

3D CMR–guided ventricular tachycardia ablation

Ablación de taquicardia ventricular guiada por resonancia cardiaca 3D

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Summary

Sustained monomorphic ventricular tachycardia (VT) is a potentially life-threatening arrhythmia, particularly prevalent in patients with structural heart disease and myocardial scarring, where reentry mechanisms predominate. Catheter ablation is a key therapeutic strategy; however, its effectiveness depends on accurate identification of the arrhythmogenic substrate. Cardiac magnetic resonance imaging (CMRI) with three-dimensional delayed enhancement (3D-DE) allows for a detailed anatomical characterization of myocardial fibrosis and borderzone channels. We present the case of a 52-year-old man with prior myocarditis, hypertension, and type 2 diabetes *mellitus*, carrying an implantable cardioverter-defibrillator, who was admitted due to multiple appropriate shocks. A 3T CMR study with 3D LGE and ADAS 3D analysis identified intramural septal fibrosis with biventricular border zone corridors. Electro-anatomical mapping confirmed low-voltage areas consistent with the three-dimensional reconstruction. Two VTs with different morphologies were induced, and their critical isthmuses were localized in right and left septal regions guided by CMR-derived anatomical information. Targeted ablation resulted in termination of both arrhythmias, without complications or recurrences during follow-up. This case illustrates the clinical value of image–electrophysiology integration, highlighting how three-dimensional CMR substrate analysis may optimize ablation strategy in complex scar-related ventricular arrhythmias.

Resumen

La taquicardia ventricular (TV) monomórfica sostenida es una arritmia potencialmente letal, con mayor incidencia en pacientes con cardiopatía estructural y cicatriz miocárdica, en la que los mecanismos de reentrada predominan. La ablación por catéter constituye una estrategia terapéutica clave; sin embargo, su eficacia depende de la adecuada identificación del sustrato arritmogénico. La resonancia magnética cardiaca (RMC) con realce tardío tridimensional (RT-3D) permite una caracterización anatómica detallada de la fibrosis miocárdica y de los canales de la zona limítrofe. Se presenta el caso de un hombre de 52 años de edad con antecedentes de miocarditis, hipertensión arterial y diabetes *mellitus* tipo 2, portador de desfibrilador cardioversor implantable, quien ingresó por múltiples descargas apropiadas no esperadas del desfibrilador . La RMC 3T con secuencia RT-3D y análisis mediante *software* ADAS 3D identificó fibrosis intramural septal con corredores de zona limítrofe biventriculares. El mapeo electroanatómico confirmó áreas de bajo voltaje concordantes con la reconstrucción tridimensional. Se indujeron dos TV con morfologías distintas, cuyos istmos críticos fueron localizados en regiones septales derecha e izquierda guiadas por la información anatómica obtenida por RMC. La ablación dirigida logró la terminación de ambas arritmias, sin complicaciones y sin recurrencias durante el seguimiento. Este caso ilustra el valor clínico de la integración imagen-electrofisiología, destacando cómo la RMC tridimensional con análisis de sustrato puede optimizar la estrategia de ablación en sustratos complejos.

Introduction

Monomorphic ventricular tachycardia is characterized by wide QRS complexes with uniform morphology and a heart rate greater than 100 beats per minute (bpm). When sustained—lasting longer than 30 seconds or accompanied by hemodynamic instability—it can progress to cardiovascular collapse and constitute a potential cause of sudden death in patients (1). Its incidence varies depending on the underlying etiology and is particularly high in patients

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with chronic ischemic heart disease, especially those with reduced ejection fraction and myocardial scarring, in whom re-entry is the predominant pathophysiological mechanism (2).

The therapeutic approach to these arrhythmias is based on a multimodal strategy that includes the use of antiarrhythmic drugs, the implantation of an implantable cardioverter-defibrillator, and catheter ablation; the latter is supported by recent evidence suggesting its potential use even as a first-line strategy in selected scenarios (3).

Cardiac magnetic resonance imaging (CMR) (4) to guide ventricular tachycardia ablation has been used for several years as a promising strategy, especially in patients with significant myocardial fibrosis and recurrent ventricular arrhythmias. The integration of this technique allows for better anatomical and functional characterization of the arrhythmic substrate, which facilitates a more precise and substrate-targeted ablation strategy.

The use of three-dimensional gadolinium-enhanced delayed enhancement (3D-DE) sequences allows for a detailed assessment of the extent, location, and heterogeneity of myocardial scarring, as well as the identification of transition zones or border zones, which typically correspond to partially viable myocardial tissue that may be involved in re-entry circuits. This information can be integrated with three-dimensional electro-anatomical mapping systems, allowing the electrophysiologist to more accurately characterize the arrhythmic substrate and optimize the ablation strategy, especially in complex cases, in patients with recurrent ventricular tachycardia, or in those with extensive arrhythmic substrates or substrates that are difficult to characterize using conventional mapping.

Clinical case

We present the clinical case of a 52-year-old man with a history of hypertension and type 2 diabetes mellitus, who was diagnosed with myocarditis in 2023 and subsequently underwent implantation of an implantable cardioverter-defibrillator (ICD) for secondary prevention. One year later, the patient was admitted due to multiple unexpected appropriate shocks from the device, associated with episodes of dizziness and low blood pressure.

During interrogation and reprogramming of the ICD, repeated episodes of sustained monomorphic ventricular tachycardia were documented, so it was decided to perform an CMR using a 3-Tesla system (Skyra, Siemens Healthcare, Erlangen, Germany) with three-dimensional gadolinium late enhancement (3D-LGE) sequences, supplemented by advanced analysis of the arrhythmogenic substrate using ADAS 3D software.

The study revealed intramural septal fibrosis with a fibrotic burden of approximately 9% of the left ventricular myocardium, associated with *border zone* channels—considered potential arrhythmogenic substrates—located predominantly in the biventricular basal septal region (Figure 1). In addition, preserved left ventricular function (LVEF 54–59%) and preserved right ventricular function (RVEF 58%) were documented.

Subsequently, three-dimensional electro-anatomical mapping using CMR images processed with ADAS 3D in the CARTO system revealed an extensive low-voltage area in the right ventricular septum (Figure 2), consistent with the areas of fibrosis identified in the MRI tissue characterization.

During the electrophysiological study, a first sustained monomorphic ventricular tachycardia was successfully induced to identify the site of greatest precocity in the right basal endocardial septal region (Figure 3), consistent with the findings previously documented in the three-dimensional CMR reconstruction. Irrigated radiofrequency ablation was performed using a SmartTouch SF catheter (Biosense Webster) at a power of 40 W, with an average application time of 40 seconds per lesion, which successfully terminated the ventricular tachycardia.

Subsequently, a second ventricular tachycardia with a different morphology was induced. Thanks to the anatomical mapping previously obtained using 3D ADAS, the mapping was directed toward the basal septal region of the left ventricle, where the critical site of the arrhythmic circuit was identified. Targeted ablation was performed in this region using a Pentaray multipolar mapping catheter and an irrigated ablation catheter, resulting in termination of the arrhythmia and a return to a stable sinus rhythm (Figure 4).

As a result of the procedure, ventricular tachycardia could not be induced by programmed ventricular pacing, even with pharmacological support using dobutamine, and there was no evidence of periprocedural complications. During subsequent clinical follow-up with the ICD, no new episodes of device shocks or significant arrhythmias have been documented (Table 1).

After the procedure, the patient reported significant clinical improvement, with the resolution of dizziness episodes and no new defibrillator shocks, which improved his quality of life and sense of security.

Informed consent was obtained from the patient for the procedure and for the anonymized use of clinical information and images for academic and scientific publication purposes, in accordance with the ethical principles of the Declaration of Helsinki.

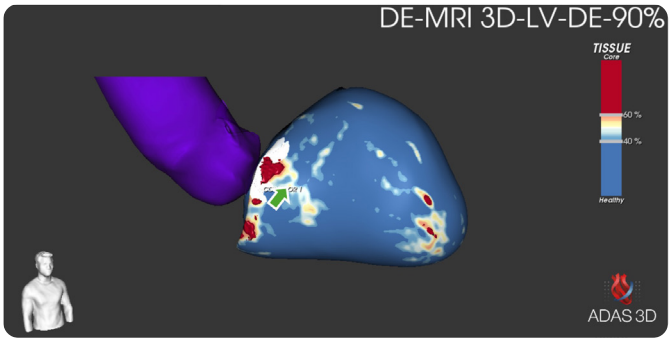
Table 1. Clinical Follow-up

Time	Clinical Event
2023	Diagnosis of myocarditis
2023	ICD implantation
2024	Appropriate TV shocks
2024	CMR with fibrosis characterization
2024	Ablation guided by CMR-ADAS integration
Follow-up	No new shocks or significant arrhythmias

Discussion

This case report describes the integration of advanced cardiovascular imaging software with state-of-the-art technology for ventricular tachycardia ablation and illustrates the value of multimodal strategies in characterizing complex arrhythmic substrates.

Current techniques for ventricular tachycardia ablation include strategies based on electro-anatomical mapping, anatomical ablation, and substrate-targeted ablation, all of which assess areas of low voltage and myocardial scarring. In addition, there are functional approaches such as activation mapping, entrainment, ILAM (isochronal late activation mapping), and other advanced techniques.



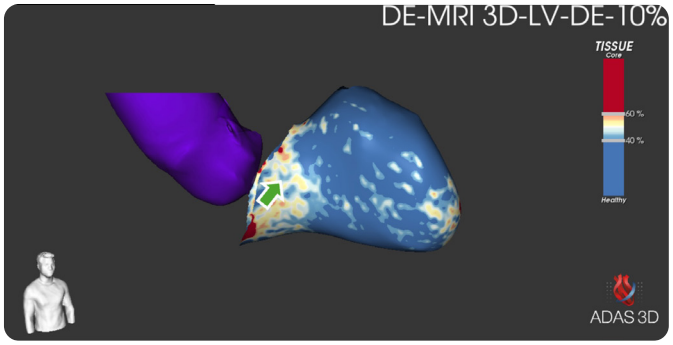


Figure 1. ADAS 3D RC. Three-dimensional reconstruction. In the basal interventricular septum (green arrow), an area of fibrosis (red) interspersed with channels in the border zone (yellow) and healthy myocardium (blue), both in the septal region of the right ventricle (left image) and in the left ventricle (right image).

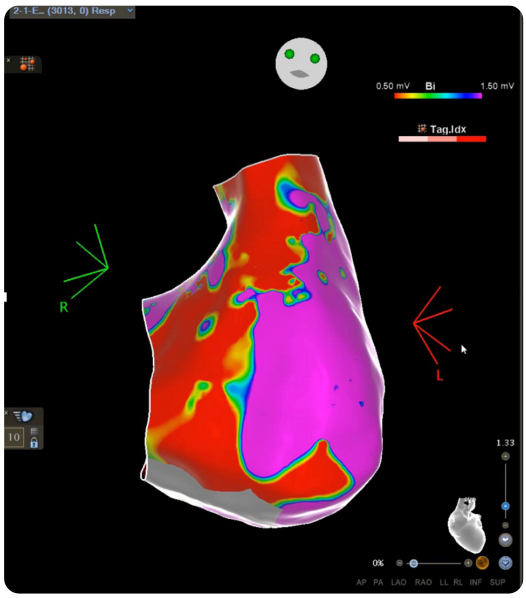


Figure 2. Right ventricular voltage map. Area of low voltage (red), likely associated with myocardial scarring, located in the septal region and the right ventricular outflow tract. Normal voltage toward the apex of the right ventricle (purple) is preserved, consistent with healthy myocardium.



Figure 3. Activation map of the first ventricular tachycardia. The left image identifies the site of greatest precocity (the origin of the ventricular tachycardia), marked with a red dot. The right image shows a monomorphic ventricular tachycardia at 145 bpm, with a left bundle branch block pattern in V1, consistent with a right ventricular origin.

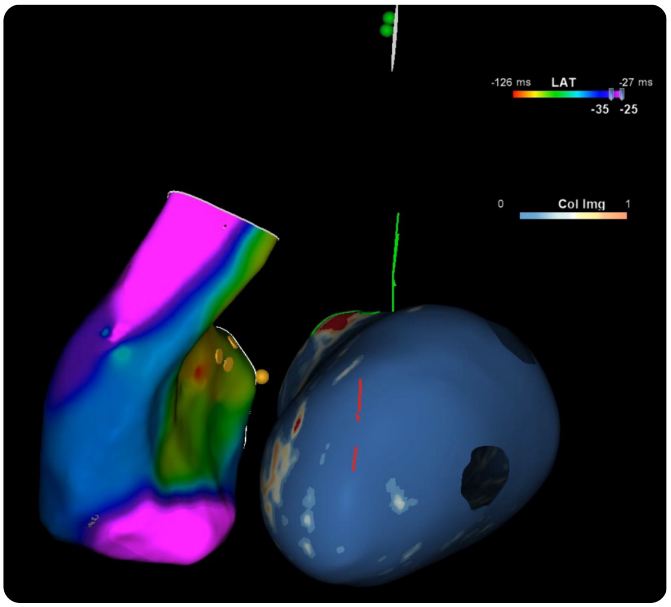


Figure 4. Ablation of a second ventricular tachycardia. The left image shows the advancement of the catheter via atrial transseptal puncture, with ablation in the septal region of the left ventricle. The right image documents a monomorphic ventricular tachycardia at 164 beats per minute, with right bundle branch block morphology in V1, consistent with a left ventricular origin.

However, the effectiveness of these strategies can vary and depends on the method used, the underlying heart disease, and the complexity of the arrhythmic substrate, with success rates differing across various published series.

CMR (4), as a widely used non-invasive diagnostic tool in cardiology, allows for an accurate assessment of biventricular function and advanced tissue characterization of the myocardium, including the identification of fatty infiltration, edema, and fibrosis—findings that may not be detected by other diagnostic modalities. In recent years, CMR has taken on an increasingly important role as a complementary tool for planning and guiding the ablation of ventricular arrhythmias, allowing for the identification of the arrhythmic substrate and the integration of images with electro-anatomical mapping systems.

The use of three-dimensional gadolinium late-enhancement (3D-GLE) sequences, with isotropic resolution of 1.4 × 1.4 × 1.4 mm on 3-Tesla MRI scanners, combined with postprocessing using

specialized software, allows for high-spatial-resolution assessment of late enhancement and detailed analysis of both ventricles and atria in any plane. This approach provides an accurate three-dimensional characterization of left ventricular myocardial fibrosis, facilitating a more comprehensive assessment of the arrhythmogenic substrate and has demonstrated superior diagnostic performance compared with conventional two-dimensional late-enhancement sequences (5).

The characterization of left ventricular fibrosis using three-dimensional delayed enhancement (3D-DE) sequences is based on the use of specialized image analysis software, such as ADAS 3D (Galgo Medical S.L., Barcelona, Spain). This approach allows for semiautomatic segmentation of the left ventricular myocardium into nine concentric layers that progressively span the myocardial thickness, from the endocardium to the epicardium. In this context, endocardial fibrosis is defined as fibrosis in which more than two-thirds of the fibrotic tissue is located in the three innermost layers; transmural fibrosis is defined as fibrosis extending from the endocardial to the epicardial layers; and epicardial fibrosis is defined as fibrosis restricted exclusively to the three outermost layers. Based on this segmentation, signal intensity is projected using trilinear interpolation to generate color-coded three-dimensional maps, which allow for the differentiation of normal myocardium (0–40% of signal intensity), border zone or heterogeneous fibrosis (40–60%), and compact fibrosis (60–100%) (6–8). In this context, heterogeneous myocardial fibrosis and *border zone channels* (BZC) represent well-established arrhythmogenic substrates, as they correspond to regions of slow conduction or critical isthmi for ventricular arrhythmias (6–9), which can be identified through electro-anatomical mapping and are potentially treatable by catheter ablation (9–11).

In this context, CMR-guided ventricular tachycardia ablation has been associated with lower post-ablation inducibility, lower recurrence at 12 months, and reduced procedure and fluoroscopy times, compared with strategies without CMR, without an increase in complications (12–14).

In this case, there was a good correlation between the areas of fibrosis identified by CMR and the low-voltage zones documented during electro-anatomical mapping, highlighting the value of integrating imaging and electrophysiology for the precise identification of the arrhythmic substrate. Although no formal quantitative analysis was performed, the anatomical concordance allowed for effective guidance of the ablation strategy.

The patient's treatment with beta-blockers and amiodarone failed to achieve adequate arrhythmia control, which supported the indication for ablation. Furthermore, significant coronary artery disease was ruled out, suggesting an arrhythmic mechanism related to non-ischemic myocardial scarring secondary to myocarditis.

Although the integration of three-dimensional CMR and advanced software involves greater technological requirements and expertise in image processing, this strategy could prove cost-effective in selected patients by optimizing the identification of the arrhythmic substrate and potentially improving clinical outcomes (15–17). These tools should be considered complementary to other contemporary strategies, such as conventional mapping, high-density mapping, or advanced functional mapping, in the modern management of ventricular tachycardia.

Limitations

This report has the limitations inherent in a single-case study, which prevents the establishment of causal relationships or the generalization of the results. Furthermore, no formal quantitative correlation was performed between the intensity of late enhancement and electro-anatomical voltage values.

Furthermore, the implementation of these strategies depends on the availability of advanced technology and specialized expertise, which may limit their applicability across all centers. Finally, prospective studies with larger sample sizes are needed to confirm the incremental clinical benefit of integrating CMR into ventricular tachycardia ablation.

Conclusion

The integration of 3D CMR with advanced substrate analysis (ADAS 3D) enabled precise characterization of myocardial fibrosis and border zone channels, which facilitated the identification of critical isthmi for ventricular tachycardia. This image-guided approach optimized the ablation strategy in a complex substrate, demonstrating its clinical value as a complementary tool in the management of scar-related ventricular arrhythmias. However, as this is a single-case study, these findings should be interpreted with caution and do not allow for definitive conclusions or generalizations. Prospective studies with a larger number of patients are needed to confirm the clinical impact of these strategies on long-term outcomes.

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