Commissioning a Plastic Scintillator Detector for clinical use in IGRT and BgRT on a PET-Linac

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Purpose / Objectives

- The RefleXion PET-Linac is a hybrid imaging-therapy platform incorporating a 6 megavoltage (MV) photon flattening filter-free ring-gantry linear accelerator (LINAC) with a 64-leaf binary multileaf collimator (MLC) and narrow jaw size (1 to 3 cm). The maximum field size of this unit for clinical use is 40 cm by 2 cm, resulting in inherently small and highly modulated treatment fields.
- Unlike helical delivery on systems such as the TomoTherapy unit, where the couch moves continuously during beam delivery, the RefleXion X1 employs a step-and-shoot approach for intensity dose distribution modulation, further emphasizing the need for high-spatial-resolution dosimetry.
- Currently, dosimetric verification for small, tracer-avid targets (e.g. lung tumor with ~1.5 cm diameter) remains challenging due to limitations of existing QA tools, including oversized ion chamber insert (e.g. A14SL that occupies about 10% of the target volume, see figure 2) and labor-intensive film dosimetry.

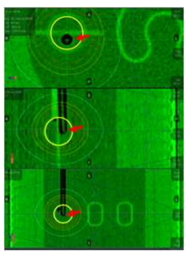

Figure 1. kV CBCT image showing the volume effect of A14SL insert (red arrow). Yellow circles represent 1.5-cm spherical target contour.

Methods and Materials

W1 was recalibrated on the RefleXion PET-linac (6MV FFF beam, maximum clinical filed size 40x2 cm2). CLR measurements were performed in a water tank using parallel and perpendicular setup with a dedicated W1 holder. The gain factor of absolute dose calibration was established with the machine specific reference field (10×2 cm²), and W1-measured output factors were compared with commissioned data. Isocenter point doses for four IGRT plans were measured with W1 and compared to the planned dose. Finally, point-dose measurement was performed for a BgRT plan using to mimic a tracer-avid target, and W1 measured dose was compared to planned dose.

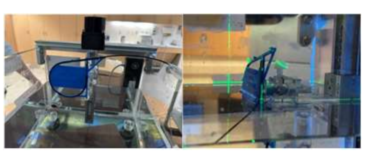

Figure 1. CLR determination with parallel setup of W1 to the beam line on RefleXion system with a blue holder for minimum cable (left) and maximum cable setup (right). The cable and detector were first aligned with the external laser and moved to the isocenter afterwards.

Results

Detector Characterization

To better understand the detector property, we first measured the CLR values and the gain factor for absolute dosimetry calibration at another two C-arm machines (Varian TrueBeam, Varian Edge) and then RefleXion, to validate the stability of W1. The CLR values and gain factors are listed in table 1. In this study, we tested perpendicular setup and parallel setup for solid water and water tank measurement with the machine specific reference field 10 cm by 2 cm.

Machine	CLR	Gain factor
TrueBeam	0.695	2.299
Edge	0.693	2.224
Reflexion	0.698	2.229

Table 1. CLR values and gain factor values for three different machines.

Output factor

Output factor was measured for clinical maximum 2 cm jaw size and MLC opening from 1.25 cm to up to 40 cm MLC defined field size and was summarized in table 2. The output factor is normalized to the charge collected for 10 cm by 2 cm field size. It showed good agreement between commission data and measured data cross all field sizes (<1%), except 1.25 cm by 2 cm field size showed a deviation of -3.5%, currently is under investigation.

Field Size (cm2)	Measured OF	Commissioned OF	% Diff
1.25x2	0.94	0.91	3.53
2.5x2	0.96	0.95	0.80
5x2	0.97	0.98	-0.28
20x2	1.01	1.01	-0.02
40x2	1.01	1.01	0.28

Table 2. Output factor measurement and commissioning data comparison. Percent difference was calculated at the right column.

Rotational output measurement with small field in solid water phantom

After measuring the output factor at the static beam delivery mode. We further tested the rotational output with 1 cm jaw by delivering a simple IGRT plan for 1.5 cm target. This test is in general challenging for A14SL ionization detector given how small the field size is. With plastic scintillator detector, the point dose measurement revealed a 2.4% higher than the treatment planning system, which is within 3% tolerance.

PSQA result for IGRT

To validate the feasibility and stability of utilizing plastic scintillator for plan point dose verification measurement, we delivered three IGRT PSQA plans (esophagus, partial brain, and rectum) with 2cm jaw setting and compared the measured absolute point dose at isocenter to the treatment planning systems calculated values. The deviations of three PSQA are 1.59%, 2.63%, and 1.57%, which are all within clinical acceptance tolerance. It demonstrated the accuracy of the dosimetric commissioning of W1 for IGRT plans on Refexion system.

BgRT plans

For a BgRT test plan with fraction dose of 11 Gy and beam delivery of 27 minutes, we utilized a 2.2 cm-diameter Na-22 coin source to mimic PET tracer avid volume. The ArcCheck phantom was filled with water, with Na-22 source in the target, and the W1 detector was placed 2.5 cm apart from the radioactive tracer. We measured the W1 response without beam delivery for 27 minutes and recorded the collected charges of W1 introduced by the tracer. Then, we proceeded with pre-treatment PET scanning and followed with the treatment session while W1 was used for the point dose measurement. We confirmed that the charge signal from the tracer is about 1% from the measurement with beam delivery. After subtracting the background signal from PET tracer, the point dose measurement was 2.4% higher than the planned dose. This result showed that W1 plastic scintillator, even with the signal perturbation contributed by radioactive tracer, can be utilized to replace A14SL for BgRT measurement while offering enhanced dosimetric sensitivity due to its small active volume.

Discussion

- This study represents the first commissioning and application of W1 plastic scintillator detector (W1) on a PET-Linac system, for both IGRT and BgRT
- The small active volume of the W1 detector (1x1x3mm3) makes it particularly well suitable candidate for such clinical application on RefleXion system.
- We successfully conducted absolute point dose measurement with clinical IGRT plans
- A further novel contribution of this study is the evaluation of radioactive tracer-induced effects on W1 performance.
- The detector was broken and was found because of unusually high background channel 1 reading. The detector was repaired by the manufacturer. We conducted a post-repair test, and confirmed that the CLR value changed slightly but overall, the detector showed consistent performace.

Reference

- M. Guillot, L. Gingras, L. Archambault, S. Beddar, and L. Beaulieu, "Spectral method for the correction of the Cerenkov light effect in plastic scintillation detectors: A comparison study of calibration procedures and validation in Cerenkov light-dominated situations," Med. Phys. 38, 2140-2150 (2011).
- Standard imaging 4792-01_Exradin_W1_Scintillator_Calibration_Tech_Note_1

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