy Plan. 73, 944–951.

Zhang, Y., Huang, Y., Ding, S., Yuan, X., Shu, Y., Liang, J., Mao, Q., Jiang, C., Li, J., 2021. A dosimetric and radiobiological evaluation of vmat following mastectomy for patients with left-sided breast cancer. Radiat. Oncol. 16 (1), 1–11.

Zhang, Y., Fu, W., Brandner, E., Percinsky, S., Moran, M., Huq, M.S., 2024. Minimizing normal tissue low dose bath for left breast Volumetric Modulated Arc Therapy (VMAT) using jaw offset. J. Appl. Clin. Med. Phys. 25, e14365. https://doi.org/10.1002/acm2.14365.

Zhou, Dejun, Nakamura, Mitsuhiro, Sawada, Yohei, Ono, Tomohiro, Hirashima, Hideaki, Iramina, Hiraku, Adachi, Takanori, Fujimoto, Takahiro, Mizowaki, Takashi, 2023. Development of independent dose verification plugin using eclipse scripting API for brachytherapy. J. Radiat. Res. 64 (1), 180–185. https://doi.org/10.1093/jrr/rrac063.