

Introduction

- Stereotactic arrhythmia radioablation (STAR) is a novel treatment for ventricular tachycardia which targets myocardial scar tissue using a single high dose of radiation¹.
- Cardiorespiratory motion causes difficulties in minimizing treatment margins for STAR.
- Dynamic tracking can reduce treatment margins by following the target's motion through treatment^{2,3}.
- A respiratory correlation model between internal and external surrogate motion guides this tracking⁴.

Aims

- Construct a cardiac phantom to simulate cardiac motion.
- Investigate the efficacy of dynamic tracking using a correlation model trained on cardiorespiratory motion.
- Determine the potential benefits of filtering out the cardiac component of motion prior to training the correlation model.

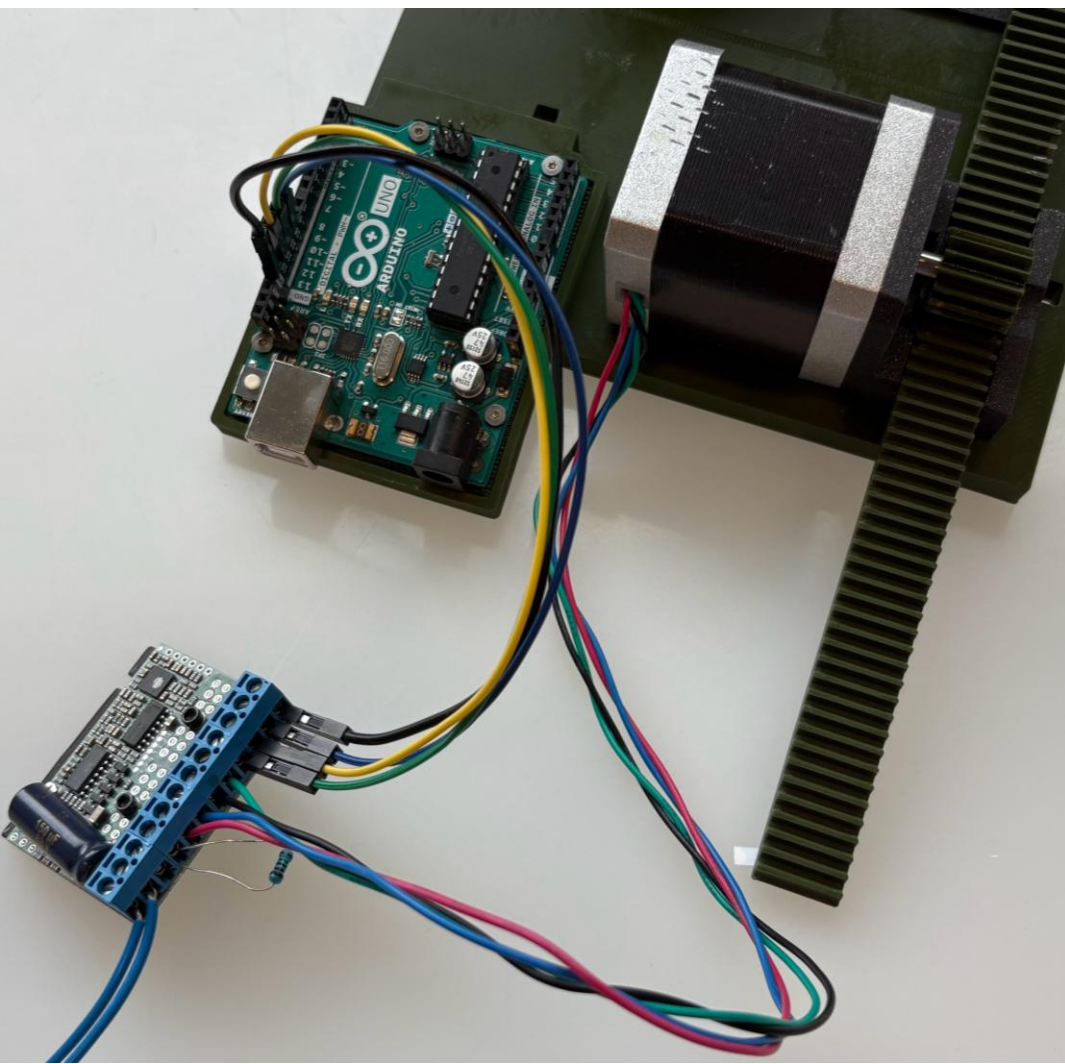


Figure 1:
Main components of the created cardiac phantom: the Arduino board, step motor driver, and stepper motor.



Figure 2:
BC Cancer Vancouver's BrainLAB ExacTrac Vero linear accelerator. Now decommissioned.

Methods

- The cardiac phantom (fig. 1) was developed using a 3D printed scaffold, Arduino UNO R3, Geckodrive G251 step motor driver, WanTai 42BYGHM809 stepper motor, and Arduino IDE software.
- A BrainLAB ExacTrac Vero linear accelerator (fig. 2) was used for data collection, with the cardiac phantom emulating realistic cardiac motion traces in conjunction with free breathing respiratory traces inputted to a respiratory BrainLAB ExacTrac gating phantom (fig. 3).
 - Vero performs dynamic tracking by generating a correlation model for the respiratory motion (via external infrared marker tracking) and an internal surrogate for the target (such as implanted fiducial markers).
- Data was collected for either cardiorespiratory trained (CR-T) or respiratory-only trained (RO-T) models, using 24 unique cardiorespiratory traces (fig. 4).
- Results for hypothetical treatments with no tracking (NT) were calculated by convolving the position discrepancy distributions of each cardiac and respiratory trace

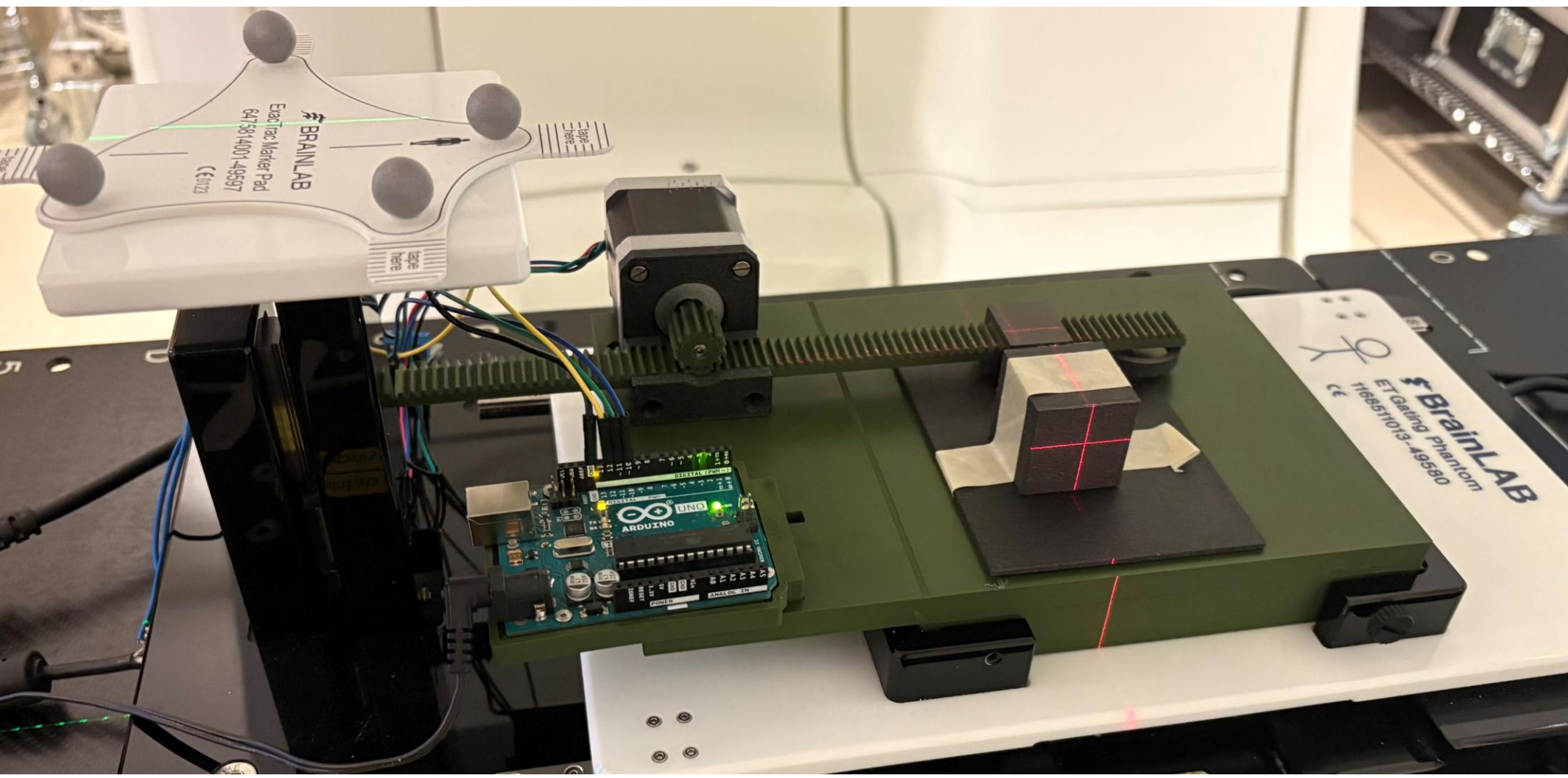


Figure 3: Setup of the cardiac phantom with the respiratory gating phantom. The taped box contains a small ceramic ball bearing, used as the target. The white chest pad with grey infrared reflectors acts as an external surrogate.

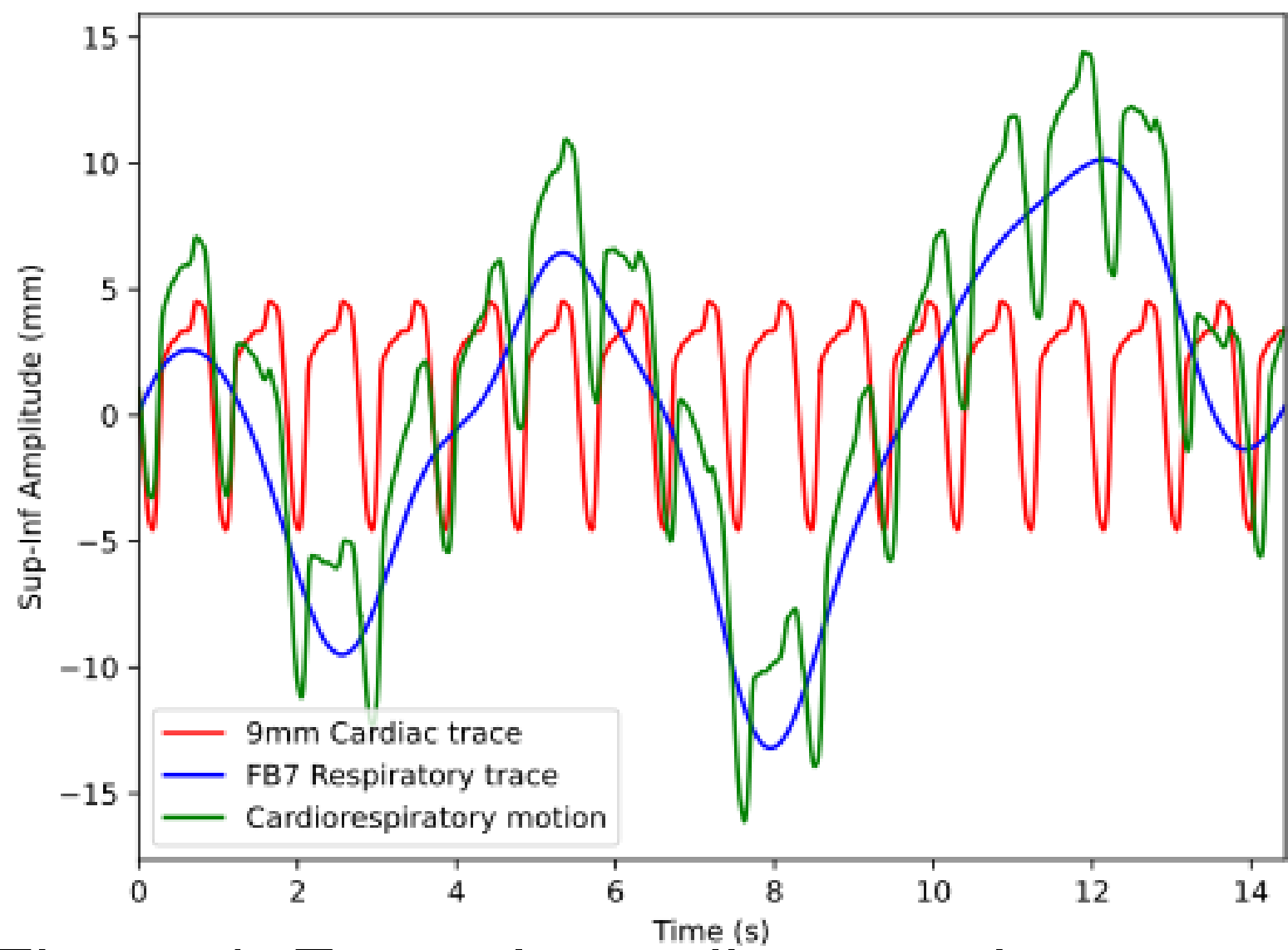


Figure 4: Example cardiac, respiratory, and cardiorespiratory trace used in the experiment. These are the most “extreme” traces used, resulting in the largest peak-to-peak amplitude cardiorespiratory trace

Results

- Simplified 95% internal target volume (ITV) margins were calculated (fig. 5).
- Dynamic tracking consistently reduced 95% ITV margins (with a single exception).
- Margin magnitudes ranked as RO-T < CR-T < NT.
- Absolute localization error data from the eight respiratory traces were collated for each cardiac amplitude (fig. 6).
- The 0 mm cardiac amplitude scenario acts as a baseline comparison for respiratory motion tracking (fig. 6A): mean localization error reduction of 2.0±1.2 mm (RO-T vs NT).
- Mean localization error reductions for the 3 (6) [9] mm cardiac amplitudes (fig 6B (C) [D]) were:
 - CR-T vs NT: 1.5±1.2 (1.3±1.0) [1.3±0.7] mm
 - RO-T vs NT: 1.4±1.2 (1.0±1.0) [0.8±0.7] mm
- For the most “extreme” trace (fig. 4), which had a half peak-to-peak amplitude of 20.7 mm, the mean absolute deviations were:
 - 5.8 mm (NT)
 - 3.2 mm (RO-T)
 - 2.7 mm (CR-T)

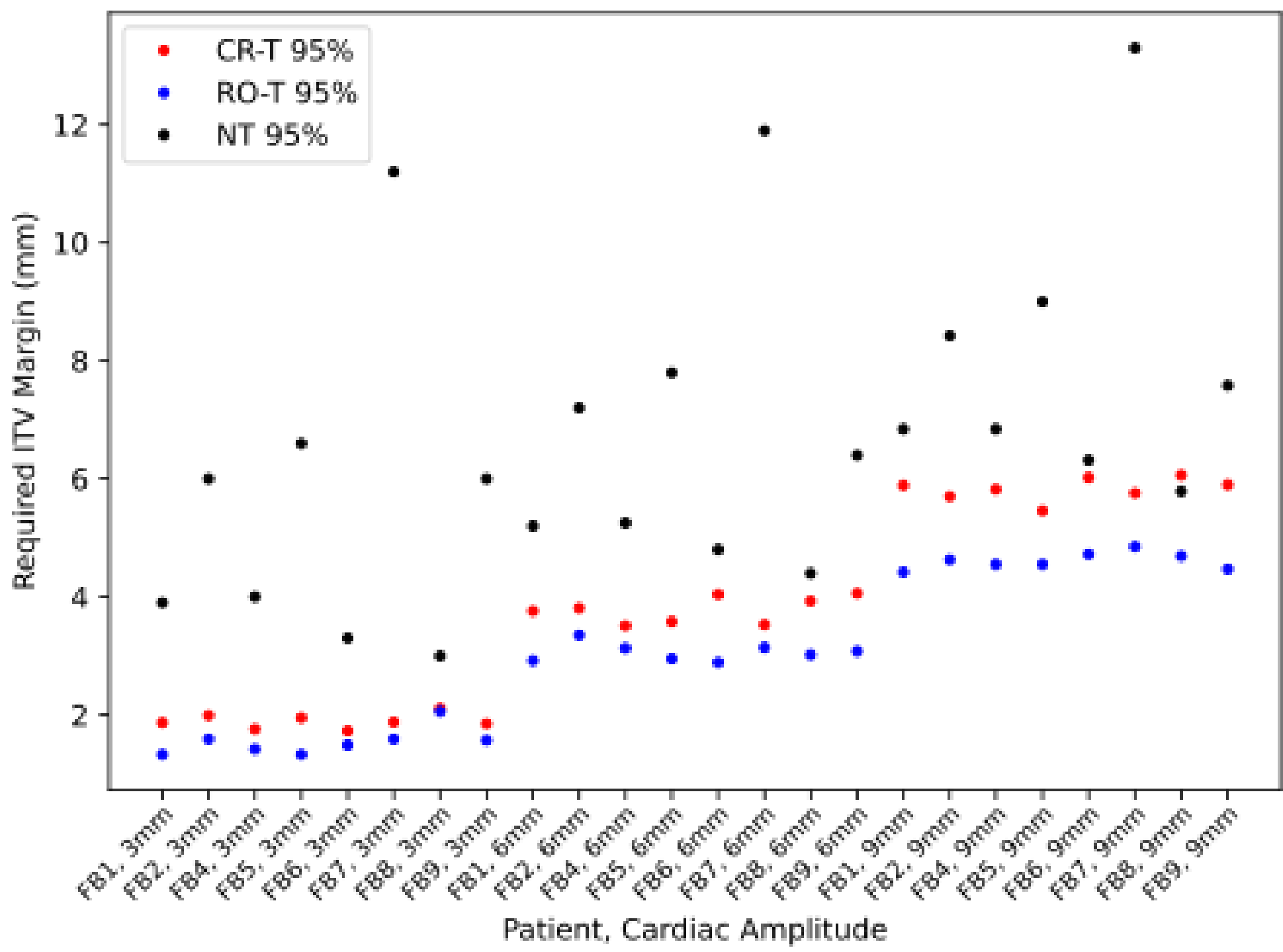


Figure 5: 95% ITV treatment margins for cardiorespiratory dynamic tracking (CR-T and RO-T models) and no tracking (NT).

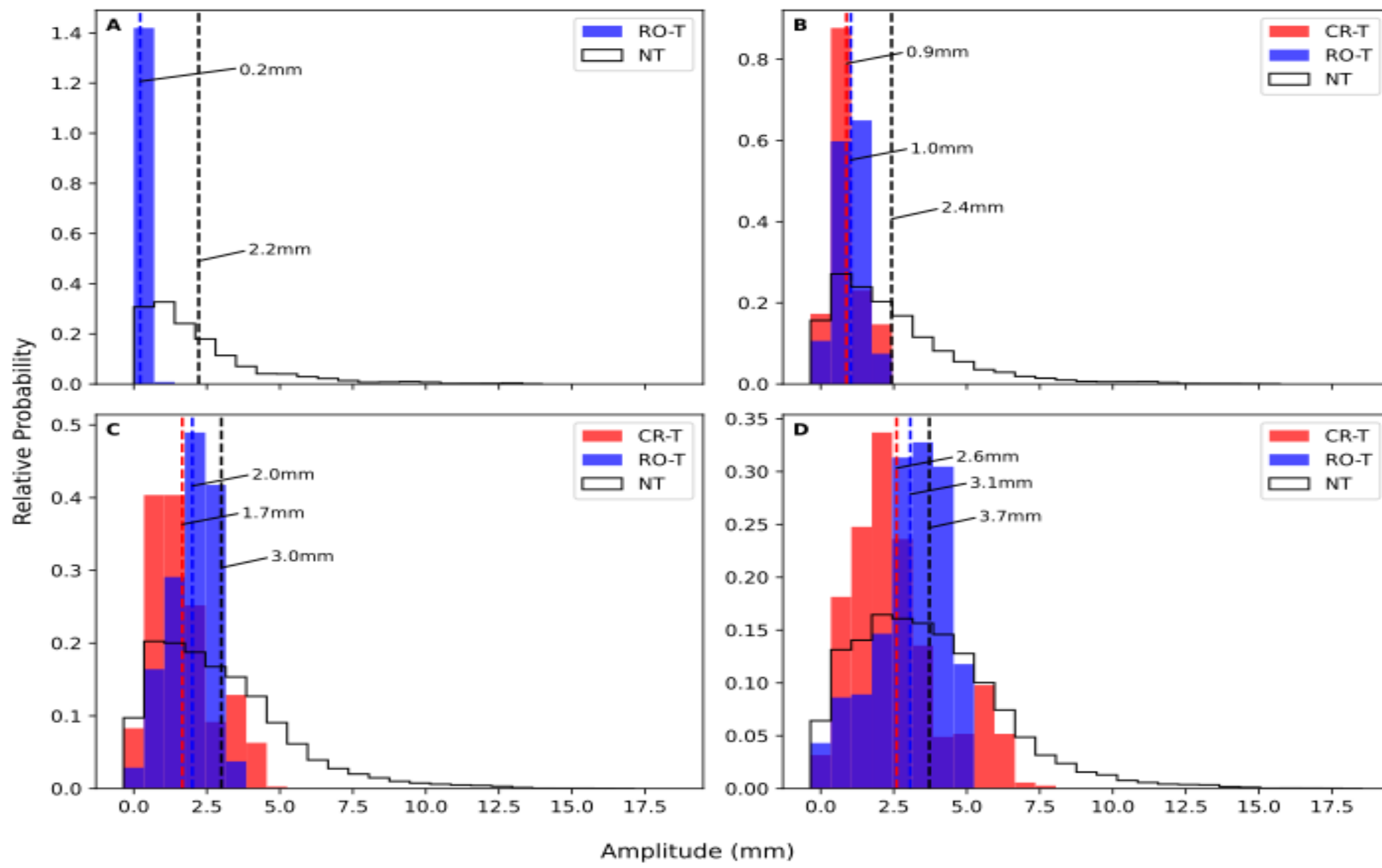


Figure 6: Combined distribution of deviations from the dynamic tracking (CR-T (red) and RO-T (blue) model) scenarios and the hypothetical no tracking (NT (black)) scenario for all respiratory traces, shown for the cardiac traces of **A.** 0 mm, **B.** 3 mm, **C.** 6 mm, and **D.** 9mm amplitudes.

Conclusions

- Dynamic tracking can reduce 95% ITV margins using a correlation model trained on cardiorespiratory motion, with further possible reductions if the cardiac motion is filtered out prior to model generation.
- Reduction of treatment margins would directly benefit STAR patients, as it would reduce the likelihood of adverse effects due to healthy tissue irradiation.

Acknowledgements

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References

1. Loo, B. W. *et al.* Stereotactic Ablative Radiotherapy for the Treatment of Refractory Cardiac Ventricular Arrhythmia. *Circulation: Arrhythmia and Electrophysiology* **8**, 748–750 (2015)
2. Van der Pol, L. H. *et al.* Analyzing Cardiorespiratory Motion and Its Dosimetric Effect on Stereotactic Arrhythmia Radio-Ablation: A STOPSTORM.eu Consortium Study. *International Journal of Radiation Oncology, Biology, Physics* **124**, 799–809 (2026)
3. Menten, M. J. *et al.* Lung stereotactic body radiotherapy with an MR-linac – Quantifying the impact of the magnetic field and real-time tumor tracking. *Radiotherapy and Oncology* **119**, 461–466. doi:10.1016/j.radonc.2016.04.019 (2016)
4. Takayama, K. *et al.* Initial validations for pursuing irradiation using a gimbals tracking system. *Radiotherapy and Oncology* **93**, 45–49. doi:10.1016/j.radonc.2009.07.011 (2009)