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Comprehensive Evaluation of Rapidarc Dynamic for Cervical Cancer with Inguinal Nodal Involvement

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ABSTRACT

Purpose:
Cervical cancer radiotherapy including inguinal lymph nodes involves large and complex targets prone to dose bridging between separated target components and increased dose to organs at risk (OARs), limiting dosimetric optimization. RapidArc Dynamic (RAD) is a VMAT optimization technique incorporating static ports to improve dose control in such target geometries. This study evaluated the utility of RAD compared with a conventional RapidArc technique.

Methods:
Twenty cervical cancer patients requiring inguinal nodal irradiation were replanned under identical prescription conditions (45 Gy in 25 fractions). RAD plans used two asymmetric arcs with the collimator fixed in static mode and eight static ports. A collimator angle of 90° was applied for inguinal nodal blocking, while 25–35° was used for cervix target coverage. Static-port (STAMP) angles were selected based on beam's-eye-view (BEV) and differed between arcs. A conventional 4-arc RapidArc plan and a faked-RAD (fRAD) plan—based on the RapidArc geometric framework with minimized static ports—were included for comparison. Evaluation metrics included PTV coverage, OAR doses, dose bridging suppression, monitor units (MU), optimization and calculation time, and blinded physician preference.

Results:
RAD achieved PTV coverage comparable to RapidArc despite using half the number of arcs. With RAD, V45Gy of the bladder, rectum, and bowel was reduced by approximately 30–60%, and bone marrow V20Gy by 3–4%. PTV hotspots and dose bridging were suppressed. The fRAD approach showed limited improvement compared with RapidArc. Optimization and calculation time was reduced by approximately 37%, and RAD plans were preferred in blinded clinical review. MU remained clinically acceptable.

Conclusion:
RAD provides equivalent target coverage with improved OAR sparing, reduced dose bridging, and enhanced optimization and calculation efficiency using a simplified two-arc geometry. fRAD offers a practical stepwise entry strategy, and RAD represents an effective solution for extended-field VMAT planning with complex targets.

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INTRODUCTION

Radiation therapy for cervical cancer involving inguinal lymph node irradiation is one of the most geometrically demanding treatment sites, characterized by an extensive longitudinal target volume with anatomically separated, non-contiguous structures on axial cross-sections. Conventional RapidArc is increasingly constrained by MLC physical limitations as target volume increases, resulting in insufficient OAR dose suppression and unintended high-dose bridging between spatially separated target volumes across non-target intervening regions. RapidArc Dynamic (RAD) integrates dynamic collimator rotation and static angle modulated ports (STAMPs) into conventional VMAT optimization to maximize dose control for complex target geometries. This study evaluated whether RAD could preserve VMAT-level dose conformity while achieving IMRT-comparable selective OAR sparing in extended-field pelvic irradiation.

METHODS AND MATERIALS

A retrospective dosimetric analysis was performed in 20 cervical cancer patients requiring inguinal lymph node irradiation (prescription: 45 Gy in 25 fractions). All plans were generated in Eclipse v18.1 with the AcurosXB algorithm under identical contours, prescriptions, and clinical constraints, and compared across three groups:

- **RAD**: 2-arc plan using dynamic collimator rotation and static angle modulated ports (4 STAMPs per arc), with STAMP orientation adjusted according to nodal target location, and field geometry adjusted to separately address inguinal nodal and cervical target regions
- **RapidArc**: conventional 4-arc plan generated according to institutional clinical protocol, combining asymmetric and full-field arcs (institutional standard, reference)
- faked-RAD (**fRAD**): a 2-arc plan generated using the same planning approach as conventional RapidArc, with the RAD algorithm applied and a single static port—the minimum required to invoke it—added, designed to isolate the algorithmic contribution of RAD beyond this baseline

Plan quality was assessed by target and OAR DVH parameters, dose bridging suppression between separated targets, planning time, and blinded physician review by radiation oncologists.

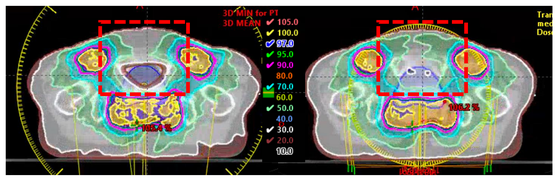

Figure 1. Dose distribution comparison between RAD (left) and conventional RapidArc (right), with magnified views (red dashed boxes) highlighting inter-target dose bridging and OAR dose.

RESULTS

RAD demonstrated approximately 45–60% lower high-dose exposure (V45Gy) to the bladder and rectum, and a reduction in bowel volume receiving high dose, compared with conventional RapidArc, while maintaining clinically acceptable target coverage.
Bone marrow V20Gy was also reduced. PTV D95% was maintained at a level comparable to RapidArc (98% range), demonstrating non-inferior target coverage. Unintended high-dose bridging between spatially separated targets and PTV hotspots were effectively suppressed with RAD.
fRAD showed limited dosimetric improvement over conventional RapidArc, consistent with its minimal static port integration.

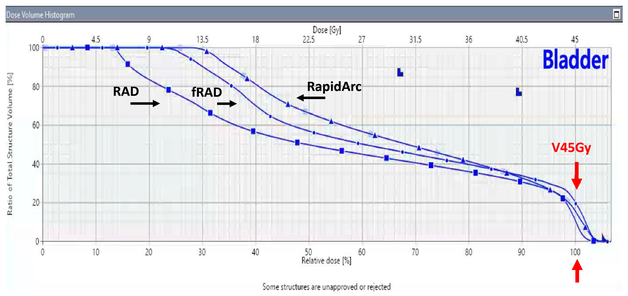

Figure 2. Representative dose-volume histogram (DVH) for an organ at risk (bladder), comparing RAD (filled squares), fRAD (filled circles), and conventional RapidArc (filled triangles).

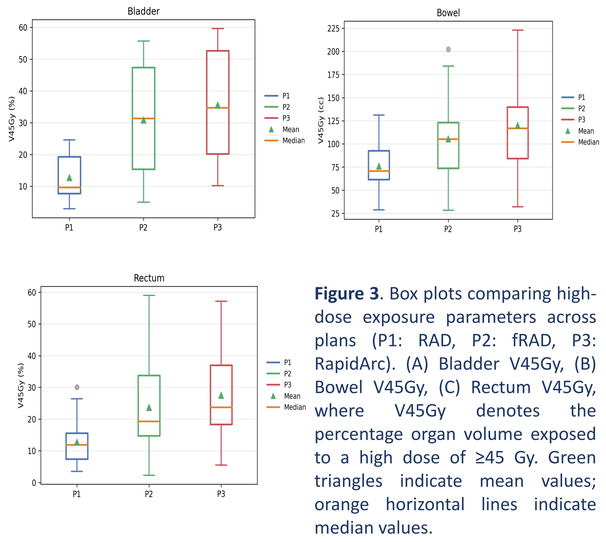

Figure 3. Box plots comparing high-dose exposure parameters across plans (P1: RAD, P2: fRAD, P3: RapidArc). (A) Bladder V45Gy, (B) Bowel V45Gy, (C) Rectum V45Gy, where V45Gy denotes the percentage organ volume exposed to a high dose of ≥45 Gy. Green triangles indicate mean values; orange horizontal lines indicate median values.

In a blinded evaluation by radiation oncologists, RAD was selected as the first-choice plan in the large majority of cases (Combined Top1: 92.5%), citing superior high-dose OAR sparing and hotspot control . RO1 selected RAD in 90.0% of cases, RapidArc in 0.0%, and fRAD in 10.0%; RO2 selected RAD in 95.0%, RapidArc in 5.0%, and fRAD in 0.0%.

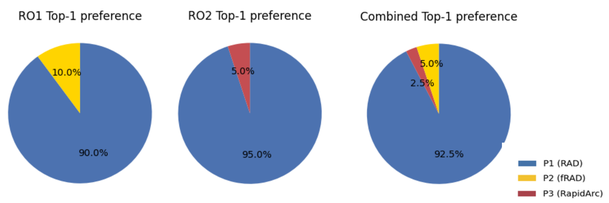

Figure 4. Blinded radiation oncologists Plan Preference (RO1, RO2, and Combined)

RAD also reduced total planning time by approximately 37% compared with RapidArc (4 min 15 s vs. 6 min 45 s).

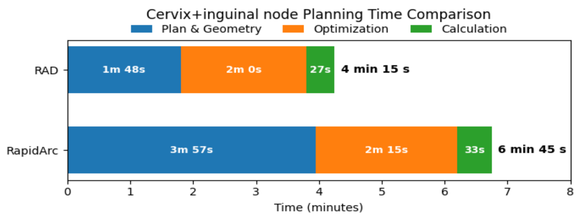

Figure 5. Comparison of planning time between RAD (top) and conventional RapidArc (bottom), shown as stacked horizontal bar graphs. Blue: plan and geometry setup time; orange: optimization time; green: calculation time.

DISCUSSION

RAD combines a simplified 2-arc geometry with strategically placed static ports (STAMP) to achieve selective OAR protection comparable to IMRT, while preserving VMAT-level target coverage. The technique effectively suppresses high-dose bridging across spatially separated target volumes — a key limitation of conventional VMAT in complex pelvic geometries.
For bulky, centrally located disease, RAD's dosimetric benefit was less pronounced than for peripheral or spatially separated targets, though it still improved planning efficiency.
Although fRAD's dosimetric gains were limited, its minimal static port requirement keeps the learning curve low, making it a reasonable starting point for centers new to RAD before transitioning to the full technique.

CONCLUSIONS

RAD maintained clinically acceptable target coverage while achieving approximately 45–60% reduction in high-dose exposure to the bladder, rectum, and bowel, and suppression of inter-target dose bridging, compared with conventional RapidArc. Bone marrow exposure was also reduced, and PTV hotspots were effectively controlled, indicating that the dosimetric benefit of RAD extends across multiple OARs rather than a single endpoint. RAD was strongly preferred by radiation oncologists in blinded review, and also reduced total planning time by approximately 37%, reflecting gains in both plan quality and workflow efficiency. fRAD remains a practical entry option despite its limited dosimetric gains, offering centers a lower-barrier route toward eventual RAD adoption. These results suggest that RAD, by combining VMAT conformality with IMRT-like selective modulation, represents a practical and clinically feasible planning strategy for extended-field pelvic targets with complex, spatially separated geometry.

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