Replacing Gamma Knife Beamprofiles On Film with Point-Detector Scans

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INTRODUCTION

The Gamma Knife is a stereotactic radiosurgery tool specialized for intracranial disease. Its 192 sources are separated in eight independently selectable sectors and each sector can be aligned with 4mm, 8mm or 16mm diameter collimation. The resulting spatially-fixed focal size is smaller than comparable techniques such as Cyberknife or linac based SRS. This small focal size in combination with a high-precision couch positioning system achieves radiological accuracy below 0.5 mm. The small field size and its steep dose gradient require, among other tests, the following quality assurance (QA) that can be performed with a point detector: A daily QA for verification of coincidence of the radiation field with the patient positioning system; a monthly verification of timer accuracy, linearity, constancy; and an annual measurement of output factors, beam profiles and focal spot precision. The three levels of QA are currently performed with a diode detector, an ionization chamber, and the microdiamond detector and GAFchromic film, respectively.

AIM

Film dosimetry is a time-consuming, multi-step procedure that generally requires manual image processing at parts of the data analysis. This project investigates the feasibility of replacing film measurements for Gamma Knife beam profiles with point-detector scans based readily available QA equipment.

METHOD

We used the (red) Leksell Gamma Knife® Solid Water Dosimetry phantom with custom inserts for phantom-based detector measurement, the (grey) Elekta ABS plastic phantom for film measurement, and a 3D-printed adapter mounted on Elekta's new film holder for in-air measurements. No additional buildup was used with the detectors during in-air measurements. AAPM TG-178[1] reported on the ABS, Solid Water and a liquid water phantom for a dosimetry intercomparison and any of these three were deemed suitable for Gamma-Knife dosimetry.

Three detectors were chosen: the Capintec PR05 ionization chamber that is used for monthly QA, the PTW microdiamond detector that replaced film for relative output measurements at our annual QA, and the Standard Imaging W2 scintillator.

In-air scans were used because unlike Linac water tank profile measurements where the detector is moving through the spatially fixed tank, here the detector **and** the phantom are moving in the radiation field. Attenuation differences do not need to be accounted for and phantom scatter is neglected in the in-air approach. The scanning positions are setup in a treatment plan in the Gamma Plan TPS and delivered in clinical mode.

Treatment Data

Target	Shots	Prescription	100% [Gy]	Max [Gy]	X [mm]	Y [mm]	Z [mm]	Width [mm]
A:W2	40	20.0 Gy @ 100%	20.0	20.0	100.0	100.0	100.0	60

Total number of shots: 40
Treatment plan name: 16mm trans dose
Dose algorithm: TMR 10
Beam-on time: 11.9 min
Dose grid resolution in targets: standard

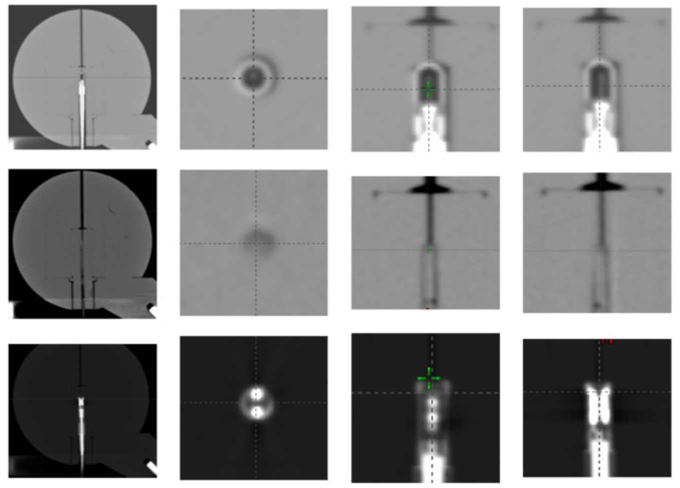
Run 1 (90 degrees)

Run-Step	Shot	X [mm]	Y [mm]	Z [mm]	Collimator [sectors 1-8]	Time [min]	Notes
1-1	A1	101.0	100.0	100.0	4 4 4 4 4 4 4 4	0.30	

Header of the treatment plan delivering 40 shots in x from 95mm to 105mm with y and z at 100mm; solid water phantom for detector scans, the in-air adapter and the ABS phantom for film measurements.

RESULTS

CT images of the detector position within the solid water phantom



PR05 ionization chamber

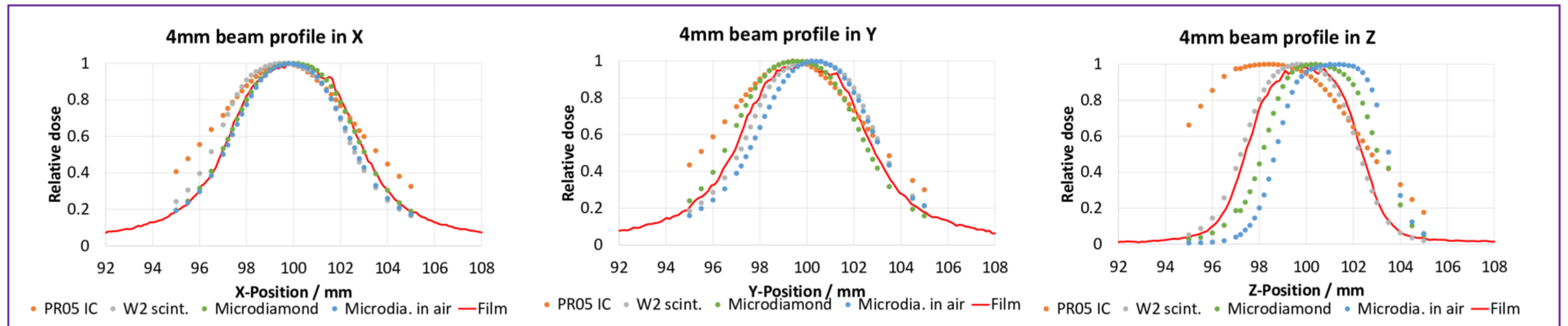
The PR05 detector is an air-filled ion chamber with a large volume of 0.07cm³. Wall and stem are well visualized. The chamber is placed at the end of the custom insert; geometric offset was 0.5mm in both, x and y.

W2 scintillator

The 1x1 mm Exradin W2 scintillator has a volume of 0.0008cm³ , a k_Q of 1.000 and is water equivalent. Thus there is minimal contrast with the solid water phantom and the position can only be estimated; geometric offset estimation was 0.5mm or less .

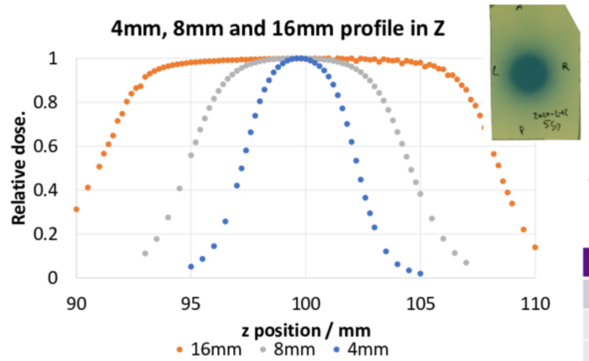
Microdiamond

The microdiamond detector has an extremely small volume of only 0.000004cm³. The sensitive volume is nearly water equivalent but electrodes attached to the diamond require a windowing of the image where the position is blurred and the small sensitive volume is indiscernible.



Profile scans in x, y and z direction for irradiation with all 8 sectors set at the 4mm collimator using four types of detectors. The table summarizes the full width half maximum (FWHM) and center position of each scan and the calculated FWHM of the treatment planning system using the TMR10 model. Further corrections in the z-direction show better agreement.

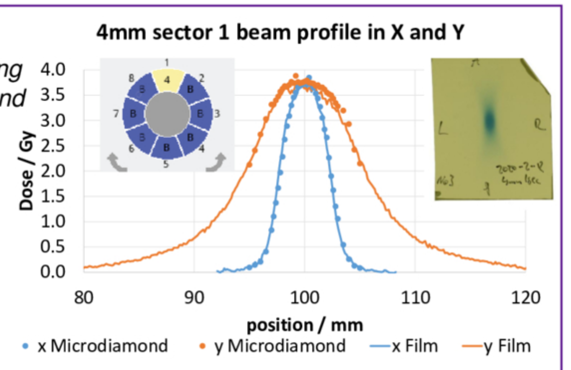
	TMR10	Film	PR05 IC	Microdiamond	W2 scintillator	Microdiamond in air
FWHM in X [mm]	6.16	6.11	8.00	6.10	6.00	5.80
FWHM in Y [mm]	6.16	6.11	8.00	6.30	6.10	5.60
FWHM in Z [mm]	5.04	5.09	7.80	4.80	5.00	4.90
Position in X [mm]		100	99.5	100.00	99.55	99.90
Position in Y [mm]		100	99.5	99.55	100.35	100.20
Position in Z [mm]		100	98.90	100.60	99.70	101.5



Left: Profile scans in z direction for irradiation with all 8 sectors set at the 4mm, 8mm and 16mm collimator using the W2 scintillator. The table summarizes the FWHM and the TMR10 prediction.

Right: Profile scans in x and y demonstrating the asymmetric focal spot for irradiation of a single sector (sector 1). Non circular shots are an important tool to improve conformity for irregular-shaped targets.

	Collimator	TMR10	W2 scintillator
FWHM in Z [mm]	4	5.04	5.00
FWHM in Z [mm]	8	9.80	9.60
FWHM in Z [mm]	16	17.44	17.40



DISCUSSION

Profile measurements with small field detectors (W2-scintillaor and microdiamond) closely follow the film profiles. FWHM agreement is well within the 1mm tolerance required for annual QA. The ion-chamber (PR05), as expected, exhibits unacceptable broadening due to volume-averaging. The in-air profile is narrower due to a lack of build-up and scatter.

The measurement geometry in the dosimetry phantom scan differs in a subtle way from film or in-air scans. While the depth of the detector remains fixed relative to the phantom surface, the phantom moves relative to isocenter and collimated beams altering the source-to-surface distance during the scan. Profile distortion was not, however, observed.

The radiation isocenter in the scanned profiles offset is on the order of half a millimeter in x, y, and z. This offset, as confirmed by CT, is due to alignment errors between phantom isocenter and detector points of measurement. Tolerance for the total offset vector Δr=√(ΔX^2+ΔY^2+ (ΔZ^2) is 0.4 mm and was not achieved by any of our detector scanning geometries. Interestingly, a recent study showed that the Gamma Knife® Icon™ CBCT in combination with vendor provided data can reduce geometric uncertainty in the effective point of measurement to 0.1 mm [2]. GAFchromic EBT3 film measurements using the Pin-Point test to verify coincidence of radiation focal point (RFP) with the patient-positioning system (PPS) detect offsets of 0.1mm.

CONCLUSION

Quality assurance test at the Gamma Knife can be streamlined by replacing film-based QA of beam profiles with detector measurements.

FWHM values demonstrated that both QA beam profiles with the microdiamond and W2 scintillator measurements in-phantom are viable replacements for the film-based profile test. Data was digitally available in scan times as low as two minutes and post-processing can be easily automated.

The submillimeter precision required for assessment of the RFP and PPS coincidence was not achieved due to uncertainty in detector positioning. Incorporating Gamma Knife® Icon™ CBCT imaging at phantom setup and vendor-provided information on detector geometry might allow us to extend our technique as a viable replacement for positioning verification in the future .

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REFERENCES

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