Knowledge-Based Planning for Ventricular Tachycardia SBRT

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ABSTRACT

This work aimed to develop and evaluate a knowledge-based planning (KBP) model for ventricular tachycardia stereotactic body radiation therapy (VT-KBP) across a heterogeneous patient cohort.

Two sets of treatment plans were compared: (1) Clinical plans, and (2) VT-KBP model-generated. Plans were normalized so the prescribed dose covered 95% of a PTV. The performance of VT-KBP was evaluated against the clinical plan across several dosimetric endpoints.

Overall, the KBP model was able to generate plans that satisfied the constraints from the literature and were comparable to the clinically approved plans.

A VT-SBRT KBP model is feasible for clinical integration and can standardize planning, potentially improving the efficiency for highly irregular VT anatomies and substrates

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INTRODUCTION

- SBRT has emerged as a promising treatment for refractory ventricular tachycardia (VT), demonstrating reduced VT recurrence and favorable long-term outcomes.
- Reported SBRT-related toxicities are generally delayed and manageable, such as pericarditis and pericardial effusion occurring months after treatment, whereas conventional catheter ablation can be associated with severe acute complications within days.
- VT-SBRT is typically delivered using volumetric modulated arc therapy (VMAT), allowing highly conformal delivery of a large radiation dose in a single treatment fraction.
- Treatment planning is challenging because VT target volumes vary substantially in size, shape, and proximity to critical cardiac and thoracic structures.
- Many VT patients require urgent treatment due to life-threatening arrhythmias or VT storm, leaving limited time for plan development and optimization [1-3].
- The absence of extensive long-term clinical data and standardized planning guidelines can lead to variability in planning approaches and plan quality among institutions and planners.
- To address these challenges, this study developed a knowledge-based planning (KBP) model aimed at standardizing VT-SBRT planning and generating high-quality treatment plans for a diverse range of VT cases

METHODS AND MATERIALS

Patient Selection

- This retrospective study included 48 VT-SBRT patients treated to 25 Gy in a single fraction between 2018 and 2025.
- The PTV volumes ranged from 26.3–200.7 cc, with substantial variation in target location and proximity to adjacent organs at risk (OARs).

Target Volume Generation

- Target delineation was performed by a multidisciplinary team of radiation oncologists, electrophysiologists, and medical physicists.
- Respiratory-gated 4D-CT and, when available, cardiac-gated imaging were combined with electrophysiologic mapping to define arrhythmogenic myocardial tissue and surrounding critical structures.
- The complete planning workflow typically required 3–4 days, although urgent clinical situations occasionally necessitated accelerated planning.

Model Development and Validation

- Of the 48 cases, 33 were used to train the KBP model and 15 independent cases were reserved for validation.
- All training plans met institutional planning objectives and dose constraints consistent with the RAVENTA and SMART-VT protocol

RESULTS

Key Results

- The KBP model produced VT-SBRT plans that achieved all clinical goals.
- On average, KBP maximum doses to critical structures were as follows: aorta: 11.2 Gy; esophagus: 6.7 Gy; bronchial tree/trachea, 2.3 Gy; spinal canal: 2.8 Gy; and ICD: 0.108 Gy.
- The KBP model produced plans with average CI and GI of 0.92 and 3.14, respectively, 0.89 and 3.24 in the clinical plans.
- Figure 1 shows the distribution for two sample cases that were optimized manually and through KBP without user intervention.
- Our model was able to generate plans comparable to clinically approved plans for two heterogenous VT cases.
- The KBP model was able to achieve better dose conformality and gradient index compared to the clinical plan for complex case (Fig. 2, bottom row)
- Overall, the KBP model was able to generate plans that satisfied the constraints from the literature and were comparable to the clinically approved plans.

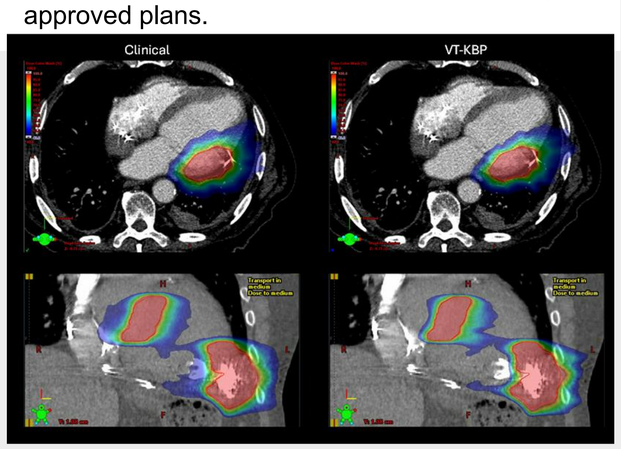

Figure 1: An example of clinically generated plans (left column) and through KBP (right column) for a simple case (top row) and a complex case (bottom row).

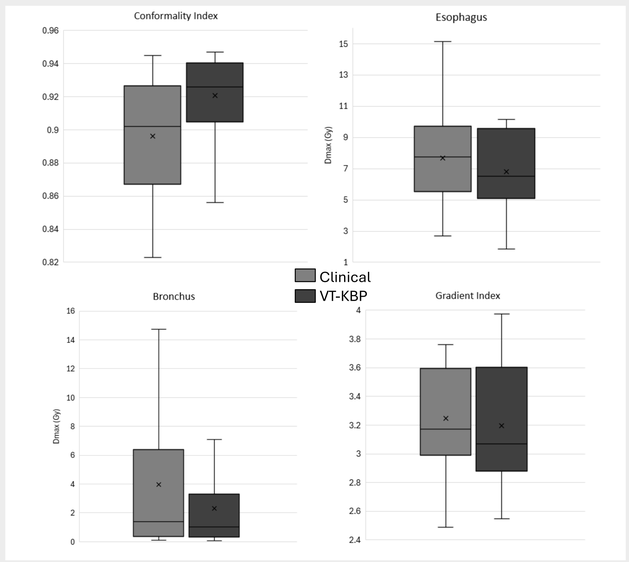

Figure 2. Box plot of Gradient Index, Conformality Index, Bronchus, and LAD over validation cases.

DISCUSSION

- Several treatment planning benchmark studies have been conducted for VT [4-6]; however, treatment planning and clinical data are limited owing to novelty of the treatment technique and lack of clinical results on larger cohorts.
- In this setting, a KBP model can provide real-time insight into tradeoffs between target coverage and OAR sparing, and to our knowledge, this study is the first to demonstrate the feasibility of applying a KBP approach to VT.
- Target coverage remained consistent, while reductions were observed in OAR dose metrics and conformity indices for most cases, while a slight dose increase was noticed for a few cases, including the stomach, lungs, and left atrium.
- Analysis of 33 clinical cases used to train the KBP model demonstrated notable reductions in dose to several OARs compared to the fifteen clinical treatment plans.
- In particular, the model achieved a reduction in coronary artery dose (17.28 Gy vs. 19.03 Gy), which is clinically relevant in lowering the risk of late effects such as coronary artery disease and ischemia.

CONCLUSIONS

- This study evaluated a knowledge-based planning (KBP) approach to improve the efficiency and consistency of VT-SBRT treatment planning.
- Compared with both clinical plans and plans generated by less experienced planners, the KBP model produced clinically acceptable plans with improved OAR sparing and substantially reduced planning time.
- These results demonstrate the potential of KBP to enhance plan quality, standardization, and workflow efficiency in VT-SBRT. Future studies should focus on larger-scale validation and clinical integration to support broader adoption

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