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Temperature-Guided Radiofrequency Catheter Ablation of Accessory Pathway

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Objectives : *This study was performed to evaluate the usefulness of temperature-guided radiofrequency catheter ablation for the elimination of accessory pathway conduction in patients with Wolff-Parkinson-White syndrome.*

Methods : *Temperature-guided radiofrequency catheter ablation was attempted in 138 patients with 144 accessory pathways (88 pathways along the left free wall, 5 in the anteroseptal region, 2 in the midseptal region, 19 in the posteroseptal region and 30 along the right free wall). The energy source was a HAT 200S which regulated the power automatically to the set temperature of 70℃. Radiofrequency current was delivered through a thermocatheter to the atrial or ventricular side of mitral or tricuspid annulus.*

Results : *Accessory pathway conduction was eliminated in 130 of 144 pathways (90.3%). The mean power outputs of the successful ablations at the atrial side of the annulus were higher than those at the ventricular side (34.0±8.9W versus 20.0 ±7.6W, $p<0.01$). but the maximum temperatures were lower at the atrial side of the annulus than those at the ventricular side (66.4±14.0℃ versus 77.2±6.4℃, $p< 0.01$).*

There were 3 non-fatal complications (2.1%), 2 patients with hemopericardium and 1 with femoral artery thrombus, during or after ablation procedures.

Recurrences of AV re-entrant tachycardia or delta wave on the electrocardiogram occured in 4 patients (2.8%) who had successful second procedures. There were no late complications during a mean follow-up period of 41±25 months (range, 3 to 55).

Conclusion : *We conclude that 1) temperature-guided radiofrequency catheter ablation can be performed reliably and safely in eliminating accessory pathway conduction in patients with WPW syndrome, and 2) temperature monitoring and adjustment of the power to the set temperature during ablation would be useful for the avoidance of impedance rises and coagulum formation.*

Key Words : *Radiofrequency catheter ablation, Temperature-guided ablation, Wolff-Parkinson-White syndrome*

INTRODUCTION

During the last several years, catheter ablation techniques using radiofrequency current have developed dramatically and have become the

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method of choice for the ablation of the accessory pathways, with a success rate of more than 90%[1-4].

The ablative effect of radiofrequency energy is based on direct electrical (resistive) heating as well as passive (conductive) heating of the tissue adjacent to the ablating electrode, which induces dessication injury to the tissue and results in coagulation necrosis[5]. Delivered power can be used as a parameter to control the amount of myocardial damage under controlled experimental conditions and, generally, the amount of heat generated relates to the amount of power delivered[6]. However, in the clinical situation, a large number of variables, including power output, duration of energy delivery, contact pressure of ablation electrode, size of electrode tip and cavity blood flow may affect the lesion volume of radiofrequency energy application[7-11], and the correlation between these variables and resultant lesion volume has been demonstrated to be poor[8, 10]. Assuming that temperature itself is the basis for the electrophysiologic effects of radiofrequency energy, the temperature of the electrode-tissue interface is a more reliable and better predictor of radiofrequency lesion volume than the other variables affecting the efficiency of radiofrequency ablation[8-10].

There are very few published studies which were carefully performed to investigate the effects of temperature-guided radiofrequency catheter ablation of the accessory pathway. This investigation was performed to report the results and complications of temperature-guided radiofrequency catheter ablation for the elimination of accessory pathways in patients with Wolff-Parkinson-White syndrome.

MATERIALS AND METHODS

1. Study Population

From December 1992 to March 1997, 138 patients with symptomatic paroxysmal supraventricular tachycardia associated with accessory pathway underwent temperature-guided radiofrequency catheter ablations in our laboratory. There were 93 male and 45 female patients with a mean age of 41±14 year (range, 11 to 70). All patients had symptomatic paroxysmal supraventricular tachycardia for 14±12 years (range. 1 to 50) and had previously been treated with antiarrhythmic drugs without control of their arrhythmia or with intolerable adverse effects requiring drug withdrawal. There were two patients with tachy-brady syndrome and one patient with multiple myeloma.

2. Electrophysiologic Study

Electrophysiologic study and catheter ablation were performed under the protocols approved by the Institutional Review Board of the Seoul National University Hospital. After providing written, informed consent for the procedure, each patient was studied in the fasting state under light sedation with valium or midazolam. All antiarrhythmic drugs had been discontinued for at least 5 half-lives before the study. Three quadripolar electrode catheters were positioned in the high right atrium, his bundle, and right ventricle through femoral vein. A fourth quadripolar electrode catheter was positioned in the coronary sinus through left subclavian vein. These catheters were used for programmed electrical stimulation and for localization of the accessory pathways. Standard ECG leads I, II, III and the intracardiac electrograms were recorded simultaneously at a paper speed of 50 to 100mm/sec on a multichannel oscilloscopic recorder (EVR 130, PPG Biomedical Systems, Cardiovascular Div., Pleasantville. New York, or EP Lab, Quinton Electrophysiology Corporation). All filters were set from 30 to 500Hz. Electrical stimulation was performed with a programmable stimulator (DTU-201, Bloom Associates Ltd., Reading, Pa.), at a pulse duration of 2msec and an intensity of twice the diastolic threshold. The stimulation protocol consisted of atrial and ventricular incremental pacing and extra-stimulation to assess the conduction properties of AV node and accessory pathway, to define the mechanism of tachycardia and to locallize the accessory pathway. Standard definitions were used for the pre-excitation syndrome[12].

3. Endocardial Mapping and Ablation

A bipolar and deflectable thermocatheter (Cerablate, Dr. Osypka GmbH Medizintechnik, Ger-

many), with a built-in thermister and a large- tip electrode (length 4mm), was used for precise mapping and ablation under biplane fluoroscopic guidance. The thermocatheter was inserted through a patent foramen ovale or by retrograde transaortic approach to the atrial or ventricular side of mitral annulus for the left-sided accessory pathway, and by venous approach to the atrial side of tricuspid annulus for the right-sided accessory pathway. Target sites were selected based on the presence of the possible accessory pathway potentials near the earliest ventricular activation during antegrade accessory pathway conduction (sinus rhythm) and near the earliest atrial activation during retrograde accessory pathway conduction (AV re-entrant tachycardia or ventricular pacing)[16]. The proximity of the electrode to the annulus was confirmed by recording a distinct atrial potential[1].

Radiofrequency current (continuous wave, 500 KHz) was generated from HAT 200S (Dr Osypka GmbH Medizintechnik, Germany). The radiofrequency generator automatically delivered the power (up to a maximum of 50 W) necessary to heat the electrode tip to the set temperature of 70 ℃. Radiofrequency current was delivered for 20 to 40 seconds between the distal electrode of the ablation catheter and a large, indifferent neutral-electrode that was placed over the left scapula during sinus rhythm in patients with pre-excitation and during tachycardia or ventricular pacing in patients with accessory pathway that conducted only in the retrograde conduction. Energy delivery was stopped immediately if the catheter became dislodged or if an impedance rise was observed. Intravenous heparin was administered in a bolus dose of 5,000 units for the ablation of left-sided accessory pathway and 3,000 units for the ablation of right-sided accessory pathway at the onset of the procedure.

Thirty minutes after the final application of radiofrequency current, atrial and ventricular stimulation was repeated to verify the absence of accessory pathway conduction and to exclude the presence of another accessory pathway and other arrhythmias, such as AV nodal re-entrant tachycardia.

4. Post-ablation Management

After the procedure, the first 27 patients were monitored in the coronary care unit for 24 hours and serum creatine kinase and creatine kinase-MB fraction concentrations were measured every 8 hours for 24 hours. The remaining patients were monitored in the coronary care unit only for 3 to 6 hours and the serum enzymes were not measured.

Echocardiography was performed a day before and after the ablation procedure to evaluate specifically the integrity of the valves and to search for intracardiac thrombus, hemopericardium, and regional wall motion abnormality. All patients with successful ablation were discharged without antiarrhythmic drugs. Antiarrhythmic drug therapy was continued for the patients with failed ablation.

Patients were followed by the investigators to diagnose the recurrence of accessory pathway conduction and late complications on the basis of clinical symptoms, standard 12 lead ECG and Holter recording at one month and three months after hospital discharge.

5. Statistical Analysis

All data were expressed as mean value±SD. Statistical comparisons were performed by Student's t-test for paired values. Test results with a P value of less than 0.05 were considered statistically significant.

RESULTS

A total of 144 accessory pathways was identified in 138 patients. One hundred and thirty-two patients had one accessory pathway and 6 patients had two accessory pathways. The locations and conduction properties of the accessory pathways are shown in Table 1. Of the 144 accessory pathway, 88 pathways (61%) were located along the left free wall, 5 pathway (3%) in the anteroseptal region, 2 pathways (1%) in the midseptal region, 19 pathway (14%) in the posteroseptal region and 30 pathways (22%) along the right free wall. Accessory pathways were conducted in both antegrade and retrograde direction in 74 pathways (51%) and only in the

Table 1. Characteristics of Accessory Pathways

AP Location	No of Pathways	Antegrade and Retrograde Cond	Retrograde Cond only
LFW	88	30	58
AS	5	3	2
MS	2	2	0
PS	19	12	7
RFW	30	27	3
Total	144	74	70

AP : accessory pathway, No : number, Cond : conduction, LFW : left free wall,
AS : anteroseptal, MS : midseptal, PS : posteroseptal, RFW : right free wall

Table 2. Outcome of Temperature-Guided Catheter Ablation

AP Location	No of Pathways	Initial Procedure		Recurrence of cond	Second Procedure		Final Outcome	
		S	F		S	F	S	F
LFW	88	78	10	2	6	0	81	7
AS	5	5	0	0	0	0	5	0
MS	2	2	0	0	0	0	2	0
PS	19	18	1	0	0	0	18	1
RFW	30	21	9	2	4	0	24	6
Total	144	124	20	4	10	0	130	14

S : success, F : failure

retrograde direction in 70 pathways(49%).

1. Ablation of Accessory Pathways

Temperature-guided radiofrequency catheter ablation eliminated accessory pathway conduction successfully in 130 of 144 pathways (90.3%), 124 pathways with a single procedure and 6 pathways with a second procedure(Table 2).

Successful accessory pathway ablation required 8±9 pulses (range, 1 to 46 pulses) of radiofrequency current. The application numbers of radiofrequency current in the patients with successful ablation were highter at the atrial side of the annulus than at the ventricular side (14±14 versus 6±6, $p<0.01$).

Four patients (2.8%) had recurrences of AV re-entrant tachycardia or delta wave on the electrocardiogram after a successful ablation (Table 2). Recurrences occurred in 2 patients within 24 hours and in 2 patient 2 weeks after ablation. Second ablations were done successfully in these 4 patients. The locations of accessory pathway in the patients with recurrence were left free wall in 2 patients and right free wall in 2 patients. Ablations failed in 20 accessory pathways at initial procedure. Ten of these accessory pathways were concealed and 10 manifest. Ten pathways were along the left free wall, one pathway in the posteroseptal region and 9 pathways along the right free wall.

2. Biophysical Parameters of Successful Sites during Ablation

A computer monitor connected to the HAT 200S provided a continuous graphical display of the alpha-numerical listing of the biophysical parameters during ablation, such as radiofrequency power output, the operating temperature, the impedance and the application time during each energy application. This allowed on-line monitoring of the procedure and early identification of an impedance rise or variable wall contact of the electrode catheter. The baseline temperature measured at the target site before ablation was usually 36 to 37℃. Poor wall contract of the catheter tip, usually at the atrial side of the

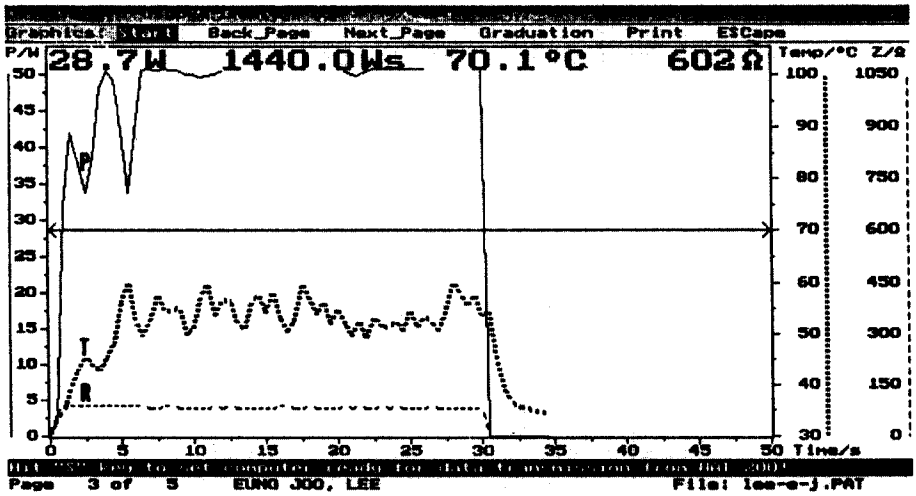

Fig. 1. Simultaneous recording of power (P), catheter tip temperature (T) and impedance (R) of the successful site at the atrial side of the tricuspid annulus during radiofrequency current application shows the poor wall contact of catheter tip. The temperature was set at 70℃. Although the catheter tip contacted poorly to the wall, repeated rises of power output upto 50 W made the peak temperature of 60℃.

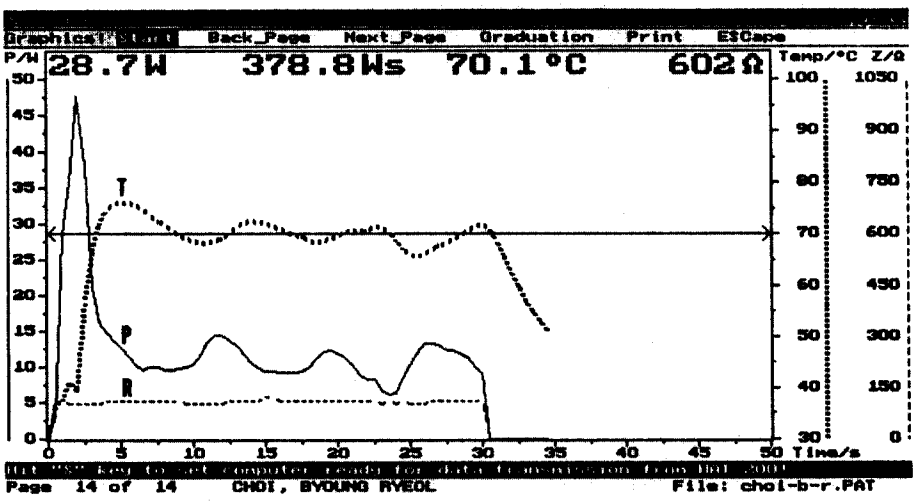

Fig. 2. Simultaneous recording of power, catheter tip temperature and impedance of the successful site at the ventricular side of the mitral annulus during radiofrequency current application shows the good wall contact of catheter tip. The temperature reached the set temperature of 70℃ in 3 seconds and persisted until the end of current application with a relatively lower output (maximum 47.5 W, mean 12.6 W).

annulus, was reflected by repeated rises of power up to 50 W and frequent power adjustments to compensate for convective heat loss, which made the tissue temperature of 60℃ with successful ablation (Fig. 1). When the catheter tip achieved a good wall contact, usually at the ventricular side of the mitral annulus, the set temperature of 70℃ was usually reached within 3 seconds and could

Table 3. Biophysical Parameters of Successful Sites During Ablation

	Ablation Site		p-value
	Atrial Side	Ventricular Side	
Number of pathways	17	46	<0.05
Total Energy (J)	1064.2±363.0	552.6±226.2	<0.01
Maximum Power (W)	50.4±0.7	39.3±9.4	<0.01
Mean Power (W)	34.0±8.9	20.0±7.6	<0.01
Maximum Temperature (℃)	66.4±4.0	77.2±6.4	<0.01
Impedance (ohms)	109.3±18.3	100.2±8.5	NS
Application Number	14±14	6±6	<0.05

NS : not significant

Table 4. Mean Power Outputs of the Successful Sites During Ablation at Atrial and Ventricular Side

Power Output (W)	Ablation Site	
	Atrial Side	Ventricular Side
<10	1	3
10-19	0	21
20-29	4	15
30-39	8	7
40-50	4	0
Total	17	46

be maintained without significant changes (Fig. 2). The biophysical parameters of successful sites during radiofrequency current application are presented in Table 3.

Successful ablation at the atrial side required total delivered radiofrequency energy of 1064.2± 363.0 J (range, 212.8 to 1449.8), maximum power ouput of 50.3±0.7 W (range, 48.4 to 50.8), mean delivered power output (calculated from total energy divided by application time) of 34.0±8.9 W (range, 6.2 to 40.6 W). maximum temperature of 66.4±14.0℃ (range, 53.5 to 96.9) and impedance of 109.3±8.3 ohms(range, 90 to 160). Successful ablation at the ventricular side required total delivered radiofrequency energy of 552.6±226.2 J (range, 101.0 to 1058.2), maximum power output of 39.3±9.4 W (range, 18.0 to 50.8), mean delivered power output of 20.0±7.6 W (range, 5.1 to 34.3), maximum temperature of 77.2±6.4℃ (range, 65.2 to 93.8) and impedance of 100.2±8.5 ohms (range, 90 to 120). Successful ablation at the atrial side of the annulus required more total

Table 5. Incidence of Developing a Coagulum Formation and/or Impedance Rise According to the Control Mode

Control Mode	Coagulum Formation and/or Impedance rise
Temperature (n=550)	8 (1.8%)
Power (n=233)	30 (12.8%)

n: number of radiofrequency energy applications.

energy, maximum power ouput and mean power output, significantly more than those of successful ablation at the ventricular side. The mean delivered power ouputs of the successful sites were between 30 and 50 W in 70.6% of the atrial side ablation and between 10 and 29 W in 78.3% of the ventricular side ablation (Table 4). Impedance measurements revealed no significant changes during ablation.

Delivery of radiofrequency energy using the power control mode resulted in a greater frequency of developing of coagulum and/or impedance rises than using the temperature mode (1.8% versus 12.8%, p<0.01, Table 5).

3. Complications

The surum levels of creatine kinase and creatine kinase-MB fraction were measured in the first 27 patients and the results were all within normal limits before and after ablation. Echocardiography did not identify an intracardiac thrombus, new cardiac valve damages or new abnormalities of ventricular wall motion. Hemopericardium occurred in 2 patients during the

ablation procedure, and pericardiostomy was done in a patient with tamponade. Right femoral arterial thrombosis occurred in a patient and was removed by Fogarty catheter.

All patients have been followed for a mean 41 ±25 months (range, 3 to 55) without late complications.

DISCUSSION

Temperature monitoring has been used to titrate radiofrequency ablation in the central nervous system for over three decades[17].

Successful ablation of the accessory pathway required marked variable power output between the sites and the power output did not predict tissue lesion size, especially at the atrial side[11]. Many factors, including power output, duration of energy delivery, contact pressure of ablation electrode, size of electrode tip, cavity blood flow, etc. are known to influence the lesion size resulting from radiofrequency ablation[7-11]. But the electrode tip temperature has been demonstrated to predict lesion volume more accurately than the other factors[5, 10]. The mean radiofrequency power outputs of the successful sites were significantly higher at the atrial side of the tricuspid and mitral annulus than at the ventricular side, but the maximum temperature was significantly lower at the atrial side than at the ventricular side in this study. The possible main reasons for the higher power output and lower temperature at the atrial side of the annulus may be the ineffective heating due to poor wall contact of the catheter tip and greater cavity blood flow. In our patients, the mean power output of the successful sites were from 30 to 50 W in 70.6% of atrial side ablation and from 10 to 29 W in 78.3% of ventricular side ablation. This result shows that the power outputs in the usual range (20-30 W) did not produce adequate heating and sufficient lesion volume in some sites, especially at the atrial side, and produced over heating and coagumum formation in other sites, especially at the ventricular side. These problems, associated with lower or higher temperatures, could be avoided in our patients by automatic power control to make the set temperature of 70℃. One of the advantages of temperature-guided catheter ablation would be the avoidance of impedance rise or coagulum formation at the catheter tip resulting in sufficient heating and lesion formation. On-line temperature monitoring was also very helpful to discriminate whether the failed ablation was due to insufficient tissue heating or incorrect positioning of the ablation catheter.

When the electrode-tissue interface temperature exceeds 100℃, tissue contiguous to the electrode desiccates, plasma proteins denature to form an insulating layer on the surface of the electrode, generally referred to as coagulum, and the electrical impedance rises abruptly[14]. These complications of tissue temperature of over 100℃ can be prevented by keeping the temperature below 100℃ for the duration of energy delivery[11, 14]. In this study, coagulum formation and/or impedance rise at the catheter tip developed less frequently in the temperature mode than in the power control mode during ablation. Tissue heating by radiofrequency energy is proportional to the square of current density in tissue and a decrease in delivered current, secondary to the insulating effect of coagulum, results in a marked decrease in heating[15]. In addition, the denatured proteins and dessicated tissue at the site of ablation are probably thrombogenic and create a nidus from which loosely adherent thrombus might embolize. When the electrical impedance rises, the catheter had to be withdrawn to inspect and remove the coagulum adherent to the electrode tip. Avoidance of catheter withdrawal to remove the coagulum on the catheter tip and time consuming repositioning in using the temperature-guided ablation will have the advantages of shorter procedure time and radiation exposure compared to power control ablation.

The recurrence rates of AV re-entrant tachycardia, after successful accessory pathway ablation using power control method, were between 3 to 12%[1-4, 13]. Accessory pathway conduction recurred in 4 patients (2.8%) after successful ablation in this study. Return of delta waves on the electrocardiogram or spontaneous paroxysmal supraventricular tachycardia was the indication of recurrence. A follow-up electrophysiologic study was not done to evaluate the recurrences of

accessory pathway conduction in our patients without symptoms suggesting recurrence of AV re-entrant tachycardia because most of the recurrences can be diagnosed clinically and the yield of routine, follow-up electrophysiological testing is very low in asymptomatic patients for the diagnosis of the recurrence of accessory pathway conduction[13].

The complication rates of radiofrequency catheter ablation of the accessory pathway in multi-center reports were 3.8 to 4.4%[19, 20]. The incidence of severe complications, including complete AV block, embolic events and cardiac tamponade was 2.3%. In our study, complications occurred in 3 patients (2.1%), 2 patients with hemopericardium and 1 patient with femoral artery thrombosis. It could not be confirmed in these 2 patients with hemopericardium whether the hemopericardium was due to either mechanical perforation or radiofrequency current induced perforation.

Results of the current study suggest that, although the long-term adverse effects of temperature-guided radiofrequency catheter ablation are unknown, temperature-guided radiofrequency catheter ablation can be performed effectively and safely to eliminate accessory pathway conduction in patients with Wolff-Parkinson-White syndrome. This method also appears to have very low incidences of coagulum formation and impedance rise at the electrode tip and may shorten the procedure time and radiation exposure and possibly increase the tissue lesion volume.

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