Design and Clinical Implementation of a 3D-Printed ArcCheck-MR Supporting Solution for Lateral QA on a 1.5T MR-Linac System

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ABSTRACT

Purpose: Patient-specific quality assurance (PSQA) for lateral targets on a 1.5 T MR-Linac (MRL) is limited by restricted couch motion and lack of dedicated positioning aids for off-axis measurements. While lateral ArcCheck-MR configurations can improve detector coverage for lateral targets, achieving consistent and reproducible phantom setup remains challenging. This work describes the design and implementation of a customized, 3D-printed stand for the ArcCheck-MR to provide reliable and repeatable positioning for lateral PSQA measurements on the MRL.

Methods: A dedicated ArcCheck-MR stand was designed using Autodesk Fusion CAD software with the goal of enforcing reproducible phantom placement without reliance on manual alignment. The stands were printed using an Ultimaker S5. The phantom was scanned with the stands in place to generate a PSQA planning image set in the Monaco treatment planning system. Electron density (ED) for the ArcCheck-MR was determined using single-beam measurements to account for energy spectrum changes associated with off-axis beam delivery. Clinical MRL treatment plans for lateral targets were recalculated on the phantom geometry and delivered using the custom stand without additional setup aids or post-delivery shifts.

Results: The design constrains lateral offset, stabilizes vertical height, and ensures consistent longitudinal positioning by docking against two indexed couch bars, minimizing rotational and translational variability between setups. A 0.5% difference in the optimal overwritten ED was observed relative to centered measurements, reflecting energy spectrum changes for off-axis beams. Three lateral PSQA plans were delivered successfully using the customized stand, with all plans achieving gamma index pass rates greater than 95% using 2 mm/3% criteria. Compared to conventional centered phantom placement, the use of the 3D-printed stand increased detected fluence by an average of 56%, improving measurement sensitivity for lateral targets.

Conclusion: The customized ArcCheck-MR stand enables the delivery of PSQA on MRL plans targeting lateral clinical sites with an intuitive, reliable, and repeatable setup.

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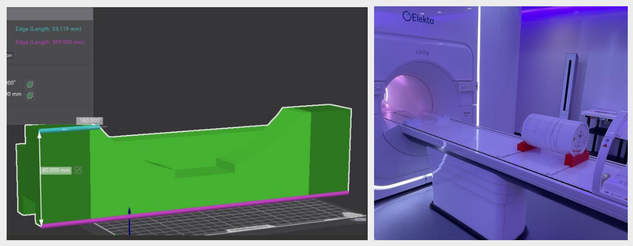
INTRODUCTION

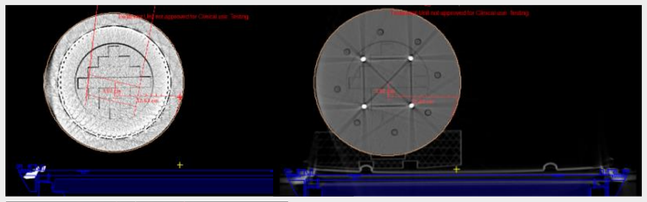
Patient-specific quality assurance (PSQA) for highly lateral treatment targets on the 1.5T MR-Linac is challenging due to restricted couch motion and the lack of dedicated positioning devices for off-axis measurements. Conventional ArcCheck placement at the treatment isocenter may provide limited detector sampling of lateral treatment beams, while manual repositioning can introduce setup variability and reduce measurement reproducibility. To address these limitations, we developed a customized 3D-printed stand that mechanically indexes the ArcCheck to the existing Elekta couch bars, enabling reproducible lateral phantom positioning without requiring additional hardware or modifications to the clinical workflow.

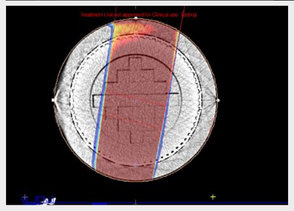
METHODS AND MATERIALS

1) Stand Design & 3D Printing



2) Commissioning- Electron Density Correction

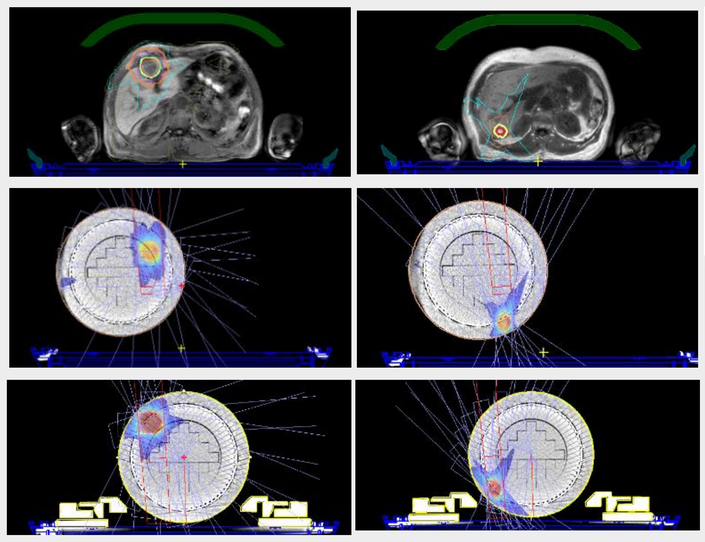




Does moving the phantom off-axis change beam characteristics?

- Measured incident/exit detector dose ratios
- Compared measurements to calculated values
- Adjusted ArcCheck electron density

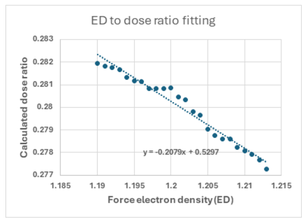
3) Patient QA Testing

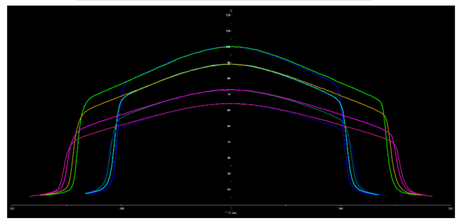


RESULTS

Electron Density

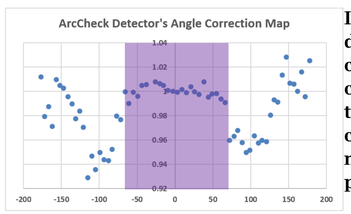
- The measured detector ratios demonstrated a small but measurable difference in beam behavior for off-axis delivery.
- Based on these measurements, an electron density of 1.200 was selected for routine use.



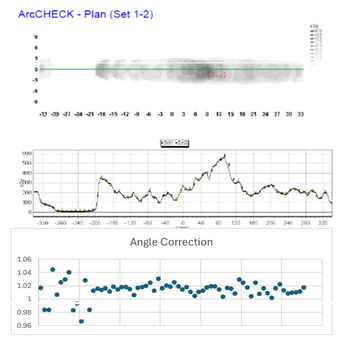


Verification: Angular Correction

- The incident angle at ArcCheck detectors was determined by the photon trace linking the entering and exit detectors, independent of gantry angle and the distance from CAX

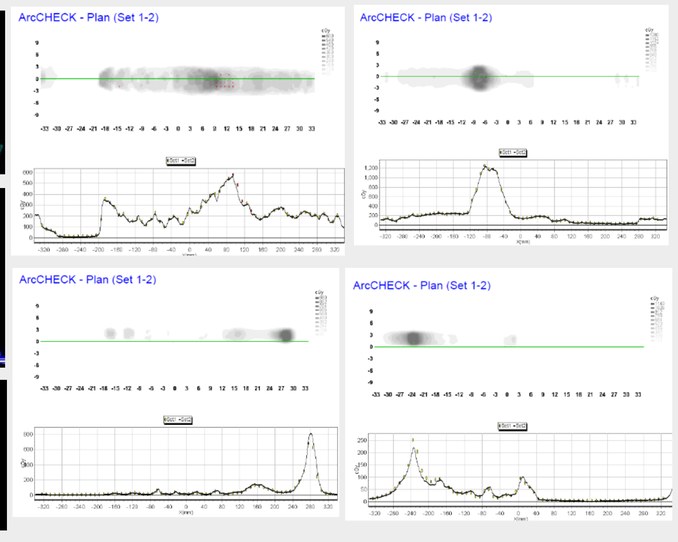


Incident angle < 60 degrees has better consistency of angle correction, meaning that target at the center of ArcCheck has more reliable PSQA performance



When using the stand to place the ArcCheck phantom laterally, we reduced the distance between the region of interest to the center. Therefore, the measurement has a more consistent angle correction.

Patient QA Results



DISCUSSION

- Commissioning of the lateral phantom geometry demonstrated that off-axis beam delivery produced a small change in the effective beam spectrum, resulting in a minor adjustment to the ArcCheck electron density assignment to improve the agreement between measured and calculated dose distributions in PSQA plans.
- Evaluation of detector angular response demonstrated an additional advantage of the lateral setup. By positioning the phantom laterally, the region of clinical interest was shifted closer to the center of the detector array, reducing the incident beam angles for the irradiated detectors and improving angular response consistency. This minimized detector angle dependence while maintaining accurate detector performance for off-axis beam delivery.
- Clinical validation demonstrated that all evaluated treatment plans achieved gamma pass rates greater than 95% using 2 mm/3% criteria. Compared with conventional centered phantom positioning, the lateral configuration also increased detected fluence by approximately 56%, improving detector sampling of highly lateral treatment beams. Together, these findings demonstrate that the customized stand provides a reproducible, accurate, and clinically feasible approach for lateral MR-Linac PSQA.

Future Work

- Evaluate a larger cohort of clinical treatment plans.
- Quantify long-term setup reproducibility across multiple users.
- Investigate applicability to additional treatment sites and MR-Linac workflows.

CONCLUSIONS

A customized 3D-printed ArcCheck-MR stand was developed to enable reproducible lateral patient-specific quality assurance (PSQA) on the 1.5T MR-Linac. The stand provided consistent phantom positioning without additional hardware or manual alignment, while maintaining accurate dose calculations following off-axis commissioning. Clinical validation demonstrated excellent agreement between measured and calculated dose distributions, with all evaluated plans achieving gamma pass rates greater than 95% using 2 mm/3% criteria. This simple, low-cost solution integrates seamlessly into the existing clinical workflow and provides a practical method to improve the reproducibility and confidence of PSQA measurements for highly lateral treatment targets.

REFERENCES

Ferris WS, Smith BR, Hyer DE, St-Aubin JJ. Technical note: A simple method for patient-specific quality assurance for lateral targets on a 1.5 T MR-Linac. J Appl Clin Med Phys. 2024 Apr;25(4):e14323. doi: 10.1002/acm2.14323. Epub 2024 Mar 1. PMID: 38426612; PMCID: PMC11005970.