Automated Whole-Breast Radiotherapy Planning for a Ring-Gantry Accelerator (Halcyon) - a Feasibility Study

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2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Purpose: The aim of this study was to assess the feasibility of automated left-sided whole-breast radiotherapy planning for Halcyon (Siemens Healthineers), and to evaluate plan quality against national clinical guidelines.

Methods: Using the Eclipse Scripting API (Siemens Healthineers), automated workflows were developed to generate whole-breast treatment plans on Halcyon based on the FAST-Forward fractionation (5fx × 5.2Gy). The plans comprised of two tangential IMRT-fields and two short (30/40°) VMAT-arcs. As part of the automated workflow, gantry angles were optimized to minimize beams-eye-view overlap between the PTV and organs at risk. The pipeline further automated application of skin flash to the IMRT-fields and assignment of optimization objectives. Optimization was performed sequentially, using the IMRT plan (≈85-95% of the total dose) as the base plan for VMAT optimization. A large IMRT proportion and short arcs limited the irradiated volume. Three patient CT datasets in deep inspiration were used to evaluate the automated workflow. Treatment plan quality was evaluated against the national breast radiotherapy protocol, which is more conservative than the original trial protocol, and robustness of target dose coverage ($D_{98\%}$≥95%) was assessed with respect to setup uncertainties (5mm).

Results: The main steps in the generation of hybrid IMRT/VMAT plans were successfully automated. All plans fulfilled the constraints of the clinical protocol. For all plans, $V_{1.3\,Gy}$ for the heart was below 20% and $V_{7.8Gy}$ for the lung was below 15%. All plans were robust to the simulated uncertainties.

Conclusion: Automated whole-breast radiotherapy planning for Halcyon was feasible and yielded high-quality plans, demonstrating proof of concept. Fullend-to-end automation was limited by the absence of proprietary, scriptable Eclipse functionalities, requiring manual creation of VMAT-arcs and assignment of base-plan and heart no-entry/exit constraints. The forthcoming study will include additional enhancements, an expanded patient cohort and pairwise comparisons with alternative planning strategies.

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INTRODUCTION

Standardized breast cancer radiotherapy planning is well suited to automation, offering the potential to reduce planning time and variability. However, anatomical differences, motion management requirements, and increasingly complex treatment techniques continue to challenge plan quality and robustness.

Hybrid approaches that combine tangential 3DCRT with limited IMRT or VMAT have been introduced to improve target coverage and dose conformity while preserving the low-dose benefits of conventional tangential techniques[1].

Halcyon (Siemens Healthineers) is a fast, ring-based treatment system with advanced image-guidance capabilities. However, its single 6 MV FFF beam energy can make it challenging to achieve uniform and conformal 3DCRT dose distributions.[2]

This study assessed the feasibility of automated left-sided whole-breast radiotherapy planning on Halcyon and evaluated plan quality against national clinical guidelines.

METHODS AND MATERIALS

Using the Eclipse Scripting API (Siemens Healthineers), automated workflows were developed to generate whole-breast treatment plans on Halcyon according to the FAST-Forward fractionation regimen (5 fractions × 5.2 Gy).

Treatment plans generated for 10 deep-inspiration breath-hold patient cases were evaluated against the FAST-Forward planning package, with additional national criteria for CTV/PTV coverage. Furthermore, robustness to setup uncertainties was assessed for the CTV using 5 mm isocenter shifts, with an acceptance criterion of $D_{98\%} \geq 95\%$.

The automated workflow consisted of the following steps:

Step 1. Add couch structure
Halcyon couch structures were inserted and positioned using the value from the Couch Vrt DICOM tag which is retrievable using an SQL query.

Step 2. Determine isocenter
The isocenter was initially positioned at the center of the CTV and subsequently shifted diagonally (medially and dorsally) within the image plane until its distances to the body and couch surfaces were both less than 45 cm, to avoid gantry collisions.

Step 3. Optimize angles for IMRT beams
Two opposing beams were created, and the gantry angles were optimized to minimize overlap between PTV and organs at risk (OARs) in the beam's-eye view, using weighting factors that were five times higher for the heart and contralateral breast (only anterior field) than for the lungs.

An additional 5 mm anterior margin was added to the contralateral breast. Figure 1 illustrates the method to find optimal angles.

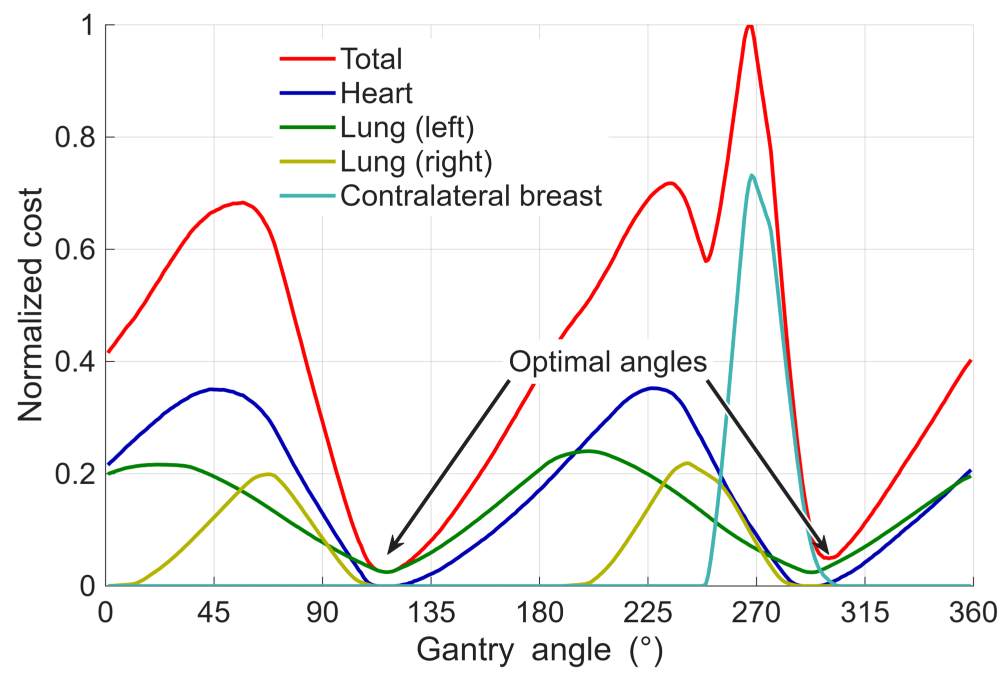

Figure 1. Illustration of the cost-function–based optimization method used to determine the optimal beam angles.

Step 4. IMRT optimization and skin flash
Fluence maps were optimized to achieve approximately 85% coverage of the PTV, while constraining the maximum dose to approximately 95% and minimizing dose to the lung to the extent reasonably achievable. Following optimization, the fluence maps were expanded by 1.5 cm laterally (X direction) and 1.0 cm caudally (Y direction). This expansion was applied to account for positioning uncertainties and potential anatomical changes such as swelling. Any fluence extending into the heart contour was removed. The steps are illustrated in Figure 2.

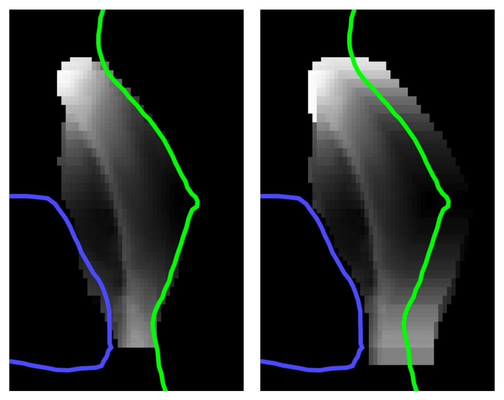

Figure 2. Fluence after optimization (left) and after skin flash and heart-directed fluence removed (right)

Step 5. VMAT optimization
The IMRT plan was selected as the base plan. The start and stop angles for the two short VMAT arcs were determined from the previously optimized angles according to Figure 3.

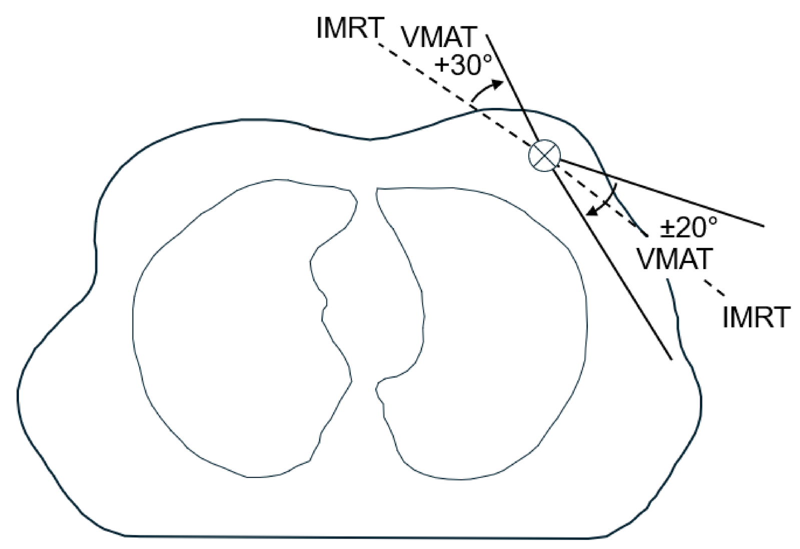

Figure 3. Beam arrangement

Objectives were chosen to achieve a uniform dose distribution within the PTV while reducing the dose to the heart and lung.

Step 6. Combine to a hybrid plan
The IMRT fluences were copied to the VMAT plan, and leaf motions were calculated to create the hybrid plan consisting of two IMRT beams and two short VMAT arcs.

RESULTS

The treatment planning workflow was successfully automated. Of the 10 generated plans, 8 met all criteria of the treatment protocol. In one case, the maximum dose to the PTV slightly exceeded the protocol limit (110.6% vs. 110.0%), while in another case the PTV coverage ($D_{98\%}$) was below the required threshold (91.1% vs. 93.0%). Results for all cases are presented in Figure 4.

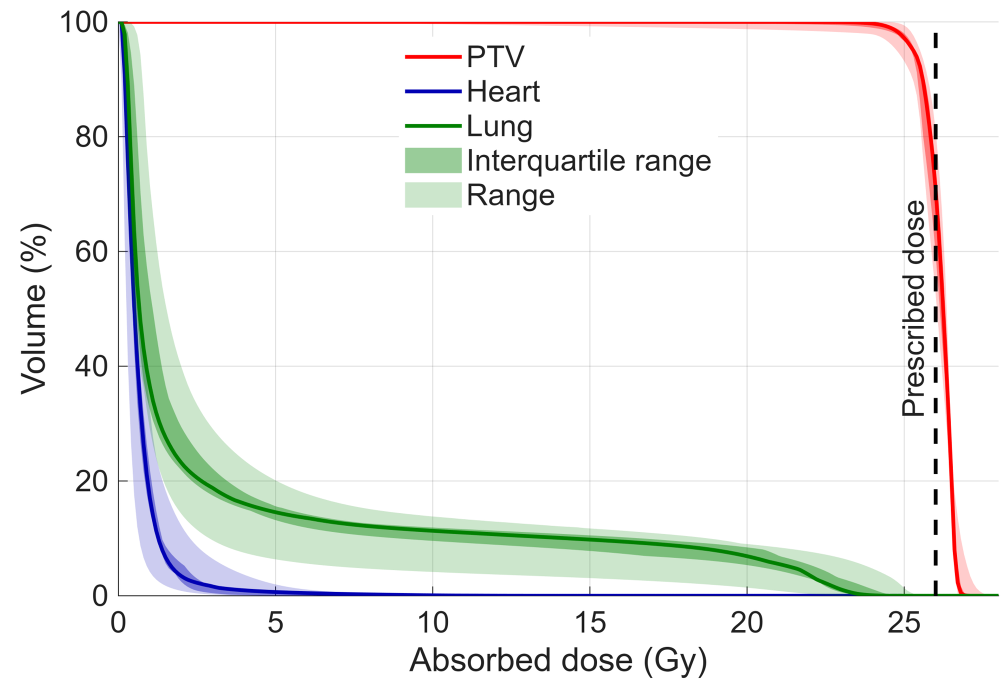

Figure 4. Dose–volume histograms (DVHs) for selected structures, showing the full range and interquartile range across all patient cases. The solid line represents the median DVH.

Only one scenario for a single plan failed to meet the acceptance criterion for CTV robustness ($D_{98\%}$ = 94.7%). All other plans were fully robust to 5 mm isocenter shifts.

DISCUSSION

The vast majority of cases fulfilled all protocol criteria. In the single case where PTV coverage was not achieved, the close proximity of the PTV to the heart limited the ability to obtain full coverage, even with manual planning on a conventional linac.

Any step of the automated process could be manually adjusted, and subsequent steps re-run sequentially to improve plan quality if needed.

Although the Eclipse Scripting API provides the functionality needed to automate the treatment planning process, further dosimetric improvements for the heart might be achievable if it enabled the use of no-entry/no-exit constraints during optimization.

CONCLUSIONS

Automated whole-breast radiotherapy planning for Halcyon using hybrid IMRT/VMAT was feasible and yielded high-quality treatment plans, demonstrating proof of concept.

REFERENCES

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