Characterization of Atrioventricular Nodal Reentry With Continuous Atrioventricular Node Conduction Curve by Double Atrial Extrastimulation

Chi-Tai Kuo, MD; Kuo-Hung Lin, MD; Nye-Jan Cheng, MD; Po-Hsien Chu, MD; Tsu-Shiu Hsu, MD; Cheng-Wen Chiang, MD; Ying-Shiung Lee, MD

Background—Characterization of typical atrioventricular nodal reentrant tachycardia (AVNRT) with continuous AVN conduction (A\textsubscript{1}A\textsubscript{2}/A\textsubscript{2}H\textsubscript{2}) curves by double atrial extrastimulation (A\textsubscript{1}A\textsubscript{2}A\textsubscript{3}) has never been systematically studied.

Methods and Results—This study was composed of 33 patients with typical AVNRT and continuous AVN conduction curves (group 1) and 103 patients with AVNRT and discontinuous AVN conduction curves (group 2). Using A\textsubscript{1}A\textsubscript{2}A\textsubscript{3} with predefined fast pathway–conducted A\textsubscript{3}, we examined the effects of slow pathway ablation on the A\textsubscript{2}A\textsubscript{3}/A\textsubscript{3}H\textsubscript{3} curves in both groups. In group 1, anterograde AVN effective refractory period (272±33 versus 277±47 ms, P>0.05) and AVN Wenckebach block cycle length (320±45 versus 343±59 ms, P>0.05) remained unchanged after ablation. A\textsubscript{3}H\textsubscript{3,max} was shorter in group 1 than group 2 (237±89 versus 395±72 ms, P<0.05) at baseline. It shortened in group 2 (395±72 versus 221±78 ms, P<0.001) but remained unchanged in group 1 (237±89 versus 214±59 ms, P>0.05) after ablation. A\textsubscript{2}A\textsubscript{3}/A\textsubscript{3}H\textsubscript{3} curves in 29 patients of group 1. A\textsubscript{3}H\textsubscript{3,max} shortened in both groups (375±81 versus 238±82 ms, P<0.001, and 419±104 versus 220±78 ms, P<0.001, respectively) in a similar fashion. Successful ablation resulted in loss of the left portion of the A\textsubscript{2}A\textsubscript{3}/A\textsubscript{3}H\textsubscript{3} curves in the 4 patients of group 1 with continuous A\textsubscript{2}A\textsubscript{3}/A\textsubscript{3}H\textsubscript{3} curves.

Conclusions—Use of A\textsubscript{1}A\textsubscript{2}A\textsubscript{3} could expose discontinuous A\textsubscript{2}A\textsubscript{3}/A\textsubscript{3}H\textsubscript{3} curves in most patients with continuous A\textsubscript{1}A\textsubscript{2}/A\textsubscript{2}H\textsubscript{2} curves. Significant shortening of A\textsubscript{3}H\textsubscript{3,max} after ablation may be indicative of successful elimination of AVNRT.

Key Words: atrioventricular node • catheter ablation • tachycardia • electrophysiology
Electrophysiology of Atrioventricular Nodal Reentry

Biomedical Instrumentation, Inc and Catheterization2000 Crossover System, Gould, Inc). Programmed electrical stimulation (model DTU-215, Bloom Associates, Ltd) was delivered by use of 2-ms rectangular impulses at twice the late diastolic pacing threshold. All intracardiac electrograms were bandpass-filtered between 40 and 500 Hz. Briefly, the stimulation protocol consisted of high right atrial and right ventricular incremental pacing to block and extrastimulus testing with at least 2 driven cycle lengths (usually 600 and 400 ms). The examination of a given patient was performed with stimulation from the same pacing sites during different protocols.

Endocardial Mapping and Radiofrequency Ablation

All patients underwent ablation through the posterior approach.6,13–17 Three zones within the triangle of Koch along the tricuspid annulus were arbitrarily defined, including the anterior third, middle third, and posterior third regions between the His-bundle recording site and coronary sinus ostium. These regions were further divided into 2 subsections, the anterior-2 (A2) and anterior-1 (A1), middle-2 (M2) and middle-1 (M1), and posterior-2 (P2) and posterior-1 (P1), respectively. The orifice of the coronary sinus was demarcated by coronary sinus venography. A 7F quadrupolar deflectable catheter (Mansfield Scientific) with a 4-mm tip electrode was used for mapping and ablation. A radiofrequency generator (RFG-3C, Radi- onics) was used to deliver energy at a power setting of 30 W for 30 seconds during each attempt. Application of energy was interrupted if junctional tachycardia did not appear within 10 seconds or if impedance rise, PR prolongation, or AVN block occurred. Lesions were basically anatomically guided and directed to the posterior, then the middle, and finally to the anterior area if necessary. The presumed ablation site was considered optimal if the bipolar electrograms recorded from the distal electrodes showed an atrial-to-ventricular electrogram amplitude ratio of 0.1 to 0.5 (usually ≤0.25).6,11,13 After each application of energy, the presence or absence of slow pathway conduction and inducibility of AVNRT was assessed with programmed electrical stimulation. The end point of a successful ablation was defined as noninducibility of AVNRT with isoproterenol infusion (at graded doses from 1 to 4 μg/min IV) and/or atropine (0.01 to 0.02 mg/kg IV), even though the residual anterograde slow pathway might be present6,11,13 without or with a single AVN echo.

Postablation Electrophysiological Evaluation

All patients underwent repeat testing with single and double atrial extrastimuli before and during the administration of isoproterenol and/or atropine, 30 minutes after successful ablation, and during a later follow-up study at 3 months. All parameters were measured on the 3 occasions. Each time, measurements were done during the baseline states.

Definitions

Dual pathway physiology was defined as discontinuous AVN conduction curves during single atrial extrastimulation. It was characterized by a ≤50-ms jump in AH after a critical range of A2 coupling intervals (10-ms decrease) during 2 different paced cycle lengths,3,11,14 resulting in a discontinuity between the curve to the right of the jump in AH (fast pathway) and the portion with the jump (slow pathway). The ERP of the fast pathway was defined on the basis of discontinuous A2/AH curves. The ERP of the AVN was defined as the longest A2 that failed to result in an H-H response. In patients with discontinuous A2/AH curves, the AVN ERP therefore reflects the ERP of the slow pathway; in those with continuous A2/AH curves, the AVN ERP refers to the shortest ERP. For each patient, the driven cycle lengths and the coupling intervals of the A3 at which ERP measurements and A2/AH curves were obtained before ablation were matched and repeated after ablation. The AHmax and AHmax were defined as the maximal AH measured during Aa and AaAa, respectively.

Statistical Analysis

Data were expressed as mean±SD. A repeated-measures analysis was applied to compare the continuous variables among 3 consecutive data points before and after ablation. Multiple-comparison analyses were performed to test the significance of continuous variables between 2 different groups. A χ² test with Yates’ correction or Fisher’s exact test was used to compare the categorical data, and a Student’s t test was performed to compare continuous variables between groups. A value of P<0.05 was considered statistically significant.

Results

Baseline

Group 1 (continuous A2/AH curve) included 33 patients, 22 women and 11 men, 55±13 years old. Group 2 (discontinuous A2/AH curve) included 103 patients, 60 women and 43 men, 48±15 years old. The 2 groups did not differ with respect to age, sex, AH interval, the AVN ERP, and retrograde AVN Wenckebach block cycle length (WCL) at the baseline. The cycle length of the induced tachycardias did not differ between groups 1 and 2. The Table summarizes the electrophysiological properties of the AVN in the 2 groups before and after ablation. Details of each patient are shown in Figure 1.

Effects of Ablation With the Posterior Approach on AVN Conduction in Group 1

Sustained AVNRT of the slow-fast form was induced in all patients before ablation. Isoproterenol infusion was required for its initiation in 12 patients (36%). Definite evidence of dual AVN physiology as shown by discontinuity of the A2/AH curve was not present in all patients before ablation.

The effects of ablation with the posterior approach on the refractory period and conduction properties of the AVN are shown in the Table. The sinus cycle length (714±191 versus 688±118 ms), AH (77±18 versus 78±15 ms), AVNCL (320±45 versus 343±59 ms), and retrograde AVNCL (369±125 versus 375±115 ms) remained unchanged after ablation (P>0.05). Of note, the anterograde AVN ERP (272±33 versus 277±47 ms, P>0.05) also remained unchanged after ablation. AHmax showed little change after ablation (237±89 versus 214±59 ms, P>0.05). Using a predetermined fast pathway–conducted Aa, AaAa was able to further disclose discontinuous A2/AH curves with an AH jump (≥50 ms) in 29 patients (Figures 2 and 3). Successful ablation resulted in the loss or marked diminution (Figures 2B and 3B) of the discontinuous A2/AH curve on the left in the former. A lack of discontinuity in the A2/
Electrophysiological Characteristics of the AV Node in Patients With and Without Discontinuous AV Conduction Curves Before and After Ablation

<table>
<thead>
<tr>
<th></th>
<th>Group 1 (n=33)</th>
<th>Group 2 (n=103)</th>
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<tbody>
<tr>
<td></td>
<td>Preablation</td>
<td>Postablation</td>
</tr>
<tr>
<td></td>
<td>714±19</td>
<td>668±118</td>
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<tr>
<td>AH</td>
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</tr>
<tr>
<td>ERP_{gr}</td>
<td>272±33§</td>
<td>277±47‡</td>
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<tr>
<td>ERP_{fp}</td>
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<td>ERP_{sp}</td>
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<tr>
<td>Ant AVNWCL</td>
<td>320±45§</td>
<td>343±59‡</td>
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<td>A_{H, max}</td>
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<tr>
<td>A_{H, max}</td>
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<tr>
<td>Ret AVNWCL</td>
<td>369±125</td>
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<tr>
<td>TCL</td>
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<tr>
<td></td>
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<td>752±145§</td>
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<td></td>
<td>78±19</td>
<td>78±19</td>
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<tr>
<td>ERP_{net}</td>
<td>274±45*</td>
<td>321±67</td>
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<td>A_{H, max}</td>
<td>366±82*</td>
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<td>Ret AVNWCL</td>
<td>395±106</td>
<td>383±95</td>
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<tr>
<td>TCL</td>
<td>336±66</td>
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</table>

SCL indicates sinus cycle length; ERP_{net}, effective refractory period of the AV node; FP, fast pathway; SP, slow pathway; Ant, anterograde; Ret, retrograde; and TCL, tachycardia cycle length. All data are expressed in milliseconds.

*P<0.0001, preablation vs postablation vs late follow-up (adjusted by age within group).
†P<0.0001, preablation vs postablation (adjusted by age within group).
‡P<0.0003, postablation vs follow-up (adjusted by age within group).
§P<0.0003, preablation vs follow-up (adjusted by age within group).

Comparison of Groups 1 and 2

Before ablation, the sinus cycle length, the anterograde AVNWCL, and the A_{H, max} and A_{H, max} showed significant differences (P<0.05) between groups 1 and 2 (Figure 1). Immediately after ablation, the sinus cycle length, AVN ERP, and AVNWCL showed significant differences (P<0.05) between the 2 groups.

Late Electrophysiological Follow-Up at 3 Months or Later

At late follow-up, the sinus cycle length, anterograde AVNWCL, and AVN ERP increased from immediate postablation studies in a similar trend (Figure 5) in both groups (Table). In group 2, the ERP of the slow pathway increased immediately after ablation (274±45 versus 316±72 ms, P<0.0001) and increased further (368±78 ms, P<0.0001) at 3-month follow-up. Conversely, the ERP of the fast pathway in group 2 shortened (366±82 versus 339±73 ms, P<0.0001) immediately after ablation but increased in the long run (406±100 ms, P<0.0001) during the late follow-up.

The baseline AH, retrograde AVNWCL, A_{H, max}, and A_{H, max} remained unchanged between the 2 postablation studies in both groups.

As a whole, there were significant differences in the tendency of the series of changes in the electrophysiological variables, including the sinus cycle length, AVN ERP, anterograde AVNWCL, and A_{H, max} among 3 measurements between the 2 groups (P<0.05, adjusted by age and time).

Discussion

Major Findings

In those with discontinuous AVN function curves during A_{A2} (group 2), the anterograde AVN ERP increased. The ERP of the residual slow pathway increased, whereas that of
the fast pathway decreased,\textsuperscript{9,14} thus narrowing the slow pathway window after ablation. In those without manifestation of discontinuous curves during A1–A2 (group 1), the anterograde AVN ERP and WCL remained unchanged after ablation. The A2H2 max was shorter in group 1 than group 2 at baseline. After ablation, A2H2 max shortened in group 2 but remained unchanged in group 1. A strong correlation between the sinus cycle length, anterograde AVNWCL, and AVN ERP was noted between immediate postablation and late studies for both groups.

Mechanisms of Failure to Demonstrate a Distinct Discontinuity

Several potential mechanisms may account for the failure to demonstrate distinct discontinuity in the AVN conduction (A1A2/A2H2) curves in otherwise typical AVNRT. Differences in the refractory periods and conduction properties between the fast and slow pathways may not be sufficiently distinct at baseline study to yield discontinuity in the A1A2/A2H2 curve.\textsuperscript{1,2,7} It is well known in the electrophysiology laboratory that discontinuous AVN conduction curves may become continuous during isoproterenol infusion,\textsuperscript{3,15–20} because the refractory period of the fast pathway could be abbreviated to the extent that the slow pathway conduction could not be achieved with single or even double atrial extrastimuli or with incremental atrial pacing.

In group 1 patients, A1A2A3 failed to expose the discontinuity of the A2A3/A3H3 curve in a minority of patients. Successful ablation with the posterior approach in these patients resulted in the loss of the tail of the A2A3/A3H3 curve representing the slow pathway. The observation that successful ablation did not produce any changes in the A1A2/A2H2 format is an important and very instructive finding. It indicates that the slow pathway, although present before the ablation, was not detectable in the above format. Conversely, the A1A2/A2H2 format, although not always manifesting the slow pathway by means of a jump, allowed the conclusion that the ablation did affect the slow pathway portion of the conduction curve. However, one cannot conclude from this...
result that the ablation eliminated the slow pathway. It is quite logical to say that the ablation may have now rendered the slow pathway not detectable in the A2 A3 /A3 H3 format as well. In other words, the elimination of the AVNRT may not necessarily be equaled with elimination of the slow pathway; thus the dual pathway electrophysiology. These findings suggest that the smooth A2 A3 /A3 H3 curve might in fact consist of 2 distinct components, which may be linked to one or the other pathway, respectively. Atrial burst pacing and isoproterenol were required for the initiation of AVNRT in 3 of these patients. One other patient required A1 A2 A3 to initiate AVNRT. The slow pathway conduction could be achieved in these circumstances to set up for reentry to occur. However, it was difficult to draw any conclusions on the electrophysiological characteristics of the AVN in such a small number of patients.

The anterograde AVN ERP, AVNWCL, and A3 H3 max remained unchanged in group 1. A3 H3 max was the only electrophysiological parameter that shortened significantly after successful ablation. To facilitate the ablation procedure, it may be much easier to use A1 A2 A3 as defined in the report to establish an acceptable therapeutic end point, ie, A3 H3 max may be a better indicator than A3 H3 max in determining and confirming the success of the ablation.

Lessons Learned From Ablation

This study further supports the hypothesis that use of double atrial extrastimulation could reveal distinct discontinuity in the A1 A2 /A2 H2 curves in most patients with smooth A1 A2 /A2 H2 curves. Of note, loss of the terminal portion of the A1 A2 /A2 H2 curves (to the left of the discontinuity) representing slow pathway conduction occurred after the elimination of the AVNRT, leaving a continuous A1 A2 /A2 H2 curve. At times, the “slow pathway” zone was only modified, leaving a discontinuous A1 A2 /A2 H2 curve after elimination of the inducibility of AVNRT. Nonetheless, A3 H3 max always shortened in a significant magnitude. In those who still failed to show discontinuous A1 A2 /A2 H2 curves during A1 A2 A3, successful ablation always resulted in the loss or marked diminution of the terminal portion of the curve on the left, which may be linked to the slow pathway component.

A3 H3 max decreased in a parallel fashion after successful ablation in both groups. Both A3 H3 max and A3 H3 max were shorter in those with smooth A1 A2 /A2 H2 curves, implying a “less decremental” slow pathway, as suggested by previous studies. The data suggest that the use of the A2 could increase the difference in conduction time of the fast and slow pathways, although the A1 A2 /A2 H2 curves remained continuous in some patients.
Limitations
In this study, we did not use autonomic blockade to control for autonomic tone. However, autonomic blockade has been shown not to affect the observed changes in postablation refractoriness.

In our A1A2A3 study, it might be true that neither “A1A2 usually at 50 to 100 ms greater than the ERP of AVN or fast pathway” nor “A2H2 <180 ms” is an indicator of fast pathway conduction. Although we always checked the AH during induction of single AVN echo, induction and maintenance of the AVNRT to determine that the predefined A2 and thus A2H2 did not fall into the slow pathway range. In fact, the predefined A2H2 was most often <150 ms. However, this would not guarantee that slow pathway–coupled A2 did not occur.

Another potential limitation is the choice of the A2, which may be arbitrary in such a way that A2H2max may not really be the longest attainable interval during A1A2A3. It is also likely that the longest attainable AH interval, AHmax, could be obtained during atrial burst pacing instead of atrial extrastimulation.

We did not routinely use a third drive cycle length to expose discontinuity of the A1A2/A2H2 and/or A2A3/A3H3 curves. It is possible that use of various atrial sites, or pharmacological intervention could have revealed discontinuity in some of the patients with smooth AVN curves.

Clinical Implications
It has been well established that total elimination or modification of the slow pathway, to the extent that repetitive AVN reentry cannot be induced, is an acceptable therapeutic end point that portends a good prognosis. However, the end point is less distinct when the AVN conduction curves do not demonstrate a classic jump at the transition from the fast to slow pathway conduction. After successful ablation, A2H2max might shorten significantly in group 1 patients, as demonstrated by Tai et al7 and Sheahan et al.2 In this study, however, the postablation A2H2max did reveal a trend to decrease, although the difference was noted to be statistically insignificant. The anterograde AVN ERP and AVNWCL also remained unchanged after ablation in this group. Because
$A_3 H_3 \text{max}$ is the only electrophysiological parameter that shortened in a greater magnitude, it may be shown that $A_3 H_3 \text{max}$ is a good (if not better) indicator compared with $A_2 H_2 \text{max}$ in potentiating a successful outcome for ablation. It is hoped that this approach will facilitate the ablation procedure in patients with smooth $A_2 A_2 /A_2 H_2$ curves who otherwise have typical AVNRT. Finally, the study suggests that a decrease of $\approx 100$ to $150$ ms in $A_3 H_3 \text{max}$ may be indicitive of clinical success. This merits further study in a large patient population.

Acknowledgments

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References

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