The Response of the Slow Atrioventricular Nodal Pathway to Temperature

Mihoko Kawabata, MD; Kenzo Hirao, MD; Nobuo Toshida, MD; Fumio Suzuki, MD; Kazumasa Hiejima, MD*

The present study attempted to determine the lowest temperature at which the slow atrioventricular nodal pathway responds to heating and the temperature necessary for successful ablation of the slow pathway in patients with atrioventricular nodal reentrant tachycardia (AVNRT). The study group comprised 23 consecutive patients (14 women, 9 men) with symptomatic AVNRT. Radiofrequency current was delivered at the slow pathway potential recording site using a HAT 200S catheter ablation system. Successful radiofrequency ablation of the slow pathway was achieved in all 23 patients. Junctional beats, suggesting the response of the slow pathway to temperature, were detected in 62 of the total 136 applications. The temperature measured at the first junctional beat was 45.4±4.2°C. The maximum temperature required for the successful ablation of AVNRT ranged from 45 to 88°C. There were no complications except for 1 patient with transient atrioventricular (AV) block. There were no recurrences of AVNRT during follow-up. The lowest temperature at which the slow pathway was responsive to heat was quite similar to that for accessory pathways or the AV junction. However, the temperature required for the successful ablation of AVNRT differed markedly among the patients. (Jpn Circ J 1999; 63: 427–432)

Key Words: Atrioventricular nodal reentrant tachycardia; Junctional beat; Radiofrequency catheter ablation; Slow pathway; Temperature

Catheter ablation using radiofrequency (RF) energy has emerged as the therapy of choice for patients with sustained supraventricular tachyrhythmias.1–4 Because thermal injury is the primary mechanism of myocardial injury in this procedure, tissue temperature is critically related to the success or failure of this therapy.5,6 Thus, monitoring of the electrode tip temperature has been proposed to facilitate effective catheter ablation by assuring adequate lesion formation, optimizing lesion size and preventing coagulum formation.6–8

Previous studies have described the response of the tissue to temperature during RF catheter ablation (RF-CA); that is, the temperature required for permanent loss of accessory pathway conduction and for atrioventricular (AV) block. The minimum temperature needed for an irreversible conduction block of an accessory pathway during RF-CA in patients with Wolff-Parkinson-White (WPW) syndrome is 48°C.9 For AV nodal conduction, the minimum temperature needed for reversible block is 45°C9 and that for irreversible block is 48–49°C.10,11 However, few studies have assessed the response of the slow AV nodal pathway to temperature.

In the present study, we attempted to determine the lowest temperature at which the slow pathway responds to heating and the temperature necessary for successful ablation of the slow pathway in patients with atrioventricular nodal reentrant tachycardia (AVNRT).

Methods

Characteristics of the Patients

The study population consisted of 23 consecutive patients with symptomatic AVNRT who underwent temperature-controlled selective slow pathway ablation. There were 14 women and 9 men with a mean age of 47±16 years. The types of AVNRT were 20 slow/fast and 3 fast/slow. The mean cycle length of AVNRT was 345.7±72.4 ms. The patients had received from 0 to 3 antiarrhythmic drugs before being referred for ablation. The patients’ characteristics are shown in Table I.

Procedure

Informed written consent was obtained from all patients prior to the procedure. The electrophysiological study was performed in a fasting, lightly sedated state using standard catheterization techniques. Three quadripolar electrode catheters were positioned at the right atrial appendage (RAA), His bundle position (HBE), and right ventricular apex. A decapolar electrode catheter was placed in the coronary sinus (CS). The stimuli used were 2 ms in duration and approximately twice the diastolic threshold in intensity, delivered by a programmed stimulator. The tracings from the surface ECG leads (I, II, V1 and V6) and bipolar intracardiac electrograms filtered at a band-pass of 50–500 Hz were displayed on a monitor and recorded on a thermal recorder at a paper speed of 100 mm/s.

Catheter ablation for AVNRT was performed by selective slow pathway ablation.12,13 Briefly, the electrode of the ablation catheter was positioned in the postero-septal region. In the right anterior oblique fluoroscopic projection, this was approximately the lowest third between the HBE catheter and the catheter as it entered the CS. A stable atrial-to-ventricular electrogram ratio of approximately 1:5

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was sought. The selection of the target site was based on the local electrogram (ie, the ‘slow pathway potential’ referred to as the ‘Asp’ potential by Jackman et al1).

In the present study, a 7F deflectable catheter with a 4-mm tip (Celebrate, Dr. Osypka GmbH, Grenzach, Germany) was used to deliver RF current from the tip electrode to a large skin electrode positioned on the back. A thermistor was incorporated into the distal electrode to allow for temperature monitoring. The energy source used for catheter ablation was a commercially available system (HAT 200S, Dr. Osypka) that delivered continuous unmodulated RF energy at a frequency of 500 kHz. During each RF application, the temperature, power output, impedance and application time were measured continuously and displayed on the computer monitor connected to the ablation catheter. The RF generator incorporated a closed feedback loop. The power supply automatically modulated the amount of power delivered (range, 0.5–50 W) so that the tip temperature approached but did not exceed the selected target temperature (40–95°C). The power output was automatically shut down if the impedance exceeded the preselected value by more than 10 ohms or if the impedance increased abruptly, or if the electrode temperature exceeded 100°C.

At each site, RF energy was delivered for 30–99 s or until dislodgement of the ablation catheter. In addition, energy application was terminated as soon as any evidence of AV or ventriculo-atrial (VA) block was detected. During the RF energy application, the occurrence of junctional beats was noted. A junctional beat was defined as any AV junctional premature depolarizations in which atrial activation proceeded initially from the AV junctional region to the RAA (low to high sequence), and the QRS complex was narrow. The initial target temperature was set at

<table>
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<th>Sex</th>
<th>Age (years)</th>
<th>AVNRT type</th>
<th>Prior medication</th>
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AVNRT, atrioventricular nodal reentrant tachycardia; V, verapamil; Di, digoxin; C, cibenzoline; A, aprindine; P, pilsciaainide; D, disopyramide; WPW (B), Wolff-Parkinson-White syndrome type B.
Temperature Required for Slow Pathway Ablation

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50–60°C and unless junctional beats appeared, the target temperature could be increased in increments of <5°C to a maximum of 95°C. If the application was interpreted as successful, attempts to re-induce AVNRT were made. Programmed stimulation to re-induce AVNRT was repeated during an infusion of isoproterenol. A successful outcome was defined as no induction or the induction of only one AV nodal echo beat with or without an intravenous isoproterenol infusion.

The time from the initiation of RF energy delivery to the onset of accelerated junctional beats was measured for all applications that induced junctional beats. The temperature and power were also measured at the initial appearance of junctional beats. The maximum temperature and power drawn during successful and unsuccessful RF applications were compared.

Data Analysis
Continuous data are expressed as mean value ± SD. Analysis of variance and paired t-test were utilized for statistical analysis. P values <0.05 were considered significant.

Results
Clinical Results
The catheter ablation of the slow pathway was successful in all 23 patients. The mean number of applications of RF energy per patient was 5.9±3.3 (range: 1–14). There were no complications except for 1 patient with transient AV block. There were no recurrences of AVNRT during follow-up from 107 to 1,003 days.

Relation Between Junctional Beats and Temperature
Of the total 136 RF applications, junctional beats were induced in 62 (45.6%). The temperature associated with the initial appearance of junctional beats is shown in Fig 1, showing a representative graph of simultaneous recordings of catheter tip temperature and the intracardiac electrograms during successful energy delivery in a patient with slow/fast AVNRT.

Histograms of the catheter tip temperature associated with the first junctional beat displayed a normal distribution (Fig 2); the temperature was most frequently in the range of 42°C and 46°C. The catheter tip temperature at onset of junctional beats was 45.4±4.2°C (range, 35–54°C). Junctional beats were observed at 20.9±20.7 s (range, 0.5–76.1 s) after the initiation of RF current delivery.

Relation Between The Outcome, Temperature, and Power
The effect of RF energy application on the inducibility of AVNRT was investigated in 35 of the 62 applications that induced junctional beats, including 23 in which the ablation was successful. The temperature measured at the first junctional beat was on average 45.4°C for the successful applications, and 45.9°C for the unsuccessful applications, with no significant difference (Fig 3). No significant difference was observed in the power measured at the first junctional beat between the successful (average 25.1 W) and the unsuccessful applications (average 28.9 W). The junctional beat onset time was 18.2±19.9 s for the successful applications, and 22.2±22.3 s for the unsuccessful applications, with no significant difference.

The maximum temperature during RF energy applications inducing junctional beats was examined. In the successful applications, the maximum temperature differed
markedly, ranging from 45 to 88°C (Fig 4).

Among the 62 RF applications that induced junctional beats, we did not investigate the effect on the inducibility of AVNRT in 27 applications because the junctional beats were faint (ie, very few isolated junctional beats, a few junctional beats occurring just before stopping the RF energy delivery). The sensitivity, specificity, and positive predictive values as predictors of successful ablation were 100%, 37%, and 100%, respectively.

**Discussion**

**Main Findings**

We investigated the response of the slow pathway to temperature to determine the minimum temperature required for inducing junctional beats and treating AVNRT. The temperature monitoring at the tip of the ablation catheter during the RF ablation of the slow pathway revealed the following: (1) the minimum temperature required for the induction of junctional beats was 45.4±4.2°C; (2) the minimum temperature required for successful RF ablation of AVNRT was 45°C; and (3) every RF application that induced junctional beats did not successfully ablate AVNRT.

In the present study, there was no significant difference in the temperature at the onset of junctional beats between the successful and unsuccessful applications. Regardless of whether AVNRT was cured, junctional beats were induced when the slow pathway was injured by heat. In successful applications, the unit of slow pathway which responds to the temperature and induces junctional beats could be critical to maintain AVNRT, whereas in unsuccessful applications, there could be other units essential to AVNRT. The temperature required for the successful ablation of AVNRT differed markedly among the patients; one explanation is that the slow pathway may consist of multiple components present in various degrees in each patient. Beckman et al reported evidence for multiple slow pathways during RF ablation in patients with AVNRT. Additional slow pathways were recognized after an RF application by (1) persistence of retrograde slow pathway conduction with a shift in the site of earliest atrial activation and an increase in VA interval or (2) persistence of AVNRT with an increased atrio-His (AH) interval and loss of anterograde slow pathway conduction at the ablation site but recording of slow pathway potentials at another site.

There was no significant difference in the mean onset time of the junctional beats between the successful and unsuccessful applications. However, even among the successful applications the onset time was widely dispersed. One reason for this is that the time required to reach an adequate temperature for inducing the junctional beats differed among the applications.

**Comparison With Previous Studies**

In an animal study, Nath et al found that the temperatures necessary for reversible and irreversible loss of excitability in ventricular myocardium were 48.0°C and 50.0°C, respectively. Haines and Watson reported a temperature range of 46.6–48.9°C in the marginal area between viable and nonviable tissue estimated in vitro using the right ventricle. Hirao et al performed temperature monitoring catheter ablation of the AV junction in dogs and the threshold temperatures at which a transient effect and a permanent effect on AV conduction were observed were 45 and 49°C, respectively.

In a clinical study, Calkins et al reported that the mean temperature achieved during the ablation of the slow pathway for the treatment of AVNRT was 59°C. Epstein et al demonstrated that the minimum temperature required for the successful ablation of the slow pathway was 48°C, and that for the appearance of junctional beats was also 48°C.

In terms of AV junction ablation, the mean temperature associated with the appearance of AV nodal block was 58–70°C. The mean temperature associated with the development of accelerated junctional beats was 47–51°C.

Most of these data were the mean temperature, not the minimum temperature. However, these results were quite similar to our present findings. The differences noted between the previously reported temperature data and the
present observations could be due to differences in the methods used for the ablation, and the measurement of the temperature.

Junctional Beats
As has been previously reported, the occurrence of junctional beats during RF energy application is a sensitive but not specific predictor of successful slow pathway ablation.12,15–18 The incidence of junctional beats during the successful ablation of AVNRT was 75–100%. The positive predictive value obtained in the present study is quite similar to those of prior reports.16,17 It has been postulated that junctional beats are due to an enhanced automaticity of AV nodal cells in response to thermal injury of the slow pathway.

Study Limitations
Blouin et al compared the effect of thermistor location on the accuracy of temperature readings.25 A thermistor embedded in the tip of the catheter is believed to be more accurate than an inner-wall thermistor. However, the temperature measured during RF energy application may be affected by catheter orientation, contact pressure, catheter stability and blood flow, among other factors.26–30 Therefore, measurements of the catheter-tissue interface temperature do not necessarily represent the myocardial temperature near the slow pathway.

Regarding WPW syndrome, disappearance of the delta wave is considered to indicate that a cure has been achieved. However, during the ablation of AVNRT, the moment of successful ablation cannot be recognized, and therefore, the temperature at that moment cannot be identified.

Clinical Implications
The results of the present study suggest that unless the electrode temperature reaches 45.4–4.2°C (mean ± SD) with sufficient power, there is little possibility of the appearance of junctional beats, and therefore the catheter orientation and electrode-tissue contact pressure should be corrected. During RF-CA of AVNRT, if junctional beats do not appear despite an increase in temperature to more than 45.4+4.2°C (mean ± SD), the ablation catheter may be at an inappropriate target site. If the inducibility of AVNRT is not eliminated by applications with sufficient temperature and junctional beats occurrence, it may be that the slow pathway consists of multiple components. To eliminate AVNRT-related slow pathway conduction, the target site should be directed anteriorly or transversely. Further trials with greater numbers of patients are needed to clarify the response of the slow pathway to temperature.

References