Dosimetric performance for large PET-Avid tumors enabled by Anchor Point Tracking and extended PET Field-of-View

Sanchit Sharma, PhD[1]; Andrew Groll, PhD[1]; Timothy Pok Chi Yeung, PhD[1]; Manoj Narayanan, PhD[1]; Gopi Kuduvalli, PhD[1]
[1]RefleXion Medical Inc

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ABSTRACT

This study evaluated the treatment plan quality and delivery accuracy of the RefleXion X2 biology-guided radiotherapy (BgRT) system using a developmental Anchor Point Tracking delivery algorithm and extended PET field-of-view (FOV) for large PET-avid targets. Three fillable spherical targets (4, 5, and 6 cm diameter), each accommodating an EBT-XD film in the coronal plane and an ionization chamber socket, were filled with ^{18}F-FDG alongside a C-shaped PET-avid organ at risk and placed in a torso-shaped phantom with uniform background activity (~5 kBq/mL; target-to-background ratio ~8:1). All treatment plans achieved ~95% PTV coverage, with conformity indices of 1.02, 1.01, and 1.01 and CI_{50} values of 3.55, 3.34, and 3.26 for the 4, 5, and 6 cm targets, respectively. Ion chamber measurements agreed with planned dose within ±1.3%, and film analysis demonstrated >90% gamma pass rates (3%/3mm) within the PTV. These results demonstrate that the X2 system can accurately plan and deliver BgRT to targets 4–6 cm in diameter while maintaining target coverage and conformity, supporting expansion of BgRT to larger tumors.

DISCLOSURE

Anchor Point Tracking is pending 510(k) clearance and is not commercially available.

CONTACT

Sanchit Sharma
RefleXion Medical Inc
Hayward, California, USA
ssharma@reflexion.com
+1-785-320-1251

INTRODUCTION

Biology-guided radiotherapy (BgRT) uses the positron emission signal from a PET-avid tumor to guide radiation delivery in near-real-time. After administration of a radiotracer such as ^{18}F-FDG, emissions from the tumor are detected by onboard PET detectors and used to direct therapeutic beamlets, allowing the tumor to serve as its own biological fiducial.

Extending BgRT to large tumors is challenging, as target size increases, the emission signal is distributed across a greater volume and plan conformity becomes harder to maintain, particularly when a target is near a PET-avid organ at risk (OAR) such as the heart. The RefleXion X2 system addresses these constraints with a 4× larger PET field-of-view and ~20× greater sensitivity than the X1 system, combined with a developmental Anchor Point Tracking algorithm.

Here, we evaluate plan quality and delivery accuracy for large PET-avid spherical targets (4–6 cm) using film and ion chamber measurements in an anthropomorphic torso phantom.

METHODS AND MATERIALS

Phantom & Target Design

- Three fillable spherical targets fabricated with diameters of **4, 5, and 6 cm**
- Each target split into two hemispheres, accommodating an **EBT-XD film** in the coronal plane
- Each target incorporated an **ionization chamber socket**
- A **C-shaped structure** represented a PET-avid organ at risk (OAR), e.g., the heart
- **Activity Distribution**
- Spherical targets and C-shaped OAR filled with ^{18}**F-FDG**
- Assembly placed within a large **torso-shaped phantom** filled with uniform background solution of water and FDG at **~5 kBq/mL**
- Resulting **target-to-background ratio (TBR) ≈ 8:1**

Treatment Planning & Delivery

- Plans were generated for the **RefleXion X2** system with a developmental **Anchor Point Tracking** algorithm
- Delivery leveraged the **extended PET field-of-view** detectors

Dosimetric Evaluation

- **Absolute point dose:** Exradin **A14SL** ionization chamber
- **2D dose distribution:** EBT-XD film, coronal plane — 1D profile comparison and **3%/3 mm absolute dose gamma analysis**
- **Plan quality metrics:** PTV coverage, conformity index (CI), and CI_{50}

RESULTS

Plan Quality

- All three targets achieved **~95% PTV coverage**
- Conformity index (CI): **1.02** (4 cm), **1.01** (5 cm), **1.01** (6 cm) — near-ideal across all sizes
- CI_{50}: **3.55** (4 cm), **3.34** (5 cm), **3.26** (6 cm) — improving with increasing target size
- Plan quality was maintained despite the adjacent PET-avid C-shaped OAR

Point Dose Accuracy (Exradin A14SL)

- Measured vs. planned dose for static targets: **+1.3%** (4 cm), **+0.03%** (5 cm), **−1.0%** (6 cm)
- All measurements within **±1.3%** of plan

2D Dose Agreement (EBT-XD Film)

- **>90% gamma pass rate** (3%/3 mm, absolute dose) within the PTV for all targets
- Good agreement between planned and measured coronal dose profiles across all target sizes

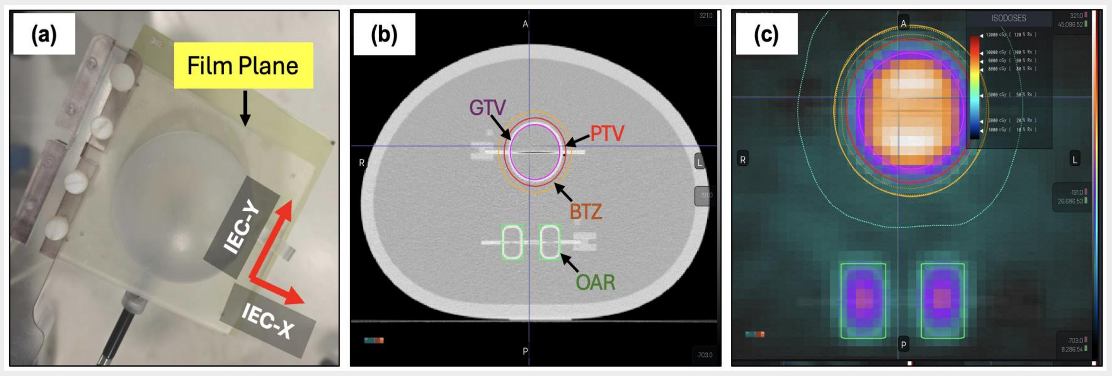

Figure 1. (a) Experimental setup for the 6 cm target showing the film plane and ion chamber socket. (b) Representative kVCT image of the phantom with overlaid GTV, PTV, Biology-Tracking Zone (BTZ), and OAR contours. (c) kVCT image of the target with overlaid modeling PET, and planned dose distribution.

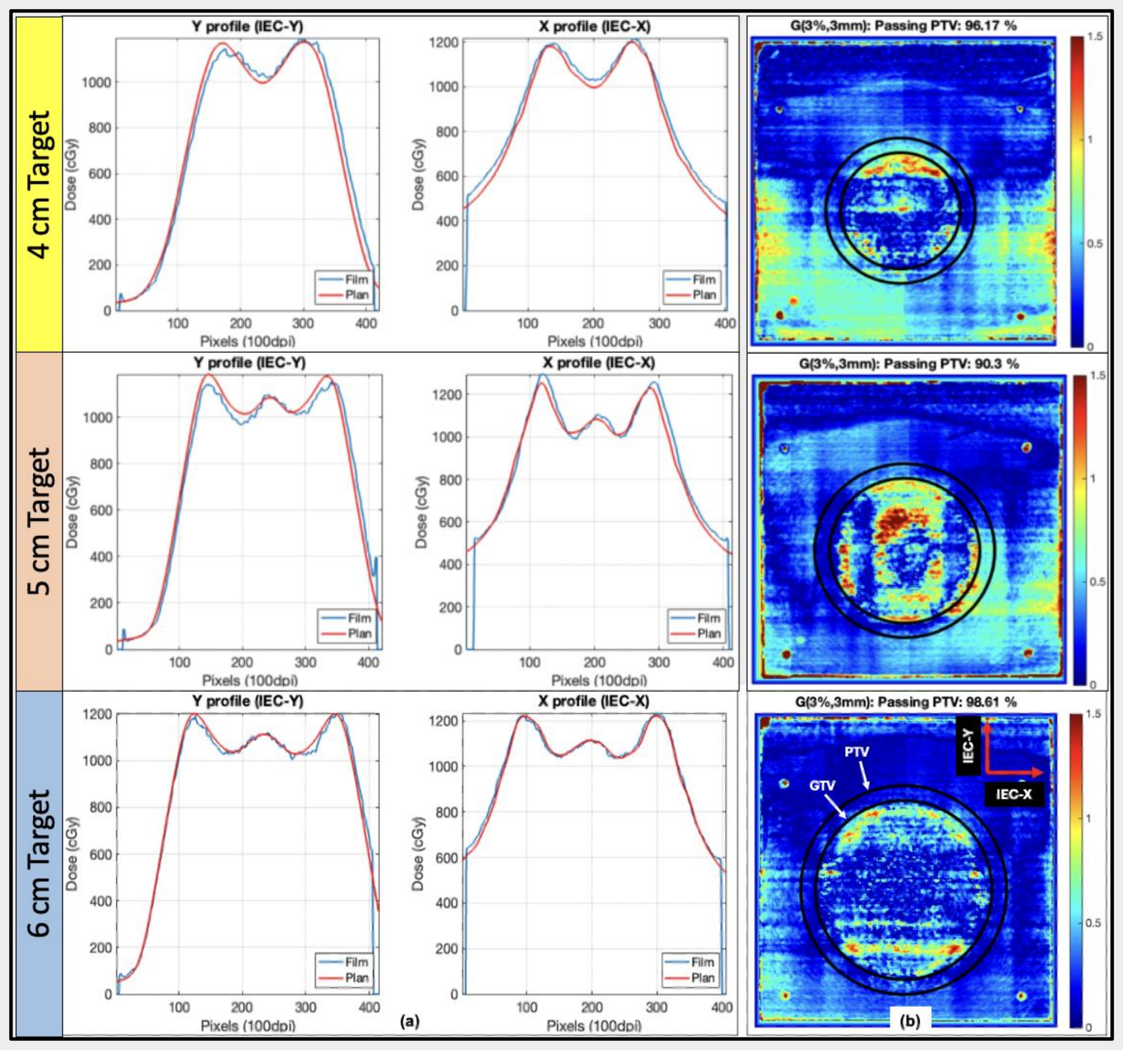

Figure 2. Film analysis for the 4, 5, and 6 cm target study. (a) One-dimensional comparison of the planned (red) and measured (blue) dose profiles from film. (c) 3%/3mm absolute dose gamma analysis on the film.

Table 1. . Plan quality and dosimetric delivery accuracy for 4, 5, and 6 cm PET-avid spherical targets. CI = conformity index; CI_{50} = 50% isodose conformity index. Ion chamber error = measured vs. planned point dose.

Target (cm)	PTV Coverage	CI	CI_{50}	Ion Chamber Error	Gamma Pass Rate (3%/3 mm, PTV)
4	~95%	1.02	3.55	+1.3%	96.17%
5	~95%	1.01	3.34	+0.03%	90.3%
6	~95%	1.01	3.26	−1.0%	96.61%

DISCUSSION

Observations and Interpretations

- These data extend accurate, conformal BgRT delivery to targets up to **6 cm**, beyond the small-target regime where BgRT has been demonstrated to date
- The extended PET FOV and increased sensitivity together provide a more robust guidance signal from a spatially distributed emission source
- $\mathbf{CI_{50}}$ **improved with target size** (3.55 → 3.34 → 3.26), indicating less intermediate-dose spill relative to target volume as the target grows
- Conformity was preserved despite an adjacent PET-avid C-shaped OAR — a realistic confounder for emission-guided delivery
- Agreement across two independent dosimeters (ion chamber ≤1.3%; film >90% gamma) supports the accuracy of both planning and delivery

Limitations & Future Work

- Phantom study with **static, spherical** targets at a single TBR (~8:1); clinical lesions are irregular, moving, and often less avid
- Film sampling limited to a single coronal plane future work will involve repeat deliveries to characterize impact of activity decay.
- Next steps: moving targets under Anchor Point Tracking, lower TBR, and irregular activity distributions.

CONCLUSIONS

- The RefleXion X2 system, leveraging extended PET-FOV detectors and a developmental Anchor Point Tracking algorithm, accurately planned and delivered BgRT to targets 4–6 cm in diameter.
- Plan quality was preserved across all target sizes: ~95% PTV coverage with near-ideal conformity (CI = 1.01–1.02), despite an adjacent PET-avid OAR.
- Delivery accuracy was confirmed by two independent dosimeters — point dose within ±1.3% (ion chamber) and >90% gamma pass (3%/3 mm) within the PTV (film).
- These results support the feasibility of expanding BgRT to larger PET-avid tumors while maintaining target coverage, conformity, and delivery accuracy.

REFERENCES

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