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Characterization of Plastic Scintillator Detector for Gamma Knife Beam Profile Measurement: A Comparison with MicroDiamond and Film

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ABSTRACT

Accurate beam profile measurement is essential for Leksell Gamma Knife (LGK) quality assurance. This study evaluated the Exradin W2 plastic scintillator as a filmless alternative for LGK beam profile measurements by comparing its performance with treatment planning system calculations, radiochromic film, and the MicroDiamond detector. The W2 demonstrated excellent agreement with established reference methods across all collimator sizes. Minor profile characteristics, including a small stem effect and volume averaging in the penumbra, were observed but had negligible impact on quality assurance performance. These results support the Exradin W2 plastic scintillator as an accurate and efficient detector for LGK beam profile dosimetry, providing a practical alternative to film for routine quality assurance.

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METHODS AND MATERIALS

The Exradin W2-1x1 scintillator was positioned in the LGK dosimetry phantom using a custom 3D-printed holder to acquire profiles for 4, 8, and 16 mm collimators. Measurements were performed by incrementally shifting the dosimetry phantom and were compared against Treatment Planning System (TPS) data, MicroDiamond, and radiochromic film measurements. Given that shifting the phantom alters the attenuation path length compared to a stationary phantom setup (i.e., film measurement), a simulation study was conducted to quantify the dosimetric differences between "phantom-move" and "detector-move" geometries. Metrics for evaluation included Full Width at Half Maximum (FWHM), penumbra, and 3D isocenter localization.

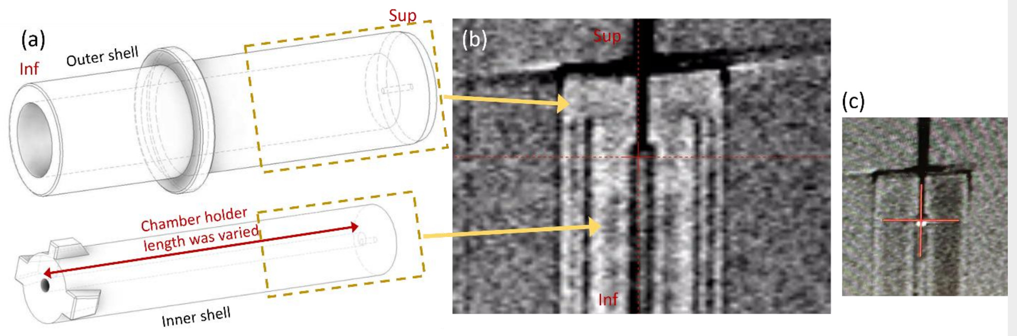

Figure 1. 3D-printed W2 holder. (a) CAD model of the custom W2 holder, (b) sagittal CBCT image of the LGK dosimetry phantom with the W2 positioned in the holder (crosshair centered at (100, 100, 100)), and (c) another sagittal CBCT scan with a dummy probe used for effective point of measurement (EPOM) localization.

Table 1. Differences in FWHM and penumbra relative to TPS reference values for the W2 detector, microDiamond detector, and EBT3 film.

Collimator	Profile Axis	W2 FWHM Diff. [mm]	Diamond FWHM Diff. [mm]	Film FWHM Diff. [mm]	W2 Penumbra Diff. [mm]	Diamond Penumbra Diff. [mm]	Film Penumbra Diff. [mm]
4 mm	X	0.0	0.1	-0.2	0.2	0.2	0.5
	Y	0.1	0.1	0.1	0.2	0.2	0.4
	Z	-0.1	-0.1	0.1	0.2	-0.1	0.1
8 mm	X	0.1	0.2	0.1	0.1	0.0	0.5
	Y	0.1	0.1	0.2	0.3	0.1	0.5
	Z	0.0	-0.1	-0.1	0.5	0.1	0.4
16 mm	X	-0.1	0.1	-0.2	-0.1	0.0	0.7
	Y	0.0	0.1	0.6	0.1	0.1	1.6
	Z	-0.1	-0.1	0.1	0.0	0.0	0.3

RESULTS

The W2 detector yielded profile metrics that agreed closely with TPS baselines and film data, with FWHM deviations generally within 0.1 mm across all collimators. Unlike the TPS or MicroDiamond profiles, the W2 measurements exhibited a slight signal elevation in the left tail attributed to a minor stem effect. This effect slightly bends the profile and became more distinct with larger collimator settings. Additionally, the 1 mm active volume length of the W2-1x1 introduced volume averaging effects that slightly impacted the sharpness of the profile falloff compared to high-resolution film. The simulation study confirmed that minor profile variations also exist due to changing attenuation with the phantom-shifting method.

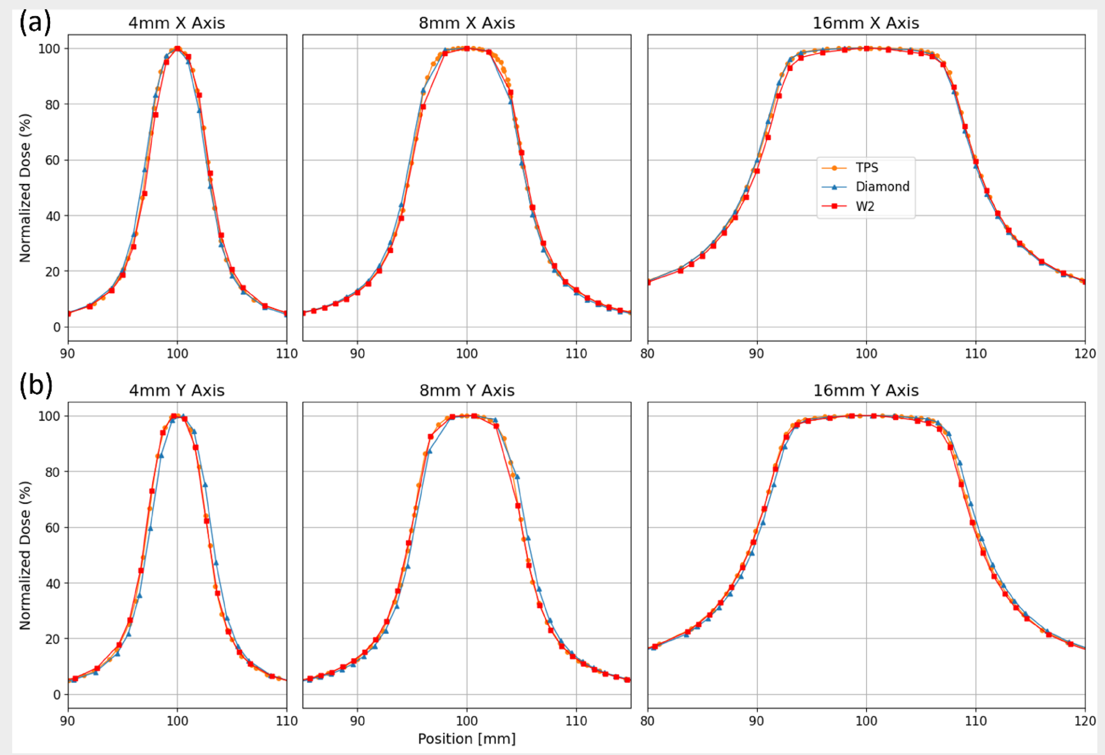

Figure 2. Comparison of beam profile plots of TPS, microDiamond, and W2-1×1 in (A) X-axis and (B) Y-axis.

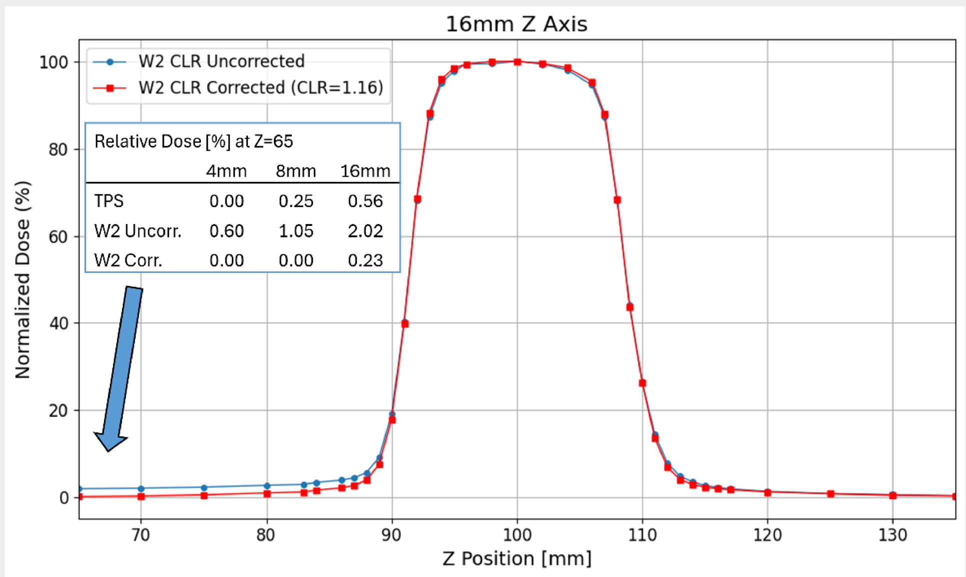

Figure 3. A 16 mm collimator Z-axis profile with and without CLR correction.

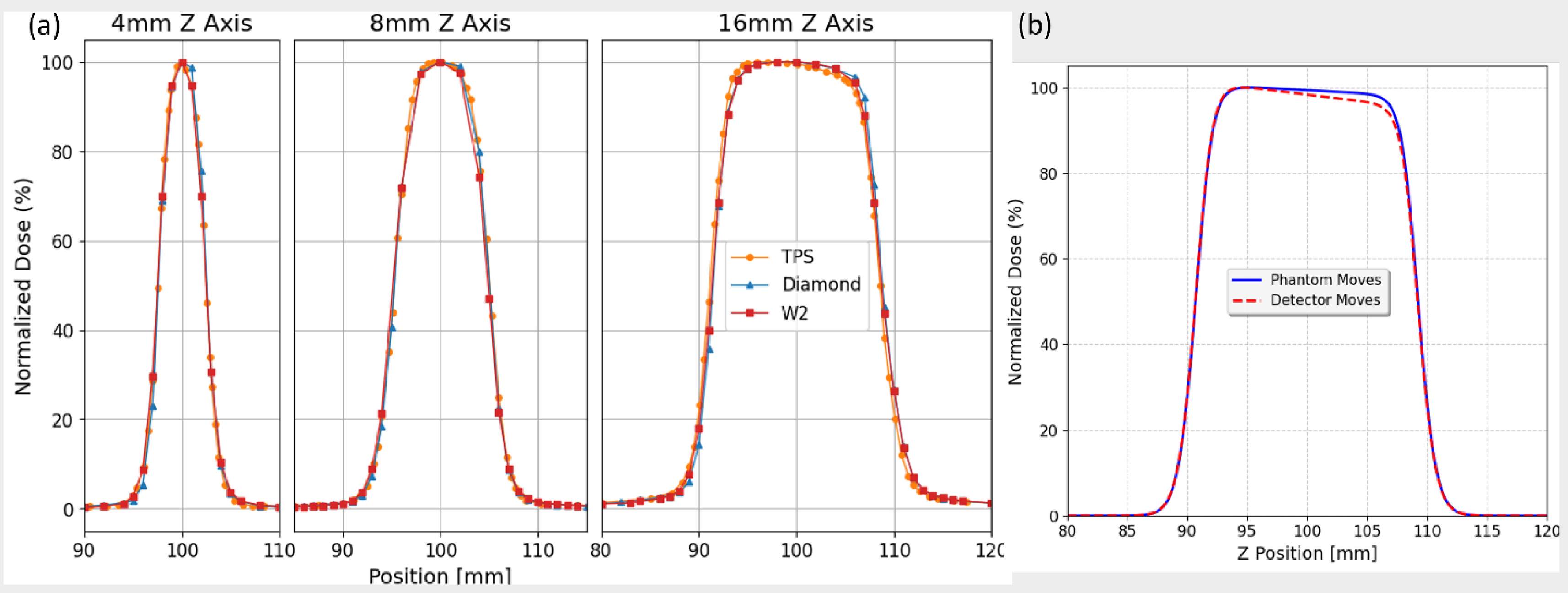

Figure 4. Z-axis profile plots of (a) 4mm, 8mm, and 16mm collimators, and (b) simulation study of the difference in Z profile when "phantom moves" vs. "detector moves".

DISCUSSION

Comparative analysis revealed that the W2 matches the submillimeter precision required for LGK dosimetry. We previously showed that X and Y profiles match well despite attenuation differences and are symmetrical. The Z axis presents a more complex challenge. Simulation of Z axis profiles with actual GK geometries demonstrated that shifting the phantom alters attenuation and results in a slightly flatter profile compared to a stationary phantom. Our measurements confirmed this geometric flattening effect with both the W2 and MicroDiamond. A minor stem effect specific to the W2 appeared as an elevated dose tail in the Z profiles which slightly bends the profile and becomes more observable with larger collimator settings. This deviation measured 2% with the W2 compared to 0.5% in the TPS at Z=65 mm with the 16 mm collimator. The 1 mm active volume length of the W2 detector also affects falloff sharpness due to volume averaging. However, these effects are subtle and do not compromise the overall accuracy of the W2 measurements.

CONCLUSIONS

We investigated active detectors including the Exradin W2 scintillator as robust real time alternatives to film. The MicroDiamond is a viable option we previously utilized but the W2 offers water equivalence and requires no energy dependence corrections. Validating the W2 workflow provides a comprehensive evaluation of active detectors for profile analysis and small field dosimetry.

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