Dual-Plane 3D-Motion Tracking in 0.35T MR-Guided SBRT: Balancing Target Coverage and OAR Protection in Liver Cancer

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INTRODUCTION

- **Stereotactic body radiotherapy (SBRT)** for upper abdominal tumors faces significant challenges due to respiratory motion.
- **Image-guided radiotherapy** often relies on surrogate markers or periodic imaging, which may not accurately reflect real-time anatomical shifts.
- **MR-guided radiotherapy (MRgRT)** has overcome some of these limitations by offering superior soft-tissue contrast and continuous planar imaging during treatment.
- **0.35T MRgRT** workflows typically track only a single target, which can be insufficient when both the tumor and adjacent organs-at-risk (OARs) move independently.

- To address this limitation, this study aimed to evaluate the clinical feasibility of a dual-target 3D-motion tracking workflow for 0.35T MRgRT in upper abdominal targets.

- The focus was on implementing real-time, dual-plane tracking to enable high-precision automatic beam gating, utilizing beam-on gating for the target and beam-off gating for the OARs.

METHODS & MATERIALS

Workflow Establishment and Patient Selection

- A pilot clinical workflow was first established and commissioned using a dual-target phantom to validate tracking accuracy.
- Abstract ID: 26469 - Dosimetric Verification of Real-Time Anatomy-Based Multiplane Dual Target Gating on a 0.35T MRI Linac
- MO-730-220 - Therapy Physics SNAP Oral: MRI in RT -Evaluating Latency In Dual-Gating MR-Guided Radiotherapy Using a Double-Motion Phantom on a 0.35T MR-Linac
- Following commissioning, the protocol was applied to a patient with primary liver cancer where the tumor was located immediately adjacent to the bowel.

Dual-Target Tracking and Gating Interface

- The workflow integrated real-time, dual-plane cine-MRI to simultaneously monitor two distinct tracking objects: the primary liver target and the adjacent bowel as the organ-at-risk (OAR).
- The system executed automatic beam gating based on these parallel streams.
- The treatment beam was programmed to turn on when the target entered its designated boundary (beam-on gating) and turn off immediately if the OAR shifted into a restricted tolerance zone (beam-off gating).

Data Analysis and Interpretation

- Data from five delivered treatment fractions were collected and analyzed.
- Evaluated metrics included cine-MRI acquisition parameters, tracking thresholds, patient-specific respiratory motion patterns, and overall treatment delivery efficiency.

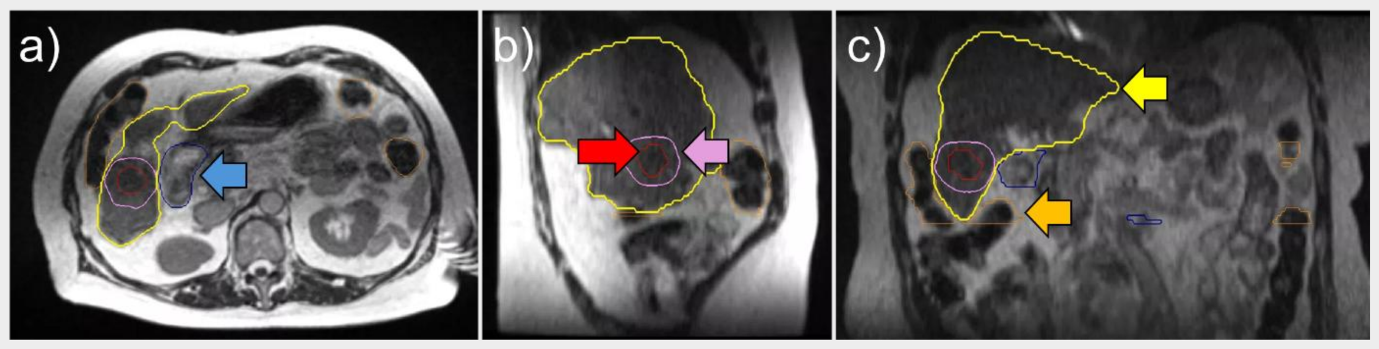

Figure 1. The lesion was treated to a definitive dose of 50 Gy in 5 fractions using free-breathing gating on exhale. Treatment was administered on a 0.35T MRgRT system (MRIdian A3i: ViewRay Systems Inc., Oakwood Village, Ohio). Planning contours of the tumor (red), whole liver (yellow), critical organs-large bowel (orange), and duodenum (blue) are shown with the 36 Gy isodose line (pink) on a) axial, b) sagittal, and c) coronal views of a 3D contrast-enhanced MRI.

RESULTS-I

Table 1. Summary of five MRgRT fractions delivered. Details of the MRgRT treatments are provided, including cine MRI imaging settings, target tracking settings, and respiratory motion management. Fraction 2 represents two delivery segments resulting from a temporary system interruption and subsequent continuation of treatment.

	Fraction 1	Fraction 2	Fraction 3	Fraction 4	Fraction 5
Treatment type	Non-adaptive	Non-adaptive	Non-adaptive	Non-adaptive	adaptive
Tracking type	Dual	Single	Dual	Single	Dual
Imaging orientation	Sagittal /Coronal	Sagittal	Sagittal /Axial	Sagittal	Sagittal /Coronal
Field of View (cm²)	31.9 x 31.9	31.9 x 31.9	31.9 x 31.9	31.9 x 31.9	31.9 x 31.9
Resolution (mm²)	3.5 x 3.5	3.5 x 3.5	3.5 x 3.5	3.5 x 3.5	3.5 x 3.5
Slice thickness (mm)	7	7	7	7	7
Frame Rate (fps)	2	4	4	4	4
Tracking target-1	Whole Liver	Whole Liver	Whole Liver	Whole Liver	Whole Liver
Boundary expansion	3mm	3mm	3mm	3mm	3mm
%ROI-1	0.5%	0.25%	0.8%	1.44%	1%
Confidence-1	88%	75%	75%	85%	80%
Patient guidance-1	Hidden	Contour	Contour	Contour	Contour
Tracking target-2	Large Bowel	-	Large Bowel	-	Large Bowel
Boundary expansion	6mm	-	6 mm	-	< 30Gy isodose line
%ROI-2	0%	-	0.8%	-	5%
Confidence-2	75%	-	75%	-	50%
Patient guidance-2	Hidden	Hidden	Hidden	Hidden	Hidden
Tracking algorithm	Standard	Standard	Standard	Standard	Standard
Motion correction	Yes	Yes	Yes	Yes	Yes
Contrast agent	No	No	No	No	No
Respiratory sensor	Air pressure sensor	Air pressure sensor	Air pressure sensor	Air pressure sensor	Air pressure sensor
Visual guidance	No	Yes	Yes	Yes	Yes
Beam delivery time (minutes)	35	15 + 2 = 17	16	10	9
Gating efficiency (%)	24	50	53	84	92
Total fraction time (minutes)	67	46 + 9 =55	39	33	48

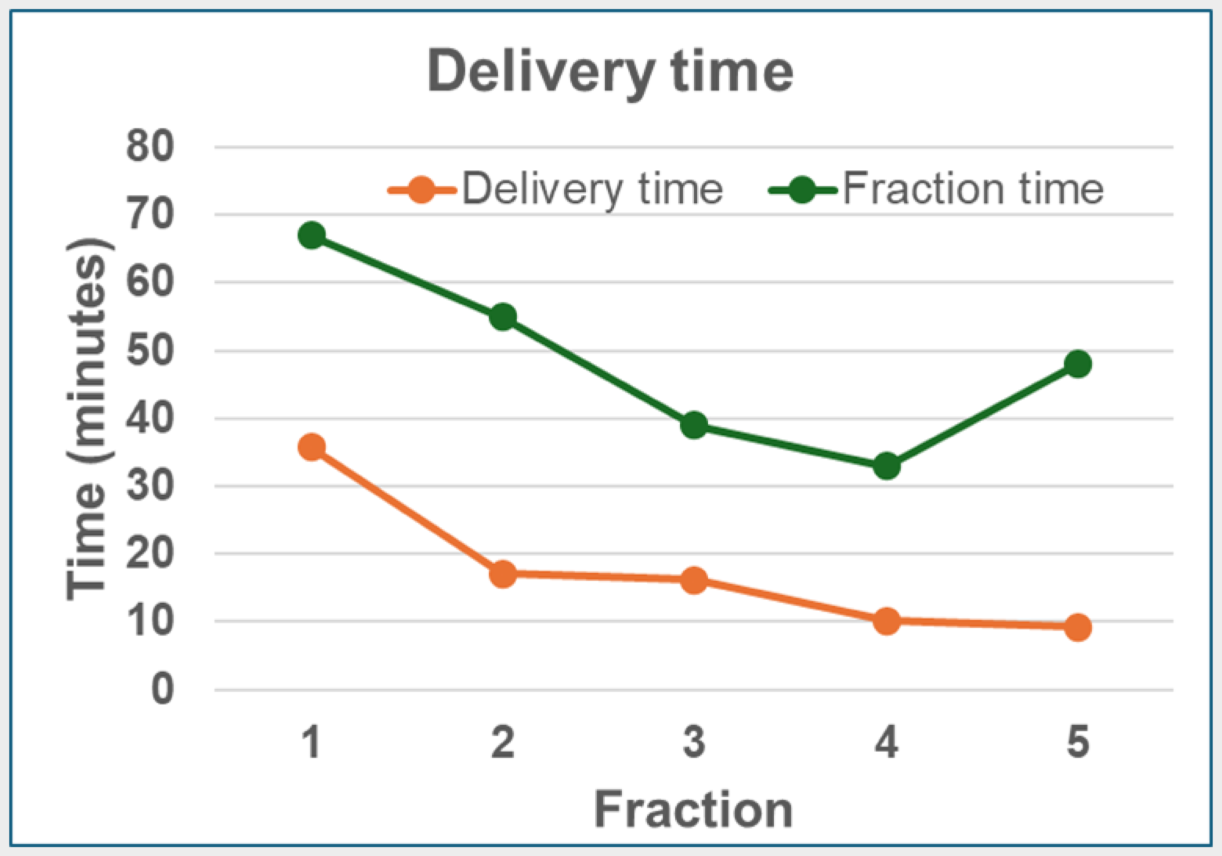

Figure 2. The plot shows the delivery time and the fraction time with steady decrease in delivery time as both the patient and clinical team became more familiar to the procedure. This improvement in beam-gating efficiency suggests that dual-plane tracking and single-plane tracking do not have an appreciable impact on delivery time.

RESULTS-II

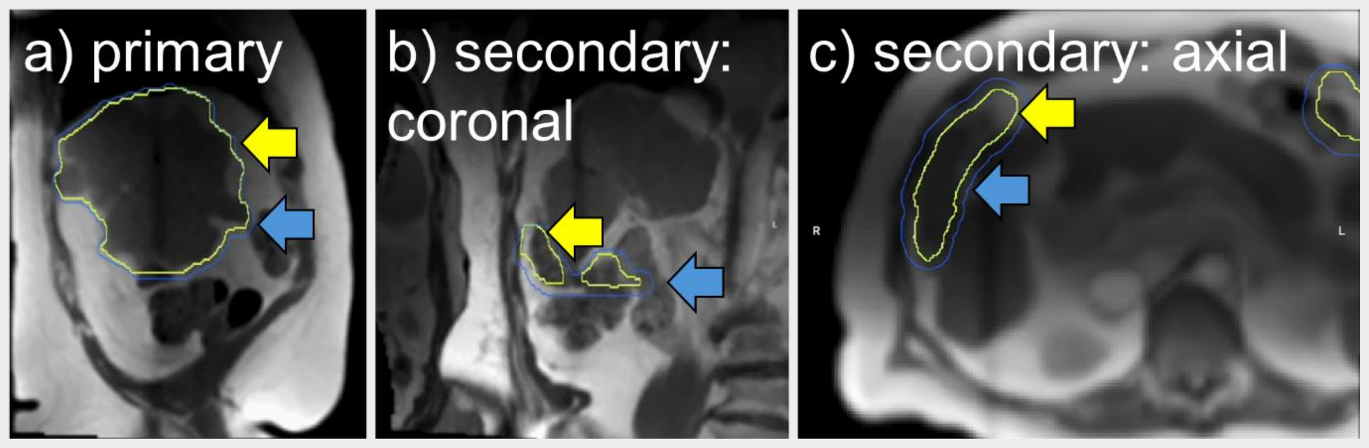

Figure 3. Selection of the target contour (yellow) and gating boundary expansion (blue) for dual-plane tracking: (a) primary target (liver) on the sagittal plane, (b) secondary tracking structure (large bowel) on the coronal plane for fraction one, and (c) secondary tracking structure (large bowel) on the axial plane for the third fraction. Gating boundary expansion parameters are provided in Table 1.

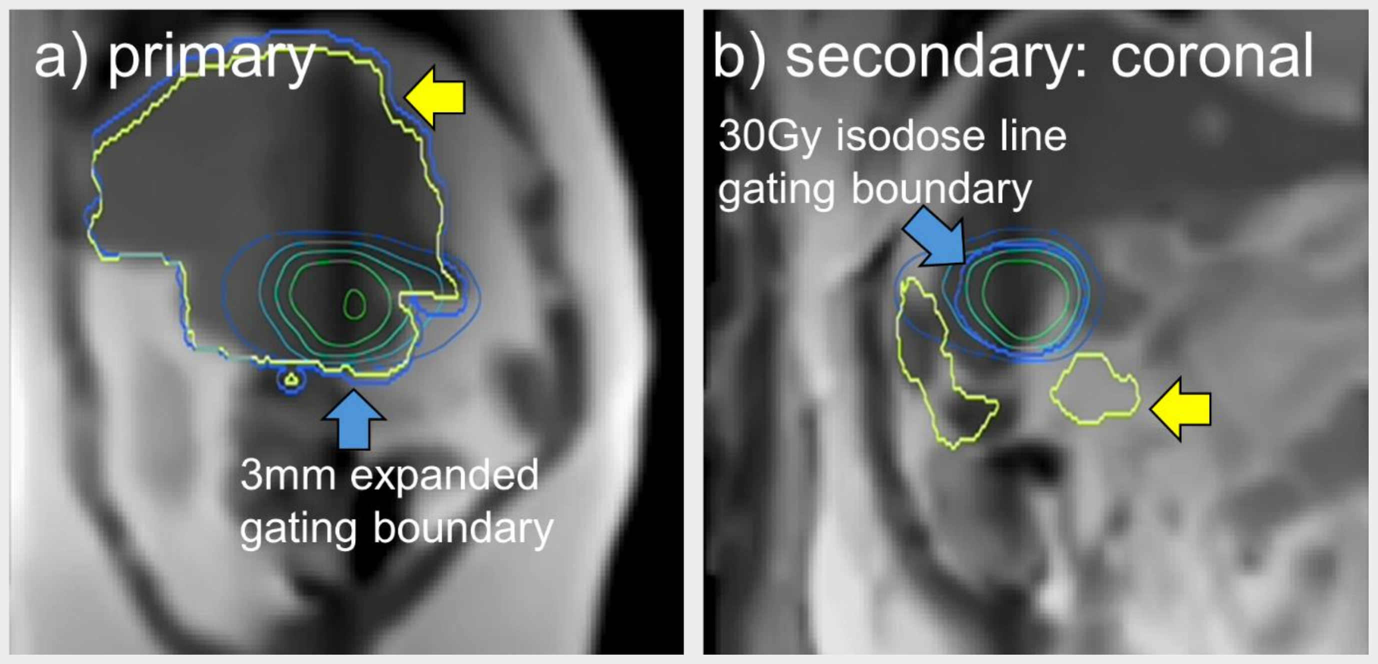

Figure 4. Real-time estimated isodose lines with the tracking contour (yellow) and gating boundary (blue) for the dual-plane tracking: (a) primary target (liver: yellow contour) with a 3mm gating boundary expansion (blue contour), and (b) secondary tracking structure (large bowel: yellow contour) with a 30Gy isodose line gating boundary (blue contour) for the fifth fraction during the on-table adaptive radiotherapy. Thin lines indicate the estimated delivered isodose lines.

DISCUSSION & CONCLUSIONS

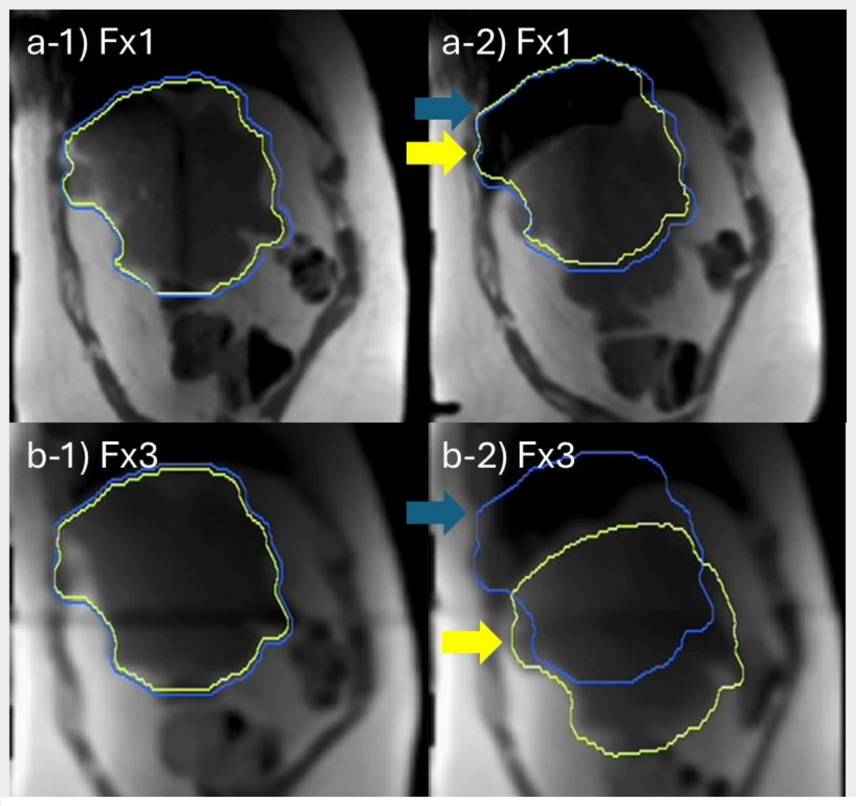

Figure 5. Example of standard structure tracking with (a) 2 fps for Fraction 1 (Fx1) and (b) 4 fps for Fraction 3 (Fx3). Blue: gating boundary; Yellow: tracking structure.

- In Fraction 1, 2FPS resulted in a less temporally smooth representation of respiratory motion compared with Fraction 2-5. The reduced frame rate likely contributed to incorrect tracking outside the boundary and more conservative beam gating within it, potentially increasing the delivery time for the first fraction.

- This dual-gating workflow allows for the simultaneous monitoring of tumors and critical structures, significantly enhancing OAR sparing without compromising treatment efficiency.

REFERENCES

1. Kim et al., "Technical note: clinical real-time multi-target, 3D-motion tracking radiation delivery on a magnetic resonance linear accelerator", Biomed. Phys. Eng. Express 12 (2026).