Electrophysiological Characteristics of Focal Atrial Tachycardia Surrounding the Aortic Coronary Cusps

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Background—Catheter ablation of atrial tachycardia (AT) arising near the coronary cusps has been reported in limited numbers of patients.1–7 The location of successful ablation targets includes the noncoronary cusp (NCC) in most case series1–5 and the left coronary cusp (LCC) in a few case reports.6,7 To date, ATs surrounding the aortic coronary cusps have been reported in limited numbers of patients.1–7 We investigated the electrophysiological characteristics of these ATs in 22 consecutive patients.

Methods and Results—This study included 22 patients (mean age±SD, 53±11 years; 86% female) with ATs arising near the aortic coronary cusps who underwent successful ablation. Activation mapping was performed during tachycardia to identify the earliest activation site. All patients achieved successful ablation through either a retrograde aortic (n=19) or a transseptal (n=3) approach. The successful ablation sites were located in the noncoronary cusp (NCC) (n=16), including 3 near the junction between the NCC and right coronary cusp. The remaining 6 cases were ablated from the left coronary cusp (LCC) (n=3) or the left atrium posterior to the LCC (n=3). For most tachycardias, there were distinctive P-wave morphological features recorded for each cusp location. Furthermore, analysis of the electrogram morphological features recorded during tachycardia at successful ablation sites revealed an atrial/ventricular (A/V) ratio >1 in 14 of 16 NCC ATs; the remaining 2, from the NCC near the junction with the right coronary cusp, showed an A/V ratio ≤1. At ablation sites in the LCC, the A/V ratio was <1 (4 of 6 patients) or 1 (remaining 2 patients). During a follow-up duration of 30±13 months, all patients were free of arrhythmias without antiarrhythmic drugs.

Conclusions—ATs surrounding the aortic coronary cusps can be safely and effectively ablated, with good long-term outcomes. In addition to the P-wave morphological features, the A/V ratio of the local electrogram recording during tachycardia facilitated the localization of successful sites. (Circ Arrhythm Electrophysiol. 2011;4:902-908.)

Key Words: atrial tachycardia ■ aortic coronary cusp ■ aortomitral junction ■ mapping ■ anatomy

Atrial tachycardias (ATs) surrounding the region of the aortic coronary cusps have been reported in limited numbers of patients.1–7 The location of successful ablation targets includes the noncoronary cusp (NCC) in most case series1–5 and the left coronary cusp (LCC) in a few case reports.6,7 To date, larger studies that investigate the electrophysiological characteristics and the safety and efficacy of catheter ablation of these ATs are still lacking. Therefore, we investigated the electrocardiographic and electrophysiological characteristics of focal ATs surrounding the aortic coronary cusps in 22 consecutive patients.

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Methods

Study Population
We studied 22 consecutive patients (aged 53±11 years, 19 female) of 145 patients presenting with focal AT who underwent radiofrequency (RF) ablation for AT in the sinus of Valsalva at our centers between July 2006 and March 2010. The 22 patients had a history of palpitations for 3.8±5.1 years, and antiarrhythmic drugs failed in at least 1 patient. One patient had valvular heart disease, and another presented with decreased left ventricular systolic function, consistent with a possible tachycardia-mediated cardiomyopathy; the remainder of the patients had no structural heart disease and had preserved left ventricular ejection fraction (62±14%) with a normal left atrial diameter (31±3 mm).

Electrophysiological Study
All antiarrhythmic drug therapy was discontinued for 5 half-lives before the study. Written informed consent was obtained from all patients before the procedure. Under fluoroscopic visualization, 2 or 3 quadripolar catheters were advanced to the high right atrium (RA), His bundle, and/or right ventricular apex. A decapolar catheter was placed in the coronary sinus. The most proximal bipole of this catheter was positioned at the coronary sinus ostium. Intracardiac electrograms were simultaneously displayed with electrocardiographic leads I, aVF, and V1 on a multichannel recording system at a paper speed of 100 to 150 mm/s (EP MED Systems; West Berlin, NJ). The bipolar signals were filtered at 30 to 500 Hz.

The electrophysiological study protocol included the following: (1) programmed stimulation and burst pacing from the high atrial atrium or coronary sinus for induction of clinical tachycardia if there...
was no spontaneous AT at baseline and (2) induction and determination of the mechanism of tachycardia using an isoproterenol intravenous infusion, if necessary. Focal atrial tachycardia was defined as centrifugal spread of activation from a single area.

Mapping and Catheter Ablation
Once the diagnosis of focal AT was established, 3D electroanatomical mapping was performed using the Navx Ensite (St Jude Medical; St Paul, Minn) or CARTO systems (Biosense Webster; Diamond Bar, Ca). The region with the earliest activation time in the right atrium was initially mapped during tachycardia. If either the tachycardia did not terminate during right atrial RF ablation or the earliest activation site in the right atrium was located near the His bundle area, further detailed mapping in the aortic cusps, via a retrograde aortic approach, and/or left atrial mapping, via a transseptal approach, was performed. Aortic angiography was performed before catheter ablation to establish the location of the coronary arteries and to delineate the anatomical features of the coronary cusps. After aortic angiography, RF application at the earliest activation site was initiated at 20 W and titrated up to 35 W for a maximum temperature of 55°C using a 4-mm nonirrigated ablation catheter. The success of the ablation procedure was defined as termination of ATs during RF energy and no further inducible AT with multiple attempts of rapid atrial burst pacing, both with and without isoproterenol.

Statistical Analysis
Continuous variables are presented as mean±SD. The earliest activation time preceding P-wave onset in the 2 groups was compared using the Student t test. Atrial/ventricular (A/V) ratios in the 2 groups were compared using Wilcoxon rank sum tests. P<0.05 was considered significant.

Figure 1. Location of successful ablation sites surrounding the aortic coronary cusps through either a retrograde aortic approach (n=19) or a transseptal approach (n=3). L indicates left coronary cusp; MV, mitral valve; N, noncoronary cusp; R, right coronary cusp; TV, tricuspid valve.

Figure 2. Top, Fluoroscopic images from a case of atrial tachycardia located in the noncoronary cusp (NCC). A and B, Catheter location at the successful ablation site in the right anterior oblique (RAO) and left anterior oblique (LAO) views. C and D, Aortic root angiograms taken from a pigtail catheter at the NCC at the same fluoroscopic angles before ablation. The successful ablation site is located at the NCC. Bottom, Intracardiac electrograms of the successful ablation target at the NCC. An atrial/ventricular (A/V) ratio >1 was observed in the local distal ablation electrogram. Abl indicates ablation catheter; CS, coronary sinus; RV, right ventricle; RVA, RV apex. Other abbreviations as in the legend to Figure 1.
Results

Mapping and Ablation

In 3 patients, AT was present on arrival to the electrophysiology laboratory, whereas the remaining cases were inducible and terminated by atrial burst pacing. The mean tachycardia cycle length of sustained AT was 340.7 ± 60.2 ms (range, 210–490 ms). During RA activation mapping, the earliest atrial activation times were recorded near the superior septum, adjacent to the His bundle. The earliest activation site in the RA preceded the His bundle atrial potential by 6.9 ± 4.6 ms.

All patients underwent successful ablation through either a retrograde aortic approach (n = 19) or a transseptal approach (n = 3) (Figure 1). Successful ablation sites were located in the NCC in 16 patients (Figure 2), including 3 near the junction between the NCC and right coronary cusp (RCC) (Figure 3). Among the 16 patients inside the NCC, initial RF ablation from the right atrium was unsuccessful in 5; in the remaining 11 patients, ablation was not attempted from the right atrium because of the close proximity to the His bundle. The remaining 6 patients were ablated from the LCC (n = 3) (Figure 4) or the left atrium posterior to the LCC at the aortomitral junction (n = 3) (Figure 5). In these 6 six patients, initial ablation attempts from the right atrium were unsuccessful. In the 3 patients with successful ablation at the aortomitral junction, the initial attempt by transseptal approach without aortic mapping was performed in 2, in whom the decision to target the left atrium was based on previous experience of the P-wave pattern on ECG, suggestive of an LCC site. In the remaining patient, ablation by a retrograde aortic approach could not terminate the AT, and ablation at the aortomitral junction by the transseptal approach finally eliminated the AT.

The earliest activation time during the 16 ATs originating from the NCC preceded the onset of the P wave by 21.3 ± 8.8 ms (range, 10–37 ms), whereas the earliest activation time during the remaining 6 ATs near the LCC preceded the onset of the P wave by 47.5 ± 14.9 ms (range, 18–60 ms). There was a significant difference between the NCC and LCC groups regarding the earliest activation time preceding P-wave onset (21.3 ± 8.8 versus 47.5 ± 14.9 ms; P < 0.01). The A/V electrogram ratios during tachycardia at all successful ablation sites were also analyzed. There was a significant difference between the 2 groups in A/V ratios (Wilcoxon W = 26, P < 0.01). At sites within the NCC, an A/V ratio > 1 was observed in 14 of 16 ATs (Figure 2); the remaining 2 with an A/V ratio ≤ 1 originated from the NCC near the junction between the NCC and RCC. At ablation sites near the LCC, an A/V ratio < 1 was recorded in 4 of 6 patients (Figures 4 and 5), with 2 remaining patients displaying an A/V ratio of 1.

For catheter ablation during AT, the first RF application targeting the earliest site in the aortic cusps or left atrium

Figure 3. Top, Fluoroscopic images from a case of atrial tachycardia near the junction between the noncoronary cusp (NCC) and right coronary cusp (RCC). A and B, Catheter location at the successful ablation site in right anterior oblique (RAO) and left anterior oblique (LAO) views. C and D, Aortic root angiograms taken from a pigtail catheter at the NCC at the same fluoroscopic angles before ablation. The successful ablation site is located near the junction between the NCC and RCC.

Bottom, The intracardiac electrograms at the successful ablation target near the junction between the NCC and RCC. An atrial/ventricular (A/V) ratio < 1 was observed in the local distal ablation electrogram. The first radiofrequency (RF) application targeting the earliest site near the junction between the NCC and RCC successfully terminated the tachycardia within 2 s. Abl indicates ablation catheter; AT, atrial tachycardia; CS, coronary sinus; HBE, His bundle. Other abbreviations are as given in the legends of Figures 1 and 2.
successfully terminated the tachycardia in 19 patients, with 2 RF applications each in the 3 remaining patients. The time to termination at the successful site was 3.8±2.6 s (range, 1–9.4 s). No junctional ectopy was observed during the ablation of the tachycardias. No complications were noted during and after catheter ablation in the aortic cusps or left atrium. During a mean follow-up of 30±13 months after catheter ablation, all patients remained free from any atrial arrhythmias without antiarrhythmic drugs. Of the 19 patients ablated from the aortic cusp region, 15 underwent echocardiography within the follow-up period, demonstrating no evidence of aortic valve abnormalities.

**ECG Characteristics**

In the 16 patients with NCC AT, the P wave during tachycardia was positive in leads I and aVL in 13 patients and isoelectric in 3 patients. In leads II, III, and aVF, the P wave was minimally positive in 13 patients and isoelectric in 3 patients. In lead V1, a negative/positive pattern was seen in 15 patients, and only 1 patient had a positive/negative pattern.

In the 6 patients with LCC or aortomitral junction AT, the P wave in leads I and aVL was negative/positive in 4 and isoelectric in 2. In all 6 patients, the P wave was positive in leads II, III, and aVF; lead V1 manifested a negative/positive pattern with a prominent positive component (Figure 6).

**Discussion**

**Major Findings**

In a large case series of ATs surrounding the aortic coronary cusps, we observed the following: (1) these ATs can be safely and effectively ablated within the aortic cusps, with good long-term outcomes; (2) the P-wave morphological features in the inferior and lateral leads can differentiate NCC from LCC ATs; and (3) the A/V ratio of the local electrogram during AT can facilitate location of the successful ablation site.

**Electrocardiographic Characteristics**

The characteristic P-wave morphological features of AT originating near the NCC were reported by Ouyang et al1 as a negative/positive P wave in leads V1 and V2 and as a positive P wave in leads I and aVL in a case series of 9 patients with NCC AT. More recently, Liu et al5 reported an isoelectric P wave in lead I and a slightly positive P wave in lead aVL in 10 of 13 cases of NCC AT, with a negative/positive P wave in lead V1 in 11 of 13 patients. Similarly, in our case series, the most important characteristic of P-wave morphological features during tachycardia was a negative/positive pattern in lead V1 in all NCC cases. Interestingly, this particular pattern was also observed in the 3 patients with LCC AT and in the 3 who were successfully ablated at the aortomitral junction. However, previous studies regarding AT arising near the aortomitral junction have yielded inconsistent
results. Gonzalez and colleagues \(^8\) reported positive P waves in lead I, a negative P wave in lead aVL, and positive P waves in lead V1 in 10 consecutive patients successfully ablated at the aortomitral junction using a transseptal approach. Another study \(^9\) described isoelectric or negative P waves in leads I and aVL and a negative/positive pattern in lead V1, which is consistent with our findings. Taking all these findings together, we propose that P-wave morphological features in leads I and aVL are likely to be the more useful ECG finding to distinguish NCC from LCC ATs. In our series, a positive P wave in leads I and aVL was more likely to be NCC AT, with a negative/positive or isoelectric P wave supportive of LCC AT, which can be reasonably explained by the more leftward position of the LCC compared with the NCC.

Mapping and Ablation of ATs

Recent small series and case reports have observed that atrial tachycardia originating near the NCC was successfully ablated with minimal risk. \(^1\)–\(^5\) However, ATs arising near the LCC are relatively rare. \(^6\)–\(^7\) In this large case series of ATs surrounding the aortic cusps, we showed that most of the cases were NCC ATs (16 of 22), and the remaining cases were from the LCC or aortomitral junction (6 of 22). All ATs were first mapped from the right atrium, with the earliest activation occurring adjacent to the His bundle region. ATs arising from the region around the coronary cusps will activate the right atrium through the interatrial septum near the His bundle area. All subjects in our series had a negative/positive P wave in lead V1, with a more prominent positive component that is suggestive of a left atrial origin of AT. These findings should help guide the decision to pursue further left-sided mapping via a retrograde aortic or transseptal approach. The retrograde aortic approach may achieve successful ablation of ATs arising near the NCC and LCC; however, aortic angiography should be mandatory to assess coronary artery origin and catheter location. If ATs arise from a region slightly superior to the LCC, ablation from within the aorta may not be possible because of close proximity with the left main coronary artery. In this case, ablation must be performed via a transseptal approach.

If an initial transseptal approach is taken, ablation of ATs arising near the NCC region may be problematic because of the thickness of the interatrial septum in this area (Figure 1). Based on our findings, if the P-wave morphological features are positive in lead I or aVL, this is suggestive of an NCC...
origin and, therefore, a retrograde aortic approach would be a reasonable initial strategy.

The differentiation of LCC from NCC ATs was mainly based on fluoroscopic images, 3D anatomical mapping, and local electrograms recorded from the aortic cusps. The NCC is located at the most inferior and posterior aspect of the aorta in the right anterior oblique view, which is close to the interatrial septum and His bundle region. The LCC is easily recognized as the most leftward aspect of the aortic root in the left anterior oblique view. The A/V ratio from the local electrogram also helps to localize the aortic cusps for successful targets. An A/V ratio > 1 should be recorded at the level of the NCC adjacent to the interatrial septum because of the thicker atrial myocardium behind the aortic wall (Figure 1). However, when AT foci were located at the NCC near the junction between the NCC and RCC, or from the LCC, an A/V ratio ≤ 1 was observed because of the relatively thicker ventricular myocardium beneath the RCC and LCC.

**Limitations**

In this study, most cases were successfully ablated from the NCC without an initial attempt at left atrial mapping. It remains unknown how many of these cases may be successfully ablated through a transseptal approach.

**Conclusion**

ATs surrounding the aortic coronary cusps can be safely and effectively ablated, with good long-term outcomes. The P-wave morphological features from the ECG during tachycardia and the A/V ratio from the local electrogram recording may help to localize sites of successful ablation.

**Disclosures**

None.

**References**


Focal atrial tachycardias (ATs), adjacent to the region of the aortic coronary cusps, were previously reported. However, detailed information related to electrophysiological characteristics and the safety and efficacy of catheter ablation of these ATs is limited. We investigated the electrophysiological characteristics of these ATs in 22 consecutive patients. The successful ablation sites in our study population included the noncoronary cusp (NCC) (n=16), the left coronary cusp (LCC) (n=3), and the left atrium posterior to the LCC (n=3). In our series, a negative/positive pattern in lead V1 was suggestive of ATs surrounding the noncoronary cusp. P-wave morphological features in leads I and aVL are likely to distinguish NCC from LCC ATs. Also, local electrograms at successful sites demonstrated an A/V ratio >1 in 14 of the 16 ATs near the NCC and an A/V ratio <1 in 4 of the 6 ATs surrounding the LCC. Our findings suggest that ATs surrounding the aortic coronary cusps can be safely and successfully ablated, with favorable long-term results. P-wave morphological features, along with the A/V ratio of the local electrogram during tachycardia, helped to localize the successful ablation site.
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