

Extending Beam Gating Quality Assurance in MR-Guided Radiotherapy: Multi-Plane Gating and Motion-Dependent Evaluation on a 0.35 T MR-Linac

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INTRODUCTION

- MR-guided radiotherapy (MRgRT) uses real-time imaging and beam gating to improve treatment accuracy for moving targets
- Current beam-gating QA protocols do not fully address common clinical practices, highlighting the need for more comprehensive quality assurance

STUDY OBJECTIVE

- Develop and validate four clinically relevant beam-gating QA tests to address the gap between current QA protocols and standard clinical workflows
- Evaluate multi-plane gating and motion-dependent target tracking to determine suitability for monthly and annual QA on a 0.35T MR-LINAC

METHODS/MATERIALS

- A 0.35 T MR-Linac and MRI-compatible motion phantom with static, moving, and deformable target inserts were used to evaluate beam-gating performance.
- Delivered dose during motion was quantified by comparing collected ion chamber charge with static measurements using percent difference.



Figure 1: MRIdian ViewRay 0.35T MR-Linac at Washington University in St. Louis

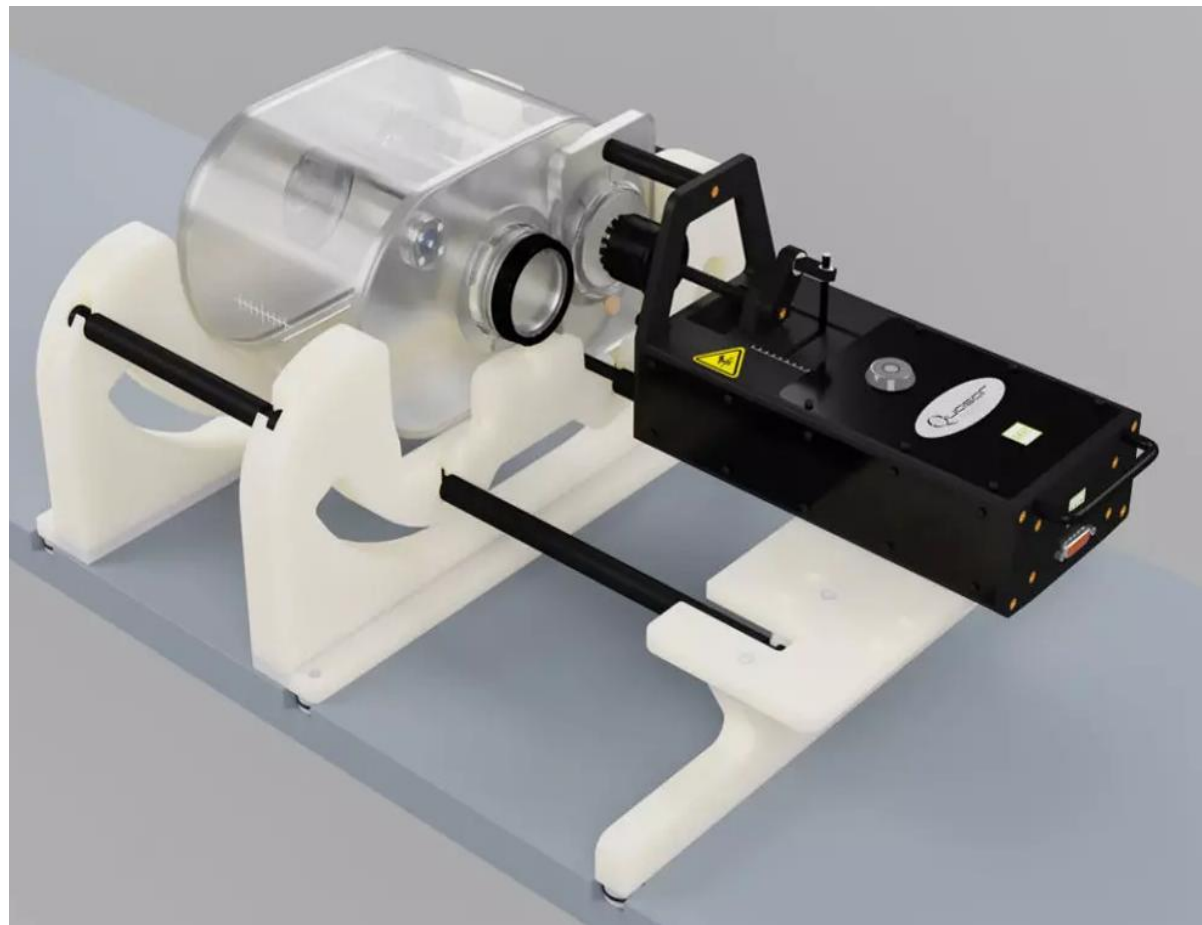


Figure 2: MRI4D QUASAR Motion Phantom, IBA Dosimetry. Motion drivers attach to inserts with internal tracking targets. Allows for adjustments of target position, target speed, amplitude, waveform type

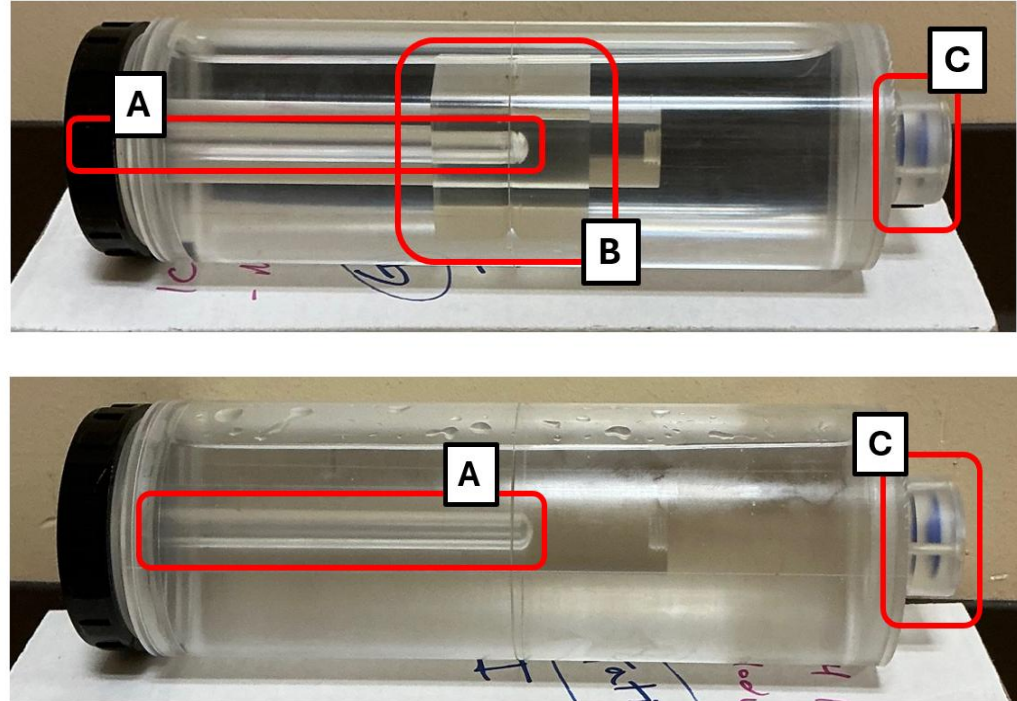


Figure 3: MRI4D QUASAR Motion Phantom Inserts. Top(A) is the central cavity for an ion chamber, (B) is the cuboidal imaging target, (C) is the insert attachment point to the motion driver.

Current Beam-Gating QA Protocol

- Current beam-gating QA protocols rely on single-plane imaging and consistent sinusoidal phantom motion
- Does not evaluate clinically relevant target anomalies, such as deformation, rotation, or irregular respiratory motion

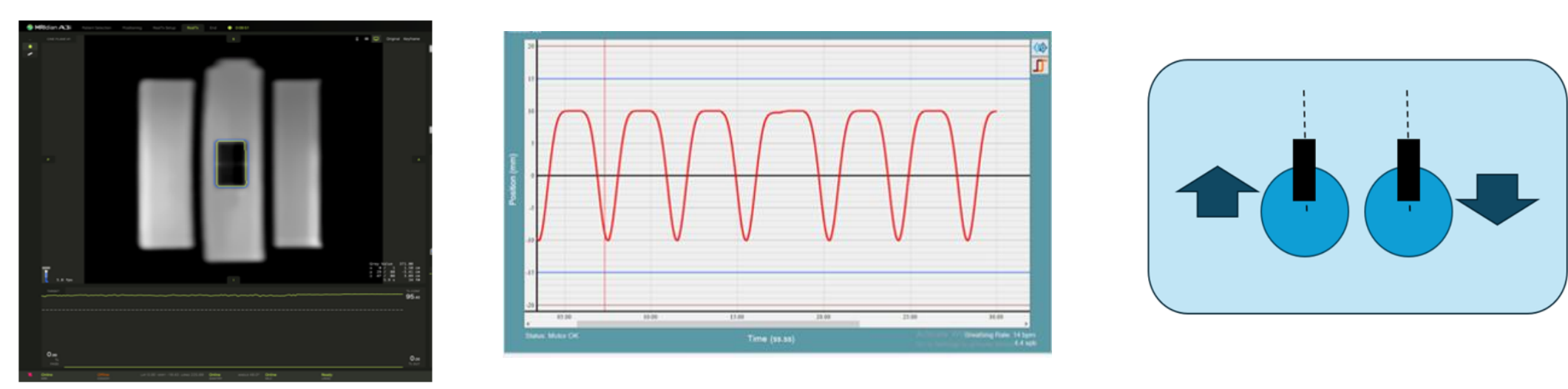


Figure 4: Current MR-Linac beam-gating QA parameters; (L to R) QUASAR motion phantom seen one viewing plane; sinusoidal waveform mimicking ideal respiration; diagram depicting non-rotating phantom

QA EXPANSION

Proposed Protocols

Multi-Plane Gating Test

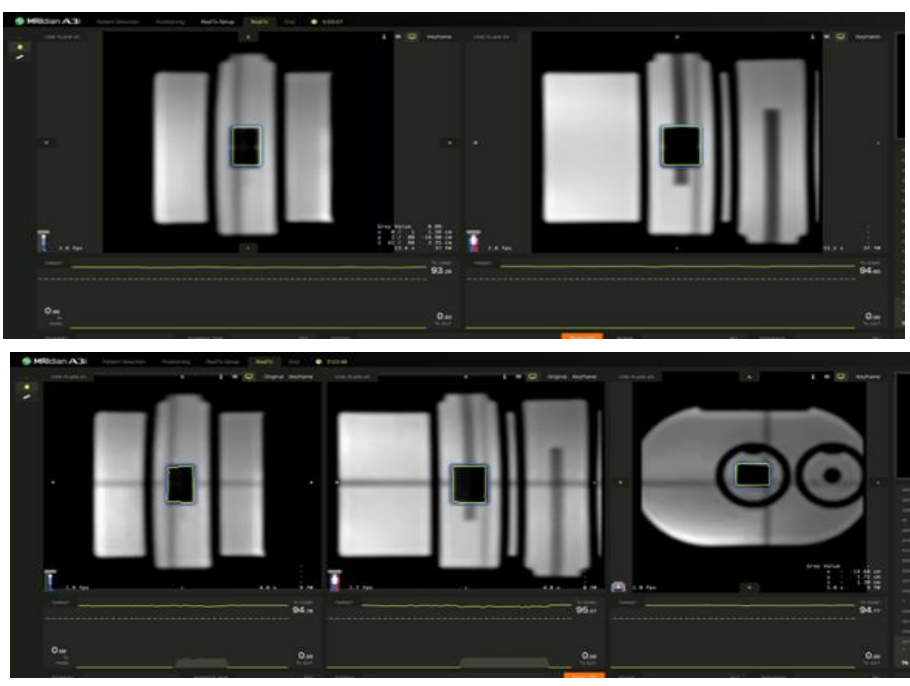


Figure 5: Examples of phantom as seen in multiple viewing planes. Top: Dual plane gating test, sagittal and coronal views. Bottom: Triple plane gating test, sagittal, coronal, and axial views

Irregular Motion Test

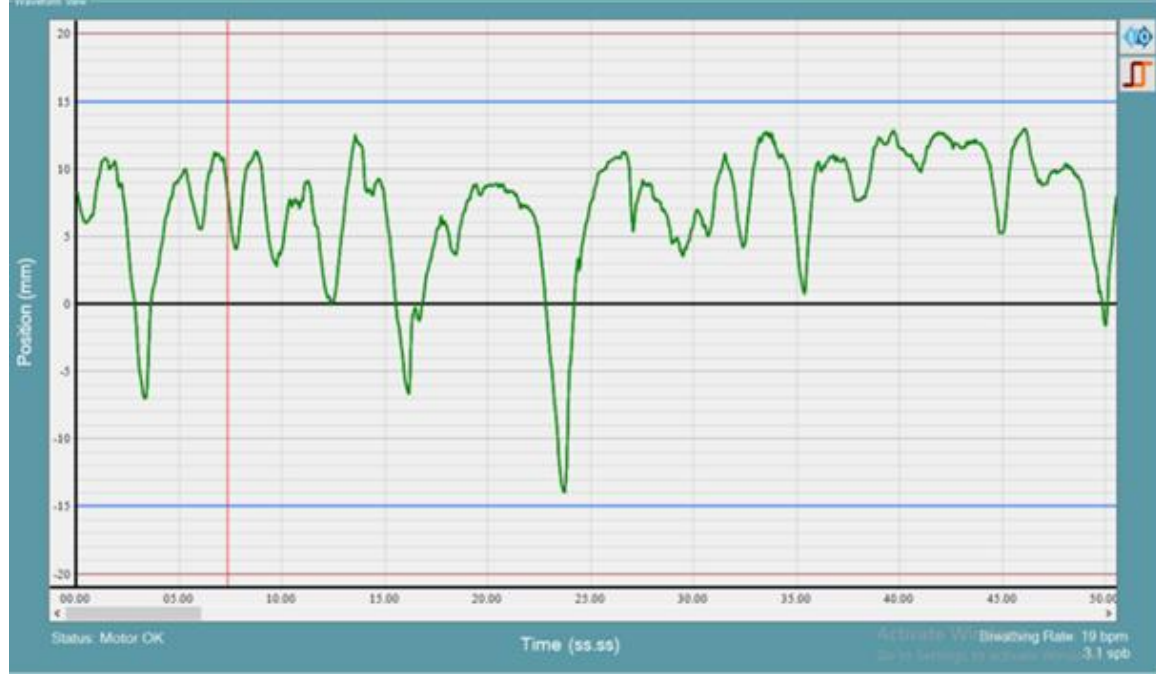


Figure 6: Sample waveform used in irregular motion test simulating irregular patient respiration. The motion driver is programmed to push the inserts in and out of the phantom according to the waveform.

Rotational Motion Test

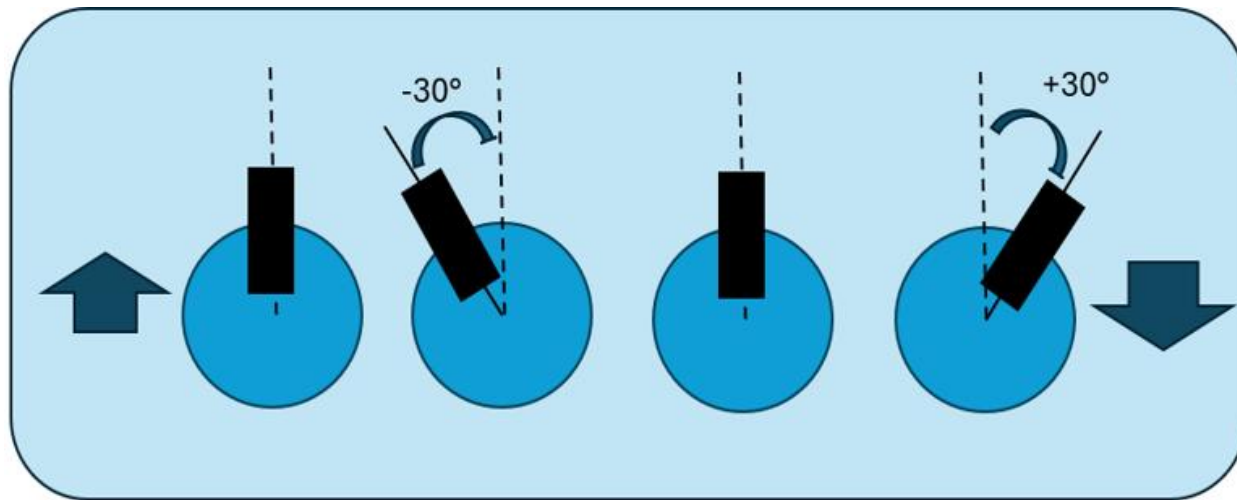


Figure 7: Diagram depicting rotational motion of moving insert. In addition to translational motion, the insert rotates 30° about the central axis to validate beam gating functionality in the presence of a rotating target

Deformable Target and Algorithm Test

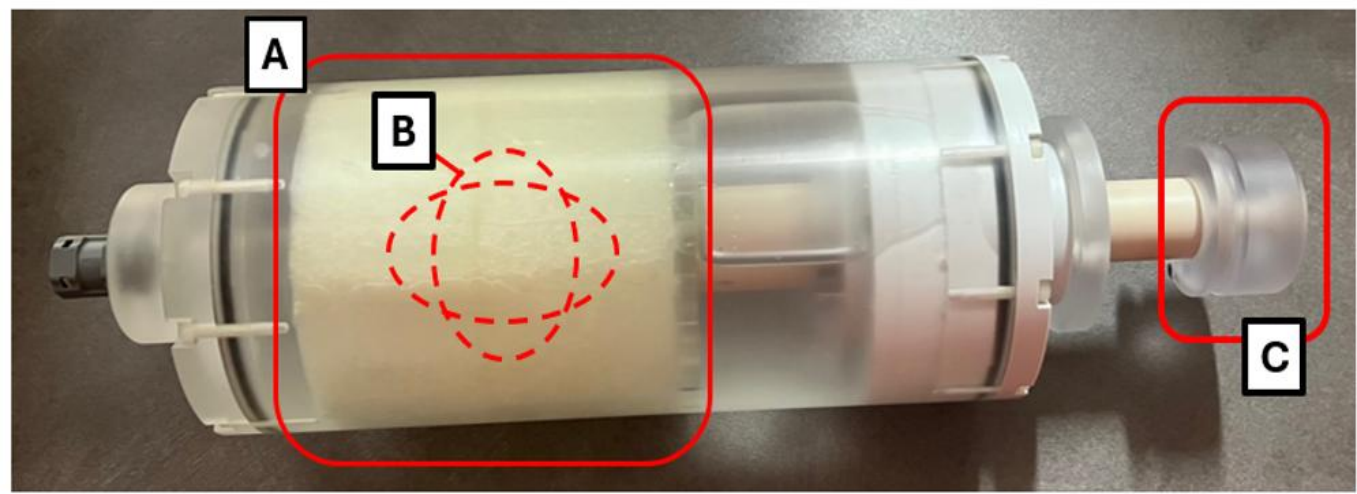


Figure 8: Deformable Target Insert. (A) sponge-like material that deforms with compression, (B) central imaging target; dashed lines indicate possible shapes in response to compression, (C) insert attachment point to motion driver

Justification

- Multi-plane gating is a standard clinical workflow
- Improves target and OAR visualization when structures are obscured in a single imaging plane

- Irregular respiratory motion is a common clinical scenario
- May affect beam-gating accuracy and dosimetric performance

- Reported target rotations of up to 30°
- Results in dosimetric differences
- motivates evaluation of tracking performance under abnormal motion conditions

- Variations in respiratory-induced target deformation influences tracking algorithm accuracy
- Tracking algorithm selection based on patient anatomy is a standard clinical workflow

RESULTS

- Validation performed by comparing gated dose measurements under motion to a static baseline using an ionization chamber.
- Performance evaluated under single- and dual-plane imaging against the AAPM TG-142 beam-gating tolerance ($\pm 2\%$).

imaging planes	single	dual	triple
cuboidal target			
multi-plane gating test	0.1%	0.6%	1.6%
irregular motion test	0.5%	1.1%	
rotational motion test	0.2%	n/a	
deformable target			
rigid target algorithm	1.5%	n/a	
deformable target algorithm	1.2%	1.2%	

Table 1: Validation of the clinical feasibility of proposed QA tests. All deliverable plans demonstrated a percent difference of $<2\%$ compared with static chamber measurements, meeting the AAPM TG-142 tolerance. The dual-plane gating rotational motion test could not be completed on the MRIdian ViewRay due to internal system errors. For dual-plane gating with a deformable target insert, the rigid target tracking algorithm was unable to maintain sufficient tracking confidence for effective beam gating.

SUMMARY/CONCLUSION

- We recommend the addition of multi-plane beam-gating tests into monthly QA to address a key gap in current clinical QA workflows.
- We recommend the addition of irregular, rotational, deformable target, and deformable tracking algorithm evaluations during annual QA to balance clinical value and workload.
- All proposed QA tests met the AAPM TG-142 dosimetric tolerance ($\leq 2\%$).
- The proposed QA framework expands MR-guided radiotherapy QA by evaluating motion management and deformable tracking performance beyond conventional QA practices.

Justified need for and validated:
Multi-Plane Gating Test
Irregular Motion Test
Rotational Motion Test
Deformable Target and Algorithm Test

REFERENCES

1. Klein EE, Hanley J, Bayouth J, Yin FF, Simon W, Dresser S, et al. Task Group 142 report: Quality assurance of medical accelerators. *Med Phys*. 2009;36(9):4197–4212. doi:10.1118/1.3190392.

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