Three-Dimensional Diose-Based Dose Profiling for Gamma Knife Collimators Using a 3D-Printed Detector Holder

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Purpose: Accurate small-field dosimetry for stereotactic radiosurgery is challenging due to steep dose gradients and detector positioning limitations. This study evaluates the feasibility of using a high-resolution diode detector, secured within a custom printed holder, to acquire three-dimensional (3D) dose profiles for Gamma Knife (GK) collimators and compares the measurements with film-based reference data.

Methods: 3D dose profile measurements were performed using three PTW semiconductor diode detectors (TN60008, TN60016, and TN60019) mounted in a custom-designed 3D-printed holder to ensure reproducible detector positioning. Measurements were acquired for 4 mm, 8 mm, and 16 mm GK collimators. Dose profiles were measured along the X, Y, and Z axes with a step size of 1 mm. For each measurement, the scanning axis was varied from 70 mm to 130 mm while the remaining two axes were held constant at 100 mm. Each spatial direction was scanned independently to maintain consistent geometry. Measured profiles were normalized by averaging values near the peak dose region to define a representative maximum, then qualitatively compared with film-based dose distributions acquired under comparable conditions.

Results: Diode-measured dose profiles demonstrated strong agreement with film-based reference data for all collimator sizes and measurement directions. Profile shape, symmetry, and field width characteristics were visually consistent between measurement techniques. The 4 mm collimator exhibited steep dose gradients that were well resolved by the diode detector, while the 8 mm and 16 mm collimators showed smooth and symmetric profiles across all spatial axes.

Conclusion: Preliminary results indicate that high-resolution diode detectors mounted in a reproducible 3D-printed holder can accurately measure 3D dose profiles for GK collimators, demonstrating good agreement with film-based data. This approach shows promise as an efficient alternative for small-field stereotactic radiosurgery quality assurance, with ongoing work extending the methodology to additional diode detectors.

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INTRODUCTION

AAPM Task Group 178 recommends annual verification of Gamma Knife (GK) Icon beam profiles, traditionally performed using film dosimetry. While film provides high spatial resolution, it is labor-intensive and susceptible to processing variability. Semiconductor diode detectors offer sub-millimeter spatial resolution, real-time readout, and potential workflow advantages. This study evaluates whether high-resolution diode detectors can reliably measure three-dimensional (3D) dose profiles for GK Icon collimators and meet TG-178 tolerances.

OBJECTIVE

To evaluate the accuracy and feasibility of using diode detectors for 3D GK Icon beam profile measurements by comparing diode-based full width at half maximum (FWHM) and penumbra metrics against film measurements and TG-178 reference data

METHODS AND MATERIALS

Detectors and System:

- GK Icon unit
- PTW diode detectors mounted in a custom-designed 3D-printed holder (Figures 1 and 2):
  - TN60008
  - TN60016
  - TN60019

Measurement Geometry:

- Profiles acquired along X, Y, and Z axes
- Step size: 1 mm
- Scan range: 70–130 mm along measurement axis
- Remaining orthogonal axes fixed at 100 mm
- Each axis scanned independently

Data Analysis:

- Profiles normalized using averaged values near peak dose
- Extracted metrics:
  - FWHM
  - 80%–20% penumbra widths
- Comparisons made against:
  - Film-based measurements
  - TG-178 nominal reference values

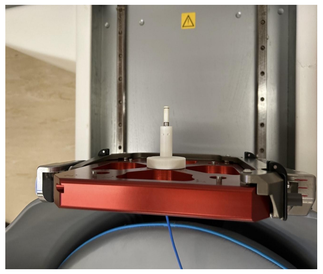

Figure 1. Aerial View of Set-up.

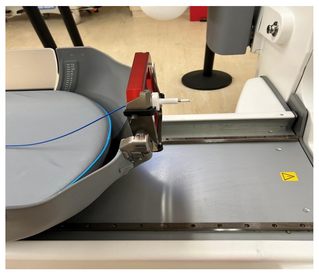

Figure 2. Side View of Set-up.

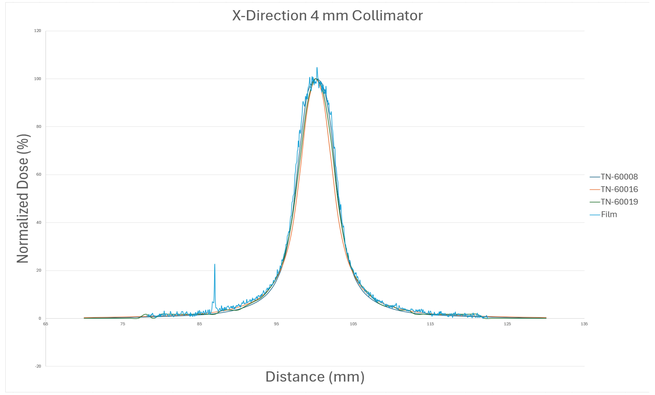

Figure 3. Graph of all diodes and film in the X-direction with a 4 mm collimator.

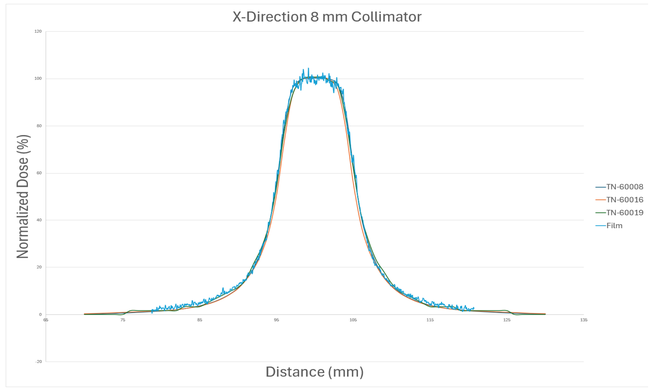

Figure 4. Graph of all diodes and film in the X-direction with an 8 mm collimator.

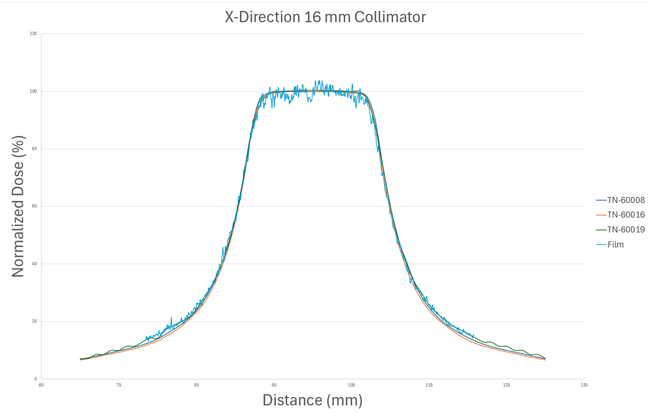

Figure 5. Graph of all diodes and film in the X-direction with a 16 mm collimator.

Table 1. FWHM and 80-20% Penumbra for all three diodes in the X-direction with all collimator sizes.

Collimator (mm)	Diode Detector	FWHM (mm)	80–20% Penumbra (mm)
4	TN60008	5.72	2.88
4	TN60016	5.14	3.31
4	TN60019	5.58	3.20
8	TN60008	11.00	3.98
8	TN60016	10.40	4.19
8	TN60019	10.90	4.41
16	TN60008	21.50	8.11
16	TN60016	21.20	7.97
16	TN60019	21.40	8.73

RESULTS

Profile Agreement:

- Strong agreement among diode detectors
- Correlation coefficients >99% for most measurements
- TN60016 showed slightly lower correlations (>98%)

FWHM Analysis:

- TN60008 and TN60019 FWHM values agreed within 1%
- TN60008 measurements up to 10% lower than other diodes, but within TG-178 1 mm tolerance
- Film-based FWHMs generally comparable but occasionally 5–10% higher
- All diode measurements within TG-178 tolerance except: Z-profile of 8 mm collimator (~1.1 mm below nominal)

Penumbra Widths:

- Diode-measured 80%–20% penumbra widths largely within 1 mm TG-178 tolerance
- TN60016 showed occasional failures at 1 mm tolerance
- All measurements (except one) met 2 mm TG-178 tolerance

DISCUSSION

Diode detectors demonstrated excellent agreement with film dosimetry and TG-178 reference data, particularly for FWHM and penumbra characterization. The reduced blurring observed in diode measurements likely explains small systematic differences relative to film. Slight deviations observed with the TN60016 detector suggest orientation- or detector-specific effects that warrant further investigation. Overall, diode-based measurements provide consistent and reproducible characterization of GK Icon beam profiles.

CONCLUSIONS

- High-resolution diode detectors accurately measure 3D GK Icon beam profiles
- All measured metrics meet AAPM TG-178 tolerance criteria
- Diode-based QA represents a practical alternative to film dosimetry
- Advantages include improved efficiency, reduced variability, and strong agreement with established reference data

Future Work:

- Automate electrometer data acquisition
- Implement automated extraction of FWHM and penumbra metrics
- Investigate detector-specific orientation effects

REFERENCES

1. AAPM Task Group 178. Quality assurance for Gamma Knife Icon systems.