Evaluating Optimizer and Geometric-Driven Gains in RapidArc Dynamic Breast Plan Quality

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ABSTRACT

Purpose: RapidArc Dynamic (RAD) introduces static-angle modulated ports (STAMPs) and a rotating collimator. It also incorporates a deterministic optimizer. This study aims to evaluate the independent effects of the optimizer versus these additional geometric features on plan quality.
Methods: Thirty retrospective cases treated to the breast/chest wall with regional nodal irradiation to 4005 cGy in 15 fractions were identified. Each case was re-planned with a (1) standard VMAT, (2) RAD-optimized VMAT plan (RADOPT) with no geometric features added, and (3) an unconstrained RAD plan (RADGEO) utilizing four STAMPS, rotating collimator, and static dominant weighting. All plans utilized two arcs and standardized objectives. Plans were normalized to 95% for RAD and 80% for VMAT. Seven organ-at-risk (OAR) DVH metrics and complexity metrics were evaluated.
Results: Hotelling's T2 test was performed and showed statistically significant differences between plan types. Post-hoc analysis shows that all OAR DVH metrics for VMAT were statistically different from both the RAD-optimized and unconstrained RAD plans. Relative to VMAT, RAD-optimized VMAT showed improved OAR sparing including contralateral breast mean dose (227 cGy vs. 274 cGy, –16.9%) and heart mean dose (248 cGy vs. 271 cGy, –8.4%). The unconstrained RAD plans showed further reductions relative to RAD-optimized, particularly in ipsilateral lung mean dose (1013 cGy vs. 1067 cGy, -5.0%) and heart mean dose (204 cGy vs. 248 cGy, -17.8%). Equivalent square length suggested higher aperture complexity in RADGEO plans (but not RADOPT), while aperture area indicated a decrease in aperture size
Conclusion: RAD breast reduces OAR doses when compared to standard VMAT. A portion of the dose reductions is attributable to the RAD optimizer. However, addition of STAMPS and rotating collimator provides further OAR sparing.

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INTRODUCTION

Standard VMAT for comprehensive breast irradiation, particularly when involving regional nodal irradiation (RNI) of the internal mammary (IMN) and supraclavicular nodes, remains one of the most geometrically taxing scenarios in radiation oncology. The concave nature of the target volume—wrapping around the lungs and heart—often necessitates significant dosimetric compromises to maintain OAR dose[1,2]. RapidArc Dynamic (RAD) introduces two primary changes: the RA2Optimize deterministic optimizer and unique geometric features, Static-Angle Modulated Ports (STAMPs) and dynamic collimator rotation. While clinical adoption is growing, it is vital for the medical physics community to understand the source of the gain. This study aims to decouple these novel components, quantifying the independent contributions of algorithmic optimization versus geometric delivery flexibility to determine if superior sparing is a result of better software math or more versatile beam delivery.

METHODS AND MATERIALS

A retrospective cohort of 30 breast cases with RNI (4005 cGy in 15 fractions) was analyzed. Identical objectives were used for each case. To isolate the variables, three distinct plans were generated for each subject using a standardized objective template:

- VMAT: Standard geometry (fixed collimator) utilizing the traditional Photon Optimizer (PO).
- RADOPT: Utilized the RAD RA2Optimize algorithm but restricted to standard VMAT geometry to isolate the optimizer effect.
- RADGEO: Utilized the full RAD tools, including four STAMPs, rotating collimator, and static dominant weighting to evaluate geometric effects. Plans were normalized to cover 95% of target in RAD. In VMAT, plans were normalized cover 80% due to dose heterogeneity. Comparative analysis included seven OAR DVH metrics and modulation complexity indices (MU/cGy, EQSL and Aperture Area).

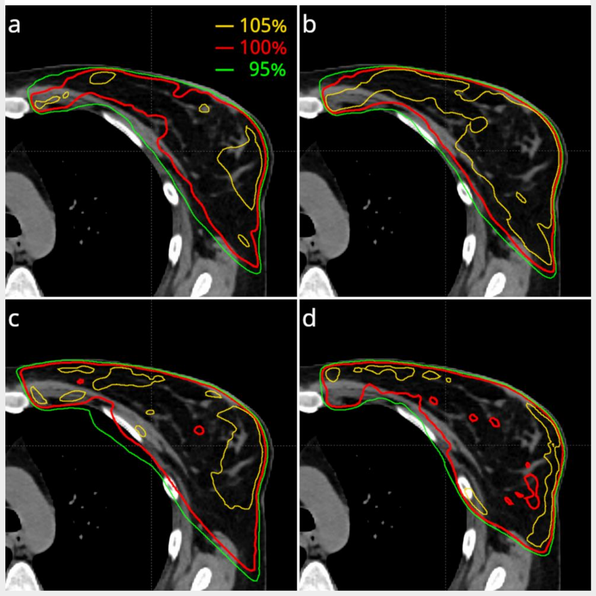

Figure 1: Same isodose lines covering target at (a) 80% with VMAT, (b) 95% VMAT, (c) 95% with RADOPT, and (d) 95% with RADGEO.

RESULTS

Both RAD plans showed better dose conformality and homogeneity (Figure 1).
Global statistical analysis using Hotelling's T^2 test confirmed statistically significant differences across all three plan configurations ($p<0.0001$). Post-hoc analysis is shown in the Table 2 below.

- The Optimizer Contribution (VMAT vs. RADOPT): Utilizing the RA2Optimize algorithm on standard VMAT geometry yielded substantial OAR sparing (Table 1).
- The Geometric Contribution (RADOPT vs. RADGEO): The addition of STAMPs and dynamic collimation provided secondary, directional sparing, most notably in the low-dose regions.

Complexity analysis (Table 3) revealed that RADOPT was not any more complex (based on equivalent square length) than VMAT. However, RADGEO exhibited more complexity. RAD plans utilize significantly smaller apertures (reduced Weighted Average Aperture) progressively from RADOPT to RADGEO. RAD uses higher monitor units per cGy as well. While this increases modulation and provides superior dose gradients, the study indicates that these trade-offs are clinically justified by the marked reduction in integral dose to critical thoracic structures.

Table 1. OAR dose statistics

	Heart	Contralateral Breast
	D_{mean} (cGy)	D_{mean} (cGy)
VMAT	271.0	273.8
RAD_{OPT}	248.4	227.4
RAD_{GEO}	204.1	218.5

	Ipsilateral Lung			Contralateral Lung	
	D_{mean} (cGy)	V_{1600} (%)	V_{400} (%)	D_{mean} (cGy)	V_{400} (%)
VMAT	1124.4	26.6%	70.0%	271.5	21.6%
RAD_{OPT}	1066.7	23.7%	62.7%	215.3	13.6%
RAD_{GEO}	1012.9	23.1%	58.8%	197.0	11.7%

Table 2. Post-hoc simultaneous confidence interval results for OARs.

VMAT vs *RAD_{OPT}*					
Organ	*Metric Type*	*Mean Difference*	*CI Lower*	*CI Upper*	*Adjusted p-value*
Heart	D_{mean} (cGy)	-22.6	-30.8	-14.5	<0.0001
Contralateral Breast	D_{mean} (cGy)	-46.4	-58.6	-34.2	<0.0001
Ipsilateral Lung	D_{mean} (cGy)	-57.7	-87.5	-27.9	<0.0001
	V_{1600} (%)	-2.9%	-3.9%	-1.9%	<0.0001
	V_{400} (%)	-7.2%	-9.3%	-5.2%	<0.0001
Contralateral Lung	D_{mean} (cGy)	-56.2	-69.5	-42.9	<0.0001
	V_{400} (%)	-8.0%	-10.1%	-5.8%	<0.0001
RAD_{OPT} vs *RAD_{GEO}*					
Organ	*Metric Type*	*Mean Difference*	*CI Lower*	*CI Upper*	*Adjusted p-value*
Heart	D_{mean} (cGy)	-44.4	-58.0	-30.7	<0.0001
Contralateral Breast	D_{mean} (cGy)	-8.9	-24.4	6.6	0.4443
Ipsilateral Lung	D_{mean} (cGy)	-51.1	-83.3	-19.0	0.0002
	V_{1600} (%)	-0.7%	-1.5%	0.1%	0.1337
	V_{400} (%)	-4.0%	-6.2%	-1.7%	0.0003
Contralateral Lung	D_{mean} (cGy)	-18.2	-29.4	-7.1	0.0002
	V_{400} (%)	-1.9%	-3.2%	-0.6%	0.0004

Table 3. Plan complexity metrics between plan types

VMAT vs *RAD_{OPT}*			
Metric	*Mean Difference*	*SD of difference*	*Adjusted p-value*
MU/dose ratio	0.81	0.39	<0.0001
EQSL	-0.08	5.86	0.943
WAA	-1621.0	993.3	<0.0001
Beam on time (s)	30.4	11.1	
RAD_{OPT} versus *RAD_{GEO}*			
Metric	*Mean Difference*	*SD of difference*	*Adjusted p-value*
MU/dose ratio	0.75	0.31	<0.001
EQSL	-4.14	4.07	<0.001
WAA	-1433.9	620.1	<0.001
Beam on time (s)	35.5	9.6	

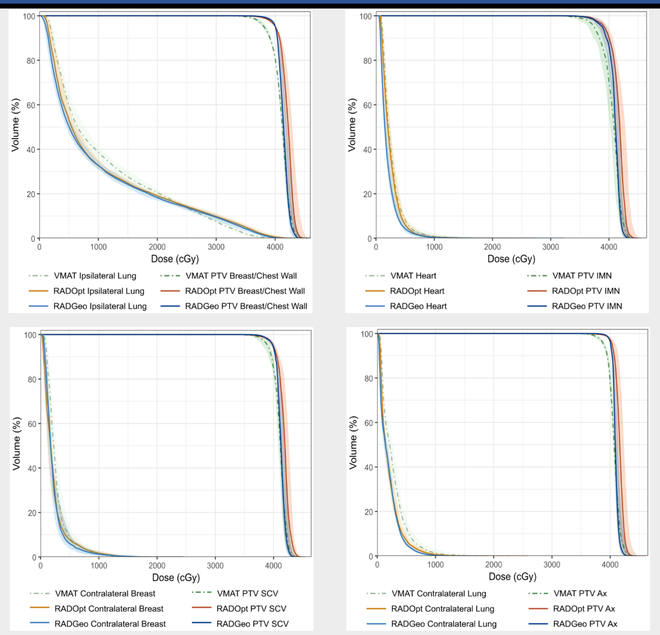

Figure 2:
Population DVH for targets and OARs.

DISCUSSION

The transition to the RA2Optimize deterministic framework represents an algorithmic change over traditional methods. Our RADOPT results showing superior OAR sparing without geometric changes suggest that standard optimizers often stall in local minima when managing the complex, competing objectives of regional nodal irradiation. While the optimizer establishes a stronger global baseline, RapidArc Dynamic (RAD) geometric features provide further precision. STAMPs and dynamic collimation enable directional dose-shaping, creating a steeper dose fall-off at the heart-lung interface. Although RAD plans exhibit higher modulation, the statistically significant reductions in heart and lung dose clinically justify the increased delivery complexity. Ultimately, RAD acts as a hybrid solution: the algorithm improves global distribution, while geometric flexibility provides the mechanical precision to protect healthy tissue.

CONCLUSIONS

RapidArc Dynamic improves OAR sparing and more conformal target coverage for complex breast irradiation compared to standard VMAT. Our findings demonstrate that while the RA2Optimize algorithm is responsible for the majority of the initial dose reductions, the addition of STAMPs and rotating collimators provides critical, clinically significant sparing for the heart and ipsilateral lung. This suggests a hybrid benefit where the optimizer improves global dose distribution, while the geometric features allow for directional sparing of critical structures. These results provide a roadmap for clinical implementation, suggesting that full unconstrained RAD should be the standard for high-complexity nodal cases.

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