2026 JOINT AAPM | COMP MEETING
JULY 19–22 | VANCOUVER, BC

Quantifying Cardiac DIR Accuracy and Dosimetric Variability for 4D Dose Accumulation in Stereotactic Arrhythmia Radioablation

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Abstract

- Objective: evaluate DIR geometry and dosimetry for ECG-4DCT-based STAR 4DDD.
- Approach: 25 XCAT phantoms and 20 patients; 10 cardiac phases; six DIR algorithms plus clinical TransMorph.
- Phantom Result: MIM best preserved target dose and had the highest 1%/1 mm gamma passing rate.
- Clinica Resultl: MPADD reached 11.3% for V_{25} and 1.15 Gy for D_{95}.
- TransMorph had highest clinical DSC but less plausible local deformation.
- Significance: geometry alone is insufficient for reliable STAR dose accumulation.

Study Scale

25 XCAT phantoms | 20 clinical patients | 10 ECG phases

Introduction

- STAR is a noninvasive option for refractory cardiac arrhythmias.
- A single high-dose fraction is sensitive to motion-induced dose blurring.
- Cardiac pulsation causes local deformation of targets and substructures.
- 4DDD requires mapping dose across cardiac phases using DIR.
- DIR errors can compromise target coverage and cardiac-substructure dose monitoring.
- ECG-4DCT cardiac motion is challenging because of torsion, contrast change, and through-plane motion.

Motion Challenge

Localized contraction, torsion, and contrast variation make cardiac DIR difficult.

Clinical Need

Quantify whether DIR uncertainty changes target coverage and cardiac-substructure dose.

Methods

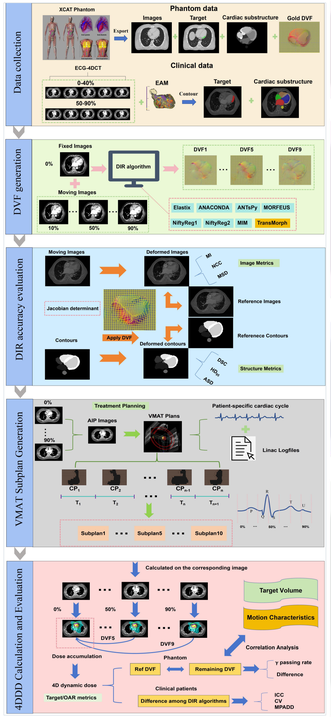

Figure 1. Workflow from ECG-4DCT data collection to 4DDD calculation and evaluation.

Data

25 XCAT phantoms
20 clinical patients
10 ECG phases

DIR Algorithms

ANACONDA | MORFEUS
Elastix | MIM
NiftyReg | ANTsPy
TransMorph: clinical cohort

Planning

25 Gy x 1 VMAT
Log files -> 10 subplans
Mapped to 0% end-diastole

Evaluation

Geometry: DSC / HD95 / ASD
DVF: Jacobian
Dose: D95/V25 / D50/Dmax
Variability: gamma / CV / MPADD / ICC

Results

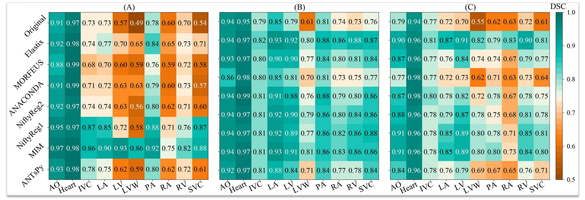

Figure 2. DIR accuracy between end-systole and end-diastole.

- Accuracy was lowest between ED and ES.
- Worst-phase XCAT DSC: MIM 0.89; NiftyReg1 0.82; MORFEUS 0.71.
- Clinical TransMorph DSC: 0.89 with implants and 0.86 without implants.
- RA, RV, and LVW were consistently difficult substructures.

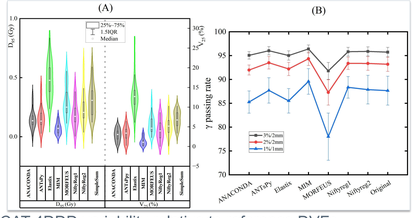

Figure 3. XCAT 4DDD variability relative to reference DVFs.

Key Dose Result

MIM: D_{95} error 0.07 Gy; V_{25} diff. 1.3%; gamma 89.6% at 1%/1 mm.

Clinical Variability

MPADD reached 11.3% for V25 and 1.15 Gy for D95.

Discussion

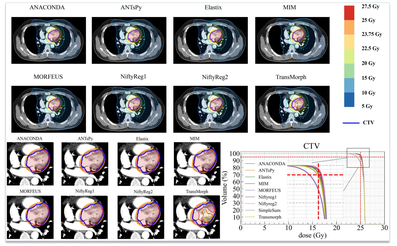

Figure 4. Representative high-variability case: 4DDD and DVH differences across DIR algorithms.

- MIM showed favorable phantom dosimetric performance.
- Image-similarity improvement did not always translate into substructural alignment.
- TransMorph improved contour overlap but showed higher negative-Jacobian rates and localized dose differences.
- Patients without metallic implants had reduced geometry and higher 4DDD variability.
- DIR-based 4DDD should be used cautiously for small, highly mobile targets.
- DIR performance should be judged by geometry, DVF plausibility, and accumulated dose together.

Conclusion

- Current DIR methods remain limited for complex cardiac motion in ECG-4DCT.
- Geometry alone cannot guarantee physiologically plausible deformation or stable 4DDD.
- Cardiac-specific, physiology-constrained DIR is needed for robust STAR dose accumulation.
- Future work should integrate coupled cardiorespiratory motion and uncertainty propagation.

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References

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3. Segars et al., 4D XCAT, Med Phys 2010.
4. Chen et al., TransMorph, Med Image Anal 2022.