Radiofrequency Catheter Ablation for Sinoatrial Node Reentrant Tachycardia

— Electrophysiologic Features of Ablation Sites —

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The aim of this study was to investigate catheter ablation of sino-atrial reentrant tachycardia (SART) and the electrophysiologic characteristics of the ablation sites. From January 1990 to October 1997, 651 patients with supraventricular tachycardia were referred and 11 patients were found to have SART. Ablation was successful in all cases with a mean number of 3.3 radiofrequency (RF) current pulses. SART terminated during 22 of 36 RF pulses. In spite of prompt termination, tachycardia could be re-induced in 3 of 11 patients with its earliest activation site shifted. At effective ablation sites, the electrograms during tachycardia were characterized as fractionated (75 ± 17 ms), and 38 ± 16 ms prior to surface P wave, and 42 ± 18 ms prior to the high right atrium. Unipolar electrograms revealed a sharp negative unipolar deflection, so called QS pattern, in 15 of 20 sites during SART and 15 of 15 sites during sinus rhythm. During effective applications, atrial premature beats (APB) with activation sequences identical to sinus rhythm appeared in 14 of 22 cases. Effective ablation sites of SART showed fractionated electrograms during tachycardia and sinus rhythm. Unipolar electrogram with a QS pattern and APB during energy application could be an indicator of the optimal ablation sites. (*Jpn Circ J* 1999; 63: 177–183)

Key Words: Ablation site; Atrial premature beat; Catheter ablation; Sino-atrial reentrant tachycardia; Unipolar electrogram

Sino-atrial reentrant tachycardia (SART) was first suggested theoretically by Barker et al¹ in 1943 as a mechanism of supraventricular tachycardia. It has been recognized since as an uncommon cause of supraventricular tachycardia and its clinical and electrophysiologic characteristics remain undefined. For example, it is not clear whether the reentrant circuit is completely confined to the sinus node or if surrounding atrial tissue is involved.

Before the catheter ablation era, pharmacological and/or surgical therapy were the only possible treatments. Now catheter ablation provides a less invasive option for treating various kinds of arrhythmias. However, there are few available reports about catheter ablation of SART and the electrophysiological characteristics of the successful ablation site.

Here we present an electrophysiological study and radiofrequency catheter ablation (RF-CA) of sustained SART in 11 patients retrospectively, and we evaluate the electrophysiological characteristics of the ablation site.

Methods

Study Population

Eleven patients with SART were referred for electro-

physiologic study and treatment of tachycardia by RF-CA. There were 10 women and 1 man with a mean age of 53.9 ± 14.3 years (range, 21–71 years). Sustained SART (lasting more than 30 s) was inducible in all patients during the electrophysiologic study. Patients with non-sustained SART were not included.

Electrophysiological Study

Before the electrophysiological study and catheter ablation, written informed consent was obtained from all patients. The electrophysiological study was performed in the fasting state and at least 5 half-lives after discontinuation of antiarrhythmic drugs. Patients were given diazepam for sedation. Three 5Fr quadripolar electrode catheters (5 mm interelectrode distance; USCI, Billerica, MA, USA) were introduced via the femoral vein and positioned in the high right atrium, His bundle region, and right ventricular apex. A 5Fr hexapolar catheter (5 mm interelectrode distance; USCI) was introduced via the subclavian vein and positioned in the coronary sinus. Surface electrocardiograms and intracardiac electrograms were monitored, recorded and analyzed using an EP Lab system (Quinton Electrophysiological Corporation, Toronto, Canada). Electrical stimulation was performed using a digital stimulator (Nihon Kohden, Tokyo, Japan) delivering 2.0 ms constant current pulses at twice the late systolic threshold ratio. The stimulation protocol consisted of atrial and ventricular incremental pacing, programmed stimulation with single atrial and ventricular extrastimuli following a 6-beat drive train. If sustained arrhythmia could not be induced in the baseline state, isoproterenol was administered and titrated to achieve at least a 20% increase in heart

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Table 1 Characteristics of the Study Patients

Patient no.	Age (yr)	Sex	Heart disease	Concomitant arrhythmia	F/U (month)	Induction mode	CL (msec)
1	61	F	None	AVNRT	42	AP, APS	375
2	47	F	None	AVNRT	33	APS	380
3	68	F	HT	None	29	AP, AES	470
4	45	F	OMC	AFL	17	APS	385
5	61	F	None	None	14	APS	430
6	71	F	None	AVNRT	11	AP, APS	450
7	46	F	None	AVRT	10	AP, APS	380
8	59	M	None	AT	7	APS	470
9	49	F	None	AVRT	6	AP, APS	450
10	65	F	None	None	4	AP	390
11	21	F	None	AVRT	9	AP	385

HT, hypertension; OMC, open mitral commissurotomy; AVNRT, atrioventricular nodal reentrant tachycardia; AFL, atrial flutter; AVRT, atrioventricular tachycardia; AT, atrial tachycardia; F/U, follow up; AP, atrial pacing; APS, atrial programmed stimulation; AES, atrial extrastimulus; CL, cycle length.

rate. The stimulation protocol was then repeated.

Adenosine triphosphate (ATP) was used to evaluate the mechanism of tachycardia and was administered as a rapid 10mg bolus injection through a subclavian catheter sheath that was introduced into the subclavian vein, followed by a 10ml bolus of normal saline flush solution. If SART was terminated by the 10mg iv, the ATP dose was reduced and re-injected in the same way until SART was not terminated by the iv injection. If the tachycardia was not terminated by the 10mg iv, the ATP dose was increased.

Either carotid sinus massage or Aschner's maneuver, or both, were performed during tachycardia to test vagal effect.

Definition of SART

Sinus node reentry was diagnosed when the following criteria, described by Narula et al² were observed: (1) morphologies of the surface P wave and endocardial activation sequence during tachycardia identical to those during normal sinus rhythm, (2) reproducible initiation and termination of tachycardia with atrial stimulation, (3) termination with ATP injection or with maneuvers that increase vagal tone, and (4) onset and termination occurring with an abrupt change in rate from normal sinus rhythm. All electrophysiologic data were measured and analyzed by 3 experienced electrophysiologists.

Ablation Procedure

After electrophysiologic evaluation, a 7Fr quadripolar, deflectable large-tip catheter (EP Technology, San Jose, CA, USA/Cardiac Pathway Corporation, Sunnyvale, CA, USA/Medtronic, Minneapolis, MN, USA) was introduced via the femoral vein for mapping and ablation. An RF current of 500kHz was delivered at 35–70V and 15–45W using a RF pulse generator (NL 50-I [Central Industry, Chiba, Japan] or EPT1000 [EP Technology] or Attackr [Medtronic]) between the distal large-tip electrode and an electrosurgical adhesive ground plate (Pfizer, USA or Niko, Denmark) on the patient's back. Current application was immediately discontinued in the event of an increase of impedance of more than 30 ohms, increase of temperature above 70°C, or dislodging of the electrode catheter. RF energy was applied until SART was no longer inducible by single and double atrial extrastimuli or by incremental atrial pacing in the baseline state and during isoproterenol infusion (1–2mg/min). Intravenous heparin was administered at an initial dose of 5000 units at the beginning of the

study, and an infusion of 1000 units/h continued during the procedure.

The RF energy application was considered effective when SART was terminated and ineffective when SART was not terminated. The electrophysiologic characteristics of all effective sites were analyzed.

Post-Ablation Electrophysiological Study and Follow-Up

The post-ablation electrophysiological study was completed 30min after the ablation procedure to determine the effects of RF ablation and to evaluate sinus node function. Surface ECG, echocardiogram, and Holter monitoring were obtained after return from the EP laboratory. All patients were discharged without antiarrhythmic drug therapy.

Outpatient follow-up visits were scheduled for 1, 2, 4, and 6 months after the procedure. Long-term efficacy was assessed clinically on the basis of the resting ECG, 24-hour Holter recording, and clinical symptoms.

Statistical Analysis

All data are expressed as mean $\pm$ standard deviation (SD). Statistical comparisons were performed using Student's t test for paired values. A p-value of <0.05 was considered statistically significant.

Results

Patient Characteristics

The clinical characteristics of the patients undergoing electrophysiologic study and catheter ablation are shown in Table 1. Only 1 patient had structural heart disease (mitral valve stenosis). One patient had hypertension and another patient had rheumatic arthritis. In all patients, the electrophysiologic consultation was prompted by recurrent episodes of palpitation. Seven patients had at least 1 episode of clinically documented symptomatic tachycardia with P wave configurations identical to those of sinus rhythms.

Baseline Electrophysiological Study

During the electrophysiological study, sustained SART was inducible by atrial programmed stimulation in 9 cases and atrial burst pacing in 7 cases. Isoproterenol was required to induce SART in 3 of the 11 cases. An inverse relationship between the prematurity of tachycardia initiating extrastimulus and the coupling interval of the first

ATP 2.5 mg

CSM

11/22/'96

Fig 1. Intracardiac ECG during adenosine triphosphate (ATP) injection and carotid sinus massage (CSM) in patient 5. (A) SART terminated by ATP 2.5mg injection. (B) SART terminated by carotid sinus massage. SR, sinus rhythm; III, surface ECG lead III; HRA, high right atrium; HBE, His bundle electrogram; CS, coronary sinus; RVA, right ventricular apex; d, distal; p, proximal.

3/27/'97

Fig 2. Termination of SART by radiofrequency (RF) energy application in patient 7. I, II, surface ECG leads I, II; ABL, ablation.

Fig 3. Successful ablation site in patient 6. I, V1, surface ECG leads I, V1; ABL, ablation; UN, unipolar; m, middle; CL, cycle length; RAO, right anterior oblique; LAO, left anterior oblique. The configuration of P wave and intra-atrial activation sequences were identical between sinus rhythm (left) and SART (middle). The ablation catheter positioned at the earliest activation site close to the sinus node (right). There the interval between the onset of local atrial activation and surface P wave was 6ms, the duration of local atrial activation was 67ms, and the unipolar electrogram revealed a QS pattern.

Fig 4. Atrial premature beat (APB) during RF energy application in patient 5. APBs (asterisk), which had activation sequences identical to those of sinus rhythm (SR), appeared during RF energy application.

tachycardia beat was found in 6 patients. The tachycardia cycle length ranged from 375 to 470 ms (mean, 415 ± 39 ms). Introduction of a single atrial extrastimulus during tachycardia reproducibly reset or terminated the tachycardia. The relationship between the coupling interval of atrial

extrastimulus and the post-extrastimulus interval showed an increasing or mixed pattern in 6 patients.

Atrioventricular reentrant tachycardia was also inducible in 3 patients. Common form atrioventricular nodal reentrant tachycardia was inducible in 3, adenosine-sensitive

ABLATION SITE

Fig 5. Catheter position during ablation (patient 3). SART terminated during the 1st and 3rd RF pulses. The earliest activation site (white arrow) during SART shifted after each RF pulse. SART became noninducible after the 4th RF pulse. There was 7 mm between the 1st and 4th ablation sites.

intra-atrial reentrant tachycardia originating from an atrioventricular (AV) node lesion was inducible in 1, and common atrial flutter was inducible in 1 patient.

Response to ATP and Vagal Maneuver

ATP was injected during SART in 6 cases to evaluate the response. SART was terminated by ATP injection in all 6 cases. The minimum dose of ATP required to terminate tachycardia was 4.3 ± 2.7 mg (range, 2.0–10.0 mg).

Vagal maneuver was performed during tachycardia in 5 cases and SART was terminated by it in all 5 patients. Tachycardia terminated without atrioventricular conduction block in all cases (Fig 1).

Catheter Ablation

Before ablation for SART, RF current application was performed for combined tachycardia. All combined tachycardias were ablated successfully and smoothly.

During mapping of SART in the high right atrium, the

earliest atrial electrogram that suggested an appropriate site of RF energy application was noted at the region of the sinus node. Eleven patients were ablated with a total of 36 RF pulses. Twenty-two of the RF pulses were successful in terminating SART (Fig 2). We successfully ablated in these 11 patients with a mean maximum wattage (32 ± 13 W; range, 14–45 W), voltage (54 ± 10 V; range, 37–70 V), and temperature ($49 \pm 4^\circ\text{C}$; range, 42–55°C) for 15–60 s, requiring a mean of 3.3 ± 1.8 RF pulses (range, 1–7).

At effective ablation sites, the mean timing of the local endocardial electrogram relative to p wave onset was 38 ± 16 ms (range, 8–65 ms) during SART, and 37 ± 23 ms (range, 6–75 ms) during sinus rhythm. Relative to high right atrial activation, the mean timing was 42 ± 18 ms (range, 15–66 ms) during SART and 31 ± 20 ms (range, 0–75 ms) during sinus rhythm. The mean duration of the local atrial electrogram during SART at the effective ablation site was 75 ± 17 ms (range, 56–123 ms) during tachycardia and 73 ± 13 ms (range, 52–95 ms) during sinus rhythm.

All atrial electrograms were markedly prolonged and fractionated during tachycardia and sinus rhythm. Fig 3 shows intracardiac electrograms during sinus rhythm and SART, and the catheter position at the successful ablation site in case 6.

Unipolar electrograms at effective sites revealed a QS pattern in 15 of 20 sites during SART and in 15 of 15 sites in which unipolar electrograms were recorded during sinus rhythm.

During effective energy applications, atrial premature beats (APB) appeared during 14 of 22 applications (64%), but appeared only during 3 of 12 (25%) ineffective applications. The difference between these 2 was statistically significant ($p < 0.05$). Intra-atrial activation sequences between sinus rhythm and APB were identical in all cases (Fig 4).

After SART was terminated once by RF current, the tachycardia was still inducible during programmed stimulation in 6 of 11 cases, and was associated with shifts in the site of earliest atrial activation from about 2 to 7 mm (mean, 4.3 mm) laterally and inferiorly from the initial site of current application (Fig 5). In these cases RF current was applied repeatedly until tachycardia became noninducible.

Post-Ablation Electrophysiological Study and Complications

Atrial programmed study with single and double extrastimuli and atrial burst pacing was performed 30 min after the last RF current application in all patients to make sure that SART became noninducible at the baseline and in the isoproterenol-infusion state. No combined arrhythmia could be induced. There was no evidence of significant sinus node dysfunction after ablation for SART in any patient. Sinus cycle lengths before and after ablation were 685 ± 95 ms and 619 ± 111 ms, respectively. Sinus node recovery times before and after ablation were 845 ± 225 ms and 777 ± 139 ms, respectively. Differences between these parameters were not statistically significant.

There were no complications such as pericardial effusion, deterioration in ventricular function, intracardiac thrombus, or a new valvular dysfunction by the estimation of echocardiogram after RF energy application.

Follow-Up

During a mean follow-up period of 17 ± 13 months (range, 4–42 months) in which no antiarrhythmic drugs were administered, neither SART nor combined tachycardia recurred. They were free from symptoms, and new arrhythmias related to RF ablation have not been detected on 24-h Holter monitoring during the follow-up periods.

Discussion

Clinical Features of SART

SART is a relatively infrequent tachycardia. From January 1990 to October 1997, 651 patients were referred to us for electrophysiologic study and catheter ablation because of supraventricular tachycardia. Eleven patients (2%) were found to have sustained SART. This 2.0% incidence is consistent with incidences reported by Josephson (3%)³, Wellens (1.8%)⁴ and Sanders et al (3.2%)⁵.

In the Gomes et al series, 11 patients had SART, and 9 of these had organic heart disease, so it was concluded that SART is frequently associated with organic heart disease.⁶ In our study there was only 1 patient with structural heart

disease. In the Sanders et al. study, only 3 of 11 SART patients had organic heart disease. Thus it may not be true that a majority of patients with SART have structural heart disease.

Gomes et al reported that no patients in their series had other arrhythmias.⁶ However, in the Sanders et al⁵ series, 9 of 11 patients had concomitant arrhythmias: atrioventricular nodal reentrant tachycardia ($n=6$), atrioventricular reciprocating tachycardia ($n=2$), and ectopic atrial tachycardia ($n=1$). Sanders et al also stated the most commonly associated supraventricular tachycardia was typical atrioventricular nodal reentrant tachycardia. In the present study 8 of the 11 patients had another tachycardia. Three of the 8 had common type atrioventricular nodal reentrant tachycardia documented at electrophysiological study, which might imply some relationship between atrioventricular nodal tachycardia and SART.

Catheter Ablation

There have been some preliminary reports about catheter ablation of SART. In 1993, Gossinger et al reported on catheter ablation in 7 cases of atrial tachycardia in the region of the sinus node.⁷ SART catheter ablation was reported by Kay et al⁸ in 4 patients, Lesh et al⁹ in 3, Sanders et al⁵ in 10, Gomes et al¹⁰ in 2 and Poty et al¹¹ in 3. Ablation was successful in all but one case without complications including sinus node dysfunction. In our study, SART was ablated successfully in all 11 cases without complication. These data suggest that RF-CA is safe and effective for the treatment of SART.

Electrophysiologic Characteristics of the Ablation Site

In the present study, features found at the effective ablation site during SART were as follows: (1) atrial activation preceding the onset of p wave by 38 ± 16 ms, (2) atrial activation preceding the onset of high right atrial activation by 42 ± 18 ms, and (3) significantly prolonged fractionated electrogram (mean duration, 75 ± 17 ms). These data are consistent with data reported by Sanders et al, Gomes et al and Kay et al. Poty et al reported that local electrogram duration and morphologic features did not seem to be relative markers of successful sites, but rather that fractionated electrograms may be more representative of diffuse atrial disease than of the exit site of tachycardia. According to the Sanders et al and Gomes et al reports, however, there was fragmentation of the electrogram at the successful site, and fragmentation suggested that the area effected was the area of slow conduction. In previous reports there have been no data concerning the electrophysiologic characteristics of the ablation site during sinus rhythm. In this study, we investigated electrograms at the effective ablation site during sinus rhythm. These electrograms were characterized as fractionated (73 ± 13 ms), and a mean of 37 ± 23 ms prior to the onset of P wave, and a mean of 31 ± 20 ms prior to the onset of the high right atrial electrogram. In our study population all atrial electrograms at the effective ablation sites were markedly fractionated not only during SART but also during sinus rhythm. We only mapped around the sinus node in the high lateral right atrium. We did not examine whether electrograms at other sites revealed fractionated potential. The significance of fractionated atrial electrograms requires further investigation and the acquisition of more data.

In our study, unipolar electrogram showed a pure negative deflection, the so-called QS pattern, at the effective

ablation site in 15 of 20 RF pulses during sinus rhythm. Unipolar electrogram during tachycardia could be a simple indicator of the optimal ablation site for SART. It also suggests that the critical regions (the reentry circuit itself or the reentry circuit exit) of SART were included in the sinus node. It has not been clarified whether the reentry circuit of SART is included within the sinus node or whether it extends to peri-nodal atrial tissue. As reported by Gomes et al¹⁰, whether the head of the sinus node or sino-atrial tissue is being ablated is still not clear. Our data might be a clue to solving these issues.

During effective energy application, APB appeared in 14 of 22 RF pulses, and appeared in 3 of 12 RF pulses during ineffective energy application. The difference was statistically significant. The activation sequence of the APB was identical to that of sinus rhythm, which probably means that the heat of the RF current reached and affected the sinus node itself. As for catheter ablation for atrioventricular nodal reentrant tachycardia, there has been a previous report¹² in which junctional rhythm during RF application was a predictor of a successful result. In the same way, these APB have the potential to be a new indicator of successful energy application for SART.

SART was successfully ablated by single applications of RF energy in 4 of 11 patients. However, in 6 patients, after SART was terminated by RF application, tachycardia could be reinduced by atrial extrastimulus, and in 3 patients it was associated with a slight shift in the site of earliest atrial activation. In these patients the earliest recorded atrial activation shifted 2–7 mm laterally or inferiorly after the initial application (mean, 4.3 mm), which indicates that successful ablation of SART requires energy application over a considerably large area, extending 2–7 mm in the region of the sinus node.

Complications and Limitations

We observed no complications. To evaluate sinus node function, we examined sinus heart rate and sinus node recovery time pre- and post-ablation, as well as ECG and 24-h Holter ECG monitoring. In previous studies sinus node dysfunction has not been caused by RF current. There might be less potential for sinus node dysfunction than we expected, which is probably because the sinus node occupied an area larger than the lesion created by the RF current.

The present study was limited by the low number of cases studied due to the infrequent occurrence of SART.

Conclusion

SART was treated successfully without sinus node dysfunction by RF-CA at the earliest atrial electrogram recording site during tachycardia. The successful site revealed a fractionated atrial electrogram not only during tachycardia but also during sinus rhythm. SART can be reinduced after termination by energy application, and it is associated with a slight shift in the site of earliest atrial activation. The QS pattern of unipolar electrograms can be a marker of the optimal ablation site, and APB appearing during energy delivery have the potential to be a predictor of successful application.

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