Selective Radiofrequency Catheter Ablation of the Slow Pathway for Common and Uncommon Atrioventricular Nodal Reentrant Tachycardia

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SUMMARY

The utility of selective radiofrequency catheter ablation of the slow pathway for the treatment of common and uncommon atrioventricular nodal reentrant tachycardia (AVNRT) was studied in 110 consecutive patients, 94 with slow-fast form common AVNRT, and 11 and 5, respectively, with the fast-slow and slow-slow forms of uncommon AVNRT. Ablation sites were determined by mapping a late and spiky “slow pathway potential” in the posterior right atrial septum in common AVNRT, and also the earliest retrograde atrial activation over the retrograde slow pathway in uncommon AVNRT. AVNRT was successfully eliminated in all patients with a mean number of radiofrequency pulses of 2.9 ± 3.0 and a mean total energy applied of 3536 ± 2996 joules. There were no early or late complications, except for transient AV block for 15 sec immediately after energy application in one common AVNRT patient, and no recurrence of AVNRT in a mean follow-up period of 24 ± 13 months. There were no significant differences between common and uncommon AVNRT in success rate, mean application number and total energy applied. However, the AVN physiology post-ablation was different. Slow pathway conduction was eliminated in only 32% of the patients post-ablation in common AVNRT, while it was eliminated in 100% in uncommon AVNRT.

Selective radiofrequency catheter ablation of the slow pathway can cure common and uncommon AVNRT effectively and safely. Common AVNRT can be eliminated irrespective of the persistence of slow pathway conduction, while uncommon AVNRT can be eliminated by the eradication of slow pathway conduction. (Jpn Heart J 1996; 37: 759–770)

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Atrioventricular nodal reentrant tachycardia (AVNRT) is one of the most common forms of supraventricular tachycardia. Permanent cure of AVNRT with the preservation of AVN conduction was initially achieved by surgical ablation of perinodal tissue. The catheter ablation technique which selectively ablates the fast or slow pathway was then developed, and selective slow pathway ablation is now the dominant non-pharmacologic curative therapy for AVNRT.

It has been well accepted that there are two types of AVNRT, common and uncommon. Slow-fast form common AVNRT with the slow pathway as an antegrade limb of reentry circuit and the fast pathway as a retrograde limb is characterized on ECG by a long PR interval, while the fast-slow form or slow-slow form of uncommon AVNRT with the fast or slow pathway as an antegrade limb and the slow pathway as a retrograde limb is characterized on ECG in general by a long RP interval. Uncommon AVNRT occurs much less frequently than common AVNRT, and it also has more variations in ECG manifestations and mechanisms.

Radiofrequency catheter ablation targeting the slow pathway has been shown to be highly effective and safe as a curative therapeutic modality in the slow-fast form of common AVNRT, however, its utility in uncommon AVNRT has not been fully investigated. In this study, the efficacy and safety of radiofrequency catheter ablation for uncommon AVNRT was compared with common AVNRT.

Methods

Study population: The study population consisted of 110 consecutive patients with AVNRT who underwent an electrophysiologic study and radiofrequency catheter ablation at Tsuchiura Kyodo Hospital from February 1992 to December 1995. There were 41 men and 69 women with a mean age of 47 ± 18 years (range 14–73). All patients had episodes of symptomatic supraventricular tachycardia documented on ECG, and no patients had apparent structural heart diseases.

Electrophysiologic study: Written informed consent was obtained from all patients. Electrophysiologic study was performed in the fasting state and at least five half-lives after discontinuation of antiarrhythmic drugs. Four 5F quadripolar electrode catheters (USCI, Billerica, USA) were introduced through the femoral and subclavian veins, and located at the high right atrium, His-bundle region,
right ventricular apex and coronary sinus. Intracardiac electrograms and body-surface electrograms were monitored and recorded using an EPAmp and EPLab (Quinton, Toronto, Canada).

The stimulation protocol consisted of atrial and ventricular incremental pacing and extrastimulation. Atrial extrastimulation using two drive cycle lengths was performed to obtain the AV conduction curves and induce AVNRT. Ventricular extrastimulation was performed to obtain the VA conduction curve and induce AVNRT. Incremental pacing was performed to obtain the AV and VA Wenckebach cycle lengths and induce AVNRT. If AVNRT could not be induced at baseline, a pacing study with the same protocol was repeated during isoproterenol infusion.

Diagnosis of common AVNRT was made based on the following findings: 1) Antegrade dual AVN pathways defined as discontinuous AV conduction curve with an increase in the A_2-H_2 interval of > 50 msec in response to a decrease in the A_1-A_2 interval of 10 msec were demonstrated; 2) initiation of the tachycardia was dependent on the achievement of a critical delay in the AH interval; 3) retrograde earliest atrial activation during tachycardia was registered in the His bundle electrogram; and 4) premature ventricular extrastimuli introduced during tachycardia when the His-bundle was refractory to retrograde conduction did not advance the subsequent atrial activation.\(^{16,24}\)

Diagnosis of the uncommon AVNRT was made based on the following findings: 1) Presence of retrograde slow pathway conduction with decremental conduction properties was demonstrated; 2) initiation of the tachycardia was related to a shift of the retrograde conduction from the fast pathway to the slow pathway or critical prolongation of the retrograde slow pathway conduction; 3) retrograde earliest atrial electrogram during tachycardia was registered at the posterior right atrial septum; 4) premature ventricular extrastimulus introduced during tachycardia when the His-bundle was refractory to retrograde conduction did not advance the subsequent atrial activation; and 5) the exclusion criteria of atrial tachycardia previously described were satisfied.\(^{16,23,24}\)

**Ablation procedure:** After electrophysiologic evaluation a 7F 4-mm tip quadripolar deflectable electrode (2-mm distal interelectrode distance, Mansfield, Webster, EPT and Elecath, Watertown, Baldwinpark, Sunnyvale and Rahway, USA) was introduced into the right atrium via the femoral vein for mapping and ablation, and positioned in the right atrial postero-septal region between the orifice of the coronary sinus and the tricuspid annulus. Ablation sites were determined by detecting the local atrial electrogram with a late and spiky "slow pathway potential" as described by Jackman et al. in common AVNRT,\(^{3}\) and by detecting the slow pathway potential and mapping the earliest retrograde atrial activation over the retrograde slow pathway in uncommon AVNRT. A
radiofrequency current of 500 KHz was delivered at 45~60 volts and 20~40 watts using a radiofrequency pulse generator NL 50-I (Central Industry, Tokyo, Japan) between the distal large-tip electrode and an electrosurgical adhesive grounding plate (Niko, Denmark) on the patient's back. Energy was applied during sinus rhythm in patients with common AVNRT, and during tachycardia or ventricular pacing in those with uncommon AVNRT. Radiofrequency energy was applied for 60~90 sec, but was immediately discontinued in the event of an increase in impedance or dislocation of the electrode. Energy application was repeated until slow pathway conduction was abolished or AVNRT was no longer inducible except for at most one AVN echo in the baseline state and during isoproterenol infusion (1~3 µg/min). Intravenous heparin was administered as an initial dose of 5000 units at the onset of the procedure and an infusion of 1000 units per hour continued during the procedure.

Follow-up evaluation: All patients had continuous ECG monitoring for 24 to 72 hours after ablation, with 12-lead ECGs and 24-hour Holter monitoring, discharged without antiarrhythmic drugs, and were evaluated on the basis of clinical symptoms, 12-lead ECG, and 24-hour Holter monitoring.

Results

Electrophysiologic study and ablation results: The induction of AVNRT in the baseline state or during isoproterenol infusion occurred in all 110 patients. The slow-fast form of common AVNRT was induced in 89 (81%) patients, fast-slow form uncommon AVNRT in 11 (10%), both slow-fast and fast-slow form AVNRTs in 5 (4.5%), and the slow-slow form of uncommon AVNRT in 5 (4.5%).

Slow-fast form common AVNRT: AVNRT was commonly induced by an atrial extrastimulus with a jump-up of the AH interval, and the earliest retrograde atrial activation was registered at the His-bundle region. A spiky slow pathway potential following a local atrial electrogram of low frequency and amplitude was recorded at the tricuspid annulus anterior to the coronary sinus ostium (Figure 1). Radiofrequency energy application at such a spiky slow pathway recording site commonly induced junctional rhythm associated with retrograde atrial activation and successfully abolished the slow pathway conduction and inducibility of AVNRT (Figure 2). A mean of 2.9 ± 2.9 applications of radiofrequency energy with a mean total energy of 3543 ± 2730 joules eliminated AVNRT in all patients (Table). Antegrade slow pathway conduction was eliminated in only 32 patients (34%), whereas slow pathway conduction remained associated with one AVN echo inducible in the remaining 62 patients (66%) (Table).
Figure 1. Slow pathway potential recording at successful ablation site in a patient with common AVNRT. Panel A: Tracings of electrocardiographic leads I, II, V1, and electrocardiograms from the high right atrium (HRA), His-bundle (HBE), ablation site (ABL), proximal coronary sinus (CS-p) and right ventricular apex (RVA). At the ablation site the late and spiky slow pathway potential (*SPP) was demonstrated following the local atrial electrogram of low amplitude and frequency. Panel B: The positions of all the catheters are shown in radiographs recorded in the right anterior oblique (RAO) and left anterior oblique (LAO) positions. The ablation catheter with a distal large tip electrode was positioned between the coronary sinus ostium and tricuspid annulus in the right posterior atrial septum.

Fast-slow form uncommon AVNRT: The electrocardiographic manifestations were characterized by a long R-P tachycardia and inverted P-waves in the inferior limb leads (Figure 3). At successful ablation sites in the posterior right atrial septum anterior to the coronary sinus ostium, spiky slow pathway potentials were recorded during sinus rhythm, and the local atrial electrogram-slow pathway potential (A-SPP) sequence during sinus rhythm was reversed and the slow pathway potential became the earliest retrograde atrial activation during AVNRT in all patients (Figure 3). Radiofrequency energy applied during AVNRT terminated AVNRT with elimination of the retrograde slow pathway conduction (Figure 4). A mean of 3.5 ± 4.4 applications of radiofrequency energy with a mean total energy of 4064 ± 4802 joules completely eliminated the retrograde slow pathway conduction and AVNRT in all 11 patients (Table).

Slow-slow form uncommon AVNRT: The electrocardiographic manifesta-
SLOW PATHWAY ABLATION IN COMMON AVNRT

Figure 2. Recordings of electrocardiograms and intracardiac electrograms during successful application of radiofrequency energy in the patient with common AVNRT shown in Figure 1. Immediately after the initiation of energy delivery during sinus rhythm, junctional beats (*) with retrograde conduction occurred consecutively as a usual finding in successful ablation of the slow pathway.

Table. Ablation Data and Outcomes

<table>
<thead>
<tr>
<th>Type of AVNRT</th>
<th>Number of patients of AVNRT</th>
<th>Elimination of SP</th>
<th>Mean No. of RF Pulses</th>
<th>Mean total RF energy (J)</th>
<th>Recurrence</th>
<th>Mean follow-up period (months)</th>
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<tbody>
<tr>
<td>Slow-fast form common</td>
<td>94 (100%)</td>
<td>94 (34%)</td>
<td>32</td>
<td>2.9 ± 2.9</td>
<td>3543 ± 2730</td>
<td>0</td>
</tr>
<tr>
<td>Fast-slow form uncommon</td>
<td>11 (100%)</td>
<td>11 (100%)</td>
<td>11</td>
<td>3.5 ± 4.4</td>
<td>4064 ± 4802</td>
<td>0</td>
</tr>
<tr>
<td>Slow-slow form uncommon</td>
<td>5 (100%)</td>
<td>5 (100%)</td>
<td>5</td>
<td>1.8 ± 1.3</td>
<td>2256 ± 1493</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>110 (100%)</td>
<td>110 (44%)</td>
<td>48</td>
<td>2.9 ± 3.0</td>
<td>3536 ± 2966</td>
<td>0</td>
</tr>
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AVNRT = atrioventricular nodal reentrant tachycardia; SP = slow pathway; RF = radiofrequency.
Figure 3. Slow pathway potential recording during atrial pacing and tachycardia at a successful ablation site in a patient with the fast-slow form uncommon AVNRT. Panel A: During atrial pacing (AP) the late and spiky slow pathway potential (SPP) following the local atrial electrogram was recorded at the ablation site (ABL). Panel B: During the fast-slow form of AVNRT local atrial electrogram-SPP sequence during atrial pacing was reversed, and the spiky slow pathway potential preceeded any retrograde atrial activation recorded at other sites. Panel C: Right oblique (RAO) and left oblique (LAO) view radiographs showing the ablation catheter (ABL) localized between the coronary sinus and tricuspid annulus in the posterior right atrial septum.

tachycardia in 2 patients without a significant lower common pathway (Figure 5). Three slow-slow form uncommon AVNRT patients with a significant lower common pathway showed electrocardiographic manifestations similar to slow-fast form common AVNRT (Figure 6). However, the earliest retrograde atrial activation was recorded in the coronary sinus contrary to slow-fast form common AVNRT (Figure 6), and ventricular pacing at tachycardia cycle length demonstrated a V-A interval longer than the H-A interval during tachycardia (Figure 6). These findings were compatible with the presence of a significant lower common pathway in this AVNRT. The presence of a lower common pathway was revealed in 3 out of 5 patients with slow-slow form uncommon AVNRT (60%). A mean of 1.8 ± 1.3 applications of radiofrequency energy with a mean total energy of 2256 ± 1493 joules eliminated both the antegrade and retrograde slow pathway conductions and AVNRT in all patients (Table).
Common AVNRT vs uncommon AVNRT: AVNRT was successfully eliminated in all 110 patients, with a mean number of radiofrequency pulses of 2.9 ± 3.0 and the mean total applied energy of 3536 ± 2966 joules (Table). There were no significant differences between common and uncommon AVNRT in acute success rate (100% vs 100%), mean application number (2.9 ± 2.9 vs 2.7 ± 2.6) or mean total energy (3536 ± 2966 joules vs 3129 ± 2111 joules) of radiofrequency current delivered. The mean application number was 1.4 ± 0.7 in the last 50 common AVNRT patients, and 1.3 ± 0.5 in the last 5 uncommon AVNRT patients.

Complications and follow-up: There were no early or late complications, except for a 15 second transient AV block immediately after energy application in one common AVNRT patient. During the mean follow-up period of 24 ± 13 months, no recurrences were observed symptomatically or electrocardiographically.
Figure 5. Recordings of electrocardiograms and intracardiac electrograms during tachycardia and ventricular pacing in a patient with the slow-slow form of uncommon AVNRT without evidence of the lower common pathway. During AVNRT the electrocardiogram demonstrated an inverted P-wave in inferior limb leads and long P-R tachycardia compatible to the slow-slow form of uncommon AVNRT shown in the left panel. Ventricular pacing at a cycle length similar to the tachycardia cycle length demonstrated a VA interval almost equal to the HA interval during tachycardia (right panel). This indicates the absence of the lower common pathway.

DISCUSSION

Successful surgical intervention of AVNRT using perinodal dissection or cryosurgery while preserving normal AV conduction provided the rationale for subsequent attempts at catheter ablation for AVNRT.1,2) Retrograde fast pathway ablation was the first used, however, this technique was virtually abandoned due to the risk of AV block. Selective slow pathway ablation was then developed as an alternative technique, and has now become established as the most effective and safest method of radiofrequency catheter ablation for AVNRT.3-14) Selective slow pathway ablation has shown high success rates with a minimal risk of development of AV block for common AVNRT, however, the efficacy of this technique for uncommon AVNRT has only been reported in a few studies.20-23)

We performed electrogram-guided slow pathway ablation in 110 consecu-
Figure 6. Recordings of electrocardiograms and intracardiac electrogams during tachycardia and ventricular pacing in a patient with the slow-slow form of uncommon AVNRT with evidence of the lower common pathway. During AVNRT the electrocardiographic manifestations with retrograde P-waves superimposed on the terminal portion of the QRS were identical with those of the slow-fast form common AVNRT shown in the left panel. Intracardiac recordings revealed the earliest retrograde atrial activation at the coronary sinus ostium, contrary to the slow-fast form of common AVNRT (left panel). Ventricular pacing at tachycardia cycle length demonstrated a VA interval definitely longer than the HA interval during tachycardia shown in the right panel. This indicates the existence of the lower common pathway.

tive AVNRT patients, including 16 with the uncommon form. The acute success rate was 100% for both common and uncommon AVNRT. No late recurrence was observed in either type of AVNRT during a follow-up period (mean 24 months). Also, ablation data such as mean number of energy applications and mean total energy applied did not show any differences between the two types of AVNRT. These findings imply that slow pathway ablation is both highly effective and safe for both uncommon and common AVNRT.

Some differences were noticed concerning the post-ablation AVN physiology. In common AVNRT patients, slow pathway conduction remained with inducibility of one AVN echo in most patients (66%). In all of the uncommon AVNRT patients, however, the antegrade and retrograde slow pathway conduction were completely eliminated. The antegrade and retrograde slow pathways were simultaneously ablated at the same site in 5 slow-slow form uncommon AVNRT patients. These observations suggest that mapping of the earliest retrograde atrial activation site over the slow pathway during tachycardia or ventricu-
lar pacing may be the best way to identify the optimal ablation site with which to eliminate the slow pathway. It is well known that the slow pathway potential, also called Jackman’s potential, is not a specific marker indicative of the location of the slow pathway. This suggests that the retrograde and antegrade slow pathways may have different anatomical structures with respect to their atrial insertions, and it is conceivable that in the retrograde slow pathway its atrial insertions might be localized and susceptible to thermal damage caused by catheter ablation. These points need to be verified.

Radiofrequency catheter ablation which targets the slow pathway can eliminate common and uncommon AVNRT effectively and safely without affecting normal atrioventricular nodal conduction. Common AVNRT can be cured irrespective of the persistence of antegrade slow pathway conduction, while uncommon AVNRT appears to be eliminated by the eradication of slow pathway conduction. These results suggest that uncommon AVNRT may have a different anatomical substrate, which is not a reversed reentry of common AVNRT. A detailed anatomy study of the substrates as well as classification of the electrophysiological mechanism of uncommon AVNRT need to be conducted in the future.

REFERENCES