Single-Setup, Multi Angle Machine QA Framework for Proton Therapy Using 4D Phantom

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ABSTRACT

Purpose: To develop a single-setup machine QA framework for multiple tests across different gantry angles in proton therapy. Current monthly QA procedures require separate setups to verify proton beam characteristics, including output consistency, scanning magnet performance, and beam collimated aperture accuracy. In addition, some of current tests are limited to point-based charge readings without spatial dose information.

Methods: A clinically used ion-chamber array detector (PTW Octavius 1500XDR) was inserted into a rotational phantom (PTW Octavius 4D). The phantom was synchronized with the gantry using an inclinometer, allowing it to rotate with the gantry and maintain the detector array perpendicular to the proton beam at all angles. Beam characteristics were measured over three consecutive days at multiple gantry angles. The evaluated tests included output consistency, as well as non-collimated and collimated Picket Fence patterns to verify scanning magnet performance and beam collimated aperture accuracy. The results were evaluated using multiple gamma analysis criteria.

Results: Output consistency results demonstrated an agreement within 1% across all tested gantry angles among different days. Picket Fence tests achieved 100% passing at 3%/3 mm for both collimated and non-collimated patterns. Non-collimated Picket Fence also passed 100% at 2%/2 mm, demonstrating highly accurate scanning magnet spot placement. For collimated Picket Fence, the passing rate dropped slightly, with minimal failing points at the field edge on one side, consistent with expected behavior of heavy-leaf collimator apertures trimming proton spots and possibly requires minor collimator alignment.

Conclusion: A single-setup rotational phantom enables comprehensive, multi-angle QA for proton therapy, providing spatially resolved verification of output, scanning magnet accuracy, and adaptive aperture performance. This approach streamlines QA, reduces setup complexity, and verifies machine performance across all gantry angles. Future work will expand this framework to include additional tests, such as range verification, toward more comprehensive and time-efficient proton therapy QA solution.

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INTRODUCTION

Proton machine QA often requires multiple detectors and repeated setup procedures to evaluate output and adaptive aperture (AA) accuracy. In the clinic we use Ion Chamber for outputs (**Fig 1.**) and we use the myQA Phoenix for AA testing (**Fig 2.**) and both setups are limited to gantry angle 0. The goal was to create a streamlined QA framework capable of evaluating multiple parameters with a single setup could improve efficiency while providing more comprehensive spatial verification of machine performance.

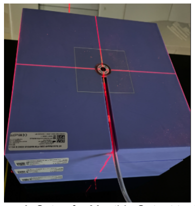

Figure 1. Setup for Monthly Output testing

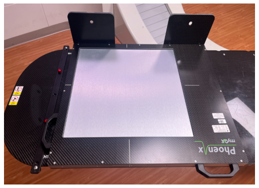

Figure 2. Setup for Monthly AA testing

METHODS AND MATERIALS

An ion chamber array detector (PTW Octavius 1500XDR) was inserted into a rotational phantom (PTW Octavius 4D). As the gantry rotates, the phantom is synchronized using an inclinometer, allowing us to test monthly at different angles perpendicular to the gantry (**Fig 3.**). We tested at angles of 0°, 45°, and 90°, recording data over three consecutive days. Data was gathered for output consistency, non-AA Picket Fence, and static AA Picket Fence tests. AA testing also examined patterns to verify scanning magnet performance and beam collimator aperture accuracy. Results were evaluated using gamma analysis criteria.

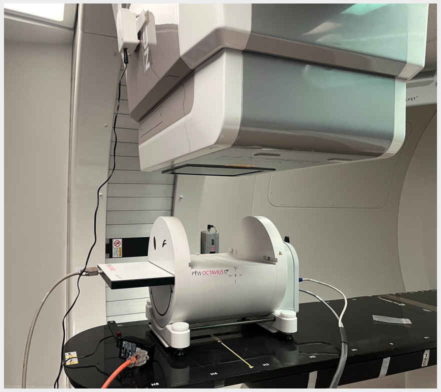

Figure 3. Setup for Rotating Octavius Phanton on Mevion Proton Machine

Table 1. Results for Maximum Output Deviation

Maximum Output Deviation		
Angle	Absolute output (Gy)	Deviation (%)
0	1.038	-0.19
45	1.041	0.10
90	1.046	0.58

Table 2. Results for Average Gamma Result for Picket Fence No AA

Picket Fence No AA - Average Gamma Results		
Angle	2%/2mm	3%/3mm
0	100	100
45	100	100
90	100	100

Table 3. Results for Average Gamma Result for Picket Fence Static AA

Picket Fence Static AA- Average Gamma Results		
Angle	2%/2mm	3%/3mm
0	90.5	100
45	91	100
90	87.8	100

RESULTS

The maximum deviation stayed under 1% across all days and angles, with a baseline output of 1.04 Gy, as seen in **Table 1**. This small deviation shows robust angle-independent beam performance. Non-collimated (no AA) Picket Fence tests had a 100% passing rate at 3%/3 mm and 2%/2 mm, as seen in **Table 2,** confirming spot accuracy and position. Collimated Picket Fence patterns (static AA) showed a 100% passing rate at 3%/3 mm, with minor failures at 2%/2 mm, as seen in **Table 3**. These 2%/2 mm failures were localized to a single field edge, consistent with expected heavy-leaf collimator trimming rather than delivery error. The system reliably captured spatial and angular characteristics of both scanning magnets and adaptive apertures, validating the feasibility and reproducibility of comprehensive multi-angle QA from a single setup.

DISCUSSION

Using the Octavius 4D phantom with the 1500XDR detector enables a single-setup approach for performing multi-angle proton machine QA, reducing repeated phantom positioning and minimizing geometric variability. The ability to keep the detector perpendicular to the beam at all gantry angles provides spatially resolved dose information that traditional point-based measurements cannot capture. This method improves detection of angular-dependent variations in output, spot placement, and collimated aperture behavior while streamlining monthly QA procedures. The framework enhances efficiency, strengthens QA sensitivity, and establishes a foundation for future expansion into range verification and additional beam quality metrics.

CONCLUSIONS

With this setup, one rotational phantom is all that's needed to run full multi-angle QA for proton therapy, checking output, scanning magnet accuracy, and adaptive aperture performance at each angle. It cuts down on setup time and gives a clearer picture of how the machine performs across the full range of gantry angles. Future work will build on this by adding more tests, like range verification, to make proton therapy QA even more thorough and efficient.