Drug-Refractory Ventricular Tachycardias After Myocarditis
Endocardial and Epicardial Radiofrequency Catheter Ablation

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Background—Ventricular tachycardia (VT) is a significant therapeutic challenge in patients with myocarditis. This study aimed to assess the efficacy and safety of radiofrequency catheter ablation (RFCA) of VT in patients with myocarditis.

Methods and Results—We enrolled 20 patients (15 men; age, 42 [28–52] years) with a history of myocarditis and drug-refractory VT; 5 patients presented with electrical storm. The median left ventricular ejection fraction was 55% (45–60%). All patients underwent endocardial RFCA with an irrigated catheter, using contact electroanatomic mapping. Recurrence of sustained VT after endocardial RFCA was treated with additional epicardial RFCA. Endocardial RFCA was acutely successful in 14 patients (70%) while in the remaining 6 (30%) clinical VT was successfully ablated by epicardial RFCA. In 1 patient, hemodynamic instability required an intra-aortic balloon pump to complete RFCA. No major complication occurred during or after RFCA. Over a median follow-up time of 28 (11–48) months, 18 patients (90%) remained free of sustained VT; 2 patients (10%, both with baseline left ventricular ejection fraction ≤35%) died of acute heart failure unrelated to ventricular arrhythmias.

Conclusions—In patients with myocarditis, RFCA of drug-refractory VT is feasible, safe, and effective. Epicardial RFCA should be considered as an important therapeutic option to increase success rate. (Circ Arrhythm Electrophysiol. 2012;5:492-498.)

Key Words: myocarditis • ventricular tachycardia • catheter ablation

Myocarditis is simply defined as an inflammatory condition mainly located in the heart muscle, although considerable uncertainties still persist as to its etiologic, pathological, and clinical subclassifications. In addition to the possibility of an aspecific flu-like prodrome, possible presentations include different degrees of heart failure (ranging from cardiogenic shock to subtly progressive chronic heart failure), chest pain, conduction anomalies, bradycardiacias, and tachyarrhythmias (including sudden cardiac death). The clinical course is also variable, as a spontaneous recovery may occur after the acute phase in up to 50% of patients, whereas chronic myocarditis and dilated cardiomyopathy sustained by viral persistence and/or autoimmune self-perpetration represent a common evolution of the disease.

Clinical Perspective on p 498

Myocarditis may cause arrhythmias both in its acute phase, due to inflammatory infiltration and myocyte necrosis, and in its chronic phase, due to immune reaction, fibrosis, and resulting electric remodeling. Therapy is essentially supportive for arrhythmias in the acute phase of disease, which can last several weeks but may regress spontaneously. Even in chronic myocarditis, therapy is largely confined to antiarrhythmic drugs, with limited efficacy, and to implantable cardioverter-defibrillator (ICD) for higher-risk cases, such as those with hemodynamically unstable ventricular tachycardia (VT) and aborted sudden cardiac death.Radiofrequency catheter ablation (RFCA) has been demonstrated to be effective in reducing VT occurrence in patients with Chagas cardiomyopathy. In nonchagasic myocarditis, isolated reports suggest that RFCA of VT may be effective, but its safety and long-term efficacy in this setting is unclear. This study evaluates safety and effectiveness of RFCA in a series of consecutive patients with persisting drug-refractory VTs after a biopsy diagnosis of myocarditis.
Methods

Patient Population
We enrolled 20 consecutive patients (15 men) with biopsy-proven myocarditis and drug-refractory VTs who had been referred for RFCA between January 2008 and December 2010. In all patients, the diagnosis of viral myocarditis was based on Dallas immunohistochemical criteria.14 The study was approved by the institutional review board, and all patients gave their written informed consent. Noninvasive investigations before RFCA included chest radiographs, 12-lead ECG, and color-Doppler echocardiography. Invasive characterization of the myocardial substrate was also performed before VT ablation and included coronary, left ventricular (LV) and right ventricular (RV) angiography, 3-dimensional electroanatomic mapping (EAM), and endomyocardial biopsy guided by EAM whenever low-voltage zones were observed, or otherwise performed at the interventricular septum.15–18

Mapping and Endocardial Ablation Procedure
Through transfemoral puncture, a quadripolar catheter was placed at the RV apex and the RV outflow tract; a ventricular stimulation study was performed with up to 3 extrastimuli to induce VT. Three-dimensional EAM was aided by CARTOSOUND intracardiac echocardiography ( Biosense Webster, Diamond Bar, CA).19–20 In all patients a 3.5-mm open irrigated ablation catheter (Biosense Webster) was used for ventricular mapping. We decided whether to map the RV or LV by presuming the most likely origin of the arrhythmia based on surface ECG criteria. During LV endocardial mapping, performed through a retrograde aortic or transseptal approach, heparin was administered intravenously to maintain a target activated clotting time of 300 seconds. Detailed substrate mapping of the chambers of interest was obtained. In accordance with previous studies, the reference value for normal endocardial bipolar signal amplitude was set at 1.5 mV.19,21 In patients with hemodynamically tolerated VT, activation mapping, entrainment mapping, and pace-mapping maneuvers were performed. If VTs were not inducible or were hemodynamically unstable, pace mapping was performed and areas of scar were circumscribed with radiofrequency (RF) pulses, delivered with a maximum power of 40 W and at a maximum temperature of 43°C. After ablation, all patients were monitored in the electrophysiology laboratory for up to an hour; also, VT reinduction was attempted with up to three ventricular extrastimuli with and without isoprenaline infusion.

Epidermal Ablation Procedure
In patients in whom endocardial ablation failed (including 3 who had undergone previous ablation at another institution), epicardial RFCA was performed, with the same instrumentation described above, with the addition of epicardial mapping via the subxiphoid approach.22 Intracardiac echocardiography was used to assess the presence of possible pericardial effusion and to locate critical structures, such as the coronary arteries. After completing EAM, the above-mentioned criteria were used to select sites for RF pulses, which were delivered with a maximum power of 45 W and at a maximum temperature of 41°C. Ablation was performed remote from the left coronary arteries, based on selective coronary angiography. In regions close to the phrenic nerve, high-output pacing (20 mA) was performed via the ablation catheter, and these locations were marked on the EAM. Postablation monitoring and reinduction attempts were performed as described above.

Clinical Follow-Up and Outcomes
After discharge, each patient was reevaluated and underwent 24-hour ECG Holter monitoring at 1, 3, and 6 months after ablation and thereafter every 6 months. In ICD carriers, device memory was used to detect VT episodes.

Table 1. Baseline Clinical Features of Enrolled Patients

<table>
<thead>
<tr>
<th>Patients (n=20)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>42 (28–52)</td>
</tr>
<tr>
<td>Male subjects</td>
<td>15/20 (75%)</td>
</tr>
<tr>
<td>LV ejection fraction, %</td>
<td>55 (45–60)</td>
</tr>
<tr>
<td>LV ejection fraction ≤40%</td>
<td>4/20 (20%)</td>
</tr>
<tr>
<td>Previous ICD implantation</td>
<td>3/20 (15%)</td>
</tr>
<tr>
<td>Previous VT ablation</td>
<td>3/20 (15%)</td>
</tr>
<tr>
<td>VT episodes in previous 6 mo</td>
<td>11 (2–18)</td>
</tr>
<tr>
<td>Spontaneous VT cycle, ms</td>
<td>335 (307–360)</td>
</tr>
</tbody>
</table>

Values express as number of patients (%) or as median (Q1–Q3).

LV indicates left ventricular; ICD, implantable cardioverter-defibrillator; VT, ventricular tachycardia.

Statistical Analysis
Continuous variables are reported as median with first and third quartiles (Q1–Q3); categorical variables are reported as frequencies and percentages. Between-group (eg, patients with recurrent VT versus those who remained free from VT at follow-up) comparisons were performed with the Wilcoxon rank sum test. Within-group comparisons of preablation and postablation values of continuous variables (eg, left ventricular ejection fraction) were performed with the Wilcoxon signed-rank test. All tests were 2-sided, and a value of P<0.05 was considered statistically significant. Statistical analyses were performed using the STATA 10.0 (Stata Corporation, College Station, TX) statistical package.

Results

Patient Characteristics
Table 1 shows the clinical characteristics of the 20 enrolled patients (median age, 42 [28–52] years; 15 men). Preablation echocardiography showed a median LV ejection fraction (LVEF) of 55% (45–60%).

EAM-guided biopsy was performed a median of 5 (3–5) months before ablation and showed in all patients active myocarditis according to Dallas criteria, with immunohistochemical evidence of activated T-lymphocytes. No evidence of sarcoid granulomas or giant cells was observed in any myocardial specimen. On the basis of persistent ventricular arrhythmias and histological findings, all patients received a diagnosis of chronic active myocarditis at the time of biopsy.

The patients had documented ventricular arrhythmias for a median of 8 (6–24) months (range, 1–36 months), and all had proven refractory to antiarrhythmic therapy with 2.1±1.4 drugs, including amiodarone in 9 patients (45%). Three patients (15%) had been previously implanted with an ICD. Five (25%) presented with electrical storm, including all 3 ICD carriers. Three patients (15%) came to our attention after an unsuccessful previous RFCA at another institution.

Table 2 summarizes electrophysiological findings in enrolled patients. Clinical VT could be induced on programmed stimulation from the endocardium in 19 of 20
patients (95%) and from the LV epicardium only in the remaining 1 (5%). The induced VTs had a median cycle length of 300 (270–350) ms, were all monomorphic, and originated from the LV in 12 of 20 (60%) patients and from the RV in the remaining 8 of 20 (40%); VTs were associated with a low voltage in 12 of 20 patients (60%), whereas the remaining 8 of 20 (40%) had no low-voltage areas on electroanatomic mapping.

In 3 of 20 patients (15%), VTs were invariably associated with hemodynamic instability and stabilization required inotropic support (in 2 patients) or intra-aortic balloon pump counterpulsation (in 1 patient). The remaining 17 of 20 (85%) had tolerated VTs and underwent complete activation and entrainment mapping.

Endocardial RFCA was acutely successful in 14 of 17 (82%) patients undergoing their first ablation at our institution; the remaining 3 of 17 (18%) cases included 2 patients in whom endocardial RFCA proved ineffective and 1 in whom no arrhythmia could be induced by endocardial RV and LV stimulation. Figure 1 shows a case of effective endocardial RFCA using electroanatomic mapping aided by intracardiac echocardiography.

In the 6 of 20 patients (30%) in whom endocardial RFCA was ineffective or infeasible, epicardial ablation was performed 10 days (range, 2–27) after the previous endocardial procedure; in these patients, VT was found to originate from the RV in 1 patient and from the LV in the remaining 5. Epicardial RFCA was performed from the coronary sinus in 1 patient and by a subxiphoid approach in the other 5, in all cases with acute success. Figures 2, 3, and 4 illustrate the case of a patient with failed endocardial RFCA and subsequent successful epicardial ablation.

No major complication occurred during the procedures or the remaining hospital stay. At discharge, antiarrhythmic drug therapy was continued in 7 of 20 patients (35%).

### Table 2. Electrophysiological and Procedural Features of Enrolled Patients

<table>
<thead>
<tr>
<th>Feature</th>
<th>Patients (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induced VT cycle, ms</td>
<td>300 (270–350)</td>
</tr>
<tr>
<td>Nontolerated VT induced</td>
<td>3/20 (15%)</td>
</tr>
<tr>
<td>No. of VTs induced per patient</td>
<td>1 (1–1)</td>
</tr>
<tr>
<td>VT origin from the RV</td>
<td>8/20 (40%)</td>
</tr>
<tr>
<td>RV outflow tract</td>
<td>6/8 (75%)</td>
</tr>
<tr>
<td>RV free wall</td>
<td>2/8 (25%)</td>
</tr>
<tr>
<td>VT origin from the LV</td>
<td>12/20 (60%)</td>
</tr>
<tr>
<td>LV outflow tract</td>
<td>4/12 (33%)</td>
</tr>
<tr>
<td>LV inferior wall</td>
<td>3/12 (25%)</td>
</tr>
<tr>
<td>LV anterolateral wall</td>
<td>5/12 (42%)</td>
</tr>
<tr>
<td>Ablation effectiveness</td>
<td></td>
</tr>
<tr>
<td>On first attempt, endocardial</td>
<td>14/20 (70%)</td>
</tr>
<tr>
<td>On second attempt, epicardial</td>
<td>6/20 (30%)</td>
</tr>
<tr>
<td>Procedural features</td>
<td></td>
</tr>
<tr>
<td>Fluoroscopy time, min</td>
<td>51 (43–91)</td>
</tr>
<tr>
<td>Total procedural time, h</td>
<td>4.5 (3.2–5.3)</td>
</tr>
<tr>
<td>No. of RF pulses</td>
<td>45 (18–66)</td>
</tr>
<tr>
<td>Maximum power, W</td>
<td>41 (38–42)</td>
</tr>
<tr>
<td>Median RF time, min</td>
<td>25 (7–44)</td>
</tr>
</tbody>
</table>

Values express as number of patients (%) or as median (Q1–Q3). VT indicates ventricular tachycardia; RV, right ventricular; LV, left ventricular; RF, radiofrequency.

Figure 1. Endocardial left ventricular ablation. Endocardial voltage map of the left ventricle in right (A) and left (B) anterior oblique views, with intersecting CARTOSOUND intracardiac echocardiography fans. C, Same echo fan as in B. Intracardiac echocardiography allows identification of aneurysmatic dilatations (white line and arrow) not observed on transthoracic echocardiogram. D, Run of nonsustained ventricular tachycardia in the same patient.
Long-Term Outcome

After a median follow-up of 28 (11–48) months, 3 of 20 patients (15%) remained on antiarrhythmic drugs: 1 patient (5%) because of frequent polymorphic premature ventricular beats and 2 (10%) because clinical sustained VT recurred. Figure 5 shows long-term freedom from recurrent VT by the Kaplan-Meier survival analysis.

One year after RFCA, there was a statistically significant increase in median LVEF (56% [45–60%] versus 60% [57–63%], P<0.001). In 1 case, after 2 years without VT episodes, the ICD was removed at the patient’s request.

Two patients (10%) died during follow-up. The 1 patient with LVEF 33% in whom intra-aortic balloon contropulsation had been necessary during RFCA ultimately died of acute heart failure 2 months after discharge; ICD interrogation excluded ventricular tachyarrhythmias as the precipitating factor. The other patient had LVEF 35% and had originally presented with electrical storm; 3 months after discharge, he had development of bacterial endocarditis requiring cardiac surgery and ultimately died of postoperative complications.

Discussion

Main Findings

This case series of consecutive patients with biopsy-proven myocarditis is the first study to evaluate prospectively the...
safety and efficacy of RFCA in this clinical setting. Our results
demonstrate that RFCA of drug-refractory VTs persisting over
months after a diagnosis of myocarditis is feasible without
major complications and is associated with a high acute success
rate. At long-term follow-up, up to 90% of patients remained
VT-free, whereas there was a small increase (about 5%) in
LVEF over time. The relative stability of ventricular function
over time corroborates the notion that patients were treated in
a phase of consolidated disease; this might suggest that the dis-
appearance of ventricular arrhythmias might be mainly cred-
ited to a successful RFCA. Moreover, during follow-up, 2 of
10 patients (10%) with reduced LVEF died, which is consistent
with current epidemiological data on myocarditis.1,8,9

**Ventricular Arrhythmias in Myocarditis**

Patients with myocarditis frequently display a wide spec-
trum of conduction disturbances, atrial and ventricular
tachyarrhythmias.23-25 When arrhythmias persist beyond the
acute phase, the arrhythmogenic substrate consists of replace-
ment fibrosis and chronic inflammation, which may be related
to self-maintaining autoimmune mechanisms or to viral
persistence when a virus is the cause. A recent study with
FDG-PET in patients with sustained monomorphic ventricu-
lar tachycardia and sarcoidosis or tuberculosis demonstrated
that myocardial inflammation may cause life-threatening ven-
tricular arrhythmias and abnormal electroanatomic mapping
findings even in the absence of scar at cardiac magnetic reso-
nance and in the presence of normal ventricular dimensions
and function.26

Moreover, it has been demonstrated that continuing myo-
cardial damage can persist even in the absence of overt inflam-
mation, for example, through the release of viral proteases
capable of cleaving cytoskeletal dystrophin.27,28

The 2006 European Society of Cardiology/American
College of Cardiology/American Heart Association guide-
lines on ventricular arrhythmias and sudden cardiac death10
recommend drug therapy for life-threatening ventricular
arrhythmias in myocarditis. In the acute phase, treatment is
usually largely supportive. This can then be associated with
possible ICD implantation if arrhythmias persist after the
acute phase despite pharmacotherapy. RFCA is not mentioned
at all in this context and is not contemplated in more specific
guidelines on myocarditis.2,3 This absence reflects the lack of
specific evidence on RFCA of VT in myocarditis, as most of
the published evidence consists of case reports.12-14,29

A significantly larger body of published evidence is avail-
able on RFCA of VTs in patients with Chagas disease, a
dilated cardiomyopathy caused by infestation by the proto-
ozoan *Trypanosoma cruzi*.11

In these patients, RFCA (both endocardial and epicardial)
has been demonstrated to reduce VT recurrences,30-32 which
might in turn help reduce shocks in ICD carriers.

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**Figure 4.** Epicardial access and tachycardia termination. A, Fluoroscopic right anterior oblique (RAO) view, showing the ablation catheter (arrow) in the pericardial space at the level of the earliest ventricular activation during ventricular tachycardia (VT). B, Radiofrequency energy applied at the site of earliest activation terminated VT during ablation.

**Figure 5.** Arrhythmia-free survival. Kaplan-Meier survival analysis shows long-term freedom from recurrent ventricular tachycardia (VT).
Similarly, effective RFCA has been reported in patients with cardiac sarcoidosis, whose inflammatory granulomatous lesions often produce structural and clinical features resembling arrhythmogenic right ventricular cardiomyopathy, representing an important cause of ventricular arrhythmias and sudden cardiac death.

Procedural Considerations

We think that the choice of resorting to an irrigated ablation catheter is justified by the need for deeper RF lesions, in consideration of the high likelihood of intramural and/or subepicardial disease involvement.

Of the utmost interest is the finding that an epicardial RFCA was needed to suppress VT in 6 of 20 patients (30%), in 5 because endocardial lesions were ineffective and in 1 because they were not attempted because RF could only be induced by LV epicardial stimulation. This supports the concept that VTs may involve intramural or epicardial reentry circuits; in fact, pathology and MRI studies indicate that in myocarditis the inflammatory process frequently starts from the epicardium. Accordingly, De Cobelli et al found that in patients with chronic myocarditis presenting with either heart failure or ventricular arrhythmias and with MRI evidence of late enhancement, the latter was intramural in 62.5% of cases and subepicardial in the remaining 37.5%. In our study, epicardial RFCA too was shown to be feasible, safe, and effective.

The use of intracardiac echocardiography is a standard approach in VT ablation for all operators involved in this study. It proved useful not just in its ability to monitor for pericardial effusion but also to locate structures of critical importance (such as the coronary arteries) and to confirm the adherence of EAM to ventricular anatomy. We think that this could also help to better visualize subtle morphological anomalies, such as microaneurysms, which were indeed present in 1 of our patients, or motion anomalies, which might suggest presence of scar.

Study Limitations

We recognize that the natural history of VTs in myocarditis has not been adequately documented; therefore RFCA success and disease regression act as reciprocal confounders when evaluating long-term freedom from VT. Even when biopsy documents immunologically active chronic inflammation, this may not necessarily be the pathological substrate sustaining VT persistence indefinitely, as inflammation may become quiescent and still arrhythmias may be caused by “spent” residual myocardial damage. A distinction between ongoing inflammation and residual injury cannot be made on clinical grounds alone, and no precise evidence basis is available on whether the two possibilities carry different prognostic implications that might justify repeat invasive and/or costly investigations. In addition, we recognize that in view of the high incidence of intramural and subepicardial disease, in selected cases, an epicardial approach to RFCA may be reasonable from the start rather than defaulting to a second-line option, as we did, and that ECG and/or MRI findings might help guide this choice.

Conclusions

RF catheter ablation of VTs in patients with chronic active myocarditis is safe, feasible, and effective in eliminating VTs. Epicardial ablation should be considered as an important option to increase the success rate in these patients.

Acknowledgments

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Disclosures

Dr Tondo has served as a member of the advisory board of Biosense Webster and has been a consultant for, and received lecture fees from, St Jude Medical. Dr Natale has received compensation for belonging to the speakers’ bureau for St Jude Medical, Boston Scientific, Medtronic, and Biosense Webster and has received a research grant from St Jude Medical. Dr Di Biase is also a consultant for Biosense Webster. Dr Di Biase is a consultant for Hansen Medical and Biosense Webster.

References

Ventricular tachycardia (VT) is a significant therapeutic challenge in patients with myocarditis. Myocarditis may cause arrhythmias both in its acute phase and in its chronic phase. Therapy is essentially supportive for arrhythmias in the acute phase of disease, which can last several weeks but may regress spontaneously. Even in chronic myocarditis, therapy is largely confined to antiarrhythmic drugs and to implantable cardioverter-defibrillators for patients with refractory VTs after a biopsy diagnosis of myocarditis. Our results demonstrate that radiofrequency catheter ablation of drug-refractory VTs persisting over months after a diagnosis of myocarditis is feasible without major complications and is associated with a high acute success rate. Of the utmost interest is the finding that an epicardial radiofrequency catheter ablation needed to suppress VT in 30% of patients. This supports the concept that VTs may involve intramural or epicardial reentry circuits, as, in fact, pathology and MRI studies indicate that in myocarditis the inflammatory process frequently involves safety and effectiveness of radiofrequency catheter ablation in a series of 20 consecutive patients with persisting VTs. In summary, radiofrequency catheter ablation of VTs in patients with chronic active myocarditis and mediastinal adenopathy due to granulomatous infiltration in patients with preserved ventricular function. J Am Coll Cardiol. 2011;58:48–55.


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