Develop and Evaluate a Fast 5D Dosimetry Estimation Algorithm for Stereotactic Arrhythmia Radioablation (STAR) Treatments

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Introduction

- Ventricular tachycardia is a leading causes of sudden cardiac death (>300,000 cases per year in US)
- Can be treated with invasive catheter ablation
  - Modestly effective (>50% recurrence)
- Alternatively, Stereotactic arrythmia radioablation (STAR) delivers >25Gy in one fraction
  - Non-invasive, promising preliminary studies
  - Phase II trials at WashU demonstrated 95% reduction in VT events

Cardiorespiratory motion makes STAR dosimetry difficult

- This makes it difficult for physicians to refine STAR therapy for future patients
- ICD metal artifacts in CT images complicate further
- Dose can be calculated retrospectively using all cardiorespiratory phases and dose averaging
  - Doing so for all phases is not clinically feasible (>4 hours via Eclipse treatment planning system)

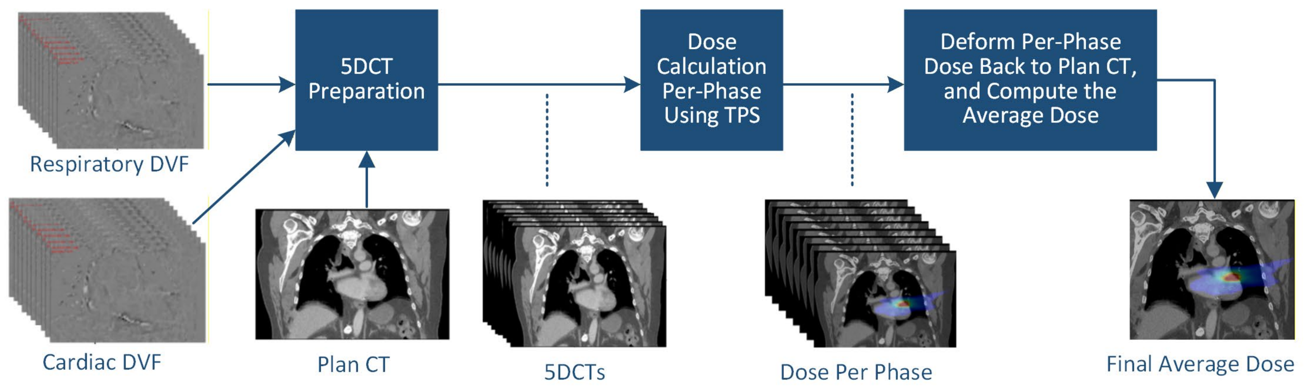

Figure 1: Traditional STAR dosimetry using 5DCT and DIR

We developed the SPM (spatial probability map) algorithm, to rapidly and precisely calculate dose for STAR treatment targets while addressing 5D motion

Methods

- ICD (implantable cardioverter defibrillator) artifacts were segmented via a trained nnUNet software[1,2]
  - Segmented leads were then inpainted with a GAN model based on the Pix2Pix framework[3]
  - These inpainted images were used for subsequent steps

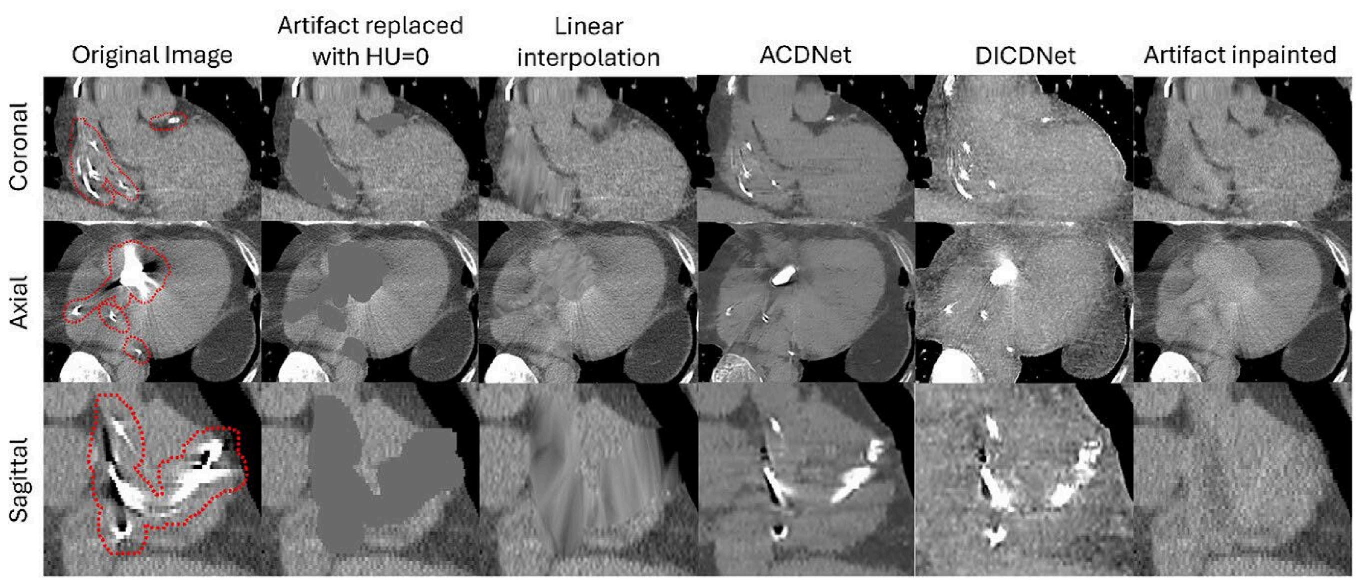

Figure 2: Cardiac ICD segmentation and inpainting results

- Cardiac motion was calculated via DIR of the breath-hold cardiac 4DCT (c4DCT), respiratory 4DCT (r4DCT) was used to calculate respiratory motion
  - These motions were joined into one DVF to create a 5D motion field

Methods

- The 5D motion field is then applied directly to the treatment plan dose volume to find the simulated dose

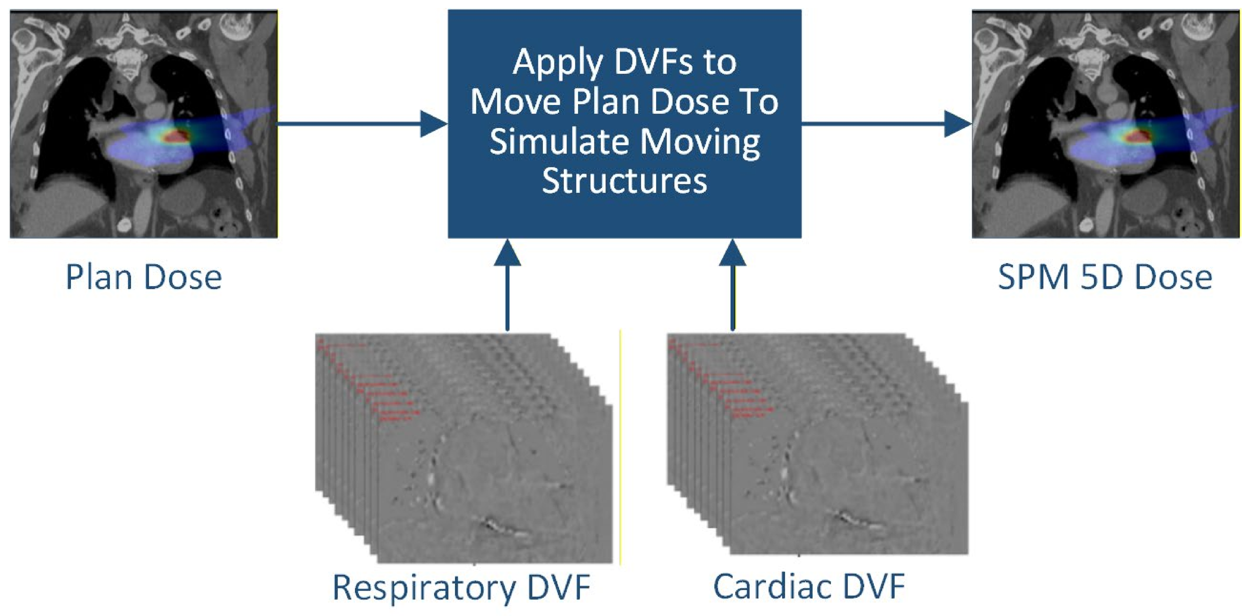

Figure 3: Simplified SPM dose calculation algorithm

- SPM approach was used to calculate 5D dose on three patient cases
  - Traditional dose calculation (Figure 1) was also run for each case as a ground truth
- The SPM approach was also applied using a varied # of cardiorespiratory phases to investigate data-limited scenarios

Results

- Cardiac artifact lead segmentation was highly effective with Dice=0.958 ± 0.008. Inpainting recreated cardiac images with structural similarity index of 0.988 ± 0.012
- For 5D dosimetry vs original treatment plan: Differences of 2% to 14% of the Dmax, Dmean, Dmin, D95, and V35Gy were measured (Figure 4)

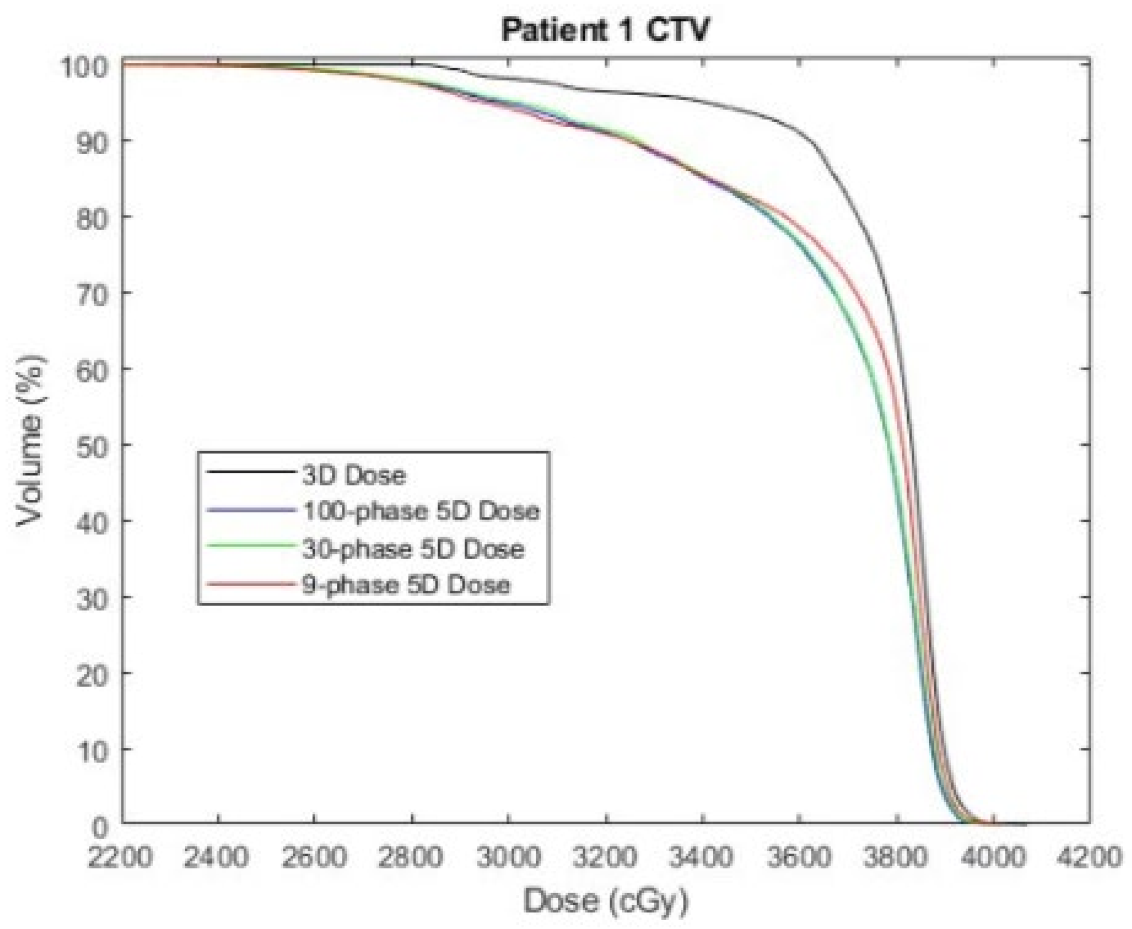

Figure 4: Dose volume comparison for clinical (3D) and 5D Dosimetry visa traditional methods

- It is possible to speed up the conventional 5D dose calculation using fewer phases, such as 30 (3 cardiac phases x 10 respiratory phases). Using 30 phases was less accurate than 100 phases and SPM.

Results

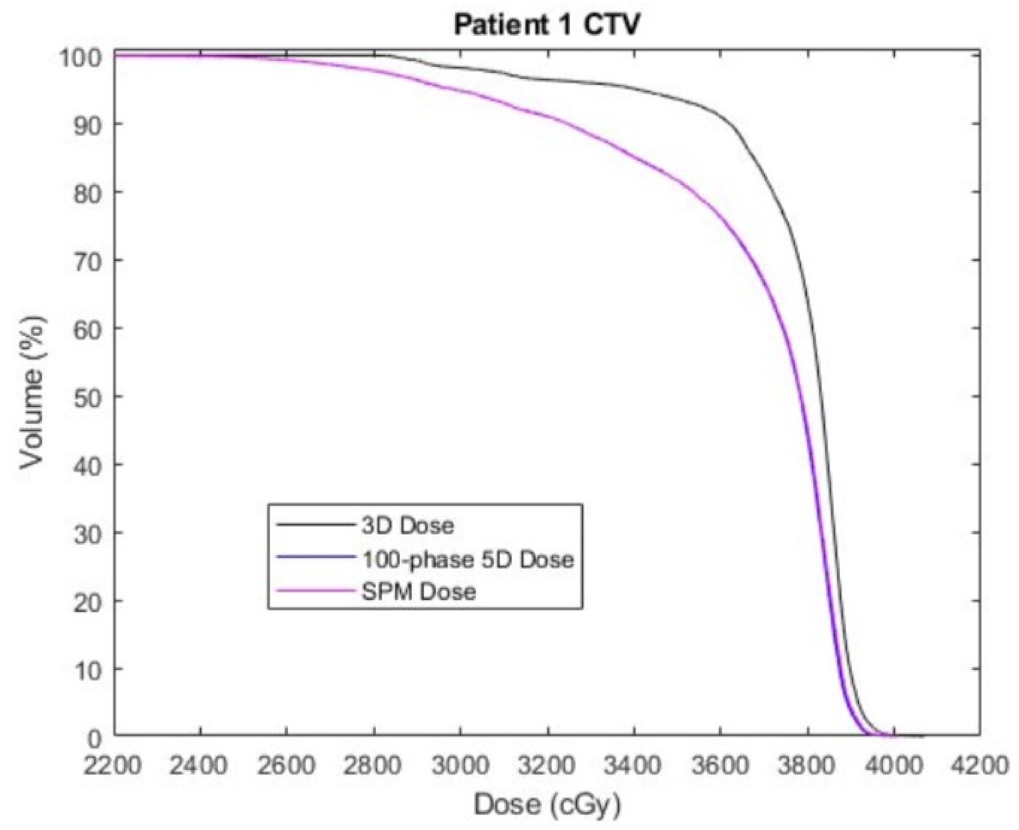

Figure 5: Dose volume comparison for traditional (3D) and SPM dosimetry for a sample patient

- SPM computation averaged <2 minutes, compared to >4 hours via Eclipse
- SPM results were statistically no different from the traditional 5D dosimetry results (<0.1% on all metrics)

Conclusions and Future Work

- The cardiac metal artifact inpainting model removed and accounted for ICD lead artifacts common for STAR patients
- The necessity of 5D dosimetry was demonstrated via differences from the treatment planning dose
  - 30 cardiorespiratory phases seemed sufficient for 5D dosimetry via traditional methods (Figure 4)
- **Compared to the traditional 5D dosimetry procedure, the SPM saves hours of manual effort while retaining calculation accuracy. (Figure 5)**
- While clinical treatment plans are optimized on static planning CTs, SPM makes it feasible to estimate how patient-specific cardiorespiratory motion affects treatment delivery.
- Expanded patient testing data can demonstrate improved generalizability

References

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2. Isensee, F. et al. nnU-Net: a self-configuring method for deep learning-based biomedical image segmentation. Nat Methods 18, 203–211 (2021).
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