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A Cost-Effective End-to-End Credentialing Test for Simulation-Omitted Direct-to-Unit Adaptive Radiotherapy

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ABSTRACT

Direct-to-Unit (Simulation-omitted) adaptive radiotherapy (ART) enables same-day treatment by generating treatment plans from diagnostic images, eliminating the need for computed tomography (CT) simulation.

These workflows rely on online plan re-optimization to account for anatomical, CT-number, and setup variations. However, no standardized end-to-end (E2E) credentialing protocol currently exists to validate the accuracy of Direct-to-Unit ART. Although customized ART phantoms are available, they are often costly and impractical onetime commissioning.

To address this gap, we developed a low-cost E2E credentialling framework using a commercially available CIRS ZEUS phantom to verify workflow accuracy while minimizing financial burden.

INTRODUCTION

Direct-to-Unit (DTU), or simulation-omitted, radiotherapy enables treatment planning directly from diagnostic imaging, eliminating the need for a dedicated CT simulation and facilitating same-day consultation and treatment for time-sensitive patients. Unlike conventional online adaptive radiotherapy (oART), where adaptation begins from a simulation CT, DTU workflows rely on diagnostic images and therefore introduce additional uncertainty in anatomy, CT calibration, and patient setup. ART platforms address these differences through online plan re-optimization, making robust adaptation essential for safe DTU implementation.

Because DTU incorporates uncertainties beyond those encountered in conventional oART, commissioning must validate not only dose delivery but also the adaptive process itself under clinically realistic variations in anatomy, CT numbers, and patient positioning. Although AAPM recommends end-to-end (E2E) commissioning for new clinical workflows, no standardized credentialing protocol or commercially available commissioning tool currently exists for DTU ART. Existing adaptive radiotherapy phantoms are often prohibitively expensive for onetime commissioning, creating a need for a practical and reproducible alternative.

To address this gap, we developed a cost-effective E2E commissioning framework using the commercially available CIRS ZEUS phantom. The proposed method enables comprehensive verification of DTU workflows without specialized hardware and is applicable to both CBCT-guided ART with direct CBCT dose calculation and MR-guided adaptive radiotherapy using density override–based dose calculation, supporting reproducible implementation across adaptive treatment platforms.

METHODS AND MATERIALS

End-to-end (E2E) commissioning was performed on Varian Ethos 2.0 and Elekta Unity adaptive radiotherapy systems using a commercially available CIRS ZEUS phantom equipped for ionization chamber and radiochromic film measurements. Digitally deformed phantom datasets were generated to emulate clinically realistic and stress-test anatomical variations between diagnostic imaging and treatment-day anatomy. IMRT pre-plans were created on both platforms and delivered using online adaptive workflows. Six adaptive treatment fractions were delivered per platform. Point-dose measurements were compared with treatment planning system calculations, while planar dose distributions were evaluated using radiochromic film and global gamma analysis to assess dosimetric accuracy.

RESULTS

Point-dose verification was performed at the planning target volume (PTV), liver, and spinal cord. All measured point doses agreed with treatment planning system calculations within 3% for high-dose regions or 3 cGy for low-dose regions. Planar dose verification using radiochromic film demonstrated excellent agreement between measured and calculated dose distributions. All film measurements achieved gamma pass rates greater than 90% using the 3%/3 mm acceptance criterion, with pass rates exceeding 98% using the more stringent 5%/3 mm criterion, surpassing the Imaging and Radiation Oncology Core (IROC) credentialing benchmark, demonstrating the robustness and reproducibility of the proposed E2E commissioning framework across both adaptive radiotherapy platforms.

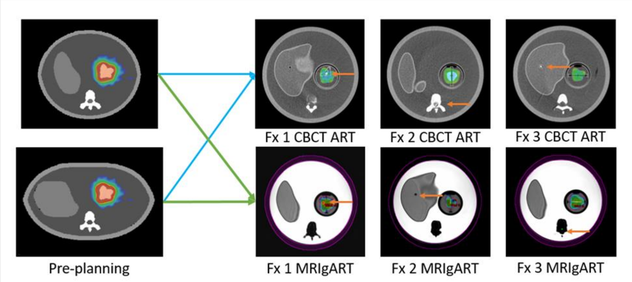

Figure 1. Three-fraction (Fx) E2E commissioning scheme for Ethos and Unity MR-Linac adaptive deliveries using minor- and large-deformation pre-plans. Orange arrows indicate point-dose locations; Fraction 1 measures target dose, and subsequent fractions measure organs of interest point doses with planar films.

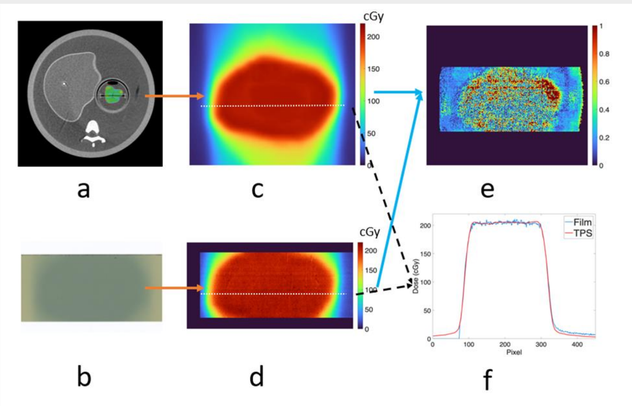

Figure 2. a) A CBCT ART plan with film in coronal orientation. b) Exposed film. c) TPS dose plane. d) Film planar dose. e) Gamma map between (c) and (d) with 3%/3 mm criterion. f) Exemplary line profiles from (c) and (d) (white dotted line).

Table 1. Point Dose and Planar Film Dose measurements

		Point Dose measurements				Film planar dose measurements		
	Fraction #	Ionization chamber location	TPS Dose (cGy)	Measured Dose (cGy)	Difference (cGy)	Film orientation	3%/3 mm pass rate (%)	5%/3 mm pass rate (%)
Minor Deformation	1 CBCT ART	PTV	205	201.2	−3.8	N/A		
	2 CBCT ART	Spinal Cord	29	30.1	1.1	Sagittal	91.1	98.3
	3 CBCT ART	Liver	35	37.2	2.2	Coronal	95.5	99.4
Large Deformation	1 CBCT ART	PTV	203	203.9	0.9	N/A		
	2 CBCT ART	Spinal Cord	30	30.1	0.1	Sagittal	93.3	98.9
	3 CBCT ART	Liver	35	35.9	0.9	Coronal	96.5	98.1
Minor Deformation	1 MRIgART	PTV	212.1	215.2	3.1	N/A		
	2 MRIgART	Liver	49.6	52	2.4	Sagittal	95.0	99.4
	3 MRIgART	Spinal Cord	15.8	17	1.2	Coronal	92.3	99.2
Large Deformation	1 MRIgART	PTV	214.3	214.7	0.4	N/A		
	2 MRIgART	Liver	28.7	30	1.3	Sagittal	90.8	98.8
	3 MRIgART	Spinal Cord	15	16	1.0	Coronal	90.8	99.0

DISCUSSION

This study presents a practical and scalable end-to-end (E2E) commissioning framework for Direct-to-Unit (DTU) adaptive radiotherapy by combining digitally deformed pre-planning phantoms with a commercially available anthropomorphic phantom. The proposed methodology provides a realistic yet controlled means of evaluating adaptive workflows under anatomical and setup variations encountered in simulation-omitted treatments.

Beyond verifying dosimetric accuracy, the framework identified workflow-specific failure modes, including CBCT truncation, suboptimal isocenter placement, and inadequate beam arrangements, demonstrating that E2E commissioning can reveal implementation issues not readily detected through conventional machine acceptance testing or patient-specific quality assurance. These findings emphasize the importance of optimizing beam geometry, planning templates, patient positioning, and imaging field of view to ensure robust DTU implementation.

Although demonstrated using a thoracic configuration, the framework is designed as a commissioning methodology rather than a site-specific solution. Institutions can adapt the digital phantom to their own DTU workflow while preserving the same commissioning principles. Furthermore, incorporation of customizable 3D-printed inserts enables simulation of site-specific anatomical heterogeneity and treatment complexity, allowing systematic stress testing across disease sites. Because the workflow relies on the widely available ZEUS phantom and standard film and ionization chamber measurements, it is readily implementable without specialized hardware. This accessible and modular design supports cross-institutional reproducibility and provides a scalable foundation for standardized commissioning and safe clinical adoption of DTU adaptive radiotherapy.

CONCLUSIONS

This work establishes a practical, low-cost credentialing methodology for Direct-to-Unit ART workflows. The approach verifies accurate online re-optimization and dose delivery, enabling safe clinical implementation and potential cross-institutional standardization.

REFERENCES

1. Wang, D., Visak, J., Domal, S., Tong, Z., Iakovenko, V., Chiu, T., ... & Lin, M. H. (2026). Development of a cost-effective end-to-end commissioning test for simulation-omitted direct-to-unit adaptive radiotherapy. Physics and Imaging in Radiation Oncology, 101028.

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