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LETTER TO THE EDITOR
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Cardiac magnetic resonance imaging AI-guided stereotactic arrhythmia radioablation for scar-related refractory ventricular tachycardia: a case report

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Scar-related ventricular tachycardia (VT) is a malignant arrhythmia with high mortality rates in patients with cardiomyopathies such as ischemic and dilated cardiomyopathy.[1] While implantable cardioverter defibrillators (ICD) effectively terminate VT episodes and prevent sudden cardiac death, recurrent ICD discharges may precipitate electrical storms and severely impair quality of life. Radiofrequency catheter ablation is another available treatment for VT but faces challenges in rapidly mapping the critical isthmus during hemodynamically unstable VT. Stereotactic arrhythmia radioablation (STAR) has emerged as a novel, non-invasive, and effective approach for refractory VT over the past decade.[2] Late gadolinium enhancement cardiac magnetic resonance (LGE-CMR), enhanced by artificial intelligence (AI) algorithms, allows precise delineation of myocardial scar and identification of arrhythmogenic substrate.[3] The integration of STAR with AI-enhanced CMR offers a promising multidisciplinary approach for treating refractory VT,[4] as illustrated in the following case report.

A 58-year-old man presented with recurrent palpitations and near-syncope in June 2022. Electrocardiogram demonstrated monomorphic VT at 196 beats/min (Figure 1A). Transthoracic echocardiography showed left ventricular end-diastolic diameter of 53 mm and left ventricular ejection fraction of 33%. LGE-CMR identified diffuse mid-wall myocardial fibrosis consistent with dilated cardiomyopathy (Figure 1B). To prevent sudden cardiac death, a single-chamber ICD (Fortify™ VR 1231-40, Abbott, USA) was implanted. The patient was maintained on metoprolol, amiodarone, and guideline-directed heart failure therapy, including an angiotensin receptor blocker and spironolactone. Comprehensive genetic panel testing revealed no pathogenic variants associated with inherited cardiomyopathies or arrhythmia syndromes. However, recurrent VT and multiple hospitalizations due to appropriate ICD discharges led to severe insomnia and anxiety, and consequently the electrical storm occurred during hospitalization (Figure 1C).

Given the patient's recurrent episodes of VT and multiple discharges from the ICD, a multidisciplinary team evaluated alternative treatments. LGE-CMR demonstrated mid-wall myocardial fibrosis, suggesting an intramural VT substrate less accessible to conventional catheter ablation.[5,6] The patient's hemodynamic instability during VT episodes further complicated invasive electrophysiological mapping. Analysis of the VT morphology showed a right bundle branch block pattern with inferior axis, localizing the likely origin to the left upper anterior septum. Based on these findings, STAR was selected as a non-invasive therapeutic option.

The LGE-CMR data of the patient were extracted to reconstruct a three-dimensional computational model of the heart (Figure 2A).[7] Computer algorithms were utilized to segment the scar region and gray zone area, and the results demonstrated that scar tissue accounted for 4.65% of

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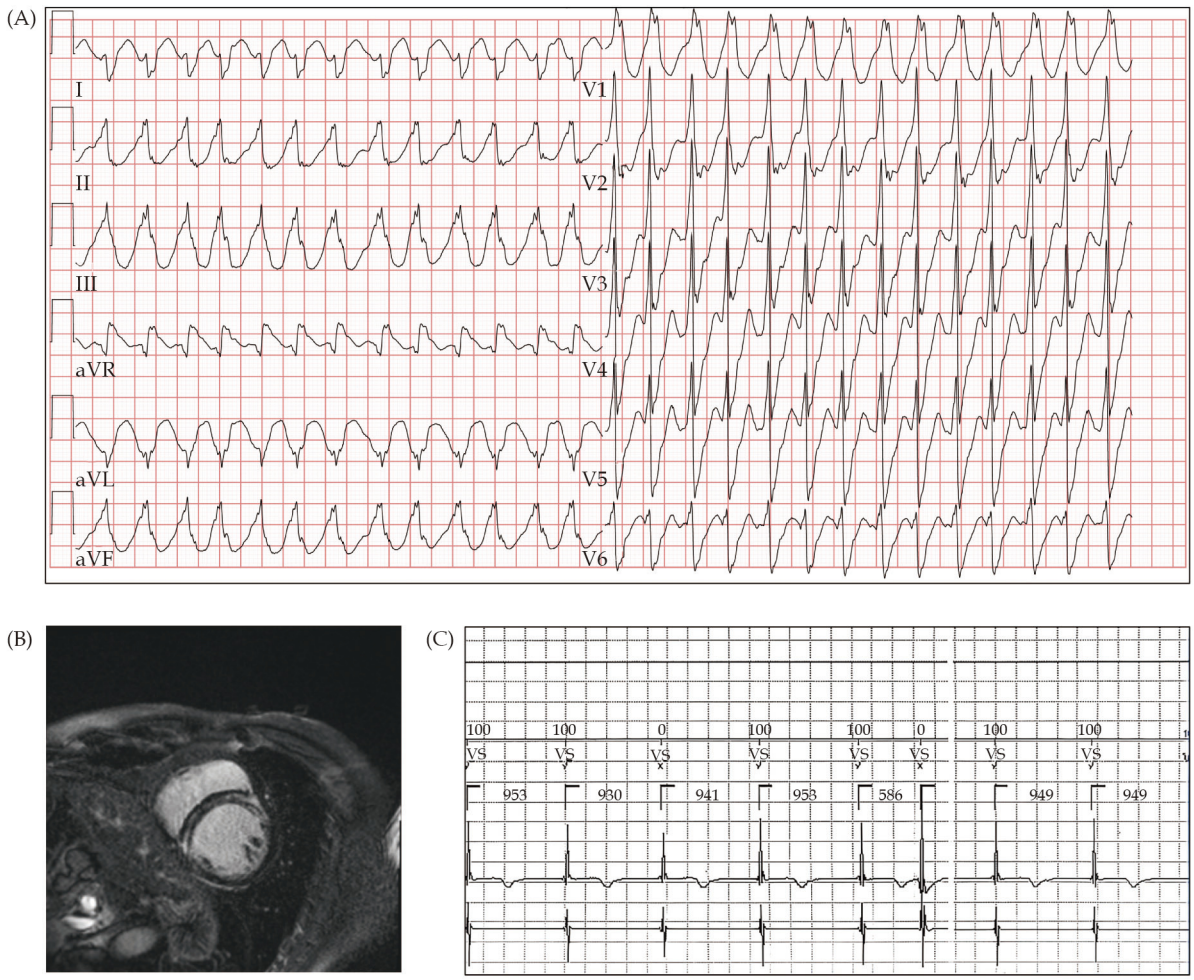


Figure 1 Pre-STAR diagnostic information. (A): ECG during the patient's VT episode; (B): CMR reveals mid-wall myocardial fibrosis in the left ventricle; and (C): VT episodes and shock therapy following ICD implantation. CMR: cardiac magnetic resonance; ECG: electrocardiogram; ICD: implantable cardioverter defibrillator; STAR: stereotactic arrhythmia radioablation; VT: ventricular tachycardia.

the total ventricular myocardium, whereas the gray zone constituted 15.14%. Electrophysiological simulations were then performed and confirmed a reentrant circuit, located in the junction of the left and right ventricles in the anterior septum (Figure 2B). A stable VT with a cycle length of 292.5 ms was induced at the upper septal region, in agreement with the clinical VT observed in the patient. Based on the three-dimensional cardiac model as well as the identified location of the key VT reentrant circuit, STAR was applied for VT treatment ultimately. The radiation target was delineated in the red area (Figure 3), which is the upper third of the anterior septum, while the yellow and blue areas are the surrounding regions. A single fraction of 25 Gy was delivered over 6 min by using a linear accelerator.[8] The procedure was well tolerated without immediate complications.

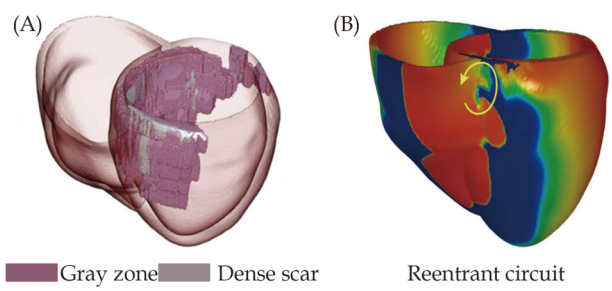


Figure 2 Treatment planning based on computational modeling and simulation. (A): Reconstruction of a three-dimensional computational model of the heart; and (B): simulated electrophysiological stimulation induces VT. VT: ventricular tachycardia.

Following STAR, the patient remained clinically stable. Electrocardiogram revealed no reduction in R-wave amplitude compared to preoperative measurements (Figure 4). Echocardiographic examinations showed that left ventricular ejection fraction was 33% preoperatively and increased to 41% on follow-up echocardiography after two months. During the 15-month follow-up period, there were no

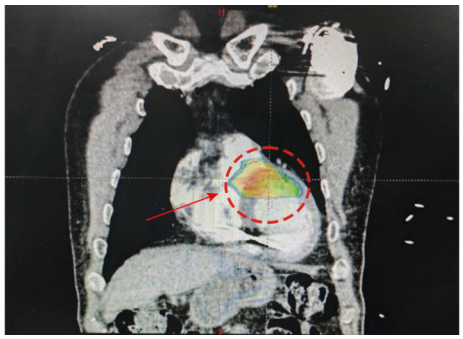


Figure 3 Radiation target delineation (red arrow) for stereotactic radioablation.

VT episodes, and the patient reported a significant enhancement in quality of life. Additionally, thyroid ultrasound, chest computed tomography, and routine blood tests revealed no signs of radiation-induced injury. In summary, cardiac radiotherapy achieved a positive therapeutic outcome.

This case demonstrates the feasibility of STAR guided by AI-enhanced CMR for refractory VT. The integration of these technologies enables precise targeting of arrhythmogenic substrates, particularly those located intramurally or in hemodynamically unstable patients. Furthermore, for patients experiencing recurrent electrical storms or those who have failed catheter ablation, STAR should perhaps be considered earlier in the treatment algorithm. The successful integration of AI-enhanced CMR and STAR in this case also serves as a valuable reference for the clinical application of other innovative therapies in the cardiovascular field, such as pulsed field ablation. However, as an emerging therapy, STAR's long-term safety profile requires careful evaluation. Potential concerns include radiation-induced tissue injury, inflammatory responses, and exacerbation of myocardial fibrosis. Notably, single-fraction high-dose radiotherapy may promote endothelial inflammation and accelerate atherosclerosis, with reports of delayed coronary stenosis emerging 1–3 years post-treatment.[9] Although no coronary complications occurred in the patient, follow-up protocols that include periodic non-invasive stress testing and scheduled coronary imaging are necessary.

There were several limitations of this report. Firstly, the patient's non- MRI (magnetic resonance imaging)-conditional ICD precluded post-treatment CMR assessment of structural changes. Secondly, the absence of follow-up electrophysiological study or coronary angiography limits confirmation of VT non-inducibility and assessment of long-term coronary safety. Therapeutic efficacy was evaluated primarily through clinical outcome, echocardiographic parameters, and ICD monitoring. Despite these constraints, the case highlights the potential of STAR combined with AI-enhanced CMR as a viable option for refractory VT. This multidisciplinary approach exemplifies the convergence of imaging, computational modeling, and radiation oncology in precision arrhythmia management.[10] As experience accumulates, protocol refinement and long-term surveillance will be essential to establish STAR's definitive role in the therapeutic armamentarium for ventricular arrhythmias.

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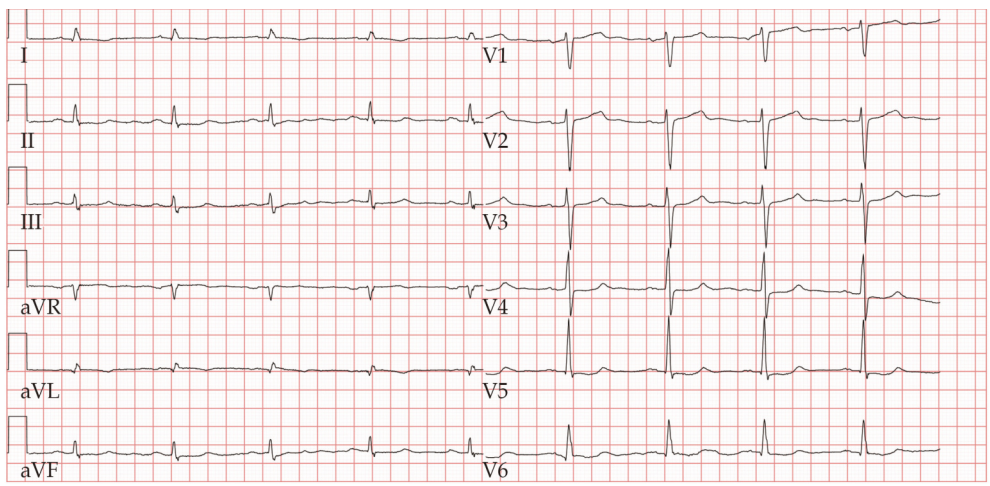


Figure 4 ECG of post-procedure at 3-month follow-up. ECG: electrocardiogram.

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