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New Diagnostic and Therapeutic Approaches to Treat Ventricular Tachycardias Originating at the Summit of the Left Ventricle
Role of Merged Hemodynamic–MRI and Alternative Ablation Sources

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*In Latin "Similia similibus curantur" or, in English,
"Like is cured by like."*
Hippocrates of Kos (460 BC – 370 BC), Greece.

The left ventricular (LV) summit is the most common site of idiopathic epicardial LV arrhythmias and frequently represents a diagnostic and a therapeutic challenge.[1] We present a case of sustained monomorphic ventricular tachycardia (SMVT) originating at the LV summit that underwent failed cryosurgical epicardial ablation and was successfully treated with the aid of merged hemodynamic and contrast-enhanced MRI (CE-MRI).

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Case

A 67-year-old man was admitted in 2010 for heart failure with severe LV dysfunction (ejection fraction 20%) initially attributed to alcohol consumption, and during the diagnostic work-up, a severe lesion at the bifurcation of the proximal left anterior descending artery with the first diagonal was percutaneously revascularized using a bifurcated drug-eluting stent, and he was discharged with the diagnosis of dilated cardiomyopathy of mixed pathogenesis (alcoholic and ischemic). In April 2011, he presented with SMVT with left-bundle branch block morphology. He underwent CE-MRI followed by an electrophysiologic study using an endocardial LV retrograde access, where frequent premature ventricular contractions (PVCs) with similar morphology to the clinical VT were ablated at the mitroaortic continuity, with partial success (ie, reduction in PVC density). The patient underwent implantable cardioverter-defibrillator (ICD) insertion and was discharged on amiodarone treatment. He remained free of arrhythmias until September 2012, when he was readmitted for a SMVT with left-bundle branch block morphology, right inferior axis at 140 beats per minute (below ICD detection rate), and early precordial transition (Figure 1). At the time of the EP study,

SMVT was not inducible with programmed stimulation during isoproterenol infusion, but the patient presented frequent PVCs with identical morphology to the clinical VT (Figure 2C). A combined endoepicardial electroanatomical mapping (NaviStar ThermoCool, 3.5-mm tip, 2-5-2 interelectrode distance, and Carto XP Navigation System; Biosense Webster, Inc, Diamond Bar, CA) followed by coronary angiography revealed the presence of a low-voltage (<1 mV) area at the epicardium of the superior LV aspect that during sinus rhythm was characterized by the presence of fragmented and late electrograms (Figure 2B), whereas the endocardial voltage and the electrogram characteristics of both outflow tracts were normal. Endocardial activation mapping of PVCs showed late activation in the right and LV outflow tracts (Figure 2A) and no QRS match with pace mapping. In contrast, activation mapping showed an earliest site at the epicardium, where an excellent pace mapping was obtained (Figure 2B and 2C). Because of the close proximity (≈1 cm) of the left main arteries, a surgical epicardial approach using cryoenergy was indicated.[2,3] The patient had constant ventricular bigeminy during the surgical procedure. Intraoperative electroanatomic epicardial mapping (NavX system; St Jude Medical, Minneapolis, MN) confirmed the observations of the percutaneous epicardial approach (Figure 3A). Cryoablation applications at −120° (CryoCath; Medtronic, Minneapolis, MN) were delivered at the level of the triangle between the left anterior descending artery and the left circumflex artery (Figure 3), during which the PVCs completely disappeared (Movie in the online-only Data Supplement) but soon resumed after rewarming. In the 48 hours after the intervention, the patient presented incessant episodes of repetitive monomorphic VT and SMVT with poor hemodynamic tolerance, despite intravenous amiodarone first and intravenous procainamide later that failed to control the arrhythmia. We reviewed the coronary angiogram and the MRI performed 1 year before the index admission. Unprocessed

Figure 1. Surface 12-lead ECG of the clinical tachycardia (**left**) suggestive of a scar-related ventricular tachycardia (VT) arising from the left ventricular summit and sinus rhythm recording with spontaneous premature ventricular contractions (PVCs; **right**) after cardioversion.SR indicates sinus rhythm.

CE-MRI images showed a near-transmural scar involving mid and basal segments of the inferior wall and extensive septal midmyocardial enhancement, especially at the anteroseptal basal and anterobasal segments, reflecting advanced fibrosis (Figure 4A). CE-MRI images were processed using proprietary software, which allowed signal intensity (SI) thresholds measurement, defining dense scar (SI >3 SD higher than remote normal myocardium, depicted in pink) and heterogeneous tissue (SI between 2 and 3 SD, depicted in blue).[4] SI mapping was able to detect a small epicardial scar area and an area of heterogeneous tissue extending from the LV summit toward

the midseptum, whereas the endocardial maps were devoid of scar (Figure 4B). Finally, merged hemodynamic–CE-MRI images were obtained as follows: after SI mapping of the left ventricle, the ventricular wall was divided in 2 layers of equal thickness and the average SI from the outer half was projected onto the 3-dimensional epicardial surface. Subsequently, this subepicardial SI map was merged with the coronary angiogram using a 2D–3D registration-based algorithm. Merged images showed that a marginal branch ran through an area of continuity of heterogeneous tissue, perpendicular to the mitral annulus (Figure 4C and 4D).
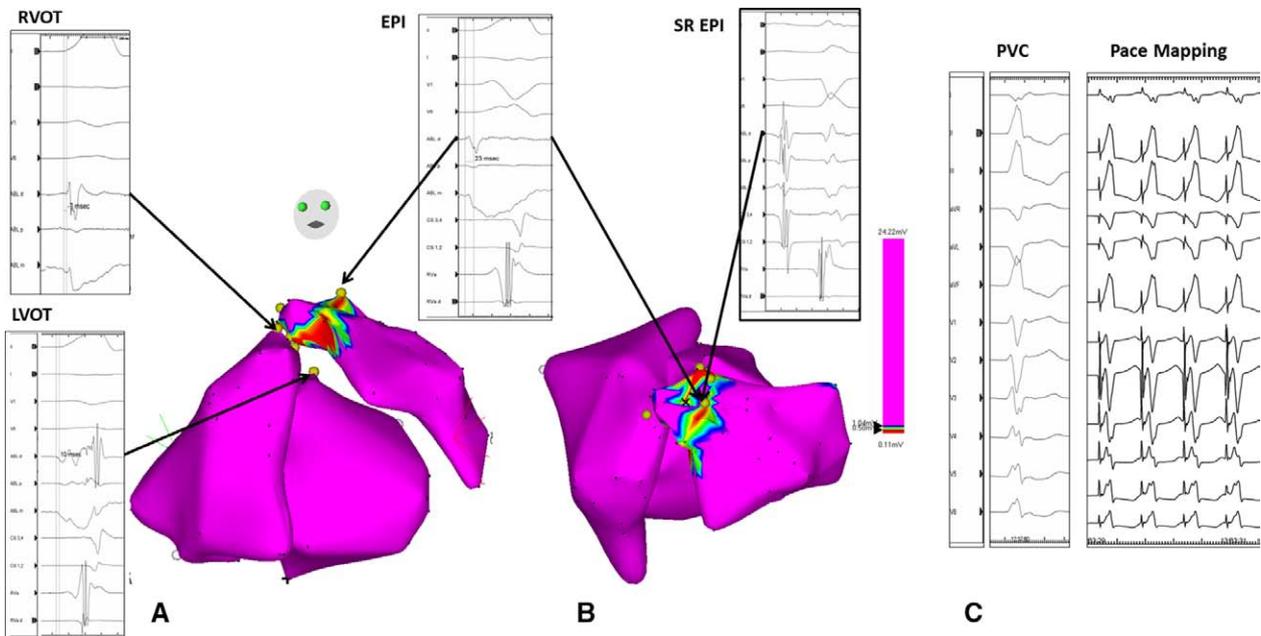
Figure 2. Combined endoepicardial voltage maps of the right and left ventricular outflow tracts (**A**; anteroposterior view) and the epicardial (EPI) aspect of the left ventricular (LV) summit (**B**; superior view), with corresponding recordings of activation mapping of the premature ventricular contraction (PVC), that show earliest activation at the EPI aspect of the LV summit, which during sinus rhythm (SR) was characterized by low-voltage, fragmented, and late electrograms (SR EPI). Pace mapping at that site showed excellent concordance with spontaneous PVCs (**C**). Normal myocardium electrograms are codified in purple (>1.5 mV), and scar-related electrograms from blue (<1.5 mV) to red (>0.5 mV). Endo indicates endocardial; LVOT, left ventricular outflow tract; PVC, premature ventricular complex; and RVOT, right ventricular outflow tract.
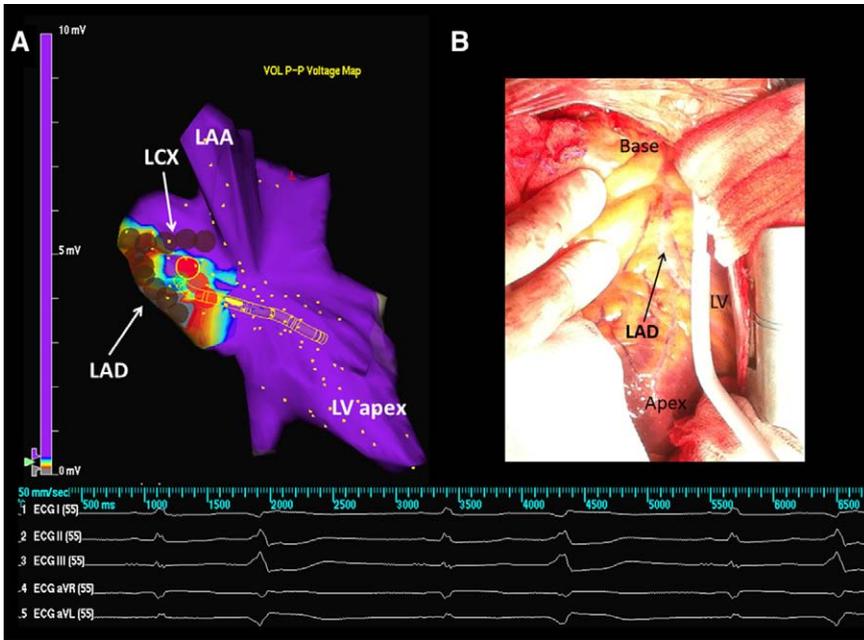
Figure 3. **A**, Intraoperative electroanatomic epicardial mapping shows an area of scar bounded by the left anterior descending artery (LAD) and the left circumflex artery (LCX; brown dots) during constant ventricular bigeminy. Cryoablation applications were delivered at that level (red dots). **B**, Anterior view of the exposed heart shows the cryoablation handheld probe positioned in the anterior paraseptal region, parallel to the LAD, with the catheter tip at the vertex of the triangle, where the ablation was performed. LAA indicates left atrial appendage; and LV, left ventricular.

Selective coronary angiography of the left coronary artery was then performed via a 6F femoral arterial sheath, and the target artery was selectively engaged using a flexible-tip guidewire (0.36 mm BMW; Abbott, IL; Figure 4E). An over-the-wire angioplasty balloon (Sprint 1.5×6 mm; Medtronic) was advanced and inflated at the ostium of the target branch, resulting in transient suppression of the SMVT (Figure in the online-only Data Supplement). Then, 1.5 mL of sterile absolute alcohol was injected and the balloon remained inflated for 10 minutes. After deflation of the balloon, contrast was injected, and despite the absence of VT, the target vessel perfusion was still present. Thus, an additional 3 mL ethanol infusion was performed and the balloon inflation was maintained for 10 minutes, and after deflation, contrast was injected, demonstrating total occlusion of the artery (Figure 4F). The patient remained free of arrhythmias without antiarrhythmic medications 5 months after the procedure.

Discussion and Teaching Points

The clinical characteristics of the case, that is, presence of different grades of PVCs and VT (alternating repetitive monomorphic VT and SMVT) together with the lack of inducibility during programmed stimulation and the focal origin, are compatible with a mechanism of the tachycardia due to triggered activity secondary to delayed afterdepolarizations.[5,6] On the 12-lead ECG, the tachycardia showed left-bundle branch block morphology with right inferior axis and a transition at lead V3. However, a substantial number of tachycardias originating either at the left or right ventricular outflow tracts demonstrate such a QRS configuration.[7] A V2 transition ratio >0.6 is a highly sensitive and specific criterion for a LV outflow track origin (Figure 1).[7] Other ECG features suggestive of an origin at the epicardial aspect of the LV outflow tract include R wave width >85 ms,[8] presence of q wave in lead I,[9] and, specifically, aVL/aVR amplitude ratio >1.75, indicating an origin at the upper part of the LV summit.[1]
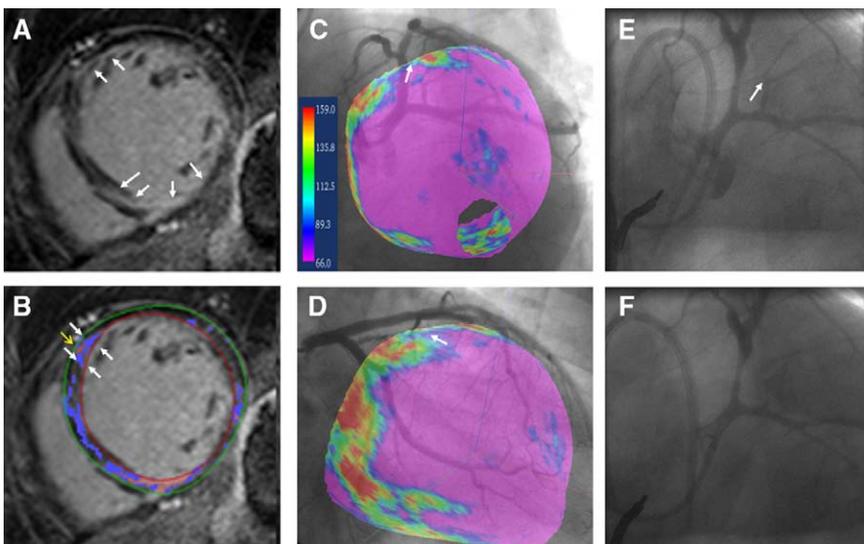
Figure 4. **A** and **B**, Contrast-enhanced MRI images, basal short-axis slices. **A**, Unprocessed images: areas of perivalvular scar (white arrows) at different levels, reflecting advanced nonischemic fibrosis. **B**, Processed images: scarred area in pink (yellow arrow), area of heterogeneous tissue in blue (white arrows). **C** and **D**, Fusion of left coronary angiogram and subepicardial scar signal intensity (SI) mapping: caudal left anterior oblique (LAO) projection (**C**); right anterior oblique projection (**D**). Merged epicardial SI mapping shows that a marginal branch runs just above an area of heterogeneous tissue (white arrows), perpendicular to the mitral annulus. **E**, Left coronary artery angiogram (caudal LAO view) showing that the first marginal branch irrigates the target area of heterogeneous tissue. **F**, Coronary angiogram after alcohol infusion, demonstrating total occlusion of the target branch.

Nevertheless, QRS morphology may be influenced by the presence and extent of myocardial scar, which can be predicted by the presence of a late precordial transition, precordial notching, and a QRS-S interval >90 ms.[10] Finally, the ECG features of the tachycardia were remarkably similar to the PVCs, suggesting a common site of origin for these arrhythmias, as does the elimination of one of them when targeting the other, making PVC ablation a more than acceptable surrogate in the case that the clinical SMVT is not inducible.[5]

Although the majority of idiopathic VTs originate in hearts without structural disease, a small subset can occur in conjunction with different entities such as coronary artery disease, valvular regurgitation or LV dysfunction, or abnormal MRI findings.[5,6] However, some forms may represent PVC-induced cardiomyopathy,[11] whereas in others, no causal relationship can be made between the tachycardia origin and the abnormal anatomic findings.[6] Most SMVTs in patients with structural heart disease are due to scar-related reentry, but occasionally other mechanisms can be responsible.[12] In fact, there is increasing evidence of the role of myocyte–fibroblast interaction in the generation of ectopic beats and triggered arrhythmias.[13] Coupling of myocytes to myofibroblasts promotes afterdepolarizations formation and may contribute to the proarrhythmic risk in fibrotic hearts.[13] Thus, in contrast to dense scar areas, heterogeneous tissue where myofibroblasts are embedded into areas of surviving myocytes represents the ideal substrate for afterdepolarizations formation in patients with dilated cardiomyopathy.[13]

In the present case, bipolar voltage mapping using standard settings showed normal values.[3] With the aim to increase the sensitivity of scar detection, we manually adjusted voltage settings and observed a scar area at the LV summit that correlated with the presence of either epicardial or intramural fibrosis on the CE-MRI images. Most importantly, 3-dimensional SI mapping was able to detect abnormal heterogeneous tissue both at the epicardial and the intramural level of the VT origin. This is in agreement with the study by Dickfeld et al[14] that showed that a surviving layer >2 mm might prevent intramural scar detection using conventional voltage settings. Thus, several strategies could be used to detect epicardial VT substrate, such as the use of a less conservative definition of scar

(<1 mV) during bipolar epicardial voltage mapping, unipolar endocardial voltage mapping, and postprocessed MRI.[4,15]

LV summit is an anatomically complex region bounded by the left anterior descending artery and the left circumflex artery that lies superior to the aortic portion of the LV (Figure 5)[16] and is the most common site of idiopathic epicardial LV arrhythmias.[1] Although these tachycardias can be ablated from within the coronary venous system, not infrequently an epicardial approach is required.[1–3,8] However, catheter ablation is unlikely to be successful in the upper part of the LV summit, the topographical region defined by the intersection of the great cardiac vein with the left circumflex artery and left anterior descending artery, namely the Brocq and Mouchet arteriovenous triangle, because of the presence of thick fat and the close proximity to the left main arteries (Figure 5).[8,17] Moreover, patients with nonischemic cardiomyopathy frequently have midmyocardial and basal LV epicardial scars that are in close proximity to major coronary arteries, making radiofrequency energy application ineffective or dangerous in these locations.[3,9] For this subgroup of patients, surgical cryoablation approach has previously been shown to be effective in select cases.[2,3] However, in the present case, despite transient suppression of the PVCs during cryoenergy delivery, the arrhythmia resumed after energy delivery ended, suggesting an intramyocardial origin. This was further confirmed after the retrospective analysis of coronary angiograms merged with CE-MRI and SI maps that allowed the identification of an area of heterogeneous tissue extending from the epicardium to the septal midmyocardium, irrigated by a permeable marginal artery.

After surgical ablation, the patient developed incessant SMVT, which seriously compromised his hemodynamic and clinical situation (Figure A in the online-only Data Supplement). Although the patient was evaluated for emergent cardiac transplantation, we decided to undergo alcohol ablation, which could be considered as a bail-out therapy. Tokuda et al[18] demonstrated that transcoronary ethanol ablation eliminates or improves arrhythmia control in two thirds of patients with previously failed endocardial and epicardial ablation procedures. Although infrequent (<2%), these cases in which alcohol ablation constitutes the only remaining option before cardiac transplant may
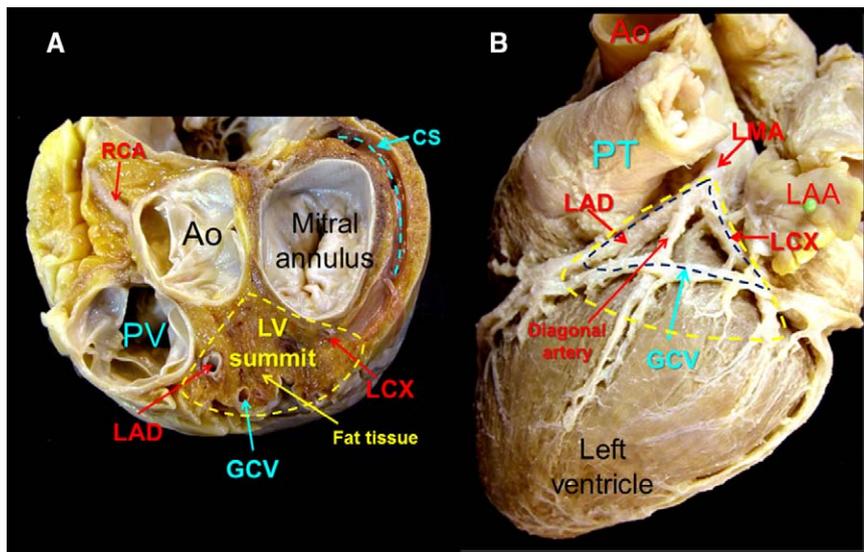

Figure 5. A, Short-axis view from the atrial side shows the relationship of the aortic valve (Ao), the pulmonary valve (PV), and the mitral annulus, surrounded by the coronary sinus (CS). Note the triangular area of the left ventricular (LV) epicardial surface bounded by the left anterior descending artery (LAD) and the left circumflex artery (LCX) that lies superior to the aortic portion of the LV ostium called LV summit (yellow dotted line), which contains abundant adipose tissue. **B**, Left lateral view of a heart specimen showing a dissection of the LV summit (yellow dashed line) bounded by the LAD and LCX, which is bisected by the great cardiac vein (GCV), which defines the upper part or triangle of Brocq and Mouchet (black dashed line) that is crossed by the diagonal artery and other minor LV branches. LAA indicates left atrial appendage; LMA, left main artery; PT, pulmonary trunk; and RCA, right coronary artery.

be performed with a moderate degree of efficacy, especially in patients in whom a deep intramyocardial VT circuit or a septal circuit is suspected.[18] Because a diagonal artery or a minor LV artery crosses the triangle of Brocq and Mouchet in 61% of patients, it could represent a target to consider in cases with failed epicardial ablation at this location.[17]

Coronary sinus mapping is the starting diagnostic approach for treating arrhythmias originating at the LV summit and is initially successful in ≈75% of patients.[1,8] However, occasionally, the ablation catheter is unable to reach the distal coronary sinus (as in the present case), there is an increase in impedance during energy delivery, or a major coronary artery is found in the proximity precluding ablation.[1,8] Transcutaneous epicardial access should be the following natural step, but catheter ablation is unsuccessful or is not even attempted in ≈50% of cases, especially those with an origin at the triangle of Brocq and Mouchet.[1] Surgical approaches using either midline thoracotomy[2,3] or minimally invasive procedures[19] allow dissection of the epicardial fat and direct application of safer ablative energy, such as cryoablation.

In conclusion, we present a case of successful alcohol ablation of an intramural VT originating at the LV summit. The procedure was aided by the use of fusion of hemodynamic–CE-MRI imaging that enabled scar characterization and coronary artery integration to the SI maps and their correlation with electroanatomical mapping information. The case highlights the anatomic difficulties found in patients with dilated cardiomyopathy and SMVT, particularly in the presence of midmyocardial scar locations close the coronary arteries. Finally, transcoronary alcohol ablation was able to terminate VT and prevent arrhythmic recurrences and is an option to be considered for select patients with difficult-to-control VT caused by nonischemic cardiomyopathy with previously failed therapeutic attempts.

Disclosures

Dr Atienza serves on the advisory board of Medtronic. The other authors report no conflicts.

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