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PET Signal Guidance In Biology-Guided Radiotherapy: Impact of Deblurring and Anchor Point Tracking on Dosimetry

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ABSTRACT

Purpose: To assess the effectiveness of a developmental anchor point tracking algorithm with PET deblurring in targeting tumors on the RefleXion X2 platform.
Methods: Planning using PET-based biology-guided radiotherapy (BgRT) on the RefleXion X2 removes target motion by deblurring the PET-avid region of the GTV. Deblurring collapses target motion into a single static frame for anchor point tumor tracking. Delivery accuracy is contingent on how well this frame of reference is preserved between the plan and delivery even with motion changes. An 18F-fluorodeoxyglucose fillable phantom was inserted into an ArcCHECK positioned on the CIRS motion platform. The phantom contained a 22 mm diameter spherical target. Studies were prepared at 10 Gy/fx using identical plan constraints with 8:1target-to-background ratios. Six studies were performed using combinations of astatic target and 15 mm cos 4-second periodic motion, and step shifts. Study 1 used a static PET based plan and delivered to a static target (static-to-static baseline).Study 2 used motion at planning and motion at delivery (motion-to-motion baseline).Study 3 tested motion at planning but no motion at delivery. Study 4 used the static PET for planning but delivered with cos motion, measuring whether the system can track when no motion was used at planning. Studies 5 and 6 used motion at planning and a +/- 10 mm step shift of a static target at delivery.
Results: The ArcCHECK measured 3%/2mm gamma pass rates were 98.6%, 97.1%,97.6%, 90.1%, 99.5% and 98.9% for Studies 1-6, respectively. When comparing Study 1and Study 4 using film, tracking was preserved with dose shape differences within thePTV.
Conclusion: BgRT plans with the highest gamma passing rates were observed when maintaining or reducing target motion at delivery. The most extreme case, Study 4,exceeded 90% 3%/2mm which could still be clinically acceptable.

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INTRODUCTION

The RefleXion X2 positron emission tomography (PET) based biology-guided radiotherapy (BgRT) system is a second-generation external beam therapy system guided by the targeted physiological uptake of radiopharmaceuticals in cancerous lesions. Some key developments introduced by the X2 include:

- **Increased Axial Field-of-View:** The X2 improves upon the geometric sensitivity of the X1 by increasing the axial field-of-view from the 5 cm to 20 cm resulting in an approximate 20x improvement in sensitivity.
- **Anchor Point Tracking:** Increased sensitivity facilitates the use of an improved tracking algorithm, termed Anchor Point Tracking (APT), which tracks lesion movement using a positional centroid spread estimate supported by maximum likelihood estimate (MLE) and an autocorrelation filter (ACF) generated at planning.
- **Tumor Point of View Treatment Planning:** The PET image data acquired during functional modeling is deconstructed into limited time sampled (LTS) PET images such that positional estimates of each LTS image can be made and each image can be binned into a discrete phase. The phase bins are then collapsed into single position. This removes the motion and collapses all PET data into a static "tumor point of view" (TPOV) frame of reference for treatment planning.

Since the X2 relies on a TPOV for planning with a new novel tracking algorithm, this work aims to evaluate if planning on a static target versus a motion deblurred target under different delivery conditions is truly equivalent.

MATERIALS AND METHODS

Experimental Materials An 18F-fluorodeoxyglucose fillable phantom, see Figure. 1, was inserted into an ArcCHECK positioned on CIRS platform. The phantom contained a 22 mm diameter spherical target. Studies were prepared at 10 Gy/fx using identical plan constraints with 8:1 target-to-background ratios.

Figure 1 (A) *CIRS motion platform mounted with CIRS motion platform (B) Ball target C-shape phantom..*

Experimental Studies:

- **Study 1** delivered to a static target using a static plan, to serve as a true TPOV-to-TPOV baseline.
- **Study 2** used the static plan but delivered to motion, measuring true planning TPOV to a moving target TPOV.
- **Study 3** used motion at planning and motion at delivery, to compare calculated TPOV, using deblur, to a moving target TPOV. Figure 2 shows an example of motion de-blur.
- **Study 4** used motion at planning but no motion at delivery, measuring calculated TPOV to true TPOV.
- **Study 5 - 6** used motion at planning and a static step shift delivery, comparing calculated TPOV to a displaced true TPOV.

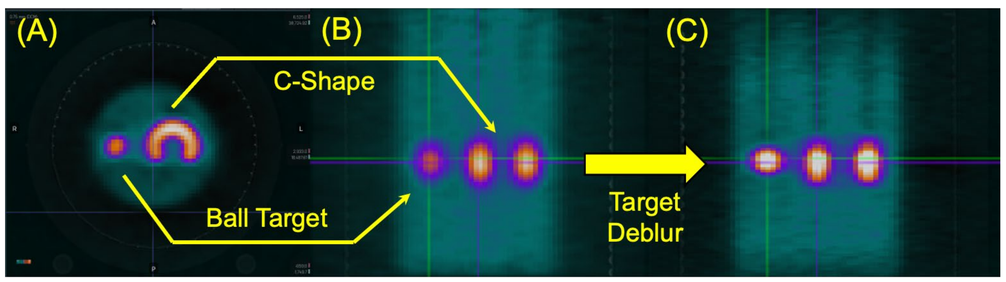


Figure 2: (A) *Transverse image an FDG filled phantom prepared with an 8:1 TBR using 22 mm ball target with an adjacent c-shape.* ***(B)*** *Coronal image of the same phantom with the CIRS motion platform set to move with a 15 mm cos4 4 second period motion trajectory.* ***(C)*** *The deblurred planning PET image where the ball target is seen to be more spherical whereas the c-shape remains blurred.*

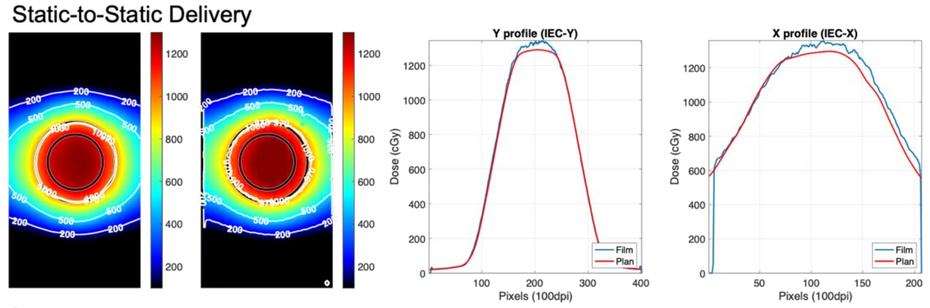
RESULTS

Key Results: Six experimental studies were performed as summarized in Table 1. All deliveries exceeded 90% 3%/2mm. Studies which delivered to static targets regardless of TPOV planning condition perform slightly better than those which delivered to motion. Static to static, motion to static, and motion to a static target with a plus or minus 10 mm displacement achieved 3%/2mm gamma values of 98.60%, 97.60%, 99.50%, and 98.90%, respectively. Studies which delivered to motion, such as static to motion and motion to motion, saw 90.10% and 97.10%, respectively.
Closer inspection of the TPOV delivery of the static to motion, the worst case, showed dose profile changes in the PTV, see Figure 2. When compared to the static-to-static delivery, both studies covered the GTV but the delivery to motion saw a peakier dose with fall off resulting in 1.56 mm radial PTV margin loss versus a 0.64 mm in the static case.

Table 1: Summary of Plan and Delivery Details with 3%/2mm Results

Planning Condition	Delivery Condition	3%/2mm
Static	Static	98.60%
Static	Motion 1.5 cm Cos4 4Sec	90.10%
Motion 1.5 cm Cos4 4Sec	Motion 1.5 cm Cos4 4Sec	97.10%
Motion 1.5 cm Cos4 4Sec	Static	97.60%
Motion 1.5 cm Cos4 4Sec	Static+10mm	99.50%
Motion 1.5 cm Cos4 4Sec	Static-10mm	98.90%

Static-to-Static Delivery



Static-to-Motion Delivery

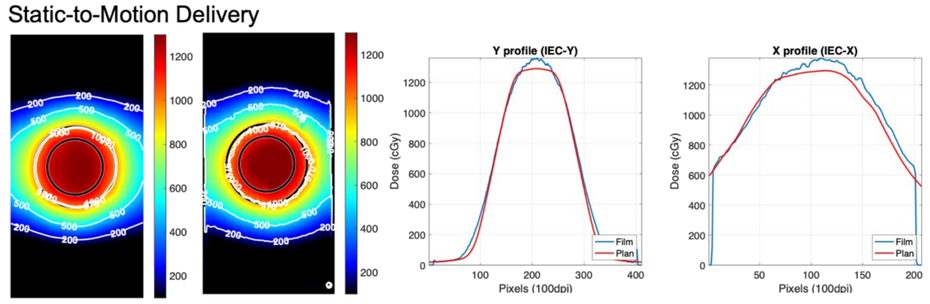


Figure 3: (TOP ROW) *Static to static delivery TPOV film. From right to left, the planned dose, the delivered dose, and the IEC-Y and IEC-X profiles.* ***(BOTTOM ROW)*** *Static to motion delivery TPOV film. From right to left, the planned dose, the delivered dose, and the IEC-Y and IEC-X profiles.*

DISCUSSION AND CONCLUSIONS

General Dosimetry: All studies produced 3%/2mm gamma results exceeding a minimum 90% threshold reserved for clinically acceptable treatment accuracy. Of the treatment plans delivered, the worst dosimetry result was observed when planning using a static target but delivering to motion.

Comments on Frame of Reference Mismatch: Given that APT largely functions using a positional centroid spread estimate to ensure accurate delivery, the static to motion delivery results, and vice versa, indicate that planning on a static target is not equivalent to planning on a motion deblurred target. It is possible that planning on a static target produces less uncertainty in the centroid estimate function than its motion deblurred complement. Dosimetry is subsequently penalized when moving toward a condition which is harder to track (a larger uncertainty condition). Further work looking at TPOV film dosimetry as a function of positional certainty is necessary to clarify the possible relationship.

ACKNOWLEDGMENTS

The RefleXIon X2 APT algorithm is currently undergoing FDA review and is not cleared for sale.