An Underrecognized Subepicardial Reentrant Ventricular Tachycardia Attributable to Left Ventricular Aneurysm in Patients With Normal Coronary Arteriograms

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Background—In patients with apparently normal hearts, ventricular tachycardia (VT) may only involve the subepicardial myocardium.

Methods and Results—Four patients with exercise-induced fast VT with right bundle branch block morphology were investigated. ECG showed a small q wave in leads II, III, and aVF during sinus rhythm (SR) in all 4 patients. Left ventricular angiography showed small inferolateral aneurysms in all patients. Coronary arteriograms were normal in all 4 patients. Six unstable VTs (cycle length, 200 to 305 ms) and 1 stable VT (cycle length 370 ms) were reproducibly induced in the 4 patients. During SR, endocardial mapping was normal in all 4 patients, and epicardial mapping showed fragmented and late potentials in the left inferolateral wall anatomically consistent with the left ventricle aneurysm. During tachycardia, epicardial mapping showed a macroreentrant VT with focal endocardial activation in the patient with stable VT, whereas in 2 patients with unstable VT, a diastolic potential was only recorded and coincided with the late potential in the same area. Epicardial ablation was performed in 3 patients and successfully abolished those VTs. No VT recurred in 2 patients during follow-up of 2 and 9 months. Clinical VT recurred 6 months after the ablation and was successfully ablated in a repeated epicardial ablation in 1 patient. In the remaining patient without epicardial ablation, an implantable cardiac defibrillator was implanted. There were multiple shocks during a follow-up of 31 months.

Conclusions—In patients with normal coronary arteriograms and left ventricle aneurysm, exercise-induced VT with right bundle branch block morphology may have a subepicardial arrhythmogenic substrate, which may be amenable to epicardial ablation. (Circulation. 2003;107:2702-2709.)

Key Words: cardiomyopathy ■ mapping ■ syncope ■ tachycardia

Exercise-induced fast monomorphic ventricular tachycardia (VT) can result in syncope in patients with apparently normal hearts. It originates from the right ventricular outflow tract (RVOT) and presents with left bundle branch block morphology and inferior axis on surface ECG in most patients.1–4 It has also been recognized that verapamil-sensitive VT with a right bundle branch block morphology (RBBB) can occur during exercise in apparently normal hearts.1–5 A recent study has demonstrated that inflammatory left ventricular microaneurysms can be a cause of apparently idiopathic ventricular tachyarrhythmias.6 We report on 4 patients with recurrent exercise-induced syncope attributable to fast VT, 1 or 2 aneurysms in the inferior-lateral wall of the left ventricle (LV), and a peculiar subepicardial arrhythmogenic substrate. This presentation may constitute a distinct clinical syndrome and may be amenable to epicardial catheter ablation.

Methods

Patient Characteristics
Four consecutive male patients (19 to 62 years) with recurrent exercise-induced syncope attributable to sustained fast monomorphic VT were investigated in our institution from April 2000 to October 2002. Clinical VT presented on 12-lead ECG with RBBB morphology in all patients (Figures 1A and 1B). The VT had been paroxysmal sustained for 2 years in patient No. 1 (age 19 years), for 2 months in patient No. 2 (age 41 years), for 14 years in patient No. 3 (age 62 years), and for 4 months in patient No. 4 (age 43 years). They had been taking a mean of 3 antiarrhythmic drugs without adequate control of their VT. Echocardiograms showed normal cardiac dimensions and function in all 4 patients. None of the patients had a history of exposure to Chagas’s disease or family history of sudden death. None of the patients had a history of exercise-induced syncope attributable to sustained fast monomorphic VT.

Electrophysiological Study
All patients underwent electrophysiologic evaluation under intravenous sedation without antiarrhythmic drugs except patient No. 2.
who was taking flecainide. Catheters were introduced to the right ventricular apex (RVA) and the RVOT under fluoroscopic guidance via the femoral veins. The stimulation protocol consisted of programmed ventricular stimulation from the RVA and RVOT at 2 drive cycle lengths with up to 3 extrastimuli and incremental burst pacing at a cycle length up to 250 ms. If the clinical VT did not occur spontaneously and was not inducible at baseline, intravenous isoproterenol infusion (2 to 5 \( \mu \)g/min) was administered to facilitate its induction.

Endocardial and Epicardial Electroanatomical Mapping

The methods of electroanatomical (EA) mapping have been described previously in detail.\(^5\) Mapping was performed with a steerable catheter with 4-mm electrode tip (irrigated Navi-Star, Biosense Webster). Bipolar electrograms were recorded on the EA mapping system (filtered at 10 to 400 Hz) and a separate Quinton EP system (filtered at 30 to 400 Hz). Endocardial mapping of the left ventricle was initially performed via the right femoral artery. Whenever endocardial mapping failed to identify an endocardial substrate, epicardial mapping was performed via a nonsurgical transsthoracic epicardial approach described previously.\(^7\)–\(^9\) Detailed mapping was carried out in the scar area defined by amplitude <0.5 mV and only presence of far-field systolic activation, in areas with diastolic potentials during tachycardia, or in areas of fragmented and late potentials during sinus rhythm (SR). The fragmented and double potentials were defined by an isoelectric interval of <50 or >50 ms, respectively, between the two components during SR. Also, the second component of the double potentials during SR was defined as late potential. The definition of low amplitude area by <1.5 mV was only used for endocardial mapping.\(^10\)–\(^11\)

A complete VT map was performed to identify the reentry circuit in the induced stable VT. Otherwise, mapping was only performed to identify the site of earliest activation or a diastolic potential. Furthermore, concealed entrainment mapping was performed to identify the critical isthmus during tachycardia.

Irrigated Radiofrequency Ablation

Irrigated radiofrequency (RF) energy was performed according to an endocardial protocol found in experimental and clinical studies.\(^12\)–\(^13\) This consisted of temperature-controlled RF delivery with a power limit of 50 W, a target temperature of 45°C, a time limitation of 110
seconds, and an infusion rate of 17 mL/min during RF delivery. Irrigated RF energy was delivered either at the site of earliest activation or across the VT critical isthmus for macroreentrant VT. Coronary angiography was performed before epicardial RF delivery to visualize the relationship between the targeted RF sites and the large coronary arteries defined by vessel diameter >1.0 mm. After 5 irrigated RF applications, the mapping catheter was exchanged to a pigtail catheter through the same 8-F sheath. Pericardial fluid was aspirated through the pigtail catheter to prevent significant accumulation. Control coronary angiography was performed after ablation.

Postablation Management and Follow-Up
After ablation, a pigtail catheter was kept in the pericardial space for 24 hours and removed after transthoracic echocardiography had excluded a pericardial effusion. All patients were monitored for 72 hours by telemetry. Follow-up information was obtained either from the referring physicians or in our outpatient clinic.

Statistical Analysis
All values are expressed as mean ± SD.

Results
ECG Characteristics
During SR, surface ECG showed a small q wave in leads II, III, and aVF in all 4 patients (Figure 2). ST-segment and T-wave changes were found in leads II, III, aVF, and V4-V6 in 2 patients. The QRS duration was normal in 3 patients and increased in patient No. 3, with incomplete RBBB. Spontaneous ventricular extrasystoles with RBBB morphology were observed in 4 patients.

Left Ventricular Angiography
LV angiography revealed normal contractility with a single aneurysm in 3 patients (Figure 3A) and 2 left ventricular aneurysms in patient No. 3. The aneurysms were located in the inferior-lateral wall. The aneurysm length during diastole was 26 ± 7 mm (17 to 34 mm) as measured by cardiac angiography (Siemens AG). The LV ejection fraction was 60 ± 7% (51% to 70%). Right ventricular and coronary angiographies were normal in all patients.

Electrophysiological Study
During the electrophysiological procedure, 1 clinical VT (cycle length, 240, 370, and 240 ms) and 1 nonclinical VT (cycle length, 200, 275, and 290 ms) were reproducibly induced without intravenous isoproterenol infusion in patients No. 1, 3, and 4, respectively. Clinical VT with a CL of
305 ms was only induced with intravenous isoproterenol infusion in patient No. 2. Induced VTs showed RBBB morphology with superior axis in 5 VTs and inferior axis in 2 (in patient No. 1 and 4). All inducible VTs except the slow VT with cycle length of 370 ms in patient No. 3 were hemodynamically unstable and required urgent termination by burst pacing in patients No. 2 and 3 and by a DC shock in patients No. 1 and 4.

**Endocardial Mapping and Ablation**

EA mapping during SR was successfully performed in all 4 patients. A mean of 174±19 points (range, 147 to 192) was acquired to reconstruct the LV with a diastolic volume of 151±31 mL (range, 129 to 204 mL). During SR, no fragmented and late potentials and no areas with low amplitude were found within the small aneurysm on endocardial mapping in any of the 4 patients (Figure 4A).

In 2 patients with hemodynamically unstable VT, irrigated RF energy was delivered at endocardial sites either guided by perfect pace mapping at the inferolateral wall near the posterolateral mitral annulus (MA) in patient No. 1 or the earliest endocardial activation in the inferolateral wall near the MA preceding the onset of the QRS complex by 27 ms in patient No. 2. The VTs were not abolished by 10 and 5 irrigated RF application, respectively. No RF energy was delivered at endocardial sites in patient No. 4.

In patient No. 3, with the slow VT (cycle length, 370 ms) on flecainide, tachycardia mapping showed a focal endocardial activation with a wide breakthrough in the inferolateral wall preceding the onset of the QRS complex by 12 ms and normal amplitude in the LV (Figure 4B). The tachycardia was not terminated by 12 irrigated RF applications (marked by brown tags).

**Epicardial Mapping and Ablation**

In patient No. 1, who had not consented to transthoracic epicardial mapping, mapping via the coronary sinus and its posterior branch during SR demonstrated a fragmented/late potential in the epicardial left inferolateral wall near the MA. However, no RF ablation in the coronary sinus or its branch was performed.

In the remaining 3 patients, a mean of 381±37 points (range, 341 to 415) was acquired to reconstruct the epicardium of both ventricles. No evidence of adhesions in the epicardial space was found in those 3 patients. An area with fragmented and late potentials of low amplitude during SR was consistently identified in the LV inferolateral wall near the MA, which was anatomically consistent with the LV aneurysm (Figures 5A and 5B). The area of abnormal potentials was 15.4 cm² with elliptical shape in patient No. 2 (Figure 5A), whereas its size was 41.6 and 18.6 cm² with trapezoidal shape in patients No. 3 and 4, respectively (Figure
5B). Pacing the site with late potentials resulted in progressive prolongation from the stimulus artifact to the following local potential, a similar QRS morphology on the surface ECG, and finally induction of the clinical and nonclinical VTs with a distinct diastolic potential in all 3 patients (Figure 6).

In patients No. 2 and 4, with hemodynamically unstable VT (2 clinical VTs and 1 nonclinical VT with inferior axis), the epicardial mapping identified a diastolic potential during all VTs at the same site as the late potential during SR (Figure 7A). Angiographically, no large coronary vessels were found near the ablation sites in those 2 patients (Figure 7B). A circular continuous lesion was delivered during SR around the area with fragmented and late potentials in patient No. 2. This resulted in 2-to-1 and subsequently 3-to-1 conduction into the area after 7 RF applications during SR and, finally, absence of the late potential within the circular lesion after 15 RF applications (Figure 7B). Two linear lesions in a cross configuration with 28 RF applications were delivered across the area with fragmented and late potentials in patient No. 4. No VT was inducible after epicardial RF ablation in those 2 patients.

In patient No. 3, maps were also performed during slow VT (cycle length, 370 ms). During epicardial mapping, a macroreentrant tachycardia was identified with a mapped cycle length of 342 ms and an isthmus between a scar area and a continuous line of double potentials (Figure 8A). Entrainment mapping additionally confirmed the tachycardia isthmus. No large coronary vessels were found in the targeted isthmus with a width of 27 mm before RF application. Twelve irrigated RF applications across the isthmus terminated the slow VT and resulted in noninducibility of any tachycardia.

Postablation Management and Follow-Up
No complications occurred in any patient. The procedure time was $481 \pm 181$ minutes ($245$ to $625$ minutes) with fluoroscopic time of $24.5 \pm 19.4$ minutes ($10.7$ to $53.2$ minutes). Implantable cardiac defibrillator implantation was performed right after the failed endocardial ablation in patient No. 1, who experienced multiple adequate shocks during 31 months of follow-up. No VT recurred in patients No. 2 and 4, who were not taking antiarrhythmic drugs during follow-up of 2 and 9 months, respectively. Clinical VT recurred without antiarrhythmic drugs 6 months after the ablation procedure in patient No. 3, in whom the VT was successfully remapped as the same reentry circuit and reablated in the same epicardial area by 7 irrigated RF applications. After ablation, spontaneous automaticity with a CL of 895 ms was observed at the ablation area in this patient (Figure 8B). No VT recurred 4 months after the second epicardial ablation procedure.
Discussion

The present study describes the EA mapping and irrigated RF ablation in the epicardial space of an exercise-induced reentrant VT with RBBB morphology attributable to arrhythmogenic LV aneurysms in patients with normal coronary arteriograms and nearly normal ventricular function.

Focal LV Aneurysm As a Cause of Malignant VT

Malignant monomorphic VTs are frequently associated with the evidence of LV aneurysms, usually as a consequence of a previous myocardial infarction with systolic bulging of the scarred myocardium. The arrhythmogenic substrate is often located in the subendocardial myocardium and is amenable to...
Reentrant VT Attributable to a Subepicardial Arrhythmogenic Substrate

Epicardial left VT was previously demonstrated by surgical and nonsurgical mapping in patients with ischemic cardiomyopathy and nonischemic heart disease. Sosa et al. reported successful epicardial catheter ablation of VT in patients with chronic Chagas’s disease, mainly involving subepicardial myocardium. However, the same group reported that in 14 patients with VT attributable to inferior wall infarction, 7 of 30 VTs had a portion of the reentry circuit identified by epicardial mapping and ablated from the epicardium.

In our study, endocardial mapping during SR was normal in all 4 patients. Epicardial mapping via the coronary sinus in 1 patient and via a nonsurgical transthoracic epicardial approach in 3 patients demonstrated an area with fragmented and late potentials of low amplitude, which electrically resembles the endocardial and epicardial findings in patients late after myocardial infarction. The relatively large area with fragmented and late potentials on the subepicardial inferolateral wall in the LV can also explain the presence of a q wave in leads II, III, and aVF in those patients.

In patient No. 3, with slow VT on flecainide, the endocardial mapping demonstrated a focal tachycardia with wide breakthrough and normal electrograms. The epicardial mapping showed a macroreentrant tachycardia with an isthmus between the scar and a continuous line of double potentials. Spontaneous automaticity was also observed after the repeated epicardial ablation in this patient. In the other 3 patients with hemodynamically unstable VT, endocardial mapping during SR was normal. Pacing the epicardial site with late potentials resulted in progressive prolongation from the stimulus artifact to the following local potential, a similar
QRS morphology on the surface ECG, and, finally, induction of the clinical VT with a distinct diastolic potential. During VT, a diastolic potential was only recorded on the epicardium and coincided with the late potential in the same area in the 2 patients with epicardial mapping. Entrainment mapping additionally confirmed that the diastolic potential was critical for the reentrant VT. Our study demonstrated that the abnormal subepicardial substrate could provide anatomical substrate for reentry but also have a property of automaticity, which may easily result in unidirectional block within the area with fragmented and late potentials and facilitate the induction of VT during exercise. These VTs may be amenable to catheter ablation in the epicardial space.

Irrigated RF Catheter Ablation
RF catheter ablation has been previously reported in the epicardial space or inside the coronary sinus in patients with subepicardial VT.7,8,19,20 In our patients with subepicardial left reentrant VT, the isthmus was identified during tachycardia or during SR by using EA epicardial mapping in 3 patients. Irrigated RF applications in the epicardial space were successfully performed. This may theoretically produce a similar lesion as an endocardial RF application with blood flow around the ablation catheter. Additionally, compared with conventional mapping, EA mapping can precisely delineate the course of the tachycardia isthmus and also mark the targeted isthmus in relation to the large coronary vessels before RF ablation. This may avoid RF injury of the coronary vessels in patients with subepicardial left reentrant VT.

Study Limitation
This small series has several limitations. First, the definition of low amplitude on epicardial mapping was not identified because of unequal distribution of fatty tissue on the epicardium. However, the area with fragmented and late potentials was demonstrated with low amplitude in our study compared with other areas on the epicardial LV. Second, long-term follow-up of patients with irrigated catheter ablation in the epicardial space is very important, because long-term effects are not known. Third, it is very difficult to evaluate the cause of the LV aneurysms with subepicardial arrhythmogenic substrate because of the lack of histological data.

Conclusion
In this study, all 4 patients presented with the following common findings: (1) exercise-induced syncope attributable to sustained fast VT with a RBBB morphology; (2) small q wave in the leads II, III, and aVF; (3) 1 or 2 small aneurysms consistently located in the inferior-lateral wall; and (4) peculiar subepicardial fragmented and late potentials of low amplitude during SR and subepicardial reentrant VT during tachycardia. These data strongly suggest that this presentation may constitute a distinct clinical syndrome. The VTs may be amenable to catheter ablation.
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