Validating real-time target tracking and adaptation in radiation therapy

Scott Crowe, Liting Yu, Sharon Gordon, Jemma Walsh, Tanya Kairn

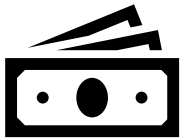
Metro North Hospital and Health Service

HERSTON BIOFABRICATION INSTITUTE

The University Of Queensland AUSTRALIA

QUT Queensland University of Technology

Disclosures



The authors have no financial interests or relationships with any of the manufacturers or vendors of equipment described in this presentation, nor with any of the commercial supporters of the EPSM Conference.

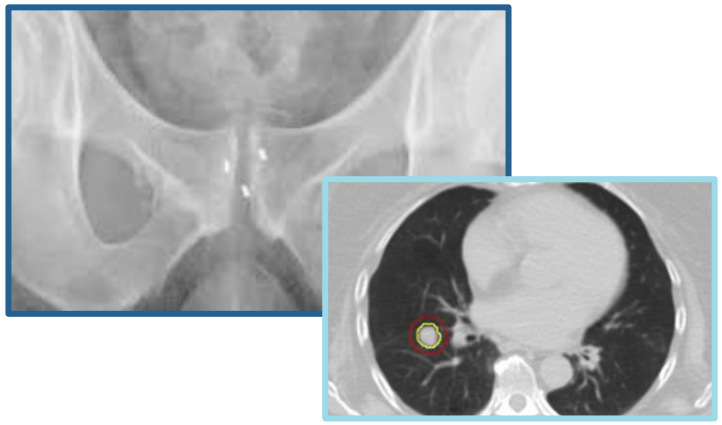
The components of this work using patient data were approved by the Royal Brisbane and Women's Hospital Human Research Ethics Committee (LNR/2020/QRBW/97008). The authors acknowledge the Royal Brisbane & Women's Hospital radiation therapists who prepared the plans for which measurement results are included in this work.

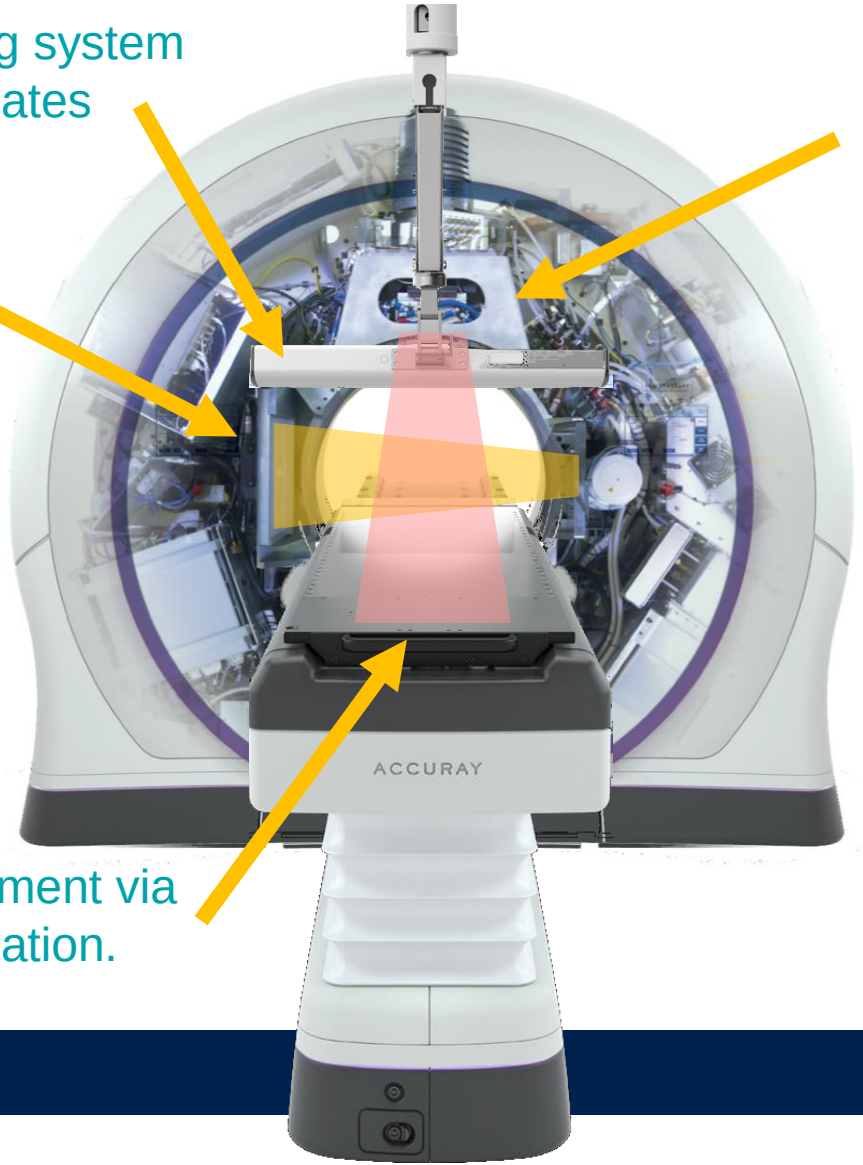
Aspects of this project have previously been presented at the June 2023 ACPSEM QLD Branch PRIMPS Meeting and October 2023 Accuray Australasian Symposium.

Accuray Radixact system

Optical tracking system for LED surrogates

Onboard kV for target-in-lung or fiducial tracking.

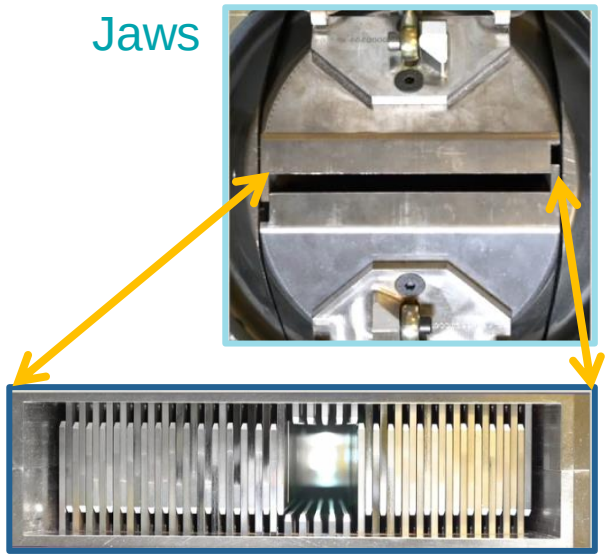




Helical treatment via couch translation.

6FFF treatment beam and exit detector pair. Allows 5 cm max jaw field size (sup-inf), and has binary 6.25 mm (@iso) leaves.

Jaws



MLCs

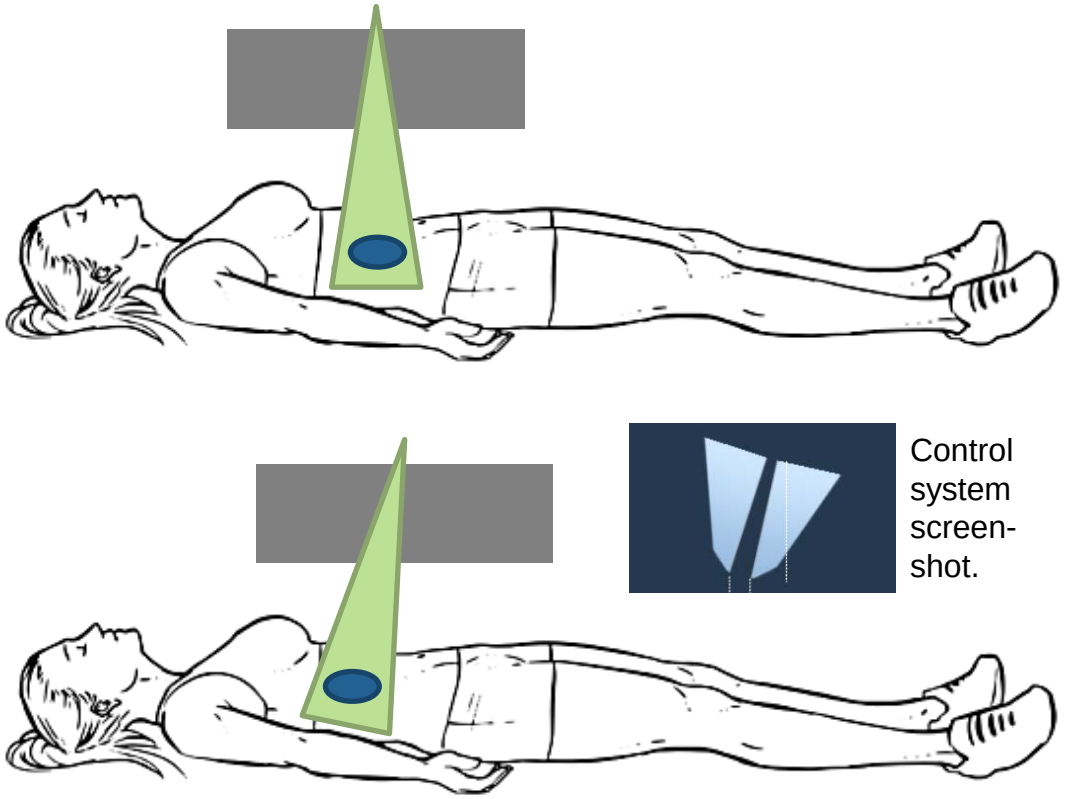
Real-time online adaptation

The Radixact Synchrony system allows real-time online motion delivery adaptation, by monitoring the position of a tumour or fiducials with imaging.

With each source rotation, 2-6 radiographs are acquired. ~100 may be acquired over treatment.

When movement of the target or surrogates is observed or predicted based on a LED-surrogate-driven correlation model, the jaw and MLCs are moved in synchrony with the target.

This adjustment is a relocation of the treatment beam – jaw tracking or binary leaf pair swap – there is no change in beam shape.



Control system screen-shot.

Radixact Synchrony

Incorrect adaptation could compromise the treatment, so it is critical to validate the performance of this technology through dosimetry measurements.

BENEFITS AND FEATURES	RISK TO BE MITIGATED
Normal tissue dose can be reduced, as instead of delivering dosing wherever the target *might* be located, it can be delivered to where it *is* located.	If we reduce the volume / margins of treatment, we may miss the target, compromising control. **We need to validate that tracking and adaptation works**.
The system has safety features that interrupt the treatment when there is a lack of confidence in target location, to reduce risk of a geometric miss.	We don't want to start treatments that need to be abandoned due to motion. **We must validate the types of motion that can be successfully tracked.**
The system has features that can be used for various anatomical sites, including lung, prostate and abdominal tumours.	Treatments of different sites have different doses, volumes, and treatment times. **We must validate performance across different plans.**

What do we need?

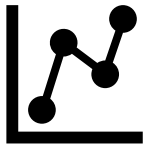
To ensure patient treatments can be delivered accurately, we need:

Treatment plans, ideally including clinically representative plans, and edge cases that may be subject to greater errors.

We've tested conventional and SBRT plans, of various doses, lengths and modulation.

Phantom patients, mimicking the appearance and properties of patients, including fiducials, and able to accommodate dosimeters.

We've done tests with multiple phantoms and targets, with film and detector array measurements.

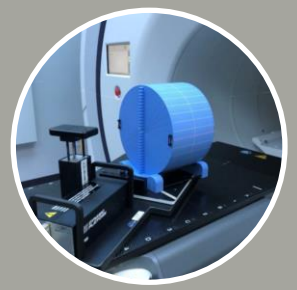


Phantom motion, ideally including target and surrogate motion, and both representative motion and edge cases subject to errors.

We've used clinically sourced motion trajectories supplied by USyd, used in other studies.

Commissioning process

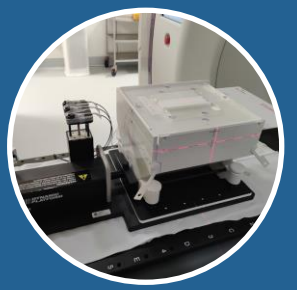
I’m going to provide an overview of E2E testing with film and our DQA process.



Acceptance testing using 1D motion platform

Commissioning using dynamic phantoms

Independent testing by USyd robotic phantom



Patient-specific testing using Octavius phantom

Lung end-to-end film measurement example

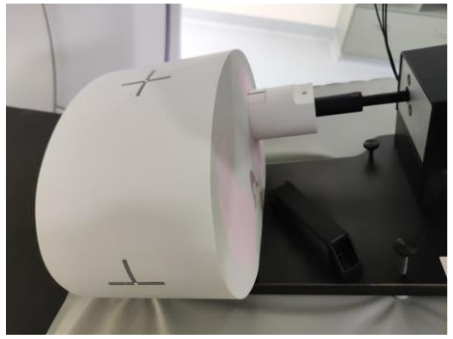
Use of CIRS dynamic thorax phantom, with 3D printed inserts containing tumours.

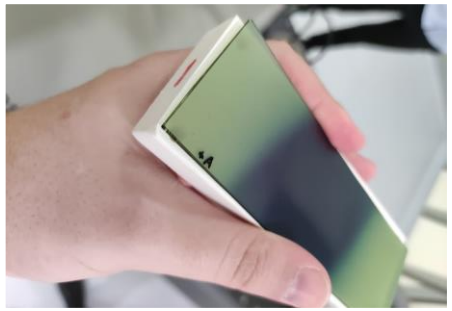
Phantom placed on 18° TBI wedge, to provide AP motion in addition to SI.

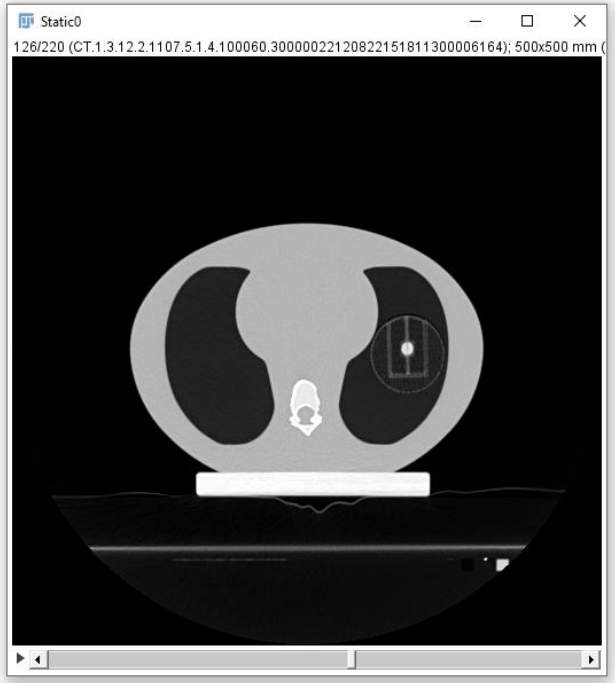
Sagittal film measurements performed in centre of tumour.

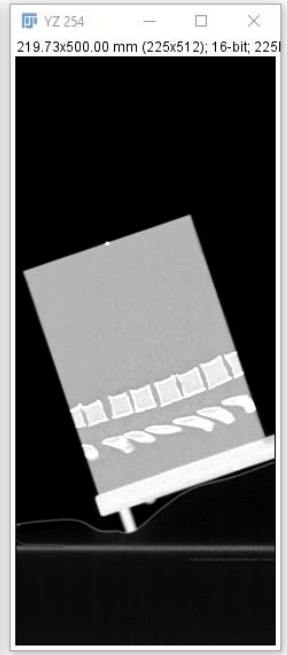
Planned with RTOG 1021, 54 Gy in 3 Fx. 19 mm SI, 6 mm AP motion. Planned to “GTV” only, no margins. 2.5 cm jaws.

Clinical motion data.

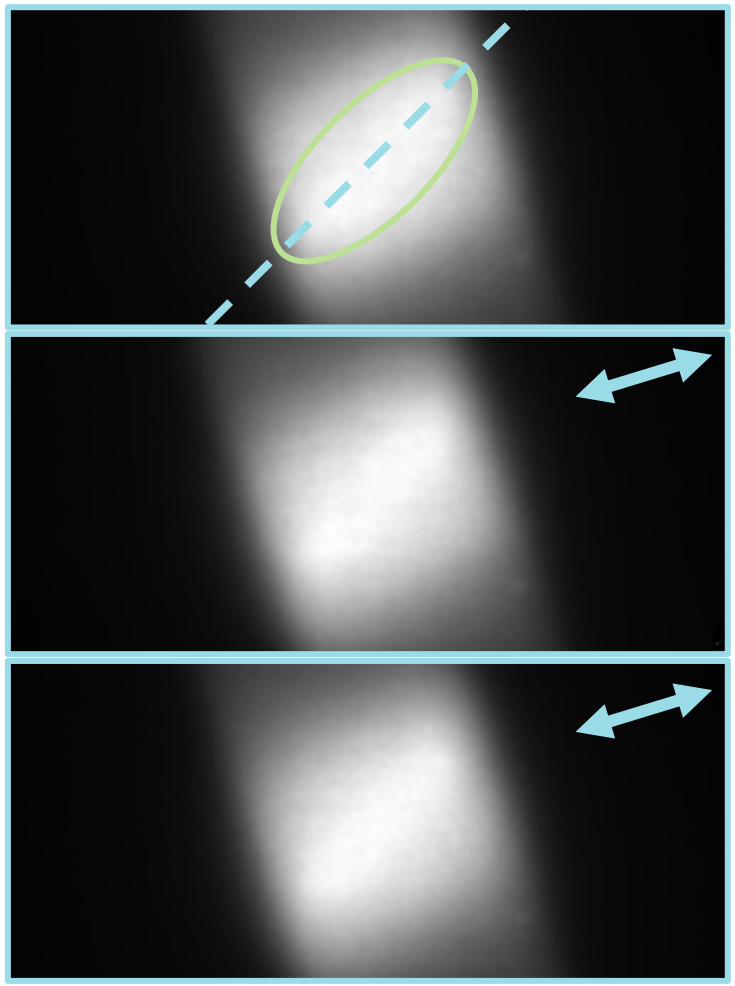








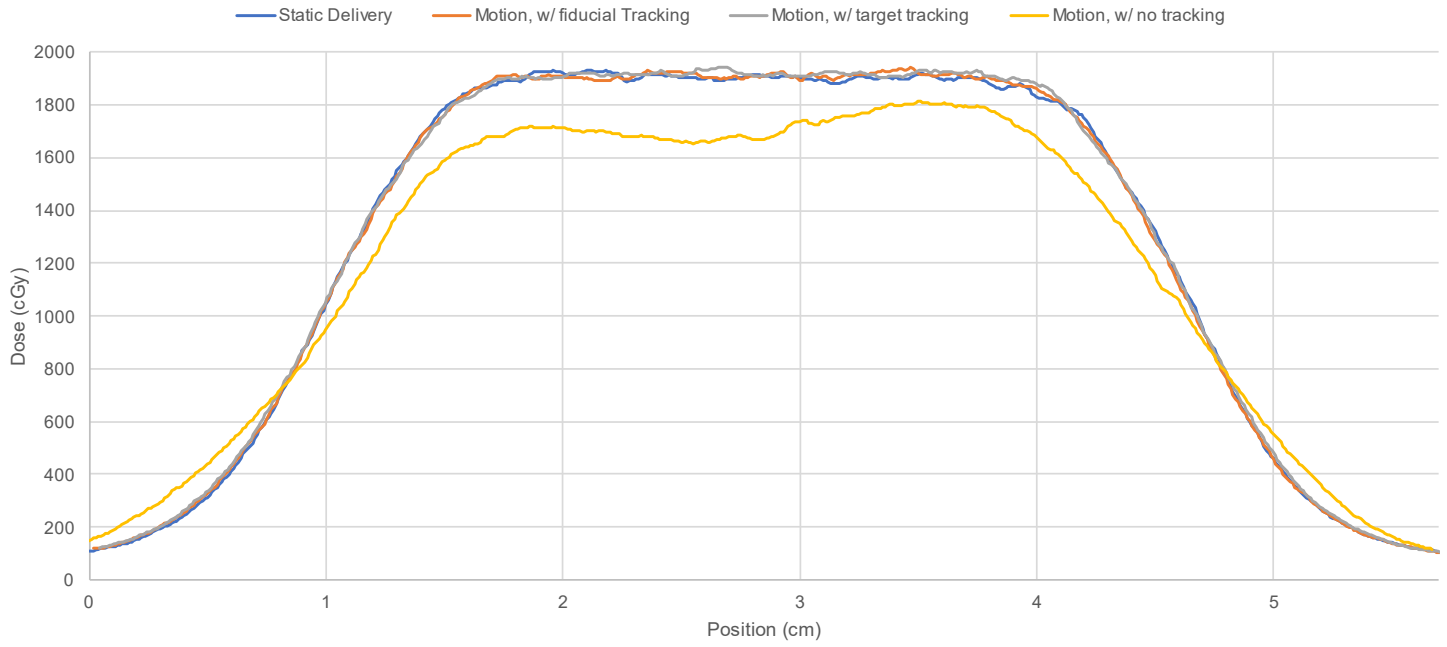
Lung end-to-end film measurement example



2%/2mm GPR > 99%

Left, top: Static delivery, tumour (highlighted) not moving.
Left, middle: Synchrony delivery, fiducial and surrogate tracking.
Left, bottom: Synchrony delivery, target and surrogate tracking.

Below: Dose profiles through tumour (along dashed line).



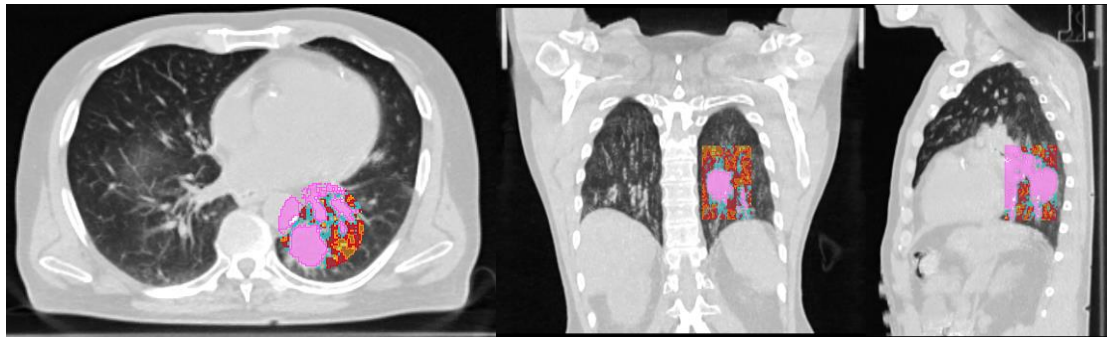
Realistic lung insert tests

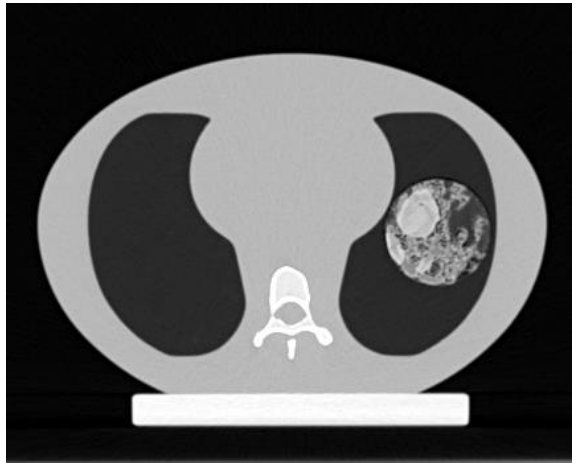
Fiducials are easy to identify in a radiograph. Spherical lung tumours surrounded by lung-equivalent media are also easy to spot.

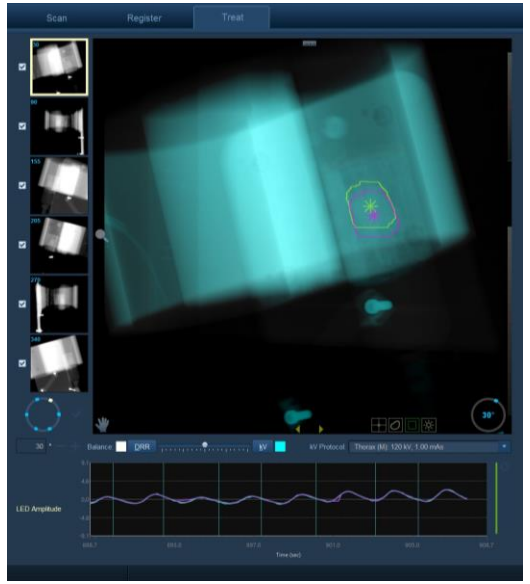
We tested a variety of “realistic” lung tumour inserts in the CIRS phantom, printed from patient CT data. These included:

- “Attached” to mediastinum or other soft tissue.
- Overlapping lesions and surrounding fibrosis.
- Tumours with fuzzy edges.

Synchrony was able to track these targets, even when the operators weren’t able to visually identify the target in the radiographs.

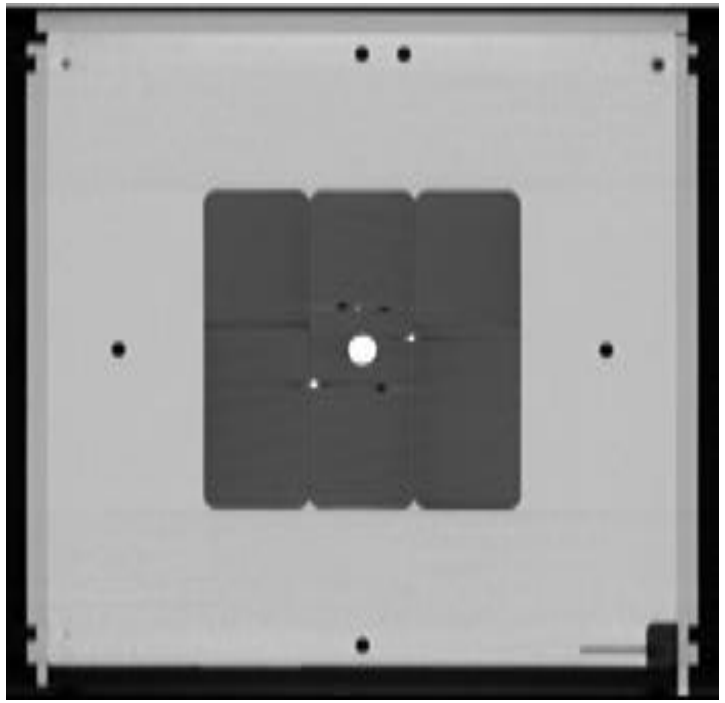


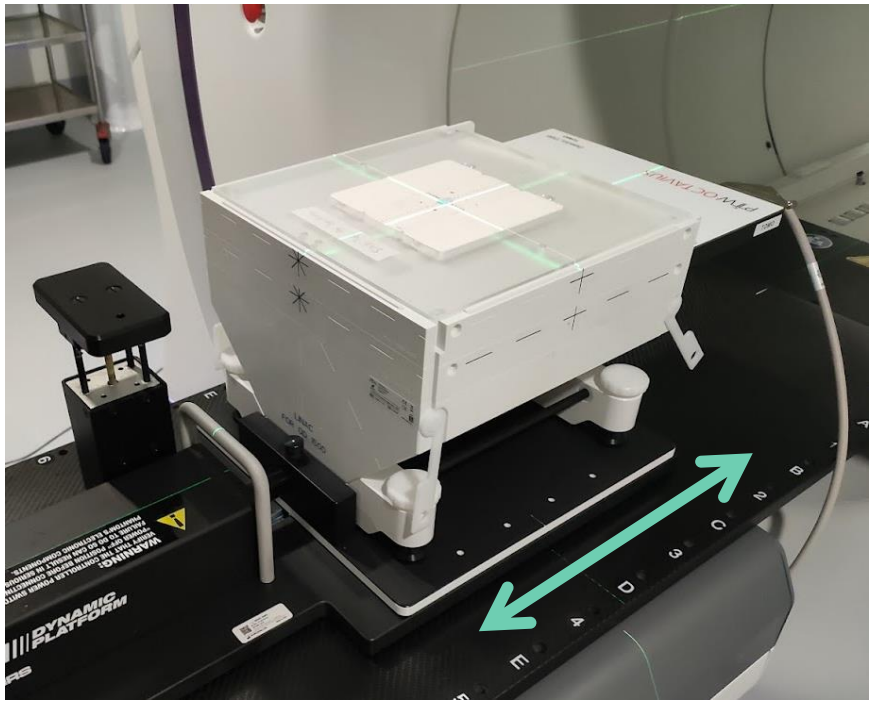




Prostate patient-specific dosimetric QA

For our patient-specific pre-treatment dosimetric QA, we have used the Octavius 1500 panel, parts of the Octavius 2 phantom, 3D-printed inserts containing QLRAD BV gold markers and a spherical lung tumour, and a CIRS 1D Dynamic Platform, for initial QA per AAPM TG 306.



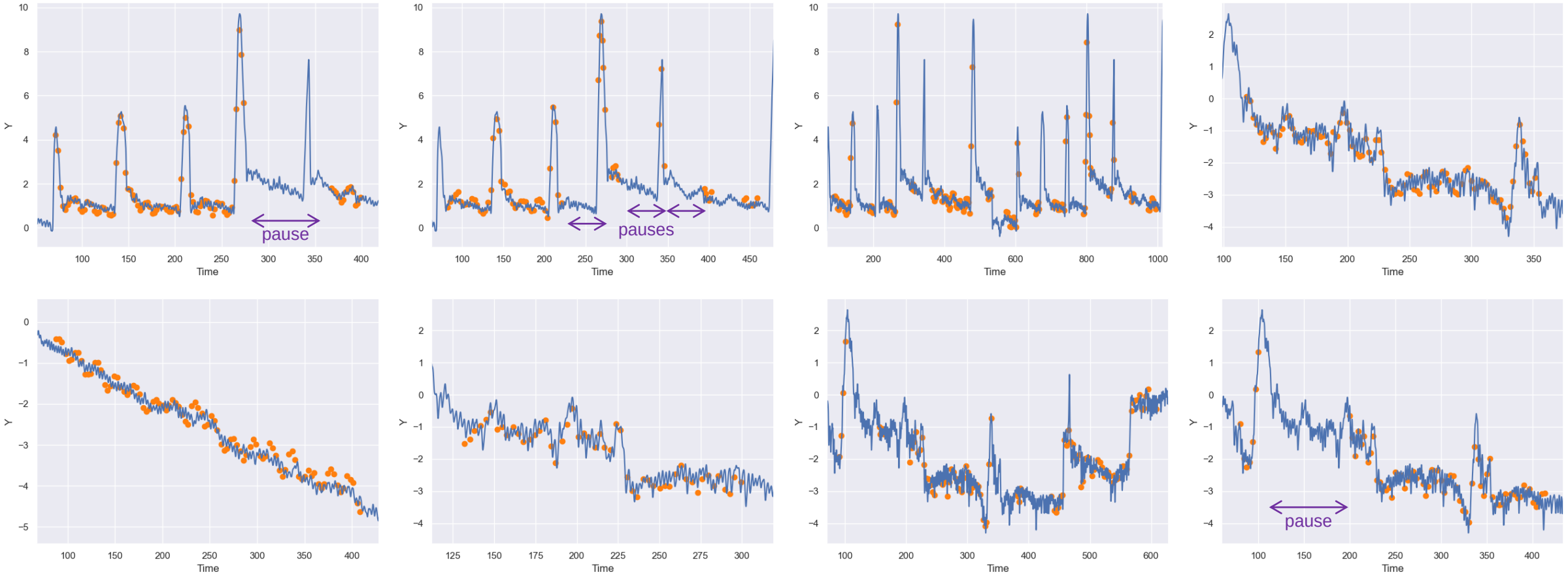


Motion includes 4mm drift, 10mm erratic, 6mm high frequency, and 1mm standard.

Clearance issues between electronics of detector array and surrogate chest wall platform require rotation of phantom to “feet-first” orientation.

Prostate patient-specific dosimetric QA

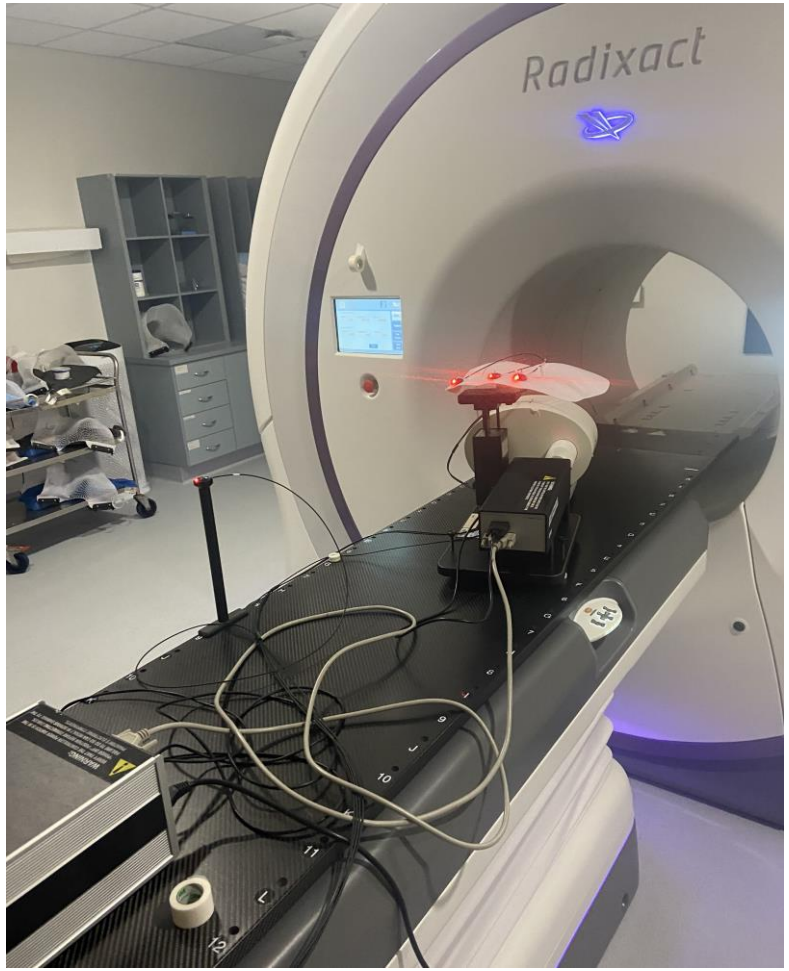
The MotionQA tool allows us to extract observed/predicted motion from the Radixact system, to compare against programmed motion. Superior-inferior motion is tracked extremely well!



Patient-specific dosimetric QA

Result	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Time (s)	242.2	235.9	246.7	239.5	285.7	170.3	263.7
Static plan	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%	100.0%
Synchrony plan, no motion	99.6%	100.0%	99.6%	99.8%	99.8%	100.0%	99.8%
Synchrony plan, stable motion	99.6%	100.0%	99.8%	99.6%	99.8%	99.6%	99.8%
Synchrony plan, cont. drift motion	99.6%	99.8%	100.0%	99.8%	99.8%	99.6%	99.8%
Synchrony plan, high freq. motion	92.4% (6 pauses)	95.5% (6 pauses)	90.5% (5 pauses)	99.4% (1 pause)	97.2% (1 pause)	95.2% (2 pauses)	95.3% (1 pause)
Synchrony plan, erratic motion	99.2% (2 pauses)	99.0% (2 pauses)	98.8% (1 pause)	99.4%	99.6%	99.6% (1 pause)	99.1%

Conclusion



The validation work gave us confidence that the Radixact system is able to accurately deliver the planned dose despite target motion (or would appropriately pause the treatment if motion was too large/irregular to track).

The limitations of this validation work are technological – ideally we would like to reproduce complex 6DoF motion of a target with independent chest wall surrogates in a realistic phantom that when imaged, produces realistic radiographs with bones, contralateral lungs, fibrosis, etc. That doesn’t exist yet!

Such a study could be used to tackle margin expansion in a robust quantitative way.