Advancing Patient Accommodation on the Elekta Gamma Knife Esprit Radiosurgery Platform: Evaluation of a Clinically Improved HDMM Camera-arm Position

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ABSTRACT

Purpose: To characterize the angular dependence of the Elekta Gamma Knife Esprit High Definition Motion Management (HDMM) system and examine the feasibility of non-standard camera angles for the treatment of larger patients.

Methods: To establish a reference, reflective markers placed on a Velmex motion phantom were positioned at the headrest location on the treatment couch to evaluate temporal latency and spatial accuracy at the default camera-arm position (60º). Two additional camera-arm positions (70º and 74º) were then evaluated against the reference. Temporal performance was assessed by observing gating event execution and spatial performance by introducing known displacements of varying magnitude (±0.5 mm, ±1.0 mm, ±1.5 mm) in the lateral direction. A clinically relevant camera-arm position was further evaluated to maximize height above the treatment couch. Finally, the camera-arm operating limit corresponding to the angle where HDMM tracking of infrared markers was lost, was assessed.

Results: Temporal latency and spatial accuracy remained consistent up to the operating limit. Both the 70º and 74º camera-arm positions executed < 200 ms gating events, consistent with the reference. The spatial accuracy of the 60º (reference), 70º, and 74º camera-arm positions was ±0.018 mm, ±0.021 mm, and ±0.019 mm, respectively. The 74º camera-arm angle maximized height above the couch at 54.4 cm. The 75º camera-arm position was found to be the operating limit as infrared marker tracking was lost.

Conclusion The HDMM system had clinically acceptable performance for all camera angles evaluated up to the operating limit, maintaining both temporal latency and spatial accuracy compared to the standard position. The proposed clinically improved 74º camera-arm position remains below the operating limit, maintains performance and allows for improved line-of-sight, thereby potentially accommodating larger patients.

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INTRODUCTION

- Gamma Knife Esprit used to treat 5-10 patients weekly
- High Definition Motion Management (HDMM) system consists of:
  - Infrared stereoscopic camera
  - Set of reference markers
  - Patient markers

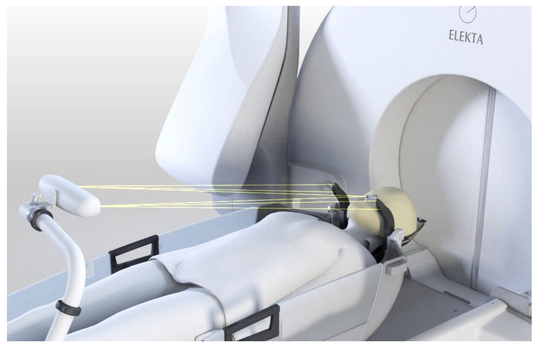


Figure 1. The HDMM system from Elekta

- HDMM system displays submillimeter accuracy[1] and is capable of beam gating if large movement is detected
- Larger patients may prevent line of sight between the camera and markers
- Feasibility of non-standard camera angles was examined to increase "height-of-eye"
  - Spatial accuracy
  - Temporal latency

METHODS AND MATERIALS

1. First, the HDMM system was evaluated at the default reference angle (60º)
2. Next, the HDMM system was evaluated at non-standard angles
3. Finally, the HDMM operating limit was assessed

- Reflective markers were placed on a VELMEX XSlide™ which was programmed to execute three stages (±0.5 mm, ±1.0 mm, ±1.5 mm) of known lateral displacements as well as exceed the gating threshold in another test

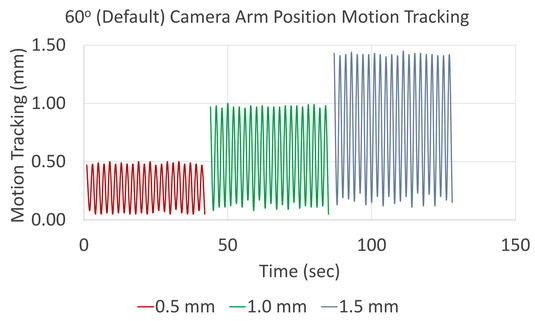
Figure 2. VELMEX XSlide™

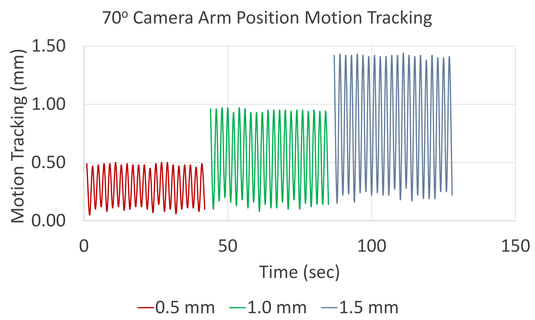
- Temporal latency was evaluated by observing gating events
- Spatial accuracy was evaluated by comparing marker tracking at new positions to the reference position in a *T-test*

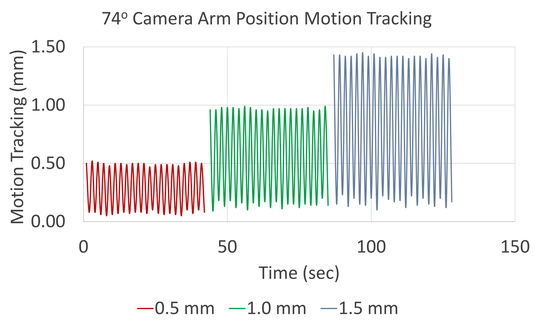
Figure 3. Testing at an alternate camera-arm position

RESULTS

The tracking waveforms associated with the three displacement stages are shown below for two non-standard camera-arm positions in addition to the default.







The mean and standard deviation of the three tracking waveforms are shown below. The coefficient of variation of the default, 70º and 74º positions are 0.120, 0.109 and 0.108, respectively. Following a T-test, p-values for the three displacement stages of the 74º camera-arm position were 0.73, 0.13 and 1.00.

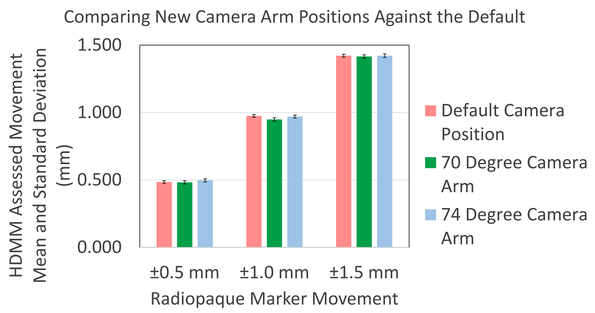


Table 1 below summarizes results and recommendations.

Table 1: Comparison of new camera-arm positions against the default reference position.

Camera-arm position	60º (Default)	70º	74º	75º (Limit)
Temporal latency (ms)	< 200	< 200	**< 200**	Unevaluable
Spatial accuracy (mm)	±0.018	±0.021	**±0.019**	Unevaluable
Height above couch (cm)	45.2	52.2	**54.4**	N/A
Proposed alternate clinical position	N/A	No	**Yes**	No
Operating limit	No	No	**No**	Yes

DISCUSSION

Non-standard positions demonstrated comparable performance to the default position in both spatial accuracy and temporal latency.

For the ± 0.5 mm displacement stage, the non-standard positions mean and standard deviation were 0.482 ± 0.012 and 0.497 ± 0.023 compared to 0.485 ± 0.021 mm for the default reference position, showing similar spatial accuracy. *T-tests* were also performed to disprove the null hypothesis (H_0) which posits that there is no statistically significant difference between datasets. For all three stages, the p-value was > 0.05 with an average value of 0.62.

Temporal latency equivalent to the default position was demonstrated for the non-standard angles by delivering a treatment plan to the VELMEX XSlide™ while the motor controller moved beyond gating threshold limits. Gating events < 200 ms were observed for the 70º and 74º positions.

No degradation of performance was observed beyond the default position. Instead, binary performance was shown. Spatial accuracy and temporal latency were maintained until the operating limit was reached.

The operating limit was identified as the angle at which the stereoscopic camera lost tracking of the markers placed on the VELMEX XSlide™ which acted as a surrogate for a patient nose[2]. 75º was assessed to be the operating limit.

The 74º camera-arm position is the proposed alternate position as it maximizes height above the couch ("height-of-eye") while maintaining HDMM performance. A consideration for the margin applied towards the operating limit should be made on an individual clinic basis. The proposed alternate position allows for an additional 9-10 cm of vertical clearance above the table which may open this treatment to an additional patient population.

CONCLUSIONS

Non-standard camera positions maintain HDMM performance in temporal latency and spatial accuracy on the Gamma Knife Esprit and may be used to treat larger patients as higher camera positions maximize vertical height above the treatment couch.

REFERENCES

1. Knutson NC, Hawkins BJ, Bollinger D, et al. Characterization and validation of an intra-fraction motion management system for masked-based radiosurgery. J Appl Clin Med Phys. 2019;20(5):21-26. DOI: 10.1002/acm2.12573.
2. Chung C, Li W, Bootsma G, et al. Clinical Evaluation of a Novel Thermoplastic Mask System with Intrafraction Motion Monitoring using IR Tracking and Cone-beam CT for Gamma Knife® Radiosurgery. Poster presented at 2014 ASTRO annual meeting, San Francisco.