Robustness of BgRT Delivery to Sudden Patient Shifts Evaluated in the X2 Platform

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ABSTRACT

A developmental Anchor Point Tracking (APT) algorithm on the RefleXion X2 platform, paired with an extended PET field of view, was tested for its ability to autonomously follow a PET-avid target and deliver accurate dose under large, sudden target shifts. A ^{18}F-FDG spherical target (about 8:1 target-to-background) in a cylindrical phantom was displaced 1.0, 1.5, and 2.0 cm inferiorly before BgRT delivery of 10 Gy dose. Delivered dose was assessed by ArcCHECK 3%/2 mm gamma analysis and EBT-XD film. Gamma pass rates stayed above 97% and PTV margin loss remained within the 3 mm specification for every case, supporting robust BgRT under abrupt target motion.

DISCLOSURE

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

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INTRODUCTION

Biology-guided Radiation Therapy (BgRT) uses real-time PET emissions from the tumor to steer the treatment, letting delivery track a biologically defined target. Clinical robustness requires that targeting stay accurate even when the patient, and therefore the tumor, shifts suddenly and by a large amount.

This work evaluates whether a RefleXion X2 system with an extended PET field of view and a developmental Anchor Point Tracking algorithm can autonomously follow a PET-avid target and deliver the planned dose while accounting for large, sudden target displacements.

METHODS AND MATERIALS

Phantom Setup
Custom cylindrical phantom containing:
22 mm ^{18}F-FDG–fillable spherical target
C-shaped organ-at-risk (OAR) insert
Uniform ^{18}F-FDG/water background (~5 kBq/mL)
Target-to-background activity ratio maintained at ~8:1.
Phantom placed within an ArcCHECK® detector array, with EBT-XD radiochromic film positioned in the target coronal plane for dose verification.

Treatment Planning
BgRT treatment plans generated on the RefleXion X2 platform.
Prescription: 50 Gy in 5 fractions to PTV = GTV + 5 mm.
Developmental Anchor Point Tracking algorithm with a Biology Tracking Zone (BTZ) sized to encompass the evaluated step shifts.

Motion Simulation
Pre-scan PET acquired in the planned configuration.
Prior to delivery, the phantom was displaced 1.0, 1.5, and 2.0 cm inferiorly to simulate sudden patient motion.

Dosimetric Evaluation
ArcCHECK®: 3%/2 mm gamma analysis.
EBT-XD film: comparison of planned and measured dose distributions, one-dimensional dose profiles, and PTV margin loss based on the 97% isodose line.

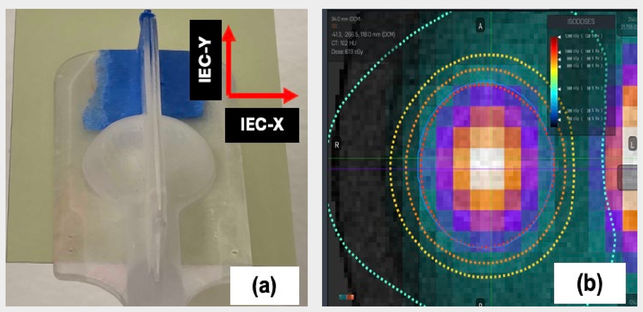

Figure 1. (a) Experimental setup illustrating the phantom configuration and coronal film plane within the target. **(b)** Modeling PET and planned dose overlayed on the kVCT localization image of the ball target.

RESULTS

Delivery Accuracy (ArcCHECK®)
- Robust BgRT delivery demonstrated across all evaluated sudden inferior displacements: **1.0, 1.5, and 2.0 cm**
- 3%/2 mm gamma pass rates: **99.2%** (1.0 cm), **97.0%** (1.5 cm), **98.5%** (2.0 cm)
- All deliveries exceeded clinically acceptable dosimetric criteria — tracking performance maintained despite large abrupt motion

Film Dosimetry
- Measured dose distributions closely matched the treatment plan
- One-dimensional profile comparisons showed strong agreement between planned and measured dose, with no clinically meaningful degradation in target coverage

PTV Margin Loss
Measured margin loss remained well within specification for all shifts: **2.3 mm** (1.0 cm), **0.6 mm** (1.5 cm), **0.9 mm** (2.0 cm)

Summary
The developmental Anchor Point Tracking algorithm maintained accurate dose delivery for sudden target displacements of up to **2.0 cm**

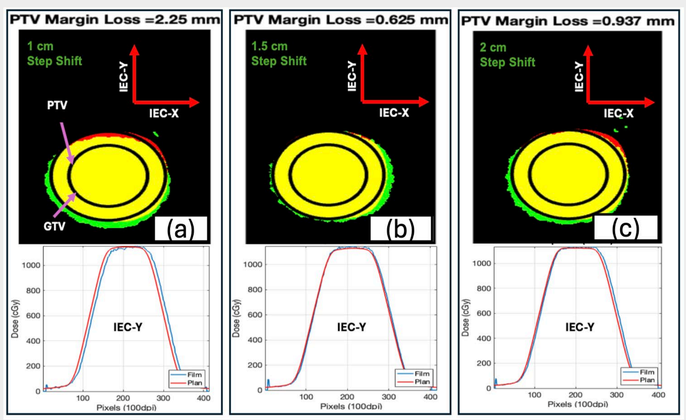

Figure 2. (a – c) Margin loss analysis and one-dimensional dose profile agreement between planned (red) and film-measured (blue) doses for 1.0 cm, 1.5 cm, and 2.0 cm sudden inferior target shifts. For the Margin loss analysis, the yellow region shows overlap between the planned and film-measured 97% isodose lines, indicating accurate dose delivery. The red region denotes where the planned 97% isodose extends beyond the measured distribution; the maximum inward distance of this region within the PTV defines margin loss. The green region denotes areas where the measured 97% isodose extends beyond the planned distribution, referred to as margin growth.

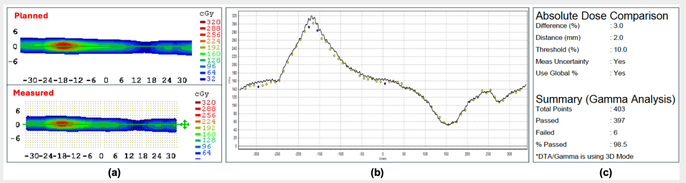

Figure 3. (a) A representation of planned and measured dose from ArcCHECK software. (b) A comparison of one-dimensional measured (dotted) and planned (solid) dose profiles. (c) 3%/2mm gamma analysis for the 2cm step shift case.

Table 1. Summary of dosimetric performance for inferior step shifts evaluated on the RefleXion X2 platform. High gamma pass rates and minimal PTV margin loss demonstrate robust BgRT delivery across all simulated motion scenarios.

Inferior Step Shift	Gamma Pass Rate (3%/2 mm)	PTV Margin Loss (mm)
1.0 cm	99.2%	2.3
1.5 cm	97.0%	0.6
2.0 cm	98.5%	0.9

DISCUSSION

First demonstration that the RefleXion X2 platform maintains accurate BgRT delivery under large, sudden target displacements, using a wider PET field of view and a developmental **Anchor Point Tracking (APT)** algorithm.

Gamma pass rates stayed **≥97%** across all tested shifts, and PTV margin loss remained **well within the 3 mm specification.**

Accuracy did not degrade with shift magnitude.

In every case, **APT autonomously followed the target** without compromising dose.

Together, these findings support the robustness of biology-guided delivery under clinically relevant motion.

CONCLUSIONS

Accurate dose delivery under all shifts. The 3%/2 mm gamma pass rates stayed high across every displacement (99.2%, 97.0%, and 98.5% for the 1.0, 1.5, and 2.0 cm shifts).

Target coverage preserved. Film-based PTV margin loss (2.3, 0.6, and 0.9 mm) remained within the specification in all cases, with no clinically meaningful loss of coverage.

Robust tracking under abrupt motion. The developmental Anchor Point Tracking algorithm autonomously followed the PET-avid target after sudden displacements of up to 2.0 cm without degrading delivered dose.

Supports efficient BgRT delivery. These results reinforce the robustness of BgRT delivered with a wider PET field of view and motivate further evaluation under clinically realistic motion.

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