Efficacy of an Anatomical Approach in Radiofrequency Catheter Ablation of Idiopathic Ventricular Arrhythmias Originating From the Left Ventricular Outflow Tract

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Background—When anatomic obstacles preclude radiofrequency catheter ablation of idiopathic ventricular arrhythmias (VAs) originating from the left ventricular outflow tract (LVOT), an alternative approach from the anatomically opposite side (endocardial versus epicardial or above versus below the aortic valve) may be considered (anatomic ablation). The purpose of this study was to investigate the efficacy of an anatomic ablation in idiopathic LVOT VAs.

Methods and Results—We studied 229 consecutive patients with idiopathic LVOT VAs. Radiofrequency ablation from the first suitable site was successful in 190 patients, and in the remaining 39 patients, it was unsuccessful or had to be abandoned because of anatomic obstacles. In 22 of these 39 patients, an anatomic ablation was successful, and the VA origins were located in the intramural LVOT in 17 patients, basal left ventricular summit in 4, and LVOT septum near the His bundle in 1. The anatomic ablation was highly successful for idiopathic VAs originating from the intramural LVOT (>75%) and lateral LVOT, whereas it was unlikely to be successful for idiopathic VAs originating from the basal left ventricular summit (25%) and sepal LVOT.

Conclusions—When a standard catheter ablation targeting the best electrophysiological measure of idiopathic LVOT VAs was unsuccessful or had to be abandoned because of anatomic obstacles, an anatomic ablation was moderately successful. These idiopathic LVOT VAs with a successful anatomic ablation commonly arose from the intramural LVOT among the left coronary cusp, aortomitral continuity, and epicardium, occasionally the basal left ventricular summit, and rarely the LVOT septum near the His bundle. (Circ Arrhythm Electrophysiol. 2017;10:e004959. DOI: 10.1161/CIRCEP.116.004959.)

Key Words: catheter ablation • endocardial • epicardial • intramural • left ventricular outflow tract • ventricular arrhythmia

For the past decade, advances in electrophysiology and the technologies of catheter ablation, combined with a better understanding of the cardiac anatomy have allowed us to increasingly recognize major sites of origins of idiopathic ventricular arrhythmias (VAs) and to improve the outcome of catheter ablation of those VAs. Catheter ablation of idiopathic VAs is usually highly successful, but sometimes can be challenging because of the anatomic barriers such as the close proximity to the important structures, including the coronary arteries and atrioventricular conduction system, intramural VA foci, and epicardial fat pads. Previous studies suggested that these anatomic barriers most often preclude catheter ablation of idiopathic VAs originating from the left ventricular outflow tract (LVOT). When it is not safe to deliver radiofrequency energy directly to LVOT VA foci or these foci cannot be reached because of the anatomic barriers, an alternative approach from the anatomically opposite side (endocardial versus epicardial or above versus below the aortic valve) may be considered. In this approach, an ablation site is not determined by the electrophysiological measures such as the earliest ventricular activation or best pace map, but by the anatomic considerations, and this approach may be defined as “anatomic approach”. The purpose of this study was to investigate the efficacy of an anatomic approach in radiofrequency catheter ablation of idiopathic VAs originating from the LVOT.

Methods

Patient Characteristics

The study population consisted of 229 consecutive patients from a single center (131 men, mean age 54±15 years [range 13–92]) with symptomatic idiopathic sustained ventricular tachycardia (VT; n=48), nonsustained VT (n=54), or premature ventricular contractions (PVCs; n=127), whose origins were identified in the LVOT, including the aortic root, summit of the left ventricle (LV), endocardial site below the aortic valve, and intramural site. Echocardiography and exercise stress testing or coronary angiography demonstrated no evidence of structural heart disease in any patients. The baseline characteristics, including the age, sex, LV function, nature of the clinical arrhythmia, and 12-lead ECG, during the VAs were recorded. The Institutional Review Board approved the study protocol, and all patients provided written, informed consent for the procedure.

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**WHAT IS KNOWN**

- Radiofrequency catheter ablation of idiopathic ventricular arrhythmias (VAs) is usually highly successful, but sometimes can be challenging because of the anatomic barriers such as the close proximity to the important structures, including the coronary arteries and ativoventricular conduction system, intramural VA foci, and epicardial fat pads. These anatomic barriers most often preclude catheter ablation of idiopathic VAs originating from the left ventricular outflow tract (LVOT).
- When it is not safe to deliver radiofrequency energy directly to LVOT VA foci or these foci cannot be reached because of the anatomic barriers, an alternative approach from the anatomically opposite side (endocardial versus epicardial or above versus below the aortic valve) may be considered. In this approach, an ablation site is not determined by the electrophysiological measures such as the earliest ventricular activation or best pace map, but by the anatomic considerations, and this approach may be defined as anatomic approach.
- The efficacy of an anatomic approach in radiofrequency catheter ablation of idiopathic VAs originating from the LVOT remains unknown.

**WHAT THIS STUDY ADDS**

- When a standard catheter ablation targeting the best electrophysiological measure of idiopathic LVOT VAs was unsuccessful or had to be abandoned because of anatomic obstacles, an anatomic catheter ablation offered a moderate degree of success.
- The idiopathic LVOT VAs with successful anatomic catheter ablation were suggested to commonly arise from the intramural LVOT among the left coronary cusp, aortomitrual continuity, and epicardium, occasionally the basal left ventricular summit, and rarely the LVOT septum near the His bundle.
- An anatomic catheter ablation was highly successful for idiopathic VAs originating from the intramural LVOT and lateral LVOT whereas it was unlikely to be successful for idiopathic VAs originating from the basal left ventricular summit and sepal LVOT.

antiarrhythmic drugs were discontinued for at least 5 half-lives before the study.

Electrophysiological Study

For mapping and pacing, a quadripolar catheter was positioned via the right femoral vein at the His bundle (HB) region, and a 6- or 7-French deflectable decapolar catheter in the coronary sinus. The coronary sinus catheter was advanced into the great cardiac vein (GCV) as far as possible until the proximal electrode pair recorded an earlier ventricular activation than the most distal electrode pair during the VAs. Mapping and pacing were performed using a 7.5-French, 3.5-mm tip irrigated ablation catheter (Navistar ThermoCool, Biosense Webster, Diamond Bar, CA) introduced from the right femoral vein for sites in the GCV or right femoral artery for the endocardial LVOT. During the procedures in the endocardial LVOT, intravenous heparin was administered to maintain an activated clotting time of >300 s. When few PVCs were observed at the beginning of the electrophysiological study, induction of the VT or PVCs was attempted by burst pacing from the right ventricular outflow tract or apex with the addition of an isoproterenol infusion.

Mapping and Radiofrequency Catheter Ablation

Activation mapping was performed in all cases to identify the earliest site of ventricular activation during the VT or PVCs. In some patients, when the VT or PVCs were frequent, electroanatomic mapping was performed as previously reported. When mapping was also performed using the distal bipolar electrodes at a pacing cycle length of 500 ms and at the minimum stimulus amplitude required for consistent capture (up to a maximum output of 20 mA and pulse width of 2.0 ms). The score for the pace mapping was determined as the number of leads with an identical height of the R wave/depth of the S wave ratio match (12 represented a perfect R wave/depth of the S wave ratio match in all 12 leads), as well as the number of leads with a fine notching match in the 12-lead ECG as previously reported (perfect pace mapping was equal to 24 points). An excellent pace map was defined as a pace map which obtained a score of ≥20.

When the earliest ventricular activation preceded the QRS on- set by at least 20 ms or an excellent pace map was demonstrated in the endocardial LVOT and GCV, unipolar radiofrequency current was applied at this site (a suitable site for ablation). When there were no suitable sites for ablation in these regions, epicardial mapping via a subxiphoid approach was performed with an irrigated ablation catheter to seek an earlier ventricular activation or excellent pace map on the LV epicardial surface as previously reported. When a more suitable site for ablation was identified on the epicardial surface, irrigated unipolar radiofrequency current was applied at that site. If a radiofrequency ablation should be avoided at that site because of a risk of collateral damage or the first irrigated unipolar radiofrequency application from the endocardial LVOT or GCV was unsuccessful, a subsequent irrigated unipolar radiofrequency application was delivered at the anatomically opposite site (endocardial versus epicardial or above versus below the aortic valve) to the first ablation site (anatomic catheter ablation). When there were multiple opposite sides, an radiofrequency ablation was first delivered at the side that was located at the shortest distance from the first ablation site or recorded an earliest ventricular activation during the VAs or best pace map among those sides. If the sequential endocardial and epicardial ablation was unsuccessful in eliminating the VA despite an appropriate radiofrequency energy delivery, irrigated unipolar radiofrequency current was simultaneously applied to the distal electrodes of 2 catheters using 2 radiofrequency generators (Stockert, Biosense Webster) at the same sites that were used for the sequential configuration (simultaneous unipolar ablation).

Irrigated radiofrequency current was delivered in the power-control mode starting at 20 W in the GCV and 30 W at the endocardial LVOT and on the epicardial surface with an irrigation flow rate of 30 mL/min. The radiofrequency power was titrated up to 30 and 40 W, respectively. The goal of radiofrequency applications was to achieve a decrease in the impedance of 8–10Ω with care taken to limit the temperature to <45°C. Before mapping and catheter ablation within the aortic sinus cusps, selective angiography of the coronary artery and aorta was performed to delineate the coronary artery ostia in the aortic sinus cusps to precisely define the location of the ablation catheter and to avoid arterial injury. During the epicardial catheter ablation using transvenous and transpericardial approaches, simultaneous left coronary angiography was performed intermittently to ensure the location of the ablation catheter relative to the left coronary arteries and to minimize the risk of thermal injury to that vessel. Radiofrequency current was not applied within 5 mm of a coronary artery. When an acceleration or reduction in the frequency of the VT or PVCs was observed during the first 30 s of the application, the radiofrequency energy delivery was continued for 60–180 s. Otherwise, the radiofrequency delivery was terminated, and the catheter was repositioned. The end point of the catheter ablation was the elimination and noninducibility of VT or PVCs during an isoproterenol infusion (4 μg/min) and burst pacing from the right ventricle (to a cycle length as short as 300 ms). After the epicardial catheter ablation and catheter ablation...
within the aortic sinus cusps, a coronary angiography was repeated to ensure that there was no evidence of injury to the coronary arteries.

**Electrocardiographic Analysis**

The simultaneous 12-lead electrocardiograms during the VAs and pace mapping were recorded digitally at a sweep speed of 100–200 mm/s in all patients for off-line analysis. The QRS morphologies, including a bundle branch block pattern, axis, and configuration in lead V6, were examined. In lead V6, the main concern was the presence of an S wave, which was considered to be a characteristic electrocardiographic finding of VAs originating from the endocardial LVOT below the aortic valve because the S wave in lead V5 or V6 is consistent with a right bundle branch block pattern, usually present in VAs with an LV endocardial origin.

The QRS duration, maximal R-wave amplitude in the inferior leads, and maximum deflection time in the precordial leads were measured with electronic calipers by 2 experienced investigators blinded to the site of the origin. The QRS duration was measured as the interval between the earliest deflection of the ventricular complex in any of the 12 simultaneous leads to the latest offset in any lead and maximum deflection time from the QRS onset to the maximum (+) or (−) deflection in each precordial lead. If there were discrepancies between those results, they were adjudicated by a third investigator. The maximum deflection index (MDI) was calculated by dividing the shortest time to the maximum deflection in any precordial lead by the QRS duration. The ratio of the Q-wave amplitude in leads aVL to aVR (aVL/aVR) and that of the R-wave amplitude in leads III–II (III/II) were also calculated. A long preordial MDI, reflecting a delayed initial activation of the LV, is considered to discriminate between an epicardial and endocardial VA origin because of the slower spread of the activation from the VA origin on the epicardial surface relative to the endocardium and the delayed global ventricular activation resulting from the later engagement of the His-Purkinje network. An MDI of ≥0.55 was used as a predictor of an epicardial focal VA origin according to previous reports.

**Follow-Up**

Follow-up after the procedure included clinic visits with 12-lead electrocardiograms and 24-hour ambulatory (Holter) monitoring, and telephone calls to all patients and their referring physicians. All patients who reported symptoms were given a 24-hour Holter monitoring or event monitor to document the cause of the symptoms. Successful catheter ablation was defined as no recurrence of any VAs during >6 months of follow-up.

**Statistical Analysis**

Continuous variables are expressed as the group mean±1 SD or median with the first and third quartiles (Q1–Q3). Comparisons of the continuous variables between the 2 groups were analyzed with the Mann-Whitney U test. The categorical variables expressed as numbers and percentages in the different groups were compared with a χ2

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ABL indicates ablation; AMC, aortomitral continuity; ASC, aortic sinus cusp; Epi, epicardial surface; GCV, great cardiac vein; LCC, left coronary cusp; LVOT, left ventricular outflow tract below the aortic valve; NA, not available; RCC, right coronary cusp; and S, suppression.
test and Yates correction, if necessary. The $P$ values were 2-sided, and statistical significance was selected at a value of $P<0.05$.

**Results**

**Mapping and Ablation**

Among the total population of 229 patients with LVOT VAs, irrigated unipolar radiofrequency ablation from the first suitable site was successful in 190 patients. The successful ablation site was located within the aortic root in 123 patients (the left coronary cusp [LCC] in 44, right coronary cusp [RCC] in 42, junction between the LCC and RCC in 31, and noncoronary cusp in 6), aortomitral continuity (AMC) in 30, LV summit in 29 (the GCV in 23, and on the epicardial surface in 6), and LVOT septum adjacent to the membranous septum in 8.

An anatomic catheter ablation was performed in the remaining 39 patients for several reasons. The radiofrequency energy delivery was limited because of a high impedance due to the epicardial fat pads in 4 patients, and a temperature rise within the GCV in 1 patient. The radiofrequency energy delivery was abandoned because the presumed ablation site was located in close proximity to the left coronary artery in 7 patients (the left anterior descending coronary artery in 5 patients and ostium of the left main coronary artery in 2) and to the HB in 1 patient. In 1 patient, no suitable sites for the ablation could be found by comprehensive mapping. In the remaining 25 patients, the first radiofrequency application was appropriately delivered, resulting in suppression of the VAs in 4 patients and no interruption in 21 patients. An anatomic catheter ablation was successful in 22 patients (Table 1). In 17 of these 22 patients, the VA origins were suggested to be located in the intramural LVOT among the LCC, AMC, and epicardium because the local ventricular activation relative to the QRS onset (V-QRS) was earlier than −10 ms or an excellent pace map was recorded at multiple different sites. Among these 17 patients, the radiofrequency ablation was successful in the LCC in 3 patients (Figure 1), AMC in 11 (Figure 2), and GCV in 3 patients (Figure 3). In 2 of the 3 patients with a successful ablation in the LCC, 15 and 21 s of radiofrequency energy deliveries were required to terminate the VAs, respectively. In 3 of the 17 patients, suppression of the VAs was observed during the unsuccessful ablation. In 4 of the remaining 5 patients, the VA origins were suggested to be located in the basal LV summit that was superior to the GCV because the V-QRS was the earliest on the epicardial side and was never earlier than −10 ms at any other sites. Among these 4 patients, the radiofrequency ablation was successful in the AMC in 3 patients and in the LCC in 1 patient. In the remaining 1 patient,
the VA origin was suggested to be located at the LVOT septum near the HB (Figure 4A). In this case, a radiofrequency energy was delivered within the RCC to avoid any damage to the atrioventricular conduction system (Figure 4A). The VA was eliminated without any damage to the atrioventricular conduction system 112 s after the radiofrequency energy delivery was initiated (Figure 4B). In 4 of the 22 patients (3 with intramural LVOT VAs and one with an LV summit VA), the VAs were not eliminated during the catheter ablation, but the VAs completely disappeared within 24 hours after the procedure and have never recurred (late success).

An anatomic catheter ablation was unsuccessful in 17 patients. However, in 5 of these patients, simultaneous unipolar ablation between the GCV and the AMC was subsequently performed, resulting in an elimination of the VAs. These VA origins were suggested to be located in the intramural LVOT between the GCV and the AMC. In the remaining 12 patients, the VA origins were suggested to be located in the basal LV summit. In 5 of these 12 patients, the VA origins were likely to be located away from any approachable sites, resulting in the failure of the anatomic catheter ablation. In 5 of the 12 patients, the VAs were suppressed by an anatomic ablation in the AMC in 1 patient, LCC in 2 patients, and GCV in 1 patient.

Comparison of the Clinical, Electrocardiographic, and Electrophysiological Characteristics Between the LVOT VAs With a Successful and Unsuccessful Anatomic Catheter Ablation

The 1 case in which the anatomic catheter ablation was successful in the RCC, was excluded from this analysis because the only VA origin in this case was located on the LVOT septum. The 5 cases in which simultaneous unipolar ablation between the GCV and the AMC eliminated the VAs, were also excluded from this analysis because it would not be appropriate to include these patients in either the group with a successful or unsuccessful anatomic catheter ablation.

There were no significant differences in the clinical characteristics, including the age, sex, LV ejection fraction, incidence of tachycardia-induced cardiomyopathy, and nature of the clinical arrhythmia between the 2 groups (Table 2). The results of the electrocardiographic and electrophysiological measures are summarized in Table 3. In terms of the QRS morphology of the VAs, a right bundle branch block pattern with right inferior axis QRS morphology was most prevalent in the successful group, whereas a left bundle branch block pattern with right inferior axis QRS morphology was most prevalent in the unsuccessful group. A precordial transition of ≤lead V1 was most prevalent in the successful group, whereas
that between leads V2 and V3 was most prevalent in the unsuccessful group. The MDI was significantly greater in the unsuccessful group than in the successful group ($P<0.0001$). There were no significant differences in the other electrocardiographic and electrophysiological measures, including the maximum R-wave amplitude in the inferior leads, III/II ratio, aVL/aVR ratio, presence of S waves in lead V6, and V-QRS at the site with the earliest ventricular activation between the 2 groups.

Comparing the LVOT VAs requiring an anatomic catheter ablation, an MDI of $<0.55$ and a precordial transition of $\leq$ lead V1, predicted a successful ablation with a sensitivity of 100% and 71%, specificity of 83% and 75%, positive predictive value of 91% and 84%, and negative predictive value of 91% and 64%, respectively.

**Discussion**

**Major Findings**

The anatomy of the LVOT is complex, and LVOT VA origins are distributed among various anatomic sites, such as the aortic root, LV summit, endocardial site below the aortic valve, and intramural site. In the LVOT, there are also several anatomic obstacles for catheter ablation, such as the coronary arteries, atrioventricular conduction system, and epicardial fat pads. Therefore, it is often challenging to identify a site for successful ablation of idiopathic LVOT VAs.

In this study, in 17% of the idiopathic LVOT VAs, a standard catheter ablation targeting the site with the earliest ventricular activation and excellent pace map was unsuccessful or had to be abandoned because of anatomic obstacles, and an anatomic catheter ablation was attempted. The anatomic catheter ablation was successful in $\approx 60\%$ of those LVOT VAs. In $\approx 20\%$ of the patients with a successful anatomic catheter ablation, a late success was observed. In 77%, 18%, and 5% of those patients with a successful anatomic catheter ablation, the VA origins were suggested to be located in the intramural LVOT among the LCC, AMC, and epicardium, basal LV summit, and LVOT septum near the HB. The anatomic catheter ablation was highly successful in the intramural LVOT VAs ($>75\%$), whereas it was unlikely to be successful in the basal LV summit VAs ($25\%$). The anatomic catheter ablation was likely to be successful when the site of idiopathic VA origins were electrocardiographically suggested to be in the endocardial and lateral LVOT, whereas it was unlikely to be successful when the site of the idiopathic VA origins were electrocardiographically suggested to be in the epicardial and septal LVOT.

![Figure 3. Cardiac tracings exhibiting the local ventricular activation in the great cardiac vein (GCV) and aortomitral continuity (AMC) during the premature ventricular contractions (PVCs; left), and fluoroscopic images exhibiting the catheter positions (right). The first radiofrequency ablation of the PVC was unsuccessful in the AMC where the earliest ventricular activation during the PVCs was recorded, and a subsequent ablation was successful within the GCV where the local ventricular activation during the PVCs was later than in the AMC. ABL indicates the ablation catheter; RAO, right anterior oblique view; RCC, right coronary cusp; and X d, p, the distal and proximal electrode pairs of the relevant catheter.](http://circep.ahajournals.org/)

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Figure 4. A. Cardiac tracings exhibiting the local ventricular activation recorded underneath and within the right coronary cusp (RCC) during the premature ventricular contractions (PVCs; left), and activation map exhibiting the successful ablation site (right). Note that the His bundle electrograms (arrowheads) were recorded during sinus rhythm at the site with the earliest ventricular activation during the PVCs underneath the RCC. A radiofrequency ablation of the PVC was successful within the RCC (the red tag in the right panel) where the local ventricular activation during the PVCs was later than underneath the RCC. B, Cardiac tracings exhibiting the successful ablation of the PVCs. The asterisks indicate the same recording time point in the 2 panels showing a continuous cardiac tracing. ABL indicates ablation; CAU, caudal; LAT, local activation time; X d, p, the distal and proximal electrode pairs of the relevant catheter; RAO right anterior oblique; and RF, radiofrequency.
Anatomic Consideration

For idiopathic LVOT VAs, anatomic catheter ablation was often required to treat idiopathic VAs originating from intramural sites and the basal LV summit. An anatomic catheter ablation was more successful in intramural LVOT VAs than basal LV summit VAs. These results were reasonable because a successful anatomic catheter ablation should be determined by the distance between the VA origin and remote radiofrequency ablation site. The distance from the endocardial or epicardial surface to the intramural VA origin should be shorter than that from the endocardial surface to the epicardial VA origin. For an anatomic catheter ablation to eliminate an epicardial VA origin, a radiofrequency lesion from an endocardial side needs to be deep enough to be transmural.

The electrocardiographic measures suggested that the anatomic catheter ablation was more successful in idiopathic VAs originating from the lateral LVOT. These results could be well explained by the anatomic background. The LV muscle tapers toward the LV base attaching to the aorta and mitral annulus (Figure 5). The lateral side of the LV summit faces the aorta and mitral annulus. Therefore, there would be a better chance for a radiofrequency lesion from the endocardial side to extend transmurally to reach idiopathic epicardial VA origins in the lateral LV summit than in the septal LV summit. Also, the closer to the LCC idiopathic epicardial VA origins are located, the better chance for a radiofrequency lesion from the LCC to transversely reach the idiopathic epicardial VA origins there would be.

In one case in this study, a radiofrequency energy delivery within the RCC successfully eliminated idiopathic VA originating from the LVOT septum underneath the RCC without any damage to the atrioventricular conduction system. Anatomically, the posterior part of the RCC is adjacent to the central fibrous body, which carries within it the penetrating portion of the HB. Anteriorly, the RCC is related to the bifurcating atrioventricular bundle and the origin of the left bundle branch. The noncoronary cusp lies superior to the central fibrous body. The HB penetrates through the central fibrous body and continues as the atrioventricular conduction bundle that then passes to the crest of the muscular ventricular septum, immediately beneath the membranous septum.

Therefore, a radiofrequency energy application should not be delivered underneath the RCC or noncoronary cusp. A previous study reported the presence of idiopathic VA origins in the LV septum below the HB. However, in the case of this study, the idiopathic VA origin was likely to be located between the RCC and His-Purkinje system. Because we have experienced only one case, the safety and efficacy remain uncertain. However, this case suggested that an anatomic catheter ablation might be an option in the treatment of idiopathic VAs originating from the vicinity of the HB.

Conclusions

When a standard catheter ablation targeting the best electrophysiological measure of idiopathic LVOT VAs was unsuccessful or had to be abandoned because of anatomic obstacles, an anatomic catheter ablation offered a moderate degree of
success. The idiopathic LVOT VAs with successful anatomic catheter ablation were suggested to commonly arise from the intramural LVOT among the LCC, AMC, and epicardium, occasionally the basal LV summit, and rarely the LVOT septum near the HB. An anatomic catheter ablation was highly successful for idiopathic VAs originating from the intramural LVOT and lateral LVOT, whereas it was unlikely to be successful for idiopathic VAs originating from the basal LV summit and sepal LVOT.

Disclosures

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