Evaluation of a Biology-guided Therapy (BGRT) System with Anchor Point Tracking Treatment Planning and Delivery

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ABSTRACT

Purpose: This work demonstrates the dosimetric performance of the developmental Anchor Point Tracking algorithm using phantom data acquired on the RefleXion X2 system with wide field-of-view PET detectors and software simulation of treatment planning and delivery.

Methods: Experiments were performed using an FDG-filled target inside an ArcCHECK or an FDG-filled target that moves freely inside a torso-shaped water phantom. PET data for treatment planning and delivery were acquired using an X2 system. One treatment plan was created using the previous X1 algorithm and a corresponding plan was created using the X2 Anchor Point Tracking algorithm that is in development. Plan quality, treatment time, and emulated delivery accuracy of the two algorithms were compared.

Results:
For all twelve experiments involving stationary or moving targets, the median treatment time using the Anchor Point Tracking algorithm was shorter by 31.5% (P = 0.00001). Plan quality improved over X1 algorithm (median CI50 = 6.3 vs. 4.4, respectively; P = 0.00001), particularly in the superior-inferior extent of an oscillating target. The 3%/3mm absolute dose gamma inside the prescription dose was significantly better with the Anchor Point Tracking algorithm (P = 0.05). Of note, the Anchor Point Tracking algorithm also performed better than the X1 algorithm when the target suddenly shifted 1 cm during treatment (gamma = 40 vs. 100%). For targets undergoing periodic motion (N = 6), delivery accuracy was evaluated using PTV margin loss, which is the radial loss of PTV coverage (mm) relative to the 97% isodose line. There was no difference in margin loss between the two algorithms (P = 0.7).

Conclusion: This work demonstrated the Anchor Point Tracking algorithm's ability to better spare normal tissue with more conformal BgRT plans without sacrificing delivery accuracy, and it was also better at responding to sudden shifts of the target during treatment.

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INTRODUCTION

The next-generation RefleXion® X2 system advances PET-guided autonomous motion management by tracking motion and bulk tumor shifts in real time, conforming dose to the moving PTV and eliminating ITV-based delivery. Building on the X1 with a 4X larger PET field-of-view, 20X greater sensitivity, and patient-tailored tracking, the X2 uniquely models its own uncertainty and latency during plan optimization, ensuring PTV coverage without ITV expansion.

This work demonstrates the dosimetric performance of the Anchor Point Tracking algorithm via software emulation of planning and delivery, with corroborating experimental validation.

METHODS AND MATERIALS

Software Simulation

- Experiments were performed using an FDG-filled target inside an ArcCHECK or an FDG-filled target that moves inside a torso-shaped water phantom

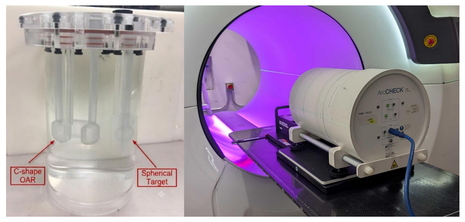


Figure 1. Experimental setup showing the fillable ArcCHECK insert (left) and ArcCHECK sitting on the CIRS motion platform. The fillable insert has a 22-mm spherical target and a C-shape organ-at-risk (OAR).

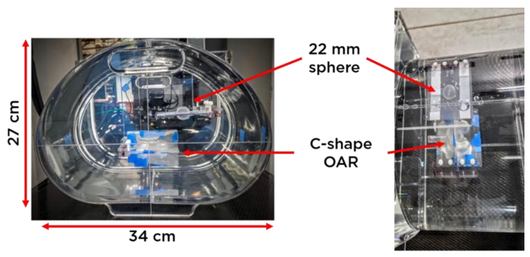


Figure 2. Experimental setup showing the fillable ArcCHECK insert (left) and ArcCHECK sitting on the CIRS motion platform. It also featured a 22-mm spherical target and C-shaped OAR.

- PET data for treatment planning and delivery were acquired using an X2 system.
- One treatment plan was created using the previous X1 algorithm and a corresponding plan was created using the X2 Anchor Point Tracking algorithm.
- Plan quality, treatment time, and simulated delivery accuracy between the X1 and X2 were compared.

Experimental Validation

- The same phantoms were used to acquire new PET scans for planning and delivery
- Instead of treatment simulation, the SCINTIX BGRT plans were delivered.
- Dosimetric accuracy was evaluated using either absolute dose gamma or PTV margin loss (maximum distance between PTV contour and the 97% isodose line of on the film [1]

SIMULATION RESULTS

Figure 3. Treatment time reduction (left) and plan conformity index of the 50% isodose (right) for 12 BGRT plans. The average treatment time reduction is 34%, Paired t-test *P* = 0.0001. The improvement of plan conformity was also statistically significant (*P* = 0.0001).

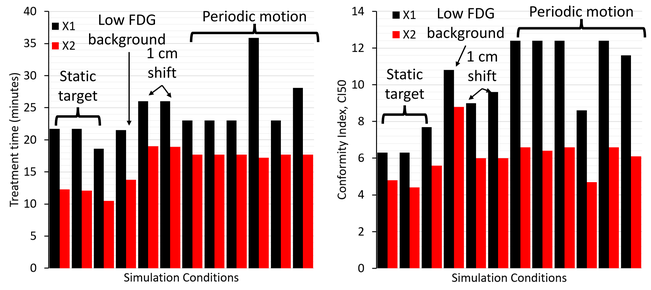
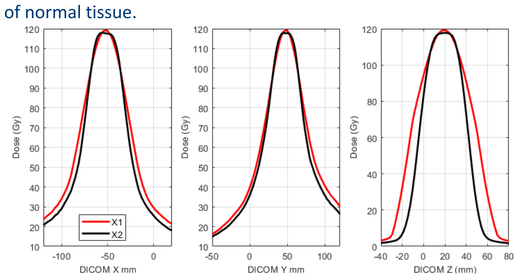


Table 1. Simulated 3%/3mm absolute dose gamma and film margin loss for each of the 12 plans. Dosimetry pass rate is defined by margin loss (< 3 mm) and not gamma [1].

		3%/3mm Absolute Dose Gamma		Simulated Film PTV margin loss (mm)	
Case #	**Tumor Motion**	**X1**	**X2**	**X1**	**X2**
1	Static	100%	100%	--	--
2	Static	100%	100%	--	--
3	Static	100%	100%	--	--
4	Low background FDG	62%	100%	--	--
5	1 cm shift	40%	100%	1.3	0.4
6	1 cm shift	39%	100%	0.2	0.5
7	Periodic motion	89%	100%	1.9	1.8
8	Periodic motion	100%	100%	0.1	0.9
9	Periodic motion	99%	100%	0.0	0.9
10	Periodic motion	100%	99%	1.8	1.4
11	Periodic motion	100%	100%	0.0	0.03
12	Periodic motion	88%	100%	1.5	1.5
	Paired t-test	**--**	**0.05**	**--**	**0.7**

Figure 4. Planned dose falloff beyond the PTV for plans created using the X1 versus X2 APT algorithm under identical dose constraints. The target was a 22-mm sphere oscillating in three dimensions, with the major axis of motion in the DICOM-Z direction. X2 algorithm had sharper dose falloff with better sparing of normal tissue.



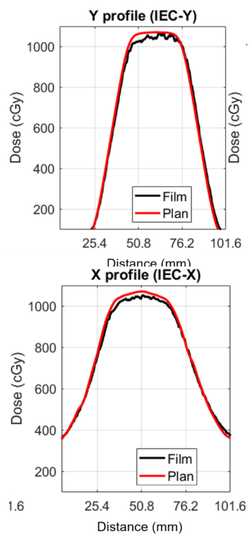
EXPERIMENTAL RESULTS

Table 2. Dosimetric accuracies for various experiments involving a static target, a target that shifted during treatment, and a target that oscillated. The targets were filled to have an FDG concentration that is 8x the background.

Case #	Tumor Motion	3%/2mm Absolute Dose Gamma
1	Static	99.0%
2	Static	98.1%
3	Static	98.7%
Case #	**Tumor Motion**	**Film Margin Loss (mm)**
3	1 cm shift	0.4
4	1 cm shift	1.4
5	1 cm shift	1.2
6	Periodic motion*	0.4
7	Periodic motion	0.7
8	Periodic motion	1.0
9	Periodic motion	1.7

* The waveform caused the target to oscillate with peak-to-peak amplitude of 6.6, 15.7, and 6.6 mm in the IEC-X, IEC-Y, and IEC-Z directions, respectively.

Figure 5. Measured vs. planned dose profiles for a target subjected to a 1 cm step shift in non-periodic tracking mode (Test #4).



EXPERIMENTAL RESULTS

Table 3. Experimental Conditions and Dosimetric Results for Static Targets Under Varying FDG Biodistribution Conditions.

Test #	Condition-of-interest	Condition at planning	Condition at delivery	3%/2 mm absolute dose gamma pass rate
1	*TBR ↑	8:1	10:1	98.1%
2	TBR ↓	8:1	6:1	99.2%
3	TBR ↓	20:1	10:1	97.5%
4	Background FDG concentration ↓ with TBR maintained	5.0 kBq/ml	3.5 kBq/ml	99.7%
5	Target size ↑	22 mm FDG-avid target	26 mm FDG-avid target	97.1%
6	Target size ↓	26 mm FDG-avid target	22 mm FDG-avid target	98.2%
Median	--	--	--	97.8%
Range	--	--	--	91.4% - 99.7%

Table 4. Experimental Conditions and Dosimetric Results for Static Targets Under Varying FDG Biodistribution Conditions.

Test #	Condition-of-interest	Condition at planning	Condition at delivery	Film margin loss (mm)
1	*TBR ↑	8:1	10:1	1.4
2	TBR ↓	8:1	6:1	2.5
3	Background FDG concentration ↓ with TBR maintained	5.0 kBq/ml	3.5 kBq/ml	1.5
4	†Target size ↑	22 mm GTV	26 mm GTV	0.0
5	†Target size ↓	26 mm GTV	22 mm GTV	1.0
Median	--	--	--	1.4
Range	--	--	--	0.0 – 2.5

DISCUSSION & CONCLUSIONS

- Experimental evidence was provided to corroborate the software simulation results.
- X2 Anchor Point Tracking algorithm demonstrated better sparing of normal tissue with more conformal BgRT plans without sacrificing delivery accuracy
- The X2 Anchor Point Tracking algorithm was also better at responding to sudden target shits during treatment.
- Under a wide range of experimental phantom conditions, SCINTIX BGRT deliveries met the X2 platform's dosimetric criteria, proving that the X2 can accurately deliver SCINTIX therapy to both static and moving targets, while also demonstrating robustness to variations in PET tracer biodistribution.
- RefleXion X2 System is cleared for FDG-guided treatment of lung and bone tumors. Anchor Point Tracking is pending FDA 510(k) clearance and is not yet commercially available.

REFERENCES

1. Groll A, Sharma S, Schmall JP, et al. A Discussion on SCINTIX® Biology-guided Radiotherapy: Dosimetry in Theory and Practice. Tech. rep. RefleXion Medical, Inc., 2025.