Electrophysiological Characteristics of Focal Atrial Tachycardia

Surrounding the Aortic Coronary Cusps

Running title: Wang et al.; Focal Atrial Tachycardia Near the Aortic Cusps

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Abstract:

**Background** - Catheter ablation of atrial tachycardia (AT) arising near the coronary cusps has been reported in limited numbers of patients. We investigated the electrophysiological characteristics of these ATs in 22 consecutive patients.

**Methods and Results** - This study included 22 patients (mean age 53±11 yrs, female 86%) 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 either through a retrograde aortic (n=19) or transseptal approach (n=3). The successful ablation sites were located in the non-coronary cusp (NCC) (n=16) including 3 near the junction between the NCC and right coronary cusp (RCC). The remaining six cases were ablated from the left coronary cusp (LCC) (n=3) or from the left atrium posterior to the LCC (n=3). For the majority of tachycardias, there were distinctive P-wave morphologies recorded for each cusp location. Furthermore, analysis of the electrogram morphology recorded during tachycardia at successful ablation sites revealed an A/V (atrial/ventricular) ratio > 1 in 14 of 16 NCC ATs; the remaining two, from the NCC near the junction with RCC showed A/V ratio ≤1. At ablation sites in the LCC, 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 ablated safely and effectively with good long-term outcomes. In addition to the P wave morphology, the A/V ratio of the local electrogram recording during tachycardia facilitated the localization of successful sites.

**Key words:** Atrial tachycardia; aortic coronary cusp; aorto-mitral junction; mapping; anatomy
Introduction

Atrial tachycardias (AT) surrounding the region of the aortic coronary cusps have been reported in limited numbers of patients [1-7]. The location of successful ablation targets include the non-coronary cusp (NCC) in most case series [1-5] and left coronary cusp (LCC) in a few case reports [6,7]. To date, larger studies which investigate the electrophysiological characteristics as well as the safety and efficacy of catheter ablation of these ATs are still lacking. Therefore, we aimed to investigate the electrocardiographic and electrophysiological characteristics of focal ATs surrounding the aortic coronary cusps in twenty-two consecutive patients.

Methods

Study Population

We studied twenty-two consecutive patients (age 53±11 years, 19 female) out of 145 patients presenting with focal AT who underwent 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 at least one failed anti-arrhythmic drugs. One patient had valvular heart disease, another presented with decreased left ventricular systolic function consistent with a possible tachycardia-mediated cardiomyopathy; the remainder had no structural heart disease and preserved left ventricular ejection fraction (LVEF: 62±14%) with normal left atrial diameter (LAD: 31±3mm).

Electrophysiology Study

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

The electrophysiological study protocol included 1) programmed stimulation and burst pacing from the HRA or CS for induction of clinical tachycardia if there was no spontaneous AT at baseline 2) induction and determination of the mechanism of tachycardia using 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, three-dimensional (3D) electro-anatomic mapping was performed utilizing the Navx Ensite (St. Jude Medical, St. Paul, MN, USA) or CARTO systems (Biosense Webster, Diamond Bar, USA). The region with earliest activation time in the right atrium was initially mapped during tachycardia. If either the tachycardia did not terminate during right atrial radiofrequency ablation, or if 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 anatomy of the coronary cusps.

Following aortic angiography, radiofrequency (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 4mm non-irrigated 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 two groups were compared using Student’s t test. A/V ratios in the two groups were compared using Wilcoxon rank sum tests. P values <0.05 were considered significant.

Results

Mapping and Ablation

In three patients, AT was present on arrival to the electrophysiology laboratory, while the remainders were inducible and terminated by atrial burst pacing. The mean tachycardia cycle length (TCL) of sustained AT was 340.7±60.2ms (210 to 490ms). During RA activation mapping, 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±4.6ms.

All patients underwent successful ablation either through a retrograde aortic approach (n=19) or transseptal approach (n=3) (Figure 1). Successful ablation sites were located in the noncoronary cusp (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 cases, and in the remaining 11 cases was not attempted from the right atrium due to close proximity with the His bundle. The remaining six cases were ablated from the left coronary cusp (LCC) (n=3) (Figure 4) or from the left atrium posterior to the LCC at the aorto–mitral junction (Figure 5) (n=3). In these 6 six cases, initial ablation attempts from the right atrium were unsuccessful. In the 3 cases with successful ablation at the aorto-mitral junction, the initial attempt by transseptal approach without aortic mapping was performed in 2 cases 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 aorto-mitral junction by 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 $21.3 \pm 8.8$ms (10 to 37ms), while the earliest activation time during the remaining six ATs near the LCC preceded the onset of the P wave by $47.5 \pm 14.9$ms (18 to 60ms). There was significant difference between the NCC and LCC group regarding the earliest activation time preceding P wave onset ($21.3 \pm 8.8$ vs $47.5 \pm 14.9$ms, $P<0.01$).

Atrial/ventricular (A/V) electrogram ratios during tachycardia at all successful ablation sites were also analyzed. There was a significant difference between the two 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 two with A/V ratio $\leq 1$, originated from the NCC near the junction between the NCC/RCC. At ablation sites near the LCC, an A/V ratio $<1$ was recorded in 4 of 6 patients (Figure 4 and 5), with two remaining cases displaying an A/V ratio $=1$.

With respect to catheter ablation during AT, the first RF application targeting the earliest
site in the aortic cusps or left atrium successfully terminated the tachycardia in 19 patients, with two RF applications each in the 3 remaining patients. The time to termination at the successful site was $3.8 \pm 2.6$ s (1 to 9.4 s). No junctional ectopy was observed during the ablation of the tachycardias. No complications were noted during and following catheter ablation in the aortic cusps or left atrium. During a mean follow up time of 30±13 months following catheter ablation, all patients remained free from any atrial arrhythmias without antiarrhythmic drugs. Of the 19 patients ablated from the aortic cusp region, 15 patients 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 lead I and aVL in 13 patients and isoelectric in 3 patients. In lead 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 one patient had a positive/negative pattern.

In the 6 patients with LCC AT, the P-wave in lead I and aVL was negative/positive in 4 patients and isoelectric in 2. In all six patients, the P wave was positive in II, III and aVF; and 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 that 1)
these ATs can be safely and effectively ablated within the aortic cusps with good long-term outcomes, 2) The P-wave morphology 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 morphology of AT originating near the NCC was reported by Ouyang et al. [1] as a negative/positive P wave in leads V1 and V2, and positive P wave in lead I and aVL in a case series of 9 patients with NCC AT. More recently, Liu et al. [5] reported an isoelectric P wave in lead I and slightly positive P wave in lead aVL in 10 out of 13 cases of NCC AT, with negative/positive P wave in leads V1 in 11 out of 13 patients. Similarly, in our case series, the most important characteristic of P wave morphology 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 as well as the 3 who were successfully ablated at the aorto–mitral junction. However, previous studies regarding AT arising near the aorto–mitral junction have yielded inconsistent results. Gonzalez and colleagues [8] reported positive P waves in lead I, negative P wave in aVL and positive P waves in lead V1 in 10 consecutive patients successfully ablated at the aorto–mitral junction using a transseptal approach. Another study [9] described isoelectric or negative P waves in lead I and aVL, and negative/positive pattern in lead V1, which is consistent with our findings. Taking all these findings together, we propose that P wave morphology in I and aVL is likely to be the more useful ECG finding to distinguish NCC ATs from LCC ATs. In our series, a positive P wave in 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 were 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 have shown that most of the cases were NCC ATs (16/22), and the remainders were from the LCC (6/22). All ATs were first mapped from the right atrium with 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 which 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 due to 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 due to the thickness of the interatrial septum in this area (Figure 1). Based on our findings, if the P wave morphology is 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 ATs from NCC ATs was mainly based on fluoroscopic images, three dimensional anatomic mapping and local electrograms recorded from the aortic cusps [10-14]. The NCC is located at the most inferior and posterior aspect of the aorta in the RAO view, which is close to the the interatrial septum and His bundle region. The LCC is easily recognized as the most leftward aspect of aortic root in the LAO 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 due to 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/RCC, or from the LCC, an A/V ratio of ≤ 1 was observed due to the relatively thicker ventricular myocardium beneath the RCC and LCC.

Limitations

In this study, the majority of 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 morphology from ECG during tachycardia and the A/V ratio from the local electrogram recording may help to localize sites of successful ablation.
Conflicts of Interest Disclosures: None

References:


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**Figure Legends:**

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

**Figure 2.** (Top) Fluoroscopic images from a case of atrial tachycardia located in the non-coronary cusp (NCC). Panels A and B show catheter location at the successful ablation site in RAO and LAO views. Panels C and D show aortic root angiograms taken from a pigtail catheter at the NCC at the same fluoroscopic angles prior to ablation. The successful ablation site is located at the NCC. (Bottom) shows the intra-cardiac electrograms of the successful ablation target at the NCC. Please note that an A/V ratio > 1 was observed in the local distal ablation electrogram. Abl=ablation catheter; CS=coronary sinus; RV=right ventricle; RVA=right ventricular apex; RAO=right anterior oblique; LAO=left anterior oblique; other abbreviations as in Figure 1.
**Figure 3.** (Top) Fluoroscopic images from a case of atrial tachycardia near the junction between the non-coronary cusp (NCC) and right coronary cusp (RCC). Panels A and B show catheter location at the successful ablation site in RAO and LAO views. Panels C and D depict aortic root angiograms taken from a pigtail catheter at the NCC at the same fluoroscopic angles prior to ablation. The successful ablation site is located near the junction between NCC and RCC. (Bottom) shows the intracardiac electrograms at the successful ablation target near the junction between NCC and RCC. Please note that an A/V ratio < 1 was observed in the local electrogram of the local distal ablation electrogram. The first RF application targeting the earliest site near the junction between NCC and RCC successfully terminated the tachycardia within two seconds. AT=atrial tachycardia; Abl=ablation catheter; HBE=His bundle; CS=coronary sinus; RF=radiofrequency ablation; other abbreviations as in Figure 1,2.

**Figure 4.** (Top) Fluoroscopic images from a case of atrial tachycardia successfully ablated from the left coronary cusp (LCC). Panels A and B show catheter location at the successful ablation site in RAO and LAO views. Panels C and D depict aortic root angiograms taken from a pigtail catheter at the NCC at the same fluoroscopic angles prior to ablation. The successful site is located at the LCC. (Bottom) shows the intracardiac electrograms at the successful ablation target near posterior portion of the LCC. The earliest atrial activation preceded the P wave in lead II by 50ms. Please note that an A/V ratio < 1 was observed in the local distal ablation electrogram. RF application at this site successfully terminated the tachycardia. Abl=ablation catheter; CS=coronary sinus; RV=right ventricle; RVA=right
ventricular apex.; other abbreviations as in Figure 1,2.

**Figure 5.** Panel A and Panel B show fluoroscopic images in RAO and LAO views from a case of atrial tachycardia successfully ablated at the aorto-mitral junction through transseptal approach. The successful site is located at the aorto-mitral junction in left atrium posterior to left coronary cusp (LCC). Panel C shows the intracardiac electrograms at the successful ablation target at the aorto-mitral junction. Please note that an A/V ratio < 1 was observed in the local distal ablation electrogram. RF application at this site successfully terminated the tachycardia. Panel D shows the electroanatomic geometry constructed using the NAVX system (St. Jude, Inc.) shown in AP and RAO views. In the RAO view depicted in Panels D, the earliest atrial activation from the right atrium mapped to an area posterior to the His bundle at the interatrial septum (white tags at the RA). The successful ablation site at the aorto-mitral junction in left atrium posterior to LCC, is marked by blue tags. Abl=ablation catheter; CS=coronary sinus; RA=right atrium; LA=left atrium; other abbreviations as in Figure 1.

**Figure 6.** Representative P-wave morphologic features on 12-Lead ECG in three separate patients with AT from non-coronary cusp (NCC), left coronary cusp (LCC) and aorto-mitral junction. Each boxed P-wave is enlarged to show the negative/positive P-wave in lead V1 (blue arrow). Note that the P-wave in lead I and aVL are positive in patients with atrial tachycardia (AT) from NCC, and negative/positive or isoelectric in patients with AT near LCC or aorto-mitral junction (red arrow).
3 Patients

3 Patients

(Transeptal approach)

3 Patients

13 Patients

MV

TV

R

L

N