Original Article

Coronary Sinus Activation Pattern in Patients with Atrioventricular Nodal Reentrant Tachycardia

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Patterns of left atrial (far-field signals) or coronary sinus (CS) muscle (near-field) have been defined in CS recordings. The purpose of this study was to define the activation patterns from the coronary sinus in patients with anterior and posterior type of atrioventricular nodal reentrant tachycardia (AVNRT) circuits.

Methods and Results: This retrospective study involved a total of 149 patients with 155 episodes of AVNRT which were divided into 3 patterns. In the anterior pattern (123 tachycardias), the atrial deflection from the His bundle electrogram preceded that from the proximal CS electrogram. In the posterior pattern (23 tachycardias), the proximal CS electrogram (CSp) was recorded earlier than the His bundle atrial electrogram. In the left atrial pattern (9 tachycardias), activation of distal CS sites preceded both proximal CS and atrial activation from the His bundle electrogram. A decapolar catheter with a 5-mm inter-electrode distance was used for CS recording. The CS electrograms were analyzed to determine the total signal duration as well as the duration of the initial component. An initial slow wave was defined as a duration exceeding 10 ms. 1) The duration of the initial component in patients with the anterior pattern was longer than in those with the posterior pattern in CSp (7.3 ± 3.1 ms vs. 4.5 ± 2.0 ms), CS7-8 (7.4 ± 2.9 ms vs. 3.8 ± 1.5 ms), CS5-6 (7.3 ms ± 3.3 ms vs. 4.4 ms ± 2.5 ms) and CS3-4 (6.7 ms ± 2.4 ms vs. 4.5 ms ± 2.0 ms) ($p < 0.01$). 2) Similarly the total electrogram duration in the CS was longer in patients with an anterior compared to a posterior pattern in CSp (38.3 ms ± 10.1 ms vs. 26.8 ± 6.1 ms), CS7-8 (31.8 ms ± 6.6 ms vs. 27.2 ms ± 6.0 ms), CS5-6 (31.3 ms ± 6.8 ms vs. 26.5 ms ± 4.9 ms), and CS3-4 (30.0 ms ± 6.3 ms vs. 25.0 ms ± 5.1 ms) ($p < 0.01$). 3) The percentage of tachycardias showing an initial slow wave followed by rapid activation was higher for anterior pattern patients compared with posterior pattern patients in CSp (62% vs. 13%), CS7-8 (79% vs. 4%), CS5-6 (72% vs. 4%), CS3-4 (54% vs. 9%) and distal CS (47% vs. 0%) ($p < 0.01$).

Conclusions: The pattern of an initial slow wave followed by a rapid wave in the CS was characteristic of an anterior AVNRT circuit and is explained by the initial involvement of far field left atrial components. In contrast, the predominant early rapid waves in the posterior AVNRT circuit are compatible with early CS activation from the right atrium.
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The precise components of the circuit responsible for atrioventricular nodal reentrant tachycardia (AVNRT) remain elusive.[1,2] Based on observations from endocardial mapping prior to surgical correction of AVNRT, two patterns have been described.[3] The most common pattern consists of earliest retrograde atrial activation in the right anteroseptal area (anterior type), while a less frequent type is characterized by the earliest atrial activation occurring in the coronary sinus (CS) region (posterior type).[4]

More recently, Jackman and colleagues have proposed involvement of the left atrium (LA) as part of the circuit in patients with the anterior pattern[5] and primary involvement of posterior nodal extension in those with the posterior pattern.[6]

Elegant work from Antz et al.[7] has demonstrated the existence of connections between the CS musculature and the LA (and right atrium (RA)). They have demonstrated the ability to distinguish near-field (CS muscle) from far-field (LA) potentials arising in the CS. In brief, they found that far-field LA potentials had a lower amplitude and longer duration compared with potentials due to activation of the CS muscle.

We hypothesized that wave front activation of the CS from the LA should be manifest by an initial slow wave followed by a rapid deflection in the CS. In contrast, activation of the CS from the RA should be attended by an initial rapid component in the CS with a shorter duration of the entire CS electrogram.

It was reasoned that initial low frequency events would reflect far field LA activity, while initial rapid activation would result from direct activation of CS musculature. Thus, initial activation of the LA followed by activation of CS muscle should result in a broad multi-component electrogram. In contrast, initial activation of CS muscle would be expected to result in a rapid initial component with a shorter total

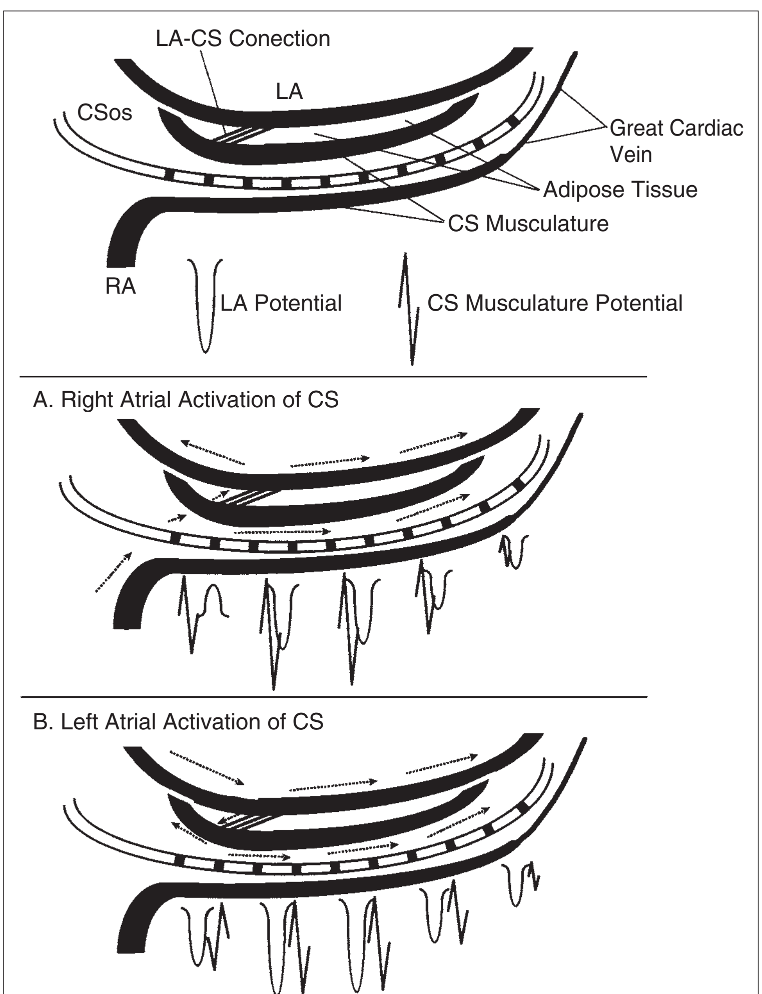

Figure 1 Top panel depicts relationship of coronary sinus (CS) and left atrium (LA) connection together with typical far-field LA and near-field CS musculature potentials. Discrete LA-CS connection are always oriented obliquely and leftward toward the LA myocardium.[18] Propagation directry to the CS would theoretically produce a short CS muscular to LA interval, because activation along the LA-CS connection would proceed to the site of earliest LA activation concomitant with the CS musculature wavefront (A). On the other hand, a LA wavefront coming from a left posteroseptal site should produce a longer electrogram duration from LA to CS musculature because the LA wavefront must activate LA prior to reaching CS musculature (B). See text for details. CSos indicates coronary sinus ostium; and RA, right atrium.

Table 1 Characteristics of tachycardias.

Pattern of Tachycardia	Number	Age (yr)	Sex	Tachycardia Cycle Length (ms)
Anterior Pattern	123 (79%)	42 ± 22 (8–79)	45M, 78F	347 ± 71 (210–542)
Posterior Pattern	23 (15%)	40 ± 18 (15–82)	15M, 8F	365 ± 76 (251–539)
Left Atrial Pattern	9 (6%)	38 ± 26 (15–79)	4M, 5F	350 ± 83 (251–533)
Total	155 (100%)	41 ± 22 (8–82)	63M, 86F*	350 ± 72 ms (210–542)

*Two patients had anterior and left Atrial pattern, 1 had 2 types of posterior pattern, 1 had posterior and left atrial pattern and 1 had 3 patterns.

electrogram duration. The rationale underlying this study is further detailed in **Figure 1**. The top panel displays the relationship of the CS to CS muscle connections and the LA. Following RA activation of the CS, superimposition of the initial sharp CS muscle activation and later activation of the LA results in an electrogram with a shorter duration (middle panel). In contrast, initial activation of the LA would be expected to produce initial far-field (LA) activation, followed by rapid activation of CS muscle (bottom panel).

The purpose of our study was to define the activation patterns shown by the CS recordings in patients with anterior and posterior AVNRT circuits.

Methods

The study was approved by the University of California, San Francisco Institutional Review Board. This was a retrospective study from September 1997 to July 2002 that involved a total of 149 patients with 155 episodes of AVNRT. Tachycardia characteristics are shown in **Table 1**. Three patients had dilated cardiomyopathy, 2 had previous coronary bypass surgery, 2 had significant mitral regurgitation, one had an atrial septal defect, and one had undergone successful ablation of a left lateral accessory pathway. The remaining 140 patients had no structural cardiac disease.

A total of 123 tachycardias showed earlier atrial deflection was on the His bundle electrogram (HBE) compared to the CS. Twenty-three tachycardias showed the pattern of a proximal CS atrial electrogram preceding the HBE atrial recording. In 9 tachycardias, the earliest recording was within the CS. Seven showed a short RP pattern and 2 showed a long RP tachycardia pattern.

Electrophysiologic Study

All antiarrhythmic drugs were discontinued for at least 5 half-lives. Written informed consent was obtained before the study. Retrograde atrial activation was recorded during AVNRT by 4 multi-electrode catheters that were positioned as described below. A decapolar catheter with a 5-mm inter-electrode distance was inserted into the CS through the right internal jugular vein. This catheter was positioned with the proximal pole in close proximity to the CS ostium. An octopolar catheter with a 2-mm inter-electrode distance was positioned to obtain the largest HBE deflection. A deflectable quadripolar catheter was positioned at the high RA. After completion of the electrophysiologic study, this catheter was used for slow pathway ablation. A quadripolar catheter with a 5-mm inter-electrode space was positioned in the right ventricle.

Standard pacing techniques[8,9] were used to evaluate the anterograde and retrograde AV node properties and the induction of tachycardia. Isoproterenol (1 to 3 μg/min) was used to facilitate the induction of AVNRT if baseline pacing failed to induce the tachycardia. After tachycardia initiation, single ventricular extrastimuli were delivered throughout the tachycardia cycle in 10 ms decrements.

The retrograde activation pattern was evaluated for all tachycardias. For short RP tachycardias, retrograde atrial activation was evaluated by premature ventricular depolarizations that failed to reset the tachycardia and this allowed for better definition of the CS electrogram. CS electrograms were analyzed at a paper speed of 400 mm/sec using a computerized recording system (Cardiolab System by Prucka Engineering Inc., Houston, Texas). Bipolar electrograms were filtered at a frequency of 30–500 Hz. The CS electrograms were analyzed with respect to total signal duration as well as the duration of the initial component.

In this study, the initial CS potential duration was defined as the interval from initial deflection to the peak or nadir of the initial wave. An initial slow wave was defined as a wave with a duration exceeding 10 ms. In addition, the total duration of the CS electrogram was measured from initial activation to electrogram termination (**Figure 2**).

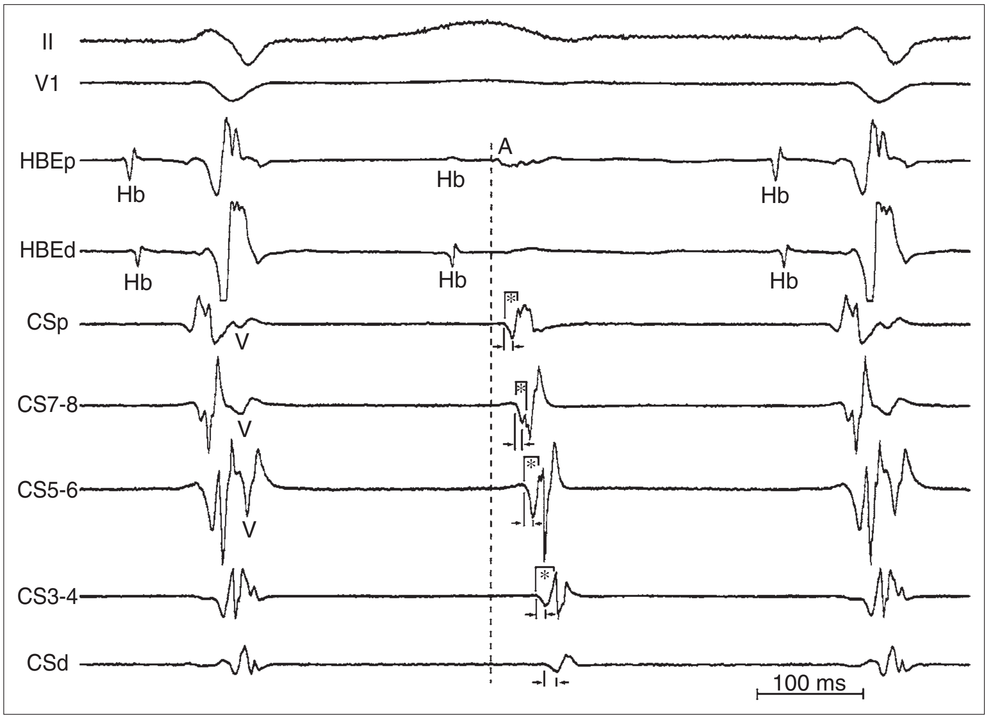

Figure 2 Simultaneous surface II and V1 and His bundle (HBEp-proximal and HBEd-distal) and coronary sinus (CSp-proximal and CSd-distal) recordings during tachycardia.
Recording from a patient with the anterior type of AVNRT recorded during an episode of two to one atrioventricular block. The atrial electrogram is clearly seen with the blocked atrial couplet. Initial slow wave at the duration exceeding 10 ms (*) was followed by a rapid activations are observed in CSp, CS 7-8, CS 5-6 and CS 3-4 electrograms. Arrows indicate the initial component; dotted line indicates earliest atrial activation site. Hb indicates His bundle potential; V, ventricular deflection; and A, atrial deflection.

Diagnosis of AV Nodal Reentry

Standard criteria[4,8–10] were used to exclude the presence of a septal accessory pathway or atrial tachycardia. Specifically, single ventricular premature depolarization either failed to advance the atrial electrogram or advanced the atrial electrogram and reset the tachycardia, while a ventricular extrastimulus delivered when the His bundle was refractory never advanced the next atrial deflection. In borderline cases, para-Hisian pacing[11] was used to exclude a septal pathway. Atrial tachycardia was excluded by characteristic responses to single ventricular extrastimuli and/or overdrive ventricular pacing.[12]

AVNRT was divided into the following 3 patterns. The anterior pattern[4] was diagnosed when the atrial deflection from the HBE preceded that from the proximal CS electrogram, while the posterior pattern[4] meant that the proximal CS electrogram was earlier than the HBE atrial electrogram. In the left atrial pattern,[13] activation within the CS preceded both proximal CS or atrial activation from the HBE.

Five out of 149 patients had more than one form of AVNRT. Two patients had both an anterior and a LA pattern, one had 2 types of posterior pattern, one had posterior and LA patterns, and one had anterior, posterior, and LA patterns.

Statistical Analysis

All values are expressed as the mean ± SD. Primarily, comparisons were made between the anterior and posterior patterns using the Mann-Whitney U test. The success rate of ablation in patients with each pattern of AVNRT was compared using the Kruskal-Wallis test with the multiple-comparison method (Student-Newman-Keuls test). A p value <0.05 was considered statistically significant.

Results

Anterior Pattern of AVNRT

This type of AVNRT showed the earliest activation of the HBE atrial electrogram. In this pattern, the CS electrogram usually showed a broad initial deflection followed by a rapid deflection (**Figure 2 and 3**). The duration of the initial component, as well

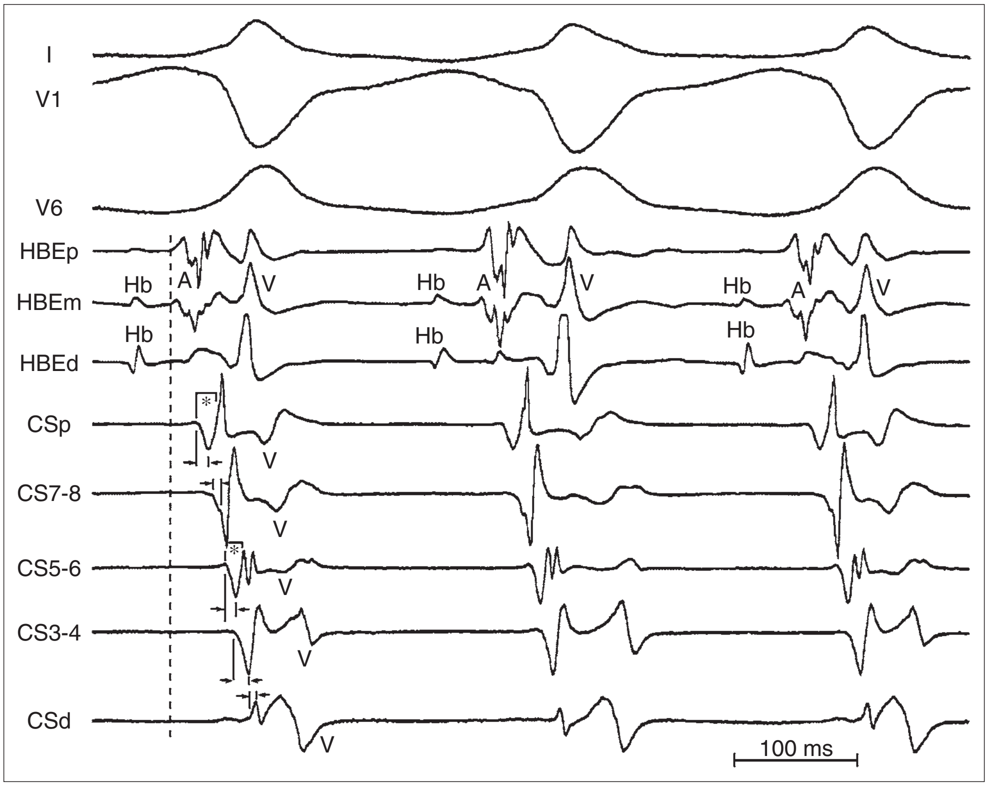

Figure 3 Illustrates an anterior pattern of AVNRT.
A left bundle branch block pattern is recorded during tachycardia and CS potentials can be easily differentiated from the ventricular deflection. CS potentials in CSp and CS 5-6 show initial slow waves (≥10 ms) followed by a rapid activation. Abbreviations as in Figure 2.

Table 2 The duration of the initial component in all coronary sinus electrodes.

Pattern	CSp	CS7-8	CS5-6	CS3-4	CSd
Anterior	7.3 ± 3.1 ms (n = 123)	7.4 ± 2.9 ms (n = 123)	7.3 ± 3.3 ms (n = 123)	6.7 ± 2.4 ms (n = 123)	7.5 ± 5.1 ms (n = 103)
Posterior	4.5 ± 2.0 ms* (n = 23)	3.8 ± 1.5 ms* (n = 23)	4.4 ± 2.5 ms* (n = 23)	4.5 ± 2.0 ms* (n = 23)	7.1 ± 3.1 ms† (n = 22)
Left Atrial	4.4 ± 2.0 ms (n = 9)	5.5 ± 1.3 ms (n = 9)	4.4 ± 2.3 ms (n = 9)	6.3 ± 3.3 ms (n = 9)	7.1 ± 2.1 ms (n = 8)

*$p < 0.01$ by Mann-Whitney U test compared with anterior pattern
†p = ns compared with anterior pattern

as the duration of the entire electrogram, is shown in **Tables 2 and 3** for all CS leads. In the anterior type of AVNRT, initial activation was usually associated with a broad CS potential.

The pattern of a slow wave followed by rapid activation (high frequency component) was also usually observed in anterior AVNRT. Specifically, an initial slow wave was observed in 93% (114/123) and an initial slow wave followed by a rapid component was seen in 62% (76/123) at the proximal CS (**Table 4**).

Posterior Pattern of AVNRT

A total of 23 tachycardias showed earlier activation of proximal CS atrial recordings compared to recordings from the HBE (**Figure 4A and 4B**).

For these patients, the duration of both the initial electrogram and total electrogram duration is detailed in **Tables 2 and 3**. The duration of the initial electrogram was significantly greater for those with the anterior type compared to those with the posterior type (**Table 2**). Similarly, the total duration of the electrogram was significantly longer in

Table 3 Total electrogram duration.

Pattern	CSp	CS7-8	CS5-6	CS3-4	CSd
Anterior	38.3 ± 10.1 ms (n = 123)	31.8 ± 6.6 ms (n = 123)	31.3 ± 6.8 ms (n = 123)	30.0 ± 6.3 ms (n = 123)	28.1 ± 6.9 ms (n = 103)
Posterior	26.8 ± 6.1 ms* (n = 23)	27.2 ± 6.0 ms* (n = 23)	26.5 ± 4.9 ms* (n = 23)	25.0 ± 5.1 ms* (n = 23)	29.6 ± 6.5 ms† (n = 22)
Left Atrial	36.5 ± 11.0 ms (n = 9)	36.0 ± 6.9 ms (n = 9)	31.4 ± 9.6 (n = 9)	29.1 ± 7.7 ms (n = 9)	32.0 ± 8.2 ms (n = 8)

*$p < 0.01$ by Mann-Whitney U test compared with anterior pattern
†p = ns compared with anterior pattern

Table 4 The percentage of tachycardias with initial duration ≥ 10 ms (slow wave) followed by a rapid deflection.

Pattern	CSp	CS7-8	CS5-6	CS3-4	CSd
Anterior	76/123 (62%)	97/123 (79%)	88/123 (72%)	66/123 (54%)	48/103 (47%)
Posterior	3/23 (13%)*	1/23 (4%)*	1/23 (4%)*	2/23 (9%)*	0/22 (0%*)
Left Atrial	2/9 (22%)	6/9 (67%)	3/9 (33%)	3/9 (33%)	3/8 (38%)

*$p < 0.01$ by Mann-Whitney U test compared with anterior pattern

patients with the anterior pattern (**Table 3**). A slow wave followed by a rapid potential was seen more commonly in anterior AVNRT (**Table 4**). An early high frequency potential followed by a slow potential, or a potential without an initial slow wave, were clearly observed in 10/23 (44%) at the proximal CS, 9/23 (39%) in CS 7-8, 10/23 (44) in CS 5-6, 9/23 (39%) in CS 3-4, and 3/22 (14%) at the distal CS, and simultaneous or near simultaneous high and low frequency potentials (a single-component potential) were observed in 6/23 (26%) at the proximal CS, 13/23 (57%) in CS 7-8, 12/23 (52%) in CS 5-6, 12/23 (52%) in CS 3-4, and 19/22 (86%) at the distal CS in patients with posterior pattern.

Tachycardia with Early Onset in the Coronary Sinus (Left Atrial Pattern)

A total of 9 patients showed the earliest activation within the CS.

The duration of the initial electrogram and total electrogram are shown in **Tables 2 and 3**.

Six out of nine patients (67%) showed CS electrogram pattern similar to that of anterior AVNRT (initial slow wave followed by a high-frequency potential at the earliest CS activation site) (**Figure 5A**) and 3/9 patients (33%) showed a pattern that was more consistent with posterior AVNRT (high-frequency potential followed by a slow wave or multiple-component potential without an initial slow wave at the earliest CS activation site) (**Figure 5B**).

Discussion

Jackman and colleagues[14] suggested that the CS activation pattern in patients with anterior (slow–fast) AVNRT differed from that in patients with posterior (slow–slow or fast–slow) AVNRT. In the present study, we investigated and quantified these differences.

A very detailed and elegant study by Antz et al.[7] using a perfused canine Langendorf preparation achieved the correlation of bipolar electrograms recorded within the CS with microelectrode recordings from the CS musculature and LA. They found that during lateral LA pacing, the CS electrogram showed a low frequency far-field (LA potential) followed by a sharp (CS muscle) near-field potential. In contrast, RA pacing produced the opposite pattern, i.e., the near-field sharp potential preceded the slow frequency LA potential. A recent anatomic study[15] showed that there are abundant connections between the proximal CS and LA and few or no connections in the region of the great cardiac vein. Moreover, these connections are always oriented obliquely, with the proximal end located closer to the CS ostium and the distal end located over the lateral LA (See **Figure 1**).

We reasoned that propagation from the RA toward the CS would result in a relatively short CS muscle to LA activation time, because initial activation of the CS muscle would be rapidly transmitted to the LA. This is similar to the findings described in

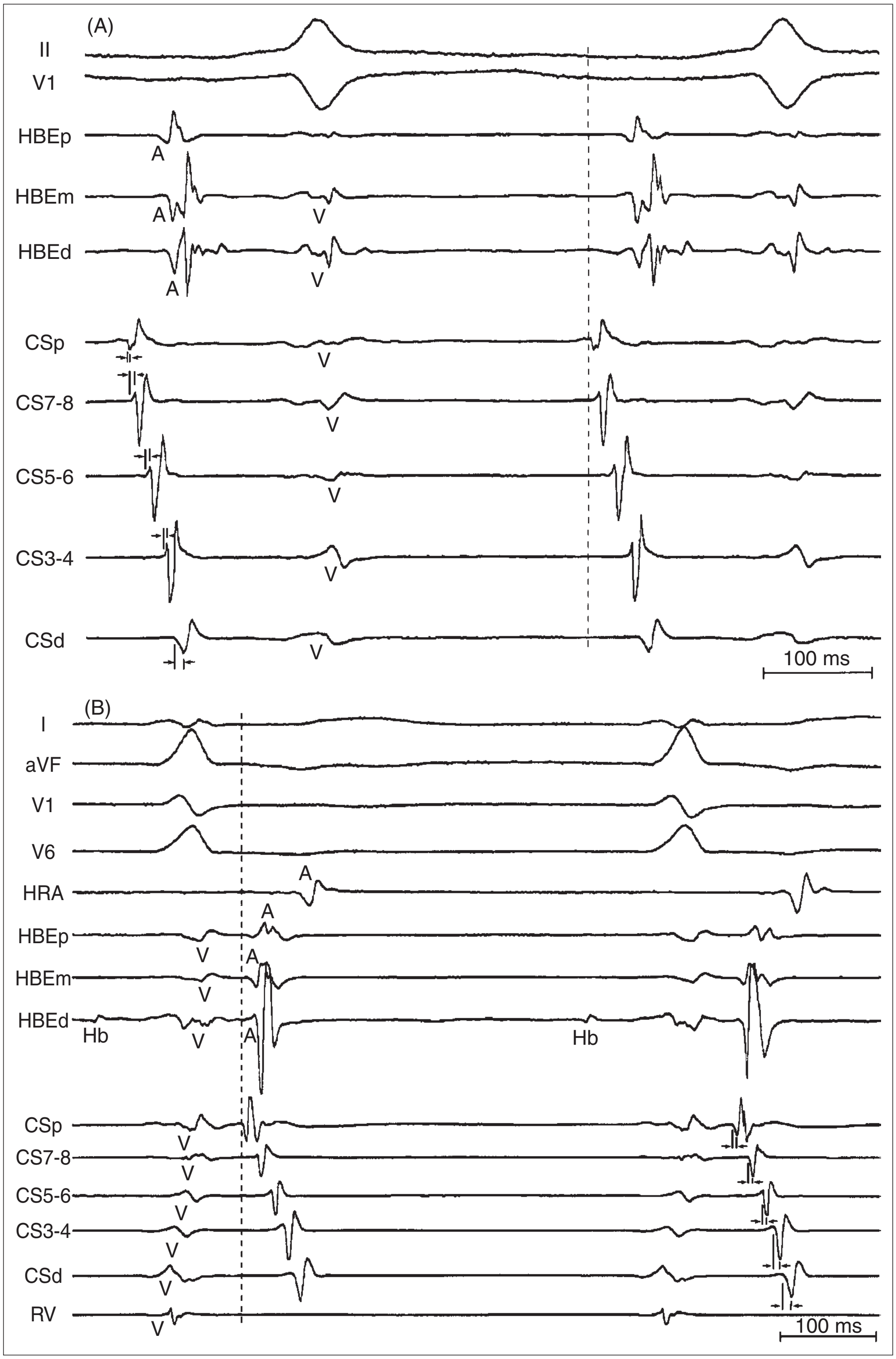

Figure 4 Illustrates 2 posterior patterns of AVNRT.

(A) Earliest activation site is CSp. Simultaneous or near simultaneous high and low frequency potentials (single component potential) were observed in all CS electrode. (B) Illustrates a posterior pattern with short RP tachycardia. The earliest activation site is located at the CSp. CS electrograms show no initial slow wave and have a narrow width. RV indicates right ventricle. Abbreviations as in Figure 2.

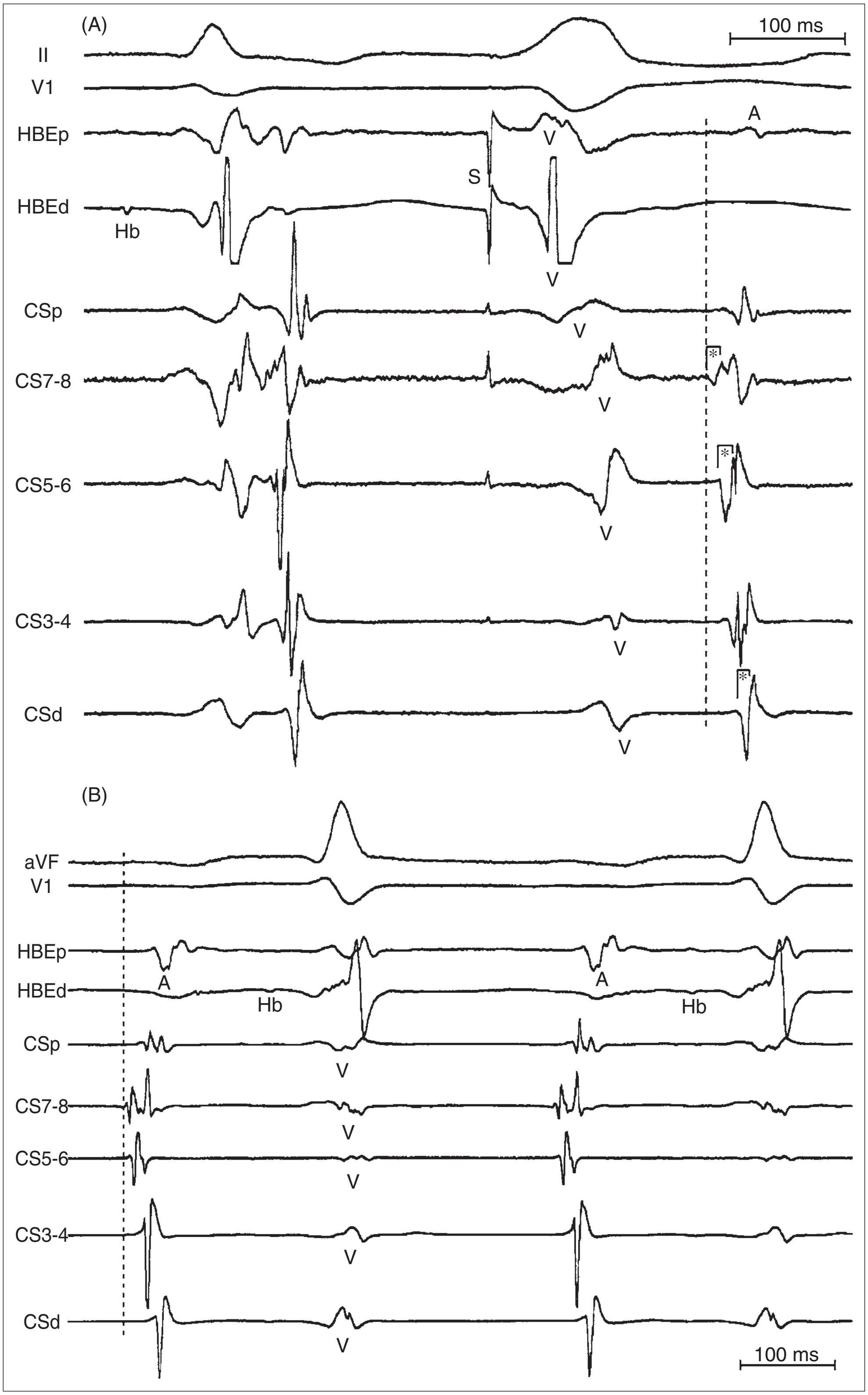

Figure 5 Illustrates a left atrial pattern of AVNRT.
(A) A premature beat unmasks the atrial activation pattern for a patient with a LA pattern. The earliest activation site (CS 7-8) shows an initial slow wave (>10 ms). (B) The earliest activation site (CS 7-8) shows an initial rapid deflection. Abbreviations as in Figure 2.

patients with obliquely coursing accessory pathways.[16] In contrast, initial LA activation (especially from a septal site) would be expected to produce an initial far-field LA potential followed by a near-field CS muscle potential. In our study, patients with anterior AVNRT usually showed a low frequency potential followed by a high frequency potential, which was consistent with early LA activation followed by CS muscle activation.

In contrast, the CS activation pattern was very different for most patients with posterior AVNRT, since the CS electrogram duration was shorter and there was an early rapid or multi-component electrogram pattern in the CS. This pattern was felt to be most consistent with CS activation from the RA. Several patients showed a pattern of early activation within the CS. These patients had a more variable CS electrogram pattern.

Implications of Findings about the Mechanism of AVNRT

AVNRT was initially thought to be an arrhythmia with the circuit largely confined to Koch's triangle,[8] i.e., the retrograde fast pathway was assumed to be located in the anterior septum and the slow pathway ran along the crest of the right ventricular summit. Recently, Jackman and colleagues[5] proposed an alternative hypothesis for the anterior type (slow–fast) of AVNRT. They suggested that the slow pathway represents right posterior nodal extension, while the fast pathway is thought to activate the left septum. Hence, they assumed that the LA was part of the AVNRT circuit. They also proposed that posterior AVNRT (i.e. slow–slow or fast–slow) involved retrograde activation of right-sided structures.[6] Our observations generally tend to support the concept of Jackman et al. However, some patients with the anterior pattern clearly had an initial rapid deflection within the initial slow wave, which suggests that multiple mechanisms may be involved. For example, a recent study using in vitro optical mapping[17] showed that AV nodal echoes and tachycardia in a canine model involved either retrograde anterior fast pathway activation and an antegrade slow pathway, or retrograde posterior activation and antegrade activation over either the anterior or intermediate pathways. The latter configurations only involved right-sided structures. It is clear that our observations do not prove any of these mechanisms. For example, recording an initial low frequency electrogram in patients with anterior AVNRT does not prove that the LA is part of the circuit. Such proof awaits direct recording and pacing from the LA septum.

Tachycardia with Early Onset in the Coronary Sinus (Left Atrial Pattern)

Some previous studies have suggested the participation of left-sided perinodal transitional cells in the reentrant circuit of AVNRT[6,18,19] and an anatomical study[20] described rightward and leftward posterior extensions of the AV node.

In the present study, tachycardia with earliest activation inside the CS demonstrated various CS activation patterns, i.e., 67% showed an initial slow wave followed by rapid activation and the remaining tachycardias did not show an initial slow wave at the earliest CS activation site. We found no correlation between the presence of an initial slow wave in the CS and the success of ablation, but our conclusions are tentative in view of the small number of patients.

The possible participation of posterior nodal extension in the reentrant circuit of these AVNRTs is controversial. Hwang et al.[13] were unsuccessful with ablation at the earliest CS activation site in 3 patients, and they speculated that the earliest CS activation site might be a bystander and not a critical part of the reentrant circuit. On the other hand, Wang et al.[6] reported successful ablation at the earliest CS activation site.

Study Limitations

The present study has several limitations. First, we did not confirm the CS ostial position using venography. Even if the CS catheter is positioned by venography, this does not ensure catheter stability throughout the study. Second, electrograms from the region of Koch's triangle were only recorded from two catheters (HBE and CS). More detailed mapping over Koch's triangle and along the tendon of Todaro may have yielded more information about the earliest activation site and allowed better differentiation between anterior and posterior AVNRT. Our study is purely observational and our conclusions about the involvement of specific structures remain tentative pending direct pacing studies either within the CS or over the left septum. Third, the existence of muscular connections between LA and CS is not clear in humans.[21] Two possible LA-CS connections (proximal and distal) were reported in a previous study using a canine model.[7] These finding may render CS electrogram analysis more complicated in the present study.

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