Right Atrial Approach for Ablation of Ventricular Arrhythmias Arising From the Left Posterior–Superior Process of the Left Ventricle

Pasquale Santangeli, MD, PhD; Mathew D. Hutchinson, MD; Gregory E. Supple, MD; David J. Callans, MD; Francis E. Marchlinski, MD; Fermin C. Garcia, MD

Background—The posterior–superior process of the left ventricle (PSP-LV) is the most inferior and posterior aspect of the basal LV that extends posteriorly to the plane of the tricuspid valve. The PSP-LV is anatomically adjacent to the inferior and medial aspect of the right atrium (RA). We report a series of patients with ventricular arrhythmias (VAs) arising from the PSP-LV and describe a mapping and ablation approach from the RA guided by intracardiac echocardiography.

Methods and Results—Mapping and ablation of the PSP-LV with an RA approach under intracardiac echocardiography guidance were performed in 5 patients with VAs (aged 44±14 years, 2 males) who had failed ablation attempts from multiple endocardial and epicardial (1 patient) sites. Mapping of the PSP-LV from the adjacent inferomedial RA was performed at sites anatomically opposite to the earliest endocardial site of activation under direct intracardiac echocardiography visualization. From the RA side of the PSP-LV, a small atrial signal and a larger ventricular signal were recorded in each case, with an activation time of 32±7 ms pre-QRS (versus 16±5 ms pre-QRS in the LV endocardium; P=0.068). We were able to capture the LV from these sites. Cryoablation was performed in 2 patients, and radiofrequency was used in the remaining 3 cases. In all patients, ablation from the RA eliminated the arrhythmia. All patients remained free of recurrent VAs after a mean follow-up of 12 (7–16) months. There were no immediate or long-term complications.

Conclusions—The PSP-LV can be a site of origin of VAs, which can be successfully eliminated from the adjacent RA under direct intracardiac echocardiographic visualization. (Circ Arrhythm Electrophysiol. 2016;9:e004048. DOI: 10.1161/CIRCEP.116.004048)

Key Words: catheter ablation ◼ echocardiography ◼ endocardium ◼ intracardiac echocardiography ◼ ventricular tachycardia arrhythmia

The posterior–superior process of the left ventricle (PSP-LV) is the portion of the basal LV wall in its most inferior and posterior aspect extending above—or basal—to the plane of the tricuspid valve.1–3 As such, the PSP-LV is anatomically adjacent to the inferomedial aspect of the right atrium (RA). To our knowledge, there has been no report of ventricular arrhythmias (VAs) originating from the PSP-LV. We describe 5 cases of VAs arising from the PSP-LV, which were mapped and successfully ablated from the adjacent inferomedial RA overlying the PSP-LV under intracardiac echocardiography (ICE) guidance.

Methods

Study Population

The study subjects were 5 patients (3 males and 2 females) aged 30 to 60 years with symptomatic recurrent VAs, in whom the successful ablation site was at the PSP-LV ablated from the RA. The clinical and electrophysiological characteristics of the patients are shown in Table. A trial of at least 1 antiarrhythmic drug had failed in all patients. In 2 patients, the index procedure represented the initial ablation attempt. The other 3 patients presented to ablation after ≥1 (range 1–2) prior ablation attempts. All patients had frequent premature ventricular contractions with a preablation burden range 10% to 30% and with evidence of decreased LV function in 3 cases (range of LV ejection fraction 30%–45%). A baseline contrast-enhanced magnetic resonance imaging was performed in 4/5 cases and showed a small area of late gadolinium enhancement only in 1 case (patient no 1). No patients had evidence of significant coronary artery disease at preprocedural stress test and cardiac catheterization. All patients gave written, informed consent before the procedure.

Electrophysiological Study and Catheter Ablation

Antiarrhythmic drugs were discontinued at least 5 half-lives before the procedure; no patient was taking amiodarone. Procedures were performed under conscious sedation. Catheters were positioned in the heart using fluoroscopic guidance. A 6-Fr quadrupolar catheter with 5-mm interelectrode distance (Bard Inc, Delran, NJ) was placed at the RV apex. A deflectable 8-Fr mapping/ablation catheter with a 3.5-mm irrigated tip and a 2-mm ring electrode separated by 1 mm (Thermocoool, Biosense Webster, Diamond Bar, CA) was advanced to the RA and RV (transvenous approach), LV (retrograde aortic approach), and coronary venous system for mapping. A 64-electrode phased-array ICE catheter (AcuNav, Acuson, Mountain View,
WHAT IS KNOWN

• The posterior–superior process of the left ventricle (PSP-LV) is the most inferior and posterior aspect of the basal left ventricle. The PSP-LV is anatomically adjacent to the inferior and medial aspect of the right atrium.

• Ventricular arrhythmias can arise from the PSP-LV, although the optimal approach to eliminate these arrhythmias with catheter ablation is unknown.

WHAT THE STUDY ADDS

• In this study, we describe 5 cases of ventricular arrhythmias arising from the PSP-LV, in which ablation within the adjacent right atrial tissue under direct intracardiac echocardiography visualization was safe and successful in eliminating the arrhythmia.

• The described approach should be considered as a potential strategy for the treatment of arrhythmias arising from the PSP-LV.

• Intraprocedural imaging with intracardiac echocardiography is crucial to detect the anatomic relationship between the PSP-LV and the right atrium and guide catheter positioning for mapping and ablation.

CA) was used to assist catheter manipulation and mapping, monitor radiofrequency energy delivery, tissue–catheter contact, and complications. In particular, ICE was crucial to define the anatomic relationship between the PSP-LV and the adjacent RA; the ICE view of the inferomedial RA adjacent to the PSP-LV was typically obtained by applying gentle clockwise torque and anterior deflection to the ICE probe from the standard home view from within the mid-RA and bringing into view the noncoronary cusp at its junction with the PSP-LV and the adjacent RA just anterior to the ostium of the coronary sinus (CS). Intravenous heparin was used to achieve an activated clotting time of ≥250 s during mapping in the LV and coronary cusp region. The site of origin of the VA was determined based on detailed activation and pace mapping. In particular, during activation mapping, the local activation time was consistently measured from the onset of the electrogram (earliest positive or negative deflection) of the distal bipole of the mapping catheter to the earliest onset of the QRS complex in any of the 12 ECG leads and to the steepest negative deflection in the unipolar signal displayed in the mapping system. Activation times were measured by 2 independent observers and displayed on a 3-dimensional electroanatomic map (CARTO, Biosense Webster, Diamond Bar, CA) as well as the EP recording system (Prucka, GE, Houston, TX). Pace-map match was visually judged by 2 observers, with each of the 12 ECG leads assessed for the QRS vector and major notching or deflections from baseline. An ideal match required identical QRS complexes between the paced beats and native VA in 12 of 12 ECG leads. Radiofrequency energy was delivered with a power of 20 to 40 W, targeting an impedance drop of 10 to 15 ohms with a maximum temperature of 45°C. During radiofrequency energy delivery, if a suppression/elimination of VAs occurred within the initial 30 s, the application was maintained and carefully titrated for 260 s. For patients treated with cryoablation, a 6-mm cryoablation catheter was used. Initial ablation was performed at −75°C and terminated if no suppression of VA, AV block, or PR prolongation was seen. Cryoablations were performed at each single site for 4 minutes. After ablation, atrial and ventricular burst pacing with and without intravenous isoproterenol (≤12 μg/min) was used to assess arrhythmia inducibility. Acute success was defined as elimination of the clinical arrhythmia during RF or cryoenergy application and the inability to induce the clinical VAs at the end of the procedure, with no recurrence during 24 hours of postprocedural hospital ECG monitoring. Antiarrhythmic drugs were not reintroduced if ablation was acutely successful. Post procedure, patients remained overnight in the hospital under continuous ECG monitoring. Beyond that, patients were followed in the outpatient clinic at our institution or by their referring physician. Information about symptoms, VA burden using 24-hour Holter, or auto-triggered transtelephonic ECG monitoring was assessed 2 to 6 months after discharge.

Statistical Analysis

Descriptive statistics are reported as mean±SD (or median and range for skewed distributions) for continuous variables and as absolute frequencies and percentages for categorical variables. Comparisons of activation times between the LV endocardial side and the RA side of the PSP-LV within each patient were performed with the Wilcoxon signed-rank test. Statistical tests were 2-sided, and a P value <0.05 was considered statistically significant. Data were analyzed by the STATA 12.1 statistical software (Stata Corporation, TX).

Results

ECG Characteristics

The ECG showed a right bundle branch block configuration with a left superior axis in 2 patients, a left bundle branch block (LBBB) configuration with a left inferior axis in 2 patients, and an LBBB morphology with a left superior axis in 1 patient (Table and Figure 1). A total of 3 patients had an early precardial transition (before lead V4), with the remaining 2 cases having no transition (positive concordance across the precordium). A monophasic R wave in lead I with an R wave amplitude in lead II greater than lead III were present in all patients. The maximum deflection index was 60%±4% (range 53%–65%). At available preprocedure ECG and Holter monitors, VAs were monomorphic and with fixed coupling intervals.

Mapping and Ablation

Detailed mapping was performed in the LV and RV in 4 patients (Table); in 1 patient, mapping was performed only in the proximal CS and RA. The coronary cusp region was mapped in 3 patients (2 with LBBB inferior axis and 1 with right bundle branch block superior axis VA; Table) and the coronary venous system (middle cardiac vein and CS ostium) in one. Before approaching the RA adjacent to the PSP-LV, the earliest activation site was recorded in the endocardial PSP-LV in all patients, with a mean activation time of 16±5 ms (range 10–20 ms) pre-QRS. Ablation at that site was attempted in 4 cases and resulted in transient VA suppression in 2 patients, while had no effect in the remaining 2 cases. Because of this temporal suppression, instead of applying longer lesions, we hypothesized targeting the directly opposite anatomic site in closest proximity. Under direct ICE visualization, the opposite site corresponded to the RA because this location cannot be accessed from the epicardium. The mapping–ablation catheter was positioned in the inferomedial RA adjacent to the PSP-LV and opposite to the site of earliest activation on the LV endocardium. At that site, a small atrial signal and a larger ventricular signal (typically 1:5 ratio) were recorded, and we could capture the LV with pacing in each case. From within the RA, the activation time was significantly earlier than the LV endocardium (mean 32±7 ms pre-QRS, range 25–40 ms; P=0.068 for comparison). Cryoablation
was performed in 2 cases, and radiofrequency energy was used in the remaining 3. In all 5 cases, delivery of ablation from within the RA (range 1–4 lesions) successfully abolished the arrhythmia (Figures 2 and 3).

Long-Term Outcomes
After a mean follow-up of 12±5 months (range 7–16 months), no patient had recurrent VAs. In 2/3 patients with LV dysfunction at baseline echocardiography, normalization of LV function at follow-up was observed at transthoracic echocardiography. In one case (patient no 3), recovery of LV function was not observed over follow-up, despite effective VA suppression, and the patient ultimately underwent implantation of an implantable cardioverter defibrillator. No acute or long-term complications were observed.

Discussion
In this study, we describe a novel approach to target VAs arising from the PSP-LV with ablation from the anatomically adjacent RA under direct ICE visualization. The technique was demonstrated feasible and safe, with complete VA elimination both acutely and after an average 1-year follow-up and no complications. To the best of our knowledge, this is also the first report of VAs arising from the PSP-LV targeted from the RA.

Anatomic Considerations
Relative to the plane of the mitral annulus, the tricuspid annular plane is inferiorly and apically displaced by ≈0.5 to 1 cm, as such the annuli are not positioned in parallel planes.1,3–5 Because of this, part of the basal inferoseptal aspect of the LV wall is directly apposed to RA tissue rather than RV tissue or epicardium.4 As described by McAlpine, the PSP-LV is the promontory of LV between the attachment of the septal leaflet of the tricuspid valve to the AV unit, the ostium of the LV, and a line drawn from the latter to the upper end of the posterior interventricular groove. Superiorly, at the apex of the triangle lies the right fibrous trigone and the posterior aspect of the atrio-ventricular membranous septum.1,3 The inferior wall of the RA lies above and lateral to the PSP-LV adjacent to the pyramidal space. The CS orifice is medial to this area.4 In addition, the atrioventricular node artery and the septal artery ascend onto the PSP-LV crossing within the fat of the pyramidal space. Therefore, a theoretical risk during ablation of the PSP-LV from the adjacent RA tissue is injury

Table. Clinical, Electrocardiographic, and Electrophysiological Details of the Study Group

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Sex</th>
<th>Baseline TTE</th>
<th>Baseline MRI</th>
<th>ECG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>M</td>
<td>LVEF=30%; Global hypokinesis</td>
<td>LVEF=40%; Global hypokinesis</td>
<td>LBBB/RBBB morphology</td>
</tr>
<tr>
<td>2</td>
<td>57</td>
<td>M</td>
<td>LVEF=45%; Global hypokinesis</td>
<td>LVEF=35%; Global hypokinesis</td>
<td>LBBB</td>
</tr>
<tr>
<td>3</td>
<td>44</td>
<td>F</td>
<td>LVEF=35%; Global hypokinesis</td>
<td>LVEF=34%; Global hypokinesis</td>
<td>LBBB</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>F</td>
<td>LVEF=55%; Normal</td>
<td>LVEF=57%; No LGE</td>
<td>RBBB</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>F</td>
<td>LVEF=65%; Mild LVH</td>
<td>LVEF=55%; No LGE</td>
<td>RBBB</td>
</tr>
</tbody>
</table>

CS indicates coronary sinus; LBBB, left bundle branch block morphology; LGE, late gadolinium enhancement; LVEF, left ventricular ejection fraction; LVH, left ventricular hypertrophy; MCV, middle cardiac vein; MRI, cardiac magnetic resonance imaging; RA, right atrium; RBBB, right bundle branch block morphology; and TTE, transthoracic echocardiography.
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The growth of the septum progresses from the apex toward the interventricular septum starts forming at ≈5 weeks when it can be identified between the trabecular portions of both ventricles.\(^8\)\(^9\) The growth of the septum progresses from the apex toward the

to the atrioventricular node or septal artery with resulting AV block. However, these complications were not observed in our series. From an embryological perspective, the human muscular

Figure 1. 12-lead ECG with the morphology of the ventricular arrhythmias arising from the posterior–superior process of the left ventricle (PSP-LV). Note the different axis in the frontal plane (inferiorly directed for patients no 1 and no 2, intermediate axis for patient no 3, and superiorly directed for patients no 4 and no 5) and different QRS configuration in lead V1 (from left bundle branch block morphology [LBBB] to right bundle branch block morphology [RBBB] configuration) may be explained to different attitudinal position of the heart (vertical vs horizontal with respect to the plane of the aortic valve) or different sites of origin (superior versus inferior) within the PSP-LV.

Figure 2. A, Electrogram demonstrating earliest endocardial activation in the posterior–superior process (PSP) of the left ventricle (LV) mapped in the LVOT below the LCC. B, Intracardiac echocardiography (ICE) catheter position. C, Electrogram in sinus rhythm demonstrating a small “a” and a larger “v” signal during sinus rhythm and earliest activation at the successful site of ablation. D, ICE showing the catheter position from the right atrial (RA) opposite to the earliest endocardial site. LV indicates left ventricle; and NCC, noncoronary cusp.
base and is simultaneous with the formation of the RV and LV that are initially in communication at the level of the base via the so-called foramen interventricolare (interventricular orifice). As the muscular septum grows, the foramen interventricolare shrinks and eventually disappears, with fusion of the muscular and membranous septa. During embryological development of the interventricular septum, there is evidence of neural crest migration of cells at the most basal aspect of the interventricular septum, which eventually becomes part of the PSP-LV. Of note, before septation, the RA has access to the RV only via the cavity of the LV. The formation of the tricuspid valve occurs in 2 phases, namely, the development of a communication between the RA and the RV and the development of the valve apparatus. In this process, the plane of the tricuspid valve is formed more apically to the plane of the mitral valve (see also above), which results in the proximity of the inferoseptal aspect of the RA to the most basal portion of the interventricular septum, which is the PSP-LV.

The anatomy of the PSP-LV and its relationships with adjacent structures are shown in Figure 4. The key steps of the embryological development of the interventricular septum (and PSP-LV) are represented in Figure 5.

Mapping and Ablation of the PSP-LV From the Adjacent RA
Periprocedural imaging with ICE was crucial to correctly position the mapping/ablation catheter in the RA aspect of the PSP-LV. To examine the PSP-LV with ICE, the catheter positioned in the standard home view within the RA should be rotated clockwise relative to the plane of the tricuspid valve. It is often necessary to flex the catheter slightly to better image the plane of the noncoronary cusp of the aortic valve and the membranous septum (Figure 2). Typically, if further rotation is applied, the superior aspect of the CS ostium is seen. At that point, counter clockwise rotation is
applied. The PSP-LV is visualized between the most posterior aspect of the noncoronary cusp and the CS ostium and medial to the tricuspid valve. At that site, we were able to record during sinus rhythm a small atrial electrogram and a larger ventricular electrogram. In each case, we were also able to capture the LV when pacing from that region, further indicating proximity to the PSP-LV tissue. In a prior case report, Kautzner et al also reported successful ablation via a CS approach of postinfarct ventricular tachycardia in a patient with prior inferior myocardial infarction; based on the fluoroscopic images showing the ablation catheter position, it is likely that the PSP-LV was targeted from the RA side similar to that described in the present study. Periprocedural imaging with ICE was crucial not only for identification of the RA tissue adjacent to the PSP-LV and to assist positioning of the mapping/ablation catheter, but also to assess in real-time tissue contact and stability during ablation. In the first 2 cases, cryoablation was performed mostly because of concerns for injury to the atrioventricular node. The subsequent 3 cases were treated with radiofrequency energy. It is important to emphasize that, in our series, the successful elimination of VAs from the adjacent RA aspect of the PSP-LV (and the unsuccessful attempts at ablation from the endocardial PSP-LV) likely indicate that the site of origin is closer to the RA aspect of the PSP-LV. This is also highlighted by the activation times recorded from the adjacent RA, which were consistently earlier than that recorded from within the LV endocardium. We also did not observe multiple VAs morphologies at preprocedure 12-lead ECGs or Holter monitors nor a change in premature ventricular contraction.

Figure 4. Anatomic description of the posterior–superior process (PSP) of the left ventricle (LV). A, A diagram of the heart showing the ventricular inflow after partial resection of the atria. The inferior wall of the right atria (RA) lies above and lateral to the PSP-LV medial to the insertion of the septal leaflet of the TV and insertion of the MV to the LV ostium. The coronary sinus (CS) orifice is medial to the infero-medial recess of the RA and not shown in this picture. B, After further removal of the RA, the PSP-LV is exposed. At the apex of the triangle is located the membranous septum and the right fibrous trigone below the insertion of the noncoronary sinus. C, An attitudinal cut of the heart through the LVOT axis and magnified in D. D, The PSP-LV below the noncoronary cusp. The most superior aspect is opposite to the insertion of the RA, and more lateral one can see the ostium of the CS. This anatomic relationship allows mapping of the PSP-LV from the RA. Reproduced from Dr K. Shivkumar with permission. Copyright UCLA Cardiac Arrhythmia Center, Wallace A. McAlpine Collection. LVOT indicates left ventricular outflow tract; MV, mitral valve; NCC, noncoronary cusp; and TV, tricuspid valve.
Ablation of LV Posterior–Superior Ventricular Tachycardia From the RA

In the presence of either of the phenomena described above, an intramural focus with different preferential exits may be suspected. Finally, given the close proximity between atrial and ventricular tissue in this region, not only PSP-LV VAs can be targeted from the RA but also other arrhythmia mechanisms are possibly ablated, including atrioventricular accessory pathways, atrioventricular nodal reentrant tachycardia, and focal atrial tachycardias.

Electrocardiographic Characteristics

In this study, we found heterogeneous ECG patterns for VAs arising from the PSP-LV (Table and Figure 1), with either an LBBB or a right bundle branch block configuration and both superior and inferior axis. This can be related to different sites of origin within the pyramidal structure of the PSP-LV (ie, either superior or inferior aspect of the PSP-LV) or to differences in the attitudinal orientation and rotation of the heart in the individual patients. However, some ECG characteristics were common and included an early precordial transition for VAs with an LBBB configuration and no precordial transition for VAs with a right bundle branch block morphology, a monophasic R wave in lead I, and an R wave amplitude in lead II greater than that in lead III. These features point toward a basal site of origin mid and inferior septal to the planes of the tricuspid and mitral valve. Finally, the VAs appeared to have a fixed coupling interval, which is most consistent with an origin from compact myocardium.

Conclusions

We describe 5 cases of VAs arising from the PSP-LV in which ablation within the adjacent RA tissue under direct ICE visualization in all cases was safe and successful in eliminating the arrhythmia. The described approach should be considered a potential strategy for the treatment of arrhythmias arising from the PSP-LV. If this approach is used, direct periprocedural imaging with ICE is crucial.

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Disclosures

None.
References

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