SU-315-GPD-T-571

2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Beam Characterization and QA Recommendations for 2.5 MV Imaging Beams in a Large Institution Network

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ABSTRACT

Purpose: Current AAPM guidelines (TG-104 and MPPG 2.b) primarily address kV or standard MV portal beams and are not well suited for low-dose-rate 2.5 MV imaging beams. This study developed and implemented a commissioning and routine QA workflow for the 2.5 MV imaging beam on C-arm LINACs across a clinical network comprising 27 LINACs.

Methods: Commissioning measured PDD10, Dmax, and absolute dose calibration using a 1D water tank and A12 ion chamber following TG-51 protocols. Flatness and symmetry were assessed using a 5-point ion chamber method. Image quality was evaluated using an MC2 phantom compared against 6 MV baselines.

Results: Dmax = 5.5 mm, PDD10 = 52.1%. 2.5 MV (HQ) provided superior CNR (40.8 vs. 30.6) and contrast (37.3% vs. 22.0%) compared to 6 MV, with comparable spatial resolution (0.4 lp/mm).

Conclusion: A comprehensive commissioning and routine QA program was established, expanding TG-104 and MPPG 2.b for network-wide implementation.

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This research was funded in part through the NIH/NCI Cancer Center support Grant/Core Grant (P30 CA008748)

INTRODUCTION

The clinical implementation of 2.5 MV imaging beams is currently limited by the absence of dedicated quality assurance (QA) standards, as existing guidelines (TG-104[1], MPPG 2.b[2]) focus primarily on kV or therapeutic MV beams; however, neither can apply to the 2.5 MV imaging beam. Unlike kV imaging beams whose output are defined by the vendor using voltage and mAs, the 2.5 MV output is solely defined by the user in the same way as other MV beams. Considering the uniqueness of this beam, the commissioning and QA of the 2.5 MV imaging beam should be tailored for the purpose.

This work aims to establish a comprehensive commissioning and routine QA framework specifically for 2.5 MV beams in a large institution network which comprises seven campuses and 27 LINACs. These recommendations ensure superior image quality at reduced patient doses while maintaining strict dosimetric and patient safety and clinical efficiency.

The 2.5 MV beam on the Varian TrueBeam system is a Flattening Filter Free (FFF) beam and operates at a dose rate of 60 MU/min. While it promises better image quality and approximately 50% less patient dose compared to standard 6 MV portal imaging, clinical adoption requires a rigorous QA program[3].

METHODS AND MATERIALS

Commissioning Measurements:

Beam commissioning measurements followed TG-51 protocols using:

- PDD10, Dmax, and absolute dose calibration
- 1D water tank with A12 ion chamber (0.6 cc Farmer-type)
- Flatness and symmetry: 5-point ion chamber method
  - Assessed at 1.0 and 1.5 cm depths at 100 cm SAD
  - 30×30 cm² field with 5 cm off-axis shift for symmetry evaluation

Image Quality Evaluation:

Image quality was evaluated using the MC2 phantom:

- Spatial resolution (line pairs per millimeter, lp/mm)
- Contrast-to-noise ratio (CNR)
- Contrast percentage
- Minimum uniformity
- Scaling discrepancy (mm)
- All metrics compared to 6 MV HQ and LD portal imaging baselines

Routine QA Protocol Development:

- Integrated recommendations from TG-104 and MPPG 2.b to develop a tiered routine QA protocol (Daily, Monthly, Annual schedule) to maintain network-wide consistency across 27 LINACs.

RESULTS

Dosimetric Characteristics:

- Dmax of approximately 5.5 mm (0.55 cm) and a PDD10 of 52.1% (compared to 6 MV Dmax = 1.5 cm and PDD10 = 67.0%).
- Profiles exhibited stable FFF characteristics with a radial flatness of -3.1% at 1.0 cm and 1.5 cm depths.
- Monthly output checks over 5 consecutive months showed excellent stability, with a mean variation of 0.3% ± 0.4%.

Image Quality:

- The 2.5 MV High Quality (HQ) mode demonstrated superior contrast and contrast-to-noise ratio (CNR) compared to 6 MV.
- CNR improved significantly to 40.77 (2.5 MV HQ) from 30.59 (6 MV HQ), a 33% increase.
- Contrast percentage improved significantly to 37.26% (2.5 MV HQ) from 22.04% (6 MV HQ), a 69% increase.
- Spatial resolution was comparable at ~0.4 lp/mm for both 2.5 MV modes (compared to 0.5 lp/mm for 6 MV).

Mode / Energy	Spatial Res. (lp/mm)	CNR	Scaling Discrep. (mm)	Contrast (%)	Min Uniformity (%)
HQ 6 MV	0.5	31.00	0	21.8	97.6
LD 6 MV	0.5	30.89	0	22.3	97.5
HQ 2.5 MV	0.4	40.77	0	37.26	96.42
LD 2.5 MV	0.4	37.67	0	37.39	96.28

Table 1. Comparison of Image Quality between 6 MV and 2.5 MV Beams (HQ/LD Modes) using MC2 Phantom.

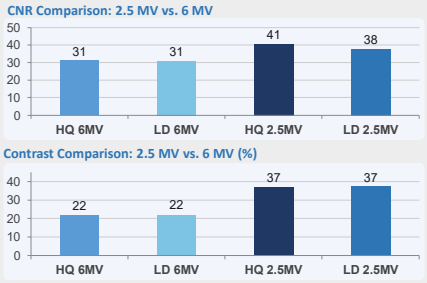

Figure 1. Comparison of CNR and Contrast (%) of 6MV and 2.5 MV beams (HQ/LD Modes)

Frequency	QA Procedure / Parameter	Tolerance
Daily	Safety / Interlocks	Functional
	Imaging-Treatment Isocenter Coincidence	1 mm
Semi-Annually	Imager Calibration	Execution
	Scaling Test	2 mm
Annually	Dosimetry: PDD10	2% from baseline
	Dosimetry: Dmax	1 mm from baseline
	Dosimetry: Output	5% from baseline
	Image Quality: Imager Calibration	Execution
	Image Quality: Spatial Resolution	0.4 lp/mm from baseline
	Image Quality: CNR	20% from baseline
	Image Quality: Contrasts (%)	10% from baseline
	Image Quality: Min Uniformity (%)	10% from baseline

Table 2. Proposed Routine QA Frequency and Tolerances for 2.5 MV Imaging Beams.

DISCUSSION

This work addresses a critical gap in clinical medical physics: the absence of dedicated commissioning and QA guidelines for 2.5 MV imaging beams. While the 2.5 MV beam is increasingly adopted due to its superior image quality and reduced patient dose (~50% lower than 6 MV), its FFF nature and unique output definition require tailored protocols.

The dosimetric data (Dmax = 5.5 mm, PDD10 = 52.1%) confirm that standard 6 MV commissioning approaches are not directly transferable. The FFF beam profile with radial flatness of -3.1% requires specific assessment criteria. Output stability of 0.3% ± 0.4% over 5 months demonstrates clinical reliability comparable to therapeutic beams.

Image quality results confirm the 2.5 MV beam's clinical advantage: 33% higher CNR and 70% improved contrast versus 6 MV, with equivalent spatial resolution. These improvements translate directly to better patient positioning accuracy and treatment verification quality.

CONCLUSIONS

1. The low-dose-rate 2.5 MV imaging beam on C-arm LINACs provides superior portal image quality (CNR and contrast) at a significantly lower patient dose (~50% reduction) compared to standard 6 MV treatment beams.
2. A comprehensive commissioning and routine QA workflow was successfully developed and deployed network-wide across 27 LINACs and 7 campuses.
3. The established tiered QA schedule and tolerances ensure network-wide safety, dose accuracy, and image quality consistency, bridging the gap in current AAPM guidelines for 2.5 MV beams.

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