Epicardial Ablation for Ventricular Tachycardia
A European Multicenter Study

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Background—The purpose of this study was to describe the epicardial percutaneous ablation experience of 6 European high-volume ventricular tachycardia (VT) ablation centers.

Methods and Results—Data from 218 patients with coronary artery disease (CAD, n=85 [39.0%]), idiopathic VT cardiomyopathy (IDCM, n=67 [30.7%]), arrhythmogenic right ventricular dysplasia/cardiomyopathy (ARCD/C, n=13 [6%]), hypertrophic cardiomyopathy (HCM, n=5 [2.3%]), and absence of structural heart disease (n=48 [22%]) undergoing epicardial subxyphoid access for VT ablation were collected. The epicardial approach was attempted as first-line treatment in 78 patients (35.8%). Acute prevention of VT inducibility was obtained in 156 patients (71.6%). There were no procedure-related deaths. Cardiac tamponade occurred in 8 patients, and abdominal hemorrhage in 1 patient. Six patients died of electrical storm recurrence within 48 hours from the procedure. After a mean follow-up of 17.3±18.2 months, 60 patients (31.4%) presented with VT recurrence (39.3% of IDCM patients; 34.7% of CAD patients; 30.8% of ARVD/C patients; 25% of HCM patients; 17.1% of patients with idiopathic VT). Twenty patients (10.4%) died during follow-up (12 of heart failure, 2 of cardiac arrest, and 6 of extracardiac causes).

Conclusions—In experienced centers, epicardial ablation of VT has an acceptable risk and favorable outcome. In selected patients, it is reasonable to consider as a first-line ablation approach. (Circ Arrhythm Electrophysiol. 2011;4:653-659.)

Key Words: ventricular tachycardia ■ radiofrequency catheter ablation ■ percutaneous epicardial mapping

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ince its publication in 1996 by Sosa and colleagues, the technique of percutaneous pericardial puncture to perform epicardial mapping and ablation has gained wide acceptance throughout electrophysiology laboratories as an adjunctive procedure for the treatment of ventricular arrhythmias. In past years, it has become clear that both endocardial and epicardial approaches may be required for an effective treatment of ventricular tachycardia (VT) in patients with nonischemic left- and right-side cardiomyopathy and sometimes in VTs occurring after myocardial infarction.

Clinical Perspective on p 659

Because of its complexity and potential risks, the technique currently is being adopted in centers with a high volume of VT ablation procedures. It is important to underline that percutaneous epicardial mapping, although considered a valid alternative to surgical mapping, is not easy, especially for nonskilled operators, and it may bear dangerous complications. The procedure currently is indicated only after a previously failed endocardial ablation, and data regarding usefulness and complications are mostly derived from single-center reports. On the grounds of this observation, we organized a European survey of centers known to run an epicardial VT ablation program to evaluate the current state of feasibility, applications, and overall safety of the procedure.

Methods

Twenty European centers involved in an endocardial or epicardial VT ablation program were invited in June 2008 to participate in the survey and to send data for all patients undergoing epicardial VT ablation between 2001 and 2009. The data included histories and diagnoses for all patients, diagnostic examinations (12-lead electrocardiography, echocardiographic examination, catheterization data), ablation reports, clinical events that occurred during inpatient care, and outpatient visit reports. The data were collected in a centralized database by the coordinating center (S Raffaele Hospital).

Seven European centers sent data for the survey. Of them, I reported only 1 epicardial VT ablation case, and the remaining reported at least

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8 cases. To avoid the confounding role of anecdotal reporting, the final participating list included 6 centers that had provided at least 8 epicardial cases. Only complete questionnaires were accepted for the data analysis, and in the case of contrasting data, a clarification query was sent. At the end of data collection, before statistical analysis, a spreadsheet was sent back to all participating centers for final agreement on the data. All centers provided an accurate assessment of patient status at 3- to 6-month intervals by regular outpatient clinical visits, including implantable cardioverter-defibrillator (ICD) interrogation and records of clinically relevant events occurring in between.

Indications for epicardial or combined endoepicardial approach as the first-line procedure were as follows:

- A VT deemed to be likely epicardial because of the 12-lead ECG of spontaneous VT or the type of underlying heart disease (idiopathic dilated cardiomyopathy [IDCM]), when available
- Absence of significant areas of low voltage at sinus rhythm endocardial mapping or an electrogram with a delayed component in spite of inducible VT
- Presence of a “pseudofocal” pattern of endocardial activation during induced VT, without significant prematurity of the local electrogram with respect to the onset of the surface QRS complex
- Presence of an intracardiac thrombus or mitral/aortic mechanical valves prosthesis.

Acute procedure outcome was considered noninducible when no monomorphic VT could be induced at the end of the study protocol, regardless of prior documentation of the clinical VT morphology (VT that has occurred spontaneously based on the analysis of 12-lead ECG QRS morphology and rate) and inducible when there was persistent inducibility of the presenting VT and of any other sustained VT. Ventricular fibrillation induction was considered as nonspecific.

Statistical Analysis
Continuous variables are reported as mean±SD. Comparisons between groups were done by χ² test for proportions.

A P<0.05 was considered statistically significant. Median event-free survival time was described in months with 95% CIs. Statistical analysis was performed with SPSS version 16 (SPSS Inc; Chicago, IL) statistical software.

Results
Study Sample
During the study period, 1836 VT ablations were performed in the 6 participating centers. Data from 222 patients who underwent epicardial mapping (193 men; age, 59±18 years; 12.1% of all VT ablation procedures) were collected. Four patients had incomplete data and were lost to follow-up and not considered for further analysis, so the study sample consisted of 218 patients (189 men; age, 59±17 years) (Table 1). Eighty-five (39.0%) patients had coronary artery disease (CAD), 67 (30.7%) had IDCM, 13 (6.0%) had arrhythmogenic right ventricular dysplasia cardiomyopathy (ARVD/C), and 5 (2.3%) had hypertrophic cardiomyopathy (HCM). The arrhythmia was idiopathic in 48 (22.0%) patients. Mean left ventricular ejection fraction was 40.5±16.4% and was <30% in 81 (37.2%) patients. One hundred forty (64.2%) patients had an ICD. The ejection fraction was 33±12% among patients with structural heart disease; 73% of them had an ICD.

Spontaneous Arrhythmia Pattern
All patients had recurrent VTs; 98 (45.0%) had experienced at least 1 episode of electrical storm (defined as the occurrence of ≥3 episodes of VT separated by >5 minutes during a 24-hour period, each resulting in an appropriate ICD treatment). The VT was incessant in 95 (43.6%) patients.

Overall, 334 VT morphologies (1.4±0.7/patient) were documented by 12-lead electrocardiography (224 VTs, 67.1% of the total morphologies) or by electrograms obtained on ICD interrogation (EGMs) for the remainder (110 VTs, 32.9%). The mean VT cycle was 353±80 ms. VT characteristics are summarized in Table 2.

Indications
The epicardial approach was attempted as first-line treatment in 78 (35.8%) patients and after the failure of a previous endocardial attempt in the remaining 140 (64.2%) patients (Table 1). As shown in Tables 3 and 4, the rate of epicardial ablation being performed as a first-line approach varied significantly among centers and etiologies. In 150 (68.8%) patients, the epicardial approach was attempted for VT recurrence after a previous endocardial ablation for the same VT; in 51 (34.0%) of them, the previous endocardial ablation had been considered acutely successful.

Ablation Strategy
The procedure was performed under conscious sedation with direct arterial blood pressure and O₂ saturation monitoring in 173 (79.4%) patients; general anesthesia with airway support was used in 45 (20.6%) patients. The subxyphoid puncture was carried out in all cases according to the technique described by Sosa et al.1,7 Because of pericardial adherence or
for anatomic problems, the pericardial access was obtained in 5 patients by a subxyphoid window and in 1 case, by a left lateral thoracotomy.11

Endo-epicardial mapping in the same procedure was performed in 191 (87.6%) patients, whereas epicardial mapping only was performed in 27 (12.4%). In some centers, preliminary placement of a guidewire into the pericardial space was performed to allow the subsequent approach to epicardial mapping according to the results of endocardial map. Electroanatomical mapping (CARTO; Biosence-Webster Inc; Diamond Bar, CA) was used to support sinus rhythm substrate evaluation and activation mapping during VT in 164 (75.2%) patients and in 9 patients with the aid of a remote nonfluoroscopic navigation system (EnSite NavX; St Jude Medical; St Paul, MN) was used in 8 (3.7%) patients. Left endocardial, right (if useful), and epicardial bipolar voltage maps were reconstructed following the current criteria for the definition of normal and scar tissue. All involved centers reported to define scar area as local bipolar electrograms ≤0.5 mV, normal tissue as local electrograms ≥1.5 mV, and abnormal myocardium as between 1.5 and 0.5 mV. Different voltage cutoffs were used in relation to the different experience of the single centers to identify zones of slow conduction inside the scar (ie, channels). Very-low-amplitude EGMs with high-frequency and late components were considered as scar area by the operators; low-amplitude EGMs with very smooth components were considered as possible fat tissue.

### Modalities of Catheter Ablation

The ablation site was selected on the basis of the following criteria: presystolic or mid-diastolic activity confirmed by entrainment pacing during VT and the presence of late fragmented potentials confirmed with pace-mapping maneuvers during sinus rhythm. Open irrigation-tip catheters were the most commonly used source of energy (80% of cases), with the power setting ranging from 20 to 40 W and irrigation rate up to 25 mL/min. Power was titrated to avoid temperature readings of >45°C or an impedance drop of >20 Ω. Nonirrigated-tip radiofrequency catheters were used in 12% of the procedures, with temperature control setting. Cryoablation was used in 16 (7.3%) patients.

The possibility of damage to the phrenic nerve at the ablation site was tested before radiofrequency current delivery in 35% of the patients by high-energy pacing. Coronary angiography was performed before radiofrequency delivery in 94 (43.1%) patients to evaluate the distance between catheter tip and main coronary artery vessels. When a near coronary artery vessel was found, the minimum distance to the ablation site was 8.6±7.8 mm.

In case of VT termination within 30 seconds of the delivery of radiofrequency beginning, the ablation was continued for 2 to 4 minutes. Further consolidation applications were performed and guided by findings from the electroanatomical map.
The mean procedural time was 204±90 minutes. The mean fluoroscopy time was 40±21 minutes.

Catheter ablation was not performed in 7 patients because of the proximity of the effective site of the ablation to the coronary arteries or the phrenic nerve in 2 and the lack of VT inducibility and the absence of substrate abnormalities at sinus rhythm mapping (presumptive intramyocardial locations) in 5. Moreover, in 14 patients, there was no evidence of epicardial reentry circuits, and the VT was interrupted during endocardial radiofrequency delivery. The end point of the procedure was noninducibility of any sustained monomorphic VT using programmed ventricular stimulation, including up to 3 extrastimuli at multiple sites or burst ventricular pacing.

**Effects of Ablation**

Catheter ablation was attempted on 289 induced VTs; 79 (36.2%) patients had >1 VT. Among the 139 (63.8%) patients with only 1 induced VT, the arrhythmia was hemodynamically tolerated in 120 (86.3%). Among the 79 patients with >1 VT, 66 (83.5%) hemodynamically tolerated all the arrhythmias, and 13 (16.5%) had at least 1 hemodynamically untolerated arrhythmia. Radiofrequency energy was delivered on the epicardial surface only in 103 VTs (35.6%), both in the endocardium and in the epicardium in 145 VTs (50.2%), and in the endocardial surface only in 41 VTs (14.2%).

Complete prevention of VT inducibility after ablation was obtained in 156 (71.6%) patients, with similar results when outcomes were analyzed according to the type of underlying heart disease as follows: 64 (75.3%) in patients with CAD, 45 (67.2%) in patients with ICDM, 9 (69.2%) in patients with ARVD/C, 2 (40.0%) in patients with HCM, and 36 (75.0%) in patients with idiopathic VT (P not significant). Ablation was attempted in 135 patients with ECG documentation of the clinical VT and in 62 patients with EGM documentation only. Prevention of VT inducibility after ablation was obtained in 43 (69.4%) patients with ICD EGM documentation only and in 113 patients (83.7%) with ECG documentation of the clinical VT (P=0.02).

One hundred two (75.6%) patients were treated by combined endo-epicardial ablation, 42 (67.7%) were treated by epicardial-only ablation, and 9 (64.3%) had an acutely successful procedure. There were 6 (4 CAD and 2 ICDM) in-hospital deaths related to early recurrence of electrical storm. The cause of death was electromechanical dissociation in 4 patients and refractory heart failure in 2; all 6 patients had an ICD.

**Procedural Complications**

There were no procedure-related deaths. Major complications were observed in 9 (4.1%) patients. Cardiac tamponade occurred in 8 (3.7%) patients undergoing combined endo-epicardial ablation (5 patients with CAD, 2 with ICDM, and 1 with idiopathic VT); in 4 of them, it became evident late after procedure termination. Six patients fully recovered within 24 hours after pericardial drainage. In 2 patients, surgical intervention was required (1 with CAD and 1 with idiopathic VT); in both instances, a right-side free wall tear resulted from a sheath without a pigtail inside left in the pericardium after the procedure.

Abdominal hemorrhage due to the puncture of a small diaphragmatic artery occurred in 1 patient with CAD who underwent combined endo-epicardial ablation. Progressive anemia, in the absence of procedural bleeding, developed 3 days after the ablation, and an abdominal CT scan revealed a subdiaphragmatic hematoma that required surgical drainage and repair of the vascular tear. The patient fully recovered.

Minor complications were observed in 17 (7.8%) patients undergoing the combined endo-epicardial procedure (13 patients with CAD, 1 with ARVD/C, and 3 with idiopathic VT). Two patients manifested an episode of acute heart failure, 1 had transient complete atrioventricular block, and 1 had a permanent left bundle branch block. In the total study sample, there also was 1 pneumonia and 1 vascular complication. A dry right ventricle puncture (ie, unintentional injection of contrast in the right ventricle without subsequent pericardial blood effusion) was reported in 5% of cases.

Forty-six (21%) patients experienced postprocedural precordial pain, which was considered severe in one half of them. After the ablation, oral steroids were used by 1 center in selected cases before 2007 and routinely thereafter. One center routinely used intrapericardial infusion of steroids, and 4 centers reported not using steroids.

**Long-Term Follow-Up**

After a follow-up of 17.3±18.2 months (range, 1–96 months), VT recurred in 60 of 191 (31.4%) patients admitted at follow-up (median VT-free survival, 51 months; 95% CI, 42–59 months). Arrhythmia recurred in 22 (39.3%) of the patients with ICDM, 26 (33.8%) with CAD, 4 (30.8%) with ARVD/C, 1 (25.0%) with HCM (25.0%), and 7 (17.1%) with idiopathic VT (P not significant). Twenty-four (40%) patients had the same morphology, and 19 (32%) patients had a different morphology. This information was missing in 17 (28.3%) patients because the arrhythmia documentation was obtained only by ICD recordings. Four patients with idiopathic VT, 18 with CAD, 14 with ICDM, 3 with ARVD/C, and 1 with HCM had an arrhythmia recurrence with a similar VT morphology; 3 patients with idiopathic VT, 8 with CAD, 8 with ICDM, and 1 with ARVD/C had a recurrence with a different VT morphology (P not significant). In the group of patients with a similar VT morphology recurrence, 20 had been treated by combined endo-epicardial ablation and 8 by epicardial-only ablation; in the group with a different VT morphology recurrence, 8 had been treated by combined endo-epicardial ablation and 7 by epicardial-only ablation (P not significant).

Electrical storm recurred in 19 (9.9%) patients (median electrical storm-free survival, 79 months; 95% CI, 70–88 months), leading to death in 5 patients of which 3 deaths were of acute refractory heart failure and 2 of electromechanical dissociation. Death occurred during follow-up in 20 (10.5%) patients; 12 died of refractory heart failure (7 patients with CAD, 5 with ICDM), 6 died of noncardiac causes, and 2 died of sudden cardiac death (both with ICDM). Heart transplantation was done in 3 patients.
Discussion

Indications
Data collected from this multicenter report show that the percutaneous epicardial ablation technique is used for a wide variety of VTs, including most frequently arrhythmias in patients with prior myocardial infarction and in those with nonischemic cardiomyopathy. A significant number of treated VTs, however, is not related to structural heart disease.

Overall, epicardial mapping alone or a combined endo-epicardial approach were undertaken as a first-line procedure in 38% of patients. This single figure supports a substantial evolution from the previous experience where the technique was undertaken in most instances as a secondary approach after the failure of a previous endocardial ablation. Over the years, a first-line epicardial approach had been advocated by the São Paulo, Brazil, group in patients with chagasic cardiomyopathy and in those with a previous inferior myocardial infarction. A high incidence of epicardial reentry circuit areas has been demonstrated in patients with ARVD and IDC, pointing out the need for an epicardial approach in those pathologies as well. Finally, surface ECG criteria suggesting an epicardial origin of a given VT have been published. The present report further suggests that both surface ECG and intracardiac mapping findings (ie, absence of diseased endocardial tissue at sinus rhythm mapping and pseudofocal activation pattern during VT) are increasingly acknowledged as indications to the epicardial approach to increase the efficacy of the first ablation procedure. The data also indicate increased electrophysiologist confidence with the technique and probably reflect the awareness of the extent of epicardial involvement in specific disease entities. On the other hand, indication of the epicardial approach as the first-choice procedure is still not homogenous. In fact, even among participating centers with a high number of procedures, the rate of first-line epicardial procedures ranged from 0% to 61%. In the present sample, an appropriate choice of a combined endo-epicardial approach was used by the majority of centers (ranging from 62%–100% of patients treated by the center), whereas general anesthesia was provided in selected cases (range among centers, 0%–38%). The choice of general anesthesia relied on the improvement of respiratory function control and, in selected cases, by the perception that it facilitates the pericardial puncture. In patient with depressed left ventricular ejection fraction, a prolonged period of hypoventilation, such as that occurring during propofol administration, may further hamper tolerance to the induced VT.

Complications
In the present study, major procedure-related complications occurred in 4.1% of patients and minor complications in 7.8% of patients. This low complication rate is consistent with prior single center and multicenter experiences (1% in Sosa et al, 1.5% in Roberts-Thomson et al, and 7% in Sacher et al study), and supports the current level of safety of the procedure. However, it must be underlined that these results have been obtained in centers with an established program of epicardial VT ablation and in the presence of surgical backup to rapidly treat any complication. Epicardial mapping and ablation still entails a potential risk of cardiac and extracardiac side effects, and its widespread use should be attempted with care.

In a series of 215 consecutive patients, Sosa et al reported 2 major complications: 1 abdominal bleeding due to damage of a diaphragmatic vessel treated by laparotomy and 1 non-Q-wave myocardial infarction due to the lesion of a marginal branch caused by radiofrequency delivery. Abdominal bleeding due to damage of a small diaphragmatic artery occurred in 1 patient in the present study sample; it should be suspected as the cause of progressive unexplained anemia in the absence of significant pericardial effusion. Another possible source of abdominal bleeding is liver perforation; thus, an accurate preoperative CT scan of the liver in patients with hepatomegaly or congestive heart failure might be useful to prevent this potentially a life-threatening complication.

The complication rate observed in the present study does not seem significantly superior to that reported for VT ablation with irrigated-tip catheters by Stevenson et al. In their multicenter experience, at least 1 procedure-related complication occurred in 25 patients over 231 treated. Twelve of those patients had a complication that significantly affected prognosis and required medical treatment.

Minor complications reported by Sosa et al were dry right ventricle puncture, drainable hemo-pericardium, and postprocedural precordial pain. Dry right ventricular puncture occurred in 4.5% of patients treated by Sosa et al and in 17% of patients in the multicenter experience of Sacher et al and was a self-limited event as reported by the operator in 5% of the patients in the present study. As suggested by Sacher et al, after an appropriate operator’s learning curve, the incidence of this minor complication is dramatically reduced. Hemo-pericardium usually does not preclude the continuation of the procedure because it is a self-limiting complication, and if blood is immediately reinfected into a femoral vein through a closed circuit, blood transfusion is not necessary. Twenty-one percent of the patients in the present study experienced...
postprocedural precordial pain, which in some could be related not only to the epicardial ablation, but also to the friction of the pigtail left in the pericardium for continuous drainage. To reduce the pain occurrence, 3 centers used routine administration of oral or intrapericardial steroids.

Phrenic nerve injury has been reported after epicardial VT ablation.\textsuperscript{23} To avoid this complication, phrenic nerve mapping by high-intensity pacing has been recommended before radiofrequency delivery in areas potentially near to the nerve course (ie, along the lateral wall of the left ventricle).\textsuperscript{24,25} In the present survey, the test was performed in 35% of cases. Once the effective ablation site is near the phrenic nerve, radiofrequency energy should not be delivered. The consistent capture of the phrenic nerve at the selected ablation site prevented the delivery of radiofrequency energy in 2 of 218 (<1%) patients. Phrenic nerve injury was not reported in our series.

The low, though not negligible incidence of late tamponade (4 of 8 patients with tamponade) provides the rationale for leaving the pericardial sheath in place after the procedure. Whenever this decision is made, it is important to have a soft additional catheter inserted through the introducer to avoid a myocardial lesion by its sharp edges.

Coronary arteries damage by radiofrequency energy may be significantly different, depending on whether it is delivered adjacent or above the artery,\textsuperscript{20,26,27} and is inversely related to the dimension of the vessel because large arteries are protected by the blood flow. Evaluation of the ablation site distance from a major branch by coronary angiography usually is recommended. Furthermore, common recommendations suggest that the distance between the ablating-tip catheter and the coronary vessel should be at least 12 mm. A novel unexpected finding of this survey is the low rate of coronary angiography use and the delivery of radiofrequency energy also near to coronary arteries. In contrast with commonly published recommendations, coronary angiogram to assess the safety of the ablation site was performed in only 43% of cases, with a wide variation among centers (15%–87%). The average distance of the ablation site from the nearest coronary artery branch was 8.6±7.8 mm.

\section*{Study Limitations}
This survey portrays the experience of 6 tertiary-care electrophysiology centers. To report on the experience of operators routinely performing epicardial mapping and ablations, data from centers with a limited number of epicardial procedures were excluded from the analysis. For these reasons, important complications that could occur in centers trying to start epicardial ablation were not described in this study. The study sample consisted of highly selected patients, the majority of whom had undergone a previous endocardial VT ablation. For this reason the present results may not be shared by less-experienced centers and operators. Furthermore, because of the retrospective nature of the study, minor complications not leading to overt alterations of patient clinical condition, such as dry right ventricle puncture, were not actively searched for and may be underestimated.

\section*{Conclusions}
In experienced, high-volume centers, epicardial ventricular ablation has an acceptable risk of complications. A combined endo-epicardial VT mapping and ablation approach within the first procedure could be evaluated in the absence of endocardial disease or in the presence of 12-lead ECG, suggesting an epicardial origin of the arrhythmia, by experienced high-volume centers. Alternative energy sources, may be considered for future development to prevent complications and to improve efficacy.

\section*{Disclosures}
Dr Zeppenfeld has served as consultant/advisory board member for St Jude Medical.

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12. Grimard C, Lacotte J, Hidden-Lucet F, Dutloit G, Gallais Y, Frank R. Percutaneous epicardial radiofrequency ablation of ventricular arrhythm-
Since its description in 1996, epicardial mapping and ablation have been used as an adjunctive procedure for the treatment of ventricular arrhythmias. This study reports on a European survey, describing the largest available sample of patients undergoing epicardial ablation from 6 experienced high-volume centers. Patients undergoing epicardial access were affected by ventricular tachycardia in the context of coronary artery disease (39.0%), idiopathic dilated cardiomyopathy (30.7%), arrhythmogenic right ventricular dysplasia/cardiomyopathy (6.0%), and hypertrophic cardiomyopathy (2.3%); in 22% of patients, the arrhythmia was idiopathic. Epicardial mapping alone or a combined endo-epicardial approach was undertaken as a first-line procedure in 38% of patients. There were no procedure-related deaths. Major complications (cardiac tamponade or abdominal hemorrhage) were observed in 4.1% of patients; minor complications occurred in 7.8% of patients. This survey depicts a widespread use of epicardial mapping and ablation as a first-line procedure and a significant evolution from previous experiences where the technique usually was undertaken only after the failure of a previous endocardial ablation. An appropriate choice of a combined endo-epicardial approach as a first-line mapping and ablation strategy may avoid a substantial number of repeated procedures and improve ablation technique outcome, particularly in patients with nonischemic cardiomyopathy, in the presence of specific ECG patterns during ventricular tachycardia and in the absence of fragmented potentials at endocardial mapping despite inducible ventricular tachycardias. The low complication rate observed in the study supports an acceptable level of safety when the procedure is performed by experienced operators in high-volume centers.
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