Practical Implementation of Multi-Target Winston-Lutz Testing Using the QUASAR Penta-Guide Phantom

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Introduction

- Accurate coincidence of radiation, mechanical, and imaging isocenters is critical for stereotactic radiotherapy. Conventional single-target Winston-Lutz testing is primarily an isocentric test and does not test off-axis target localization and accuracy.
- Multi-target Winston-Lutz (MTWL) testing can address this limitation, but clinical adoption is limited by the need for dedicated phantoms, additional acquisitions, or specialized analysis workflows.
- We developed a practical MTWL workflow using the clinically available QUASAR Penta-Guide phantom[1] and automated EPID-based analysis.

Can Multi-Target Winston-Lutz QA characterize off-axis accuracy using a clinically accessible phantom?

Methods

- Measurements were performed on a Varian TrueBeam EDGE using the QUASAR Penta-Guide phantom. Two hollow spherical targets were analyzed: the central isocenter sphere and one off-axis sphere located 7.48 cm from isocenter. Each MTWL dataset consist of nine EPID images acquired with 10 MV FFF. Each image delivered two 3 × 3 cm² MLC-defined field-in-field apertures within a single acquisition. Beam parameters were defined to bisect both targets[2].
- Image analysis used a modified Pylinac workflow. The pipeline preprocesses the EPID images and uses a circular Hough transform to localize the central and off-axis sphere projections.
- Validation used controlled couch shifts from −1 to +1 mm in lateral, longitudinal, and vertical directions. Measured MTWL offsets were compared with imposed couch translations.

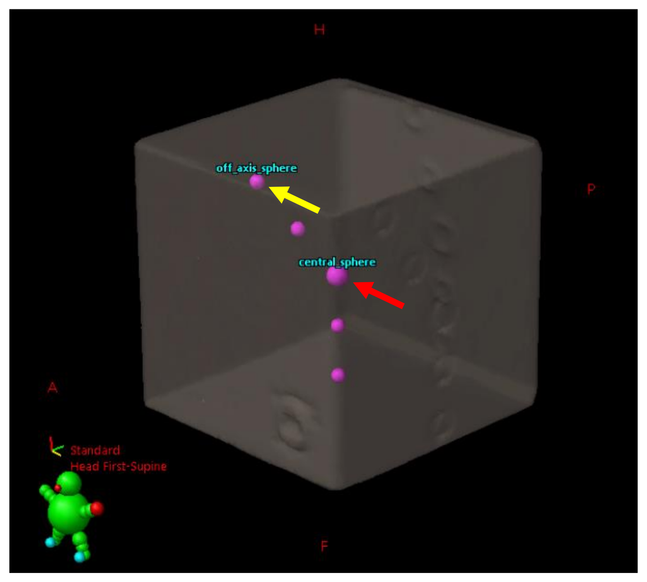

Figure 1. QUASAR Penta-Guide geometry used for MTWL. We analyzed the central isocenter sphere (red arrow) and an off-axis sphere (yellow arrow) located 7.48 cm from isocenter.

Results

- The MTWL workflow successfully detected both central and off-axis targets in all analyzed datasets. In controlled-shift validation, 28 measurement sessions were analyzed. Across the tested ±1 mm range, measured displacements showed excellent agreement. Maximum 3D error of 0.193 mm.

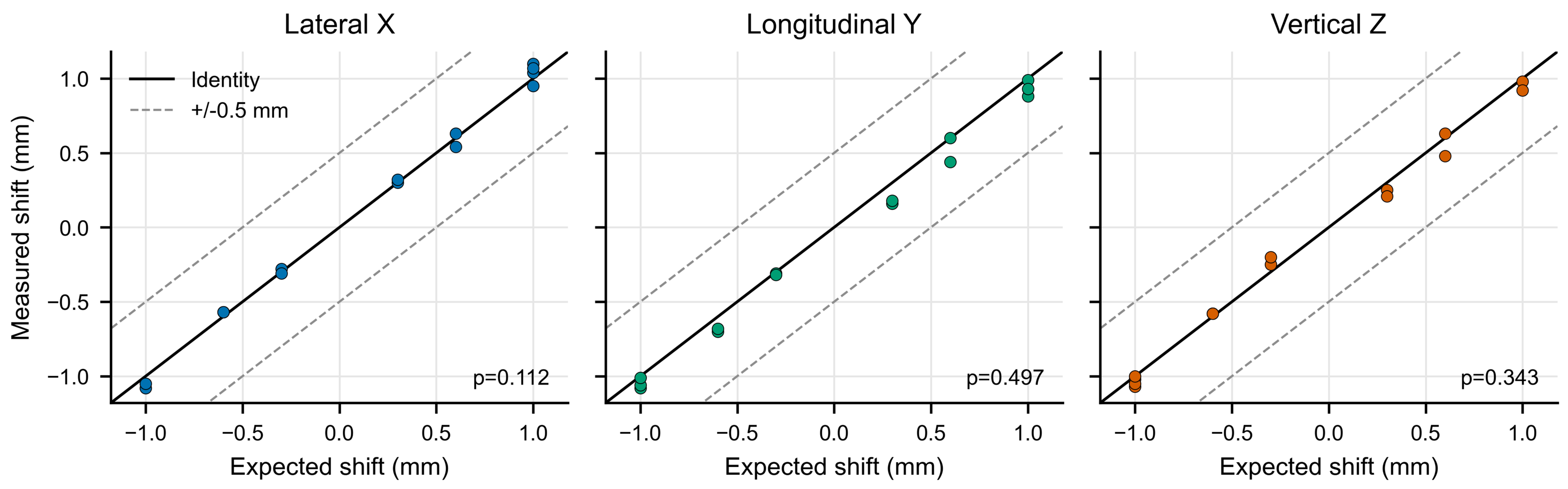

Figure 2. Controlled-shift validation. MTWL-measured shifts calculated using both spheres agreed with imposed couch translations across X, Y, and Z.

	Mean signed error (mm)	Mean absolute error (mm)	SD signed error (mm)	RMSE (mm)	Median absolute error (mm)	Maximum absolute error (mm)	p-value
Lateral X	0.004	0.038	0.047	0.047	0.03	0.1	0.112
Longitudinal Y	-0.074	0.074	0.056	0.092	0.065	0.17	0.497
Vertical Z	-0.024	0.041	0.049	0.054	0.03	0.12	0.343
All axes combined	-0.031	0.051	0.06	0.067	0.04	0.17	
3D vector error magnitude		0.107	0.048	0.117	0.105	0.193	

Table 1. Controlled-shift validation results.

- Clinical QA measurements showed that MTWL preserved conventional central-target performance while adding off-axis assessment. MTWL central results were statistically indistinguishable from STWL central results, while off-axis measurements were larger.
- Additional beam time was +190.5 seconds when compared to conventional Winston-Lutz.

	Mean maximum 2D field-to-sphere distance (mm)	SD (mm)	Median (mm)	Interquartile range (mm)	Maximum (mm)
STWL central	0.625	0.126	0.622	0.534 – 0.707	0.937
MTWL central	0.631	0.136	0.637	0.529 – 0.717	0.932
MTWL off-axis	0.834	0.138	0.812	0.729 – 0.963	1.067
MTWL off-axis - central	0.203	0.196	0.170	0.082 – 0.319	0.588

Table 2. Routine clinical Winston-Lutz QA results.

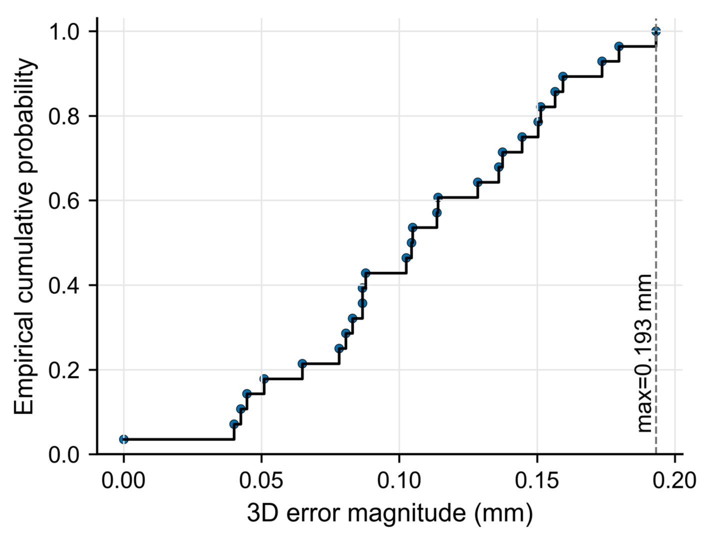

Figure 3. Empirical cumulative distribution of 3D MTWL validation error. Across controlled couch-shift testing, 75% of measurements were ≤0.146 mm, 90% were ≤0.164 mm.

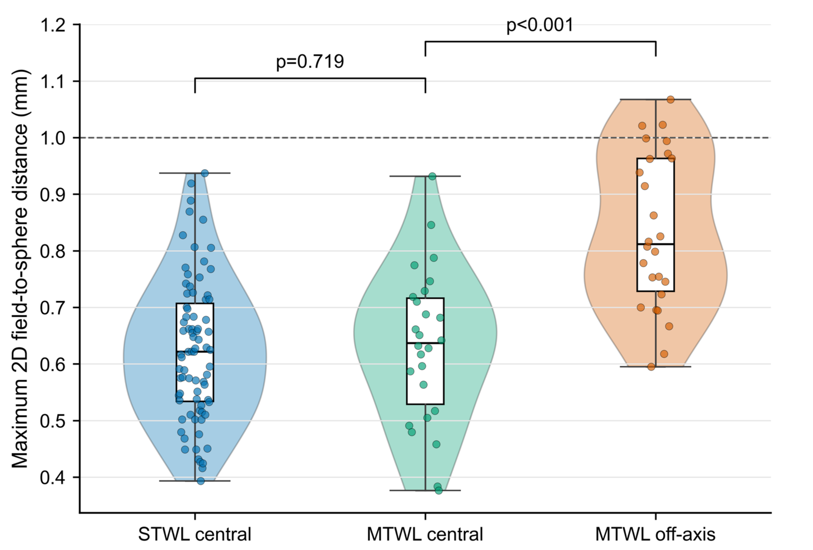

Figure 4. Clinical QA results. MTWL central-target results were comparable to conventional STWL. Off-axis MTWL measurements were larger and provided additional off-axis geometric information.

Discussion

- MTWL adds off-axis target geometric information not captured by conventional STWL, while preserving standard isocenter performance.
- Larger off-axis distances reflect:
  1. Lower off-axis target contrast.
  2. Beam nonuniformity.
  3. Phantom structure near the off-axis sphere.
  4. Increased sensitivity to residual rotational or geometric error.
- This implementation does not fully reconstruct all rotational degrees of freedom or characterize the full spatial error across the treatment volume.
- Additional routine measurements are needed to establish robust institutional baselines and action thresholds

Conclusion

- We show that MTWL can be implemented using existing clinical hardware, routine EPID acquisitions, and automated analysis. Controlled-shift validation showed submillimeter sensitivity, with maximum 3D error below 0.2 mm.
- The main workflow cost was increased machine delivery time, with MTWL adding approximately 190 seconds of beam time.
- The Penta-Guide phantom is clinically ubiquitous and multi-purpose, saving the need for additional hardware and resources.

Automated Multi-Target Winston Lutz adds off-axis geometric QA and provides sub-0.2 mm validation accuracy. This may give insight for off-axis SRS treatment target localization and margins definitions.

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More Info

Please scan to read the full abstract

References

1. IBA Dosimetry. QUASAR™ Penta-Guide Phantom. IBA Dosimetry
2. Eagle, Anton et al. "A simplified and effective off-axis Winston-Lutz for single-isocenter multi-target SRS." Journal of applied clinical medical physics vol. 24,2 (2023): e13816. doi:10.1002/acm2.13816