Temperature Monitoring During Radiofrequency Catheter Ablation of Accessory Pathways

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Background. Animal studies have suggested that the temperature of the electrode–tissue interface during radiofrequency catheter ablation accurately predicts lesion size. The purpose of the current study was to evaluate the utility of continuous temperature monitoring during radiofrequency catheter ablation in patients with Wolff-Parkinson-White syndrome.

Methods and Results. Twenty patients with manifest preexcitation were included in the study. The ablation catheter was positioned on the ventricular side of the mitral annulus for left-sided accessory pathways and on the atrial side of the tricuspid annulus for right-sided and septal accessory pathways. A thermistor imbedded in the distal electrode of the ablation catheter allowed continuous temperature monitoring during each energy application. To define the relation between power and temperature, radiofrequency current was applied several times at each site using outputs of 20, 30, 40, and 50 W. The accessory pathways were successfully ablated in each of the 20 patients. Because of marked variability in the efficiency of heating between sites, power output did not predict temperature. However, at any given site, there was a positive dose–response relation between power and temperature. Radiofrequency energy applications on the atrial side of the tricuspid annulus produced lower temperatures than did applications on the ventricular side of the mitral annulus (49±7 versus 60±16°C, p=0.0001). Transient block in the accessory pathways occurred at a mean of 50±8°C, whereas permanent block was seen at a mean of 62±15°C (p=0.0001). Less than half of the applications at outputs ≤40 W produced temperatures adequate to interrupt accessory pathway conduction. An abrupt rise in impedance caused by coagulum formation occurred only at temperatures between 95 and 100°C.

Conclusions. Temperature monitoring may facilitate radiofrequency catheter ablation of accessory pathways. By adjusting power output to ensure that adequate but not excessive temperatures have been achieved, a rise in impedance can be avoided and the total number of energy applications and procedure duration may be reduced. (Circulation 1992;86:1469–1474)

KEY WORDS • tachycardia, supraventricular • Wolff-Parkinson-White syndrome

Catheter ablation using radiofrequency energy has emerged as the technique of choice for definitive therapy of arrhythmias caused by accessory atrioventricular pathways. However, optimal energy delivery strategies have not been defined. Application of radiofrequency current to the endocardium results in resistive heating of the tissue adjacent to the ablating electrode. Multiple variables, including catheter orientation, surface area of contact, contact pressure, and cavitary blood flow may affect the efficiency of radiofrequency energy application. Therefore, there is a poor correlation between radiofrequency energy delivery parameters (e.g., power and duration) and resultant lesion size. In contrast, the temperature of the electrode–tissue interface accurately predicts radiofrequency lesion volume in vitro and in vivo. No prior studies have described the use of temperature probes in patients undergoing catheter ablation.

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Methods

Characteristics of Subjects

Catheter ablation was performed under a protocol approved by the Committee on Human Research at the University of Michigan. Twenty patients with manifest preexcitation gave written consent and were studied. The mean age was 34±14 years (14 male patients and six female patients). These patients had been symptomatic for 15±13 years and had been treated with 2.5±2.4 antiarrhythmic drugs before being referred for ablation.

Electrophysiological Testing

Electrophysiological testing was performed using three quadripolar electrode catheters positioned in the high right atrium, His bundle position, and the right
ventricular apex. Leads V₃, I, and III and the intracardiac electrograms were recorded on a Siemens Elema Mingograf 7 recorder. Pacing and extrastimulation were performed with a programmable stimulator at a pulse width of 2 msec and an intensity of twice diastolic threshold. Conduction and refractoriness of the atrioventricular node and accessory pathway were assessed, and the mechanism of tachycardia was defined. In addition, the accessory pathway was localized to a general region before detailed mapping with the ablation catheter. Four of the patients had accessory pathways located in the right free wall, six had posteroseptal pathways, and 10 had left-sided accessory pathways.

Techniques for positioning the ablation catheter have been described previously.9 A retrograde approach was used for left-sided accessory pathways. The catheter was inserted into the femoral artery and advanced across the aortic valve to the ventricular aspect of the mitral annulus. In patients with septal or right-sided accessory pathways, the catheter was introduced via the femoral vein and positioned on the atrial side of the tricuspid annulus.

Mapping was performed during sinus rhythm or atrial pacing. Target sites were selected based on the presence of discrete atrial and ventricular electrograms with early onset of local ventricular activation relative to the surface QRS. Bipolar electrograms were bandpass filtered between 50 and 500 Hz and recorded at a paper speed of 200 mm/sec. The amplitudes of the atrial and ventricular components of the signal were measured at each ablation site. Each bipolar recording was also analyzed for the presence of an accessory pathway potential defined as a high-frequency deflection distinct from the atrial and ventricular components of the signal. No attempt was made to validate the presence of accessory pathway potentials with pacing maneuvers. Each target site electrogram was also analyzed for stability. The signal was classified as stable if there was <10% variation in the atrial or ventricular electrogram amplitudes between successive beats. To determine if there was a correlation between temperature and the magnitude of ST elevation in the endocardial electrogram, unfiltered unipolar electrograms were recorded with the ablation catheter from each target site in 10 of the 20 subjects.

**Thermistor Ablation Catheter**

To accurately measure heating during radiofrequency energy application, the temperature of the tissue in contact with the ablation electrode must be measured rather than the temperature of the electrode itself or the adjacent cavitory blood. A previous study has shown that a thermistor in contact with the endocardium and thermally isolated from the delivery electrode accurately measures electrode–tissue interface temperature.10

In the present study, a standard 7F bipolar electrode catheter (EP Technologies, Inc., Mountain View, Calif.) with a deflectable shaft and a large (4 mm in length) distal electrode and 2-mm interelectrode spacing was modified to incorporate a thermistor in the tip of the distal electrode (Figure 1). The thermistor bead (Thermomedics, Inc.) was exposed to the surface and thermally insulated from the surrounding platinum electrode by a polyamide plastic sleeve. Each catheter was individually calibrated in a tank of warm saline solution using a precision fiber optic thermometer (Luxtron, Inc.). The thermistor was accurate to within ±2°C from 37 through 100°C for each of the catheters used.

**Catheter Ablation and Temperature Monitoring Protocol**

Radiofrequency energy was produced by a power supply that delivered a continuous, unmodulated sine wave output at 500 kHz (EP Technologies, Inc.). This device, via an interface with a microcomputer (Toshiba Electronics, Inc.) continuously measured, displayed, and recorded power, impedance, and tip temperature during each energy application. Radiofrequency energy was delivered between the distal electrode of the ablation catheter and a large adhesive skin electrode that was placed over the left scapula. To define the relationship between power and temperature, radiofrequency current was applied several times at each site by using incrementally higher outputs. Initially, 20 W was given for 20 seconds followed by 30 W and then 40 W for 20 seconds. This duration was chosen because a previous experimental study showed that lesions reach full size after approximately 20 seconds.11 If the maximal temperature at 40 W was <50°C, then a final application of 50 W for 20 seconds was given. Incrementally higher power outputs were used at each site regardless of the electrophysiological effects of the applications. Energy delivery was stopped immediately if the catheter became dislodged or if a rise in impedance was observed.

**Statistical Analysis**

Continuous variables are expressed as mean±1 SD. ANOVA for repeated measures was used to define the relation between power and mean temperatures. Fisher's least significant differences method for multiple comparisons was used to analyze the change in temperature with increasing power at each site. Comparisons between temperature and discrete variables were performed using the Student's t test for unpaired variables, and linear regression was used for comparison with continuous variables. A value of p<0.05 was considered significant.

**Results**

A total of 213 applications of radiofrequency energy were delivered with the thermistor catheter in the 20 patients at 94 different target sites (range, one to nine sites per patient). All patients had successful outcome
defined as the complete absence of accessory pathway conduction at the conclusion of the procedure. The mean procedure duration was 70±40 minutes, and the duration of fluoroscopy was 28±22 minutes. There were no complications.

Relation Between Temperature and Energy Delivery Parameters

The baseline temperature measured at the target site before ablation was always between 37 and 39°C. After the onset of the radiofrequency energy application, temperature rose exponentially to a steady state. The mean duration from onset to the time that temperature had reached 90% of steady state was 2.2±3 seconds. Applications that produced higher temperatures tended to take longer to reach steady state (Figure 2).

At any given power output, the steady-state temperature varied considerably from site to site. For all radiofrequency energy applications considered as a group, there was no difference in steady-state temperature between 20, 30, 40, and 50 W (51±13, 56±14, 60±17, 54±8°C; p=NS). In contrast, at each individual target site, there was a positive dose–response relation between applied power and temperature (Figure 3). The average increase in temperature at any given site between 20 and 40 W was 12±11°C (p=0.0001). The slope of the temperature versus power curve was directly proportional to the steady-state temperature at 20 W (R²=0.51, p=0.001).

An abrupt rise in impedance was noted during all eight applications of radiofrequency energy that resulted in temperatures between 95 and 100°C (Figure 4). Temperature appeared to plateau just before the impedance rise.

No impedance rise was seen at temperatures <95°C. During one application, temperature rose to 114°C without a measured change in impedance. Withdrawal and inspection of the catheter after this application revealed coagulum coating only the distal portion of the ablating electrode.

Relation Between Temperature and Catheter Position

Ablation of right-sided and posteroseptal accessory pathways on the atrial side of the tricuspid annulus resulted in lower temperatures than applications on the ventricular side of the mitral annulus used to ablate

FIGURE 2. Graphs demonstrate tip temperature vs. duration of radiofrequency (RF) energy. Panel A: Application on the ventricular side of the mitral annulus. Note that temperature reaches a steady state in ≤5 seconds. There is a substantial increase in temperature with increments in power from 20 to 40 W. Panel B: An ablation site on the atrial side of the tricuspid annulus is associated with much lower temperatures, a shorter rise time, and less of an increase in steady-state temperatures with increments in power.

FIGURE 3. Graph of dose–response relation between applied radiofrequency power level and steady-state temperature at each ablation site. Despite the marked variability in temperature for any given power level, there is a consistent positive dose–response relation at each site. Note that at poorly coupled sites (as manifest by low steady-state temperatures at 20 W) there is a shallow slope but much steeper slopes at sites with better coupling.

FIGURE 4. Plot shows abrupt rise in impedance (dashed line) during the course of radiofrequency energy application. Note that this occurs only after the tip temperature has reached a steady-state level of 95°C.
left-sided accessory pathways (48±7 versus 60±16°C, 
p=0.0001).

There were no characteristics of the target site electrogam that appeared to correlate with temperature. There was no difference in steady-state temperature at 20 W between stable and unstable sites (52±10 versus 51±12, p=NS). There was no correlation between the amplitude of the bipolar atrial or ventricular electrogram at each ablation site and the steady-state temperature at 20 W (R²=0.011, 0.103). The magnitude of ST segment elevation recorded on the unfiltered unipolar electrogram did not correlate with steady-state temperature at 20 W whether analyzed in terms of absolute value (R²=0.011) or as a fraction of the amplitude of the ventricular electrogram (R²=0.006).

Temperature and Effects on Accessory Pathway Conduction

Transient block of accessory pathway conduction was noted during 76 of 213 applications of radiofrequency energy with the thermistor catheter. The temperature associated with initial disappearance of the delta wave was measured for these applications as well as for applications that permanently eliminated accessory pathway function (Figure 5). The mean temperature at the time of transient interruption of accessory pathway conduction was 50±8°C compared with 62±15°C for applications that permanently ablated the pathway (p=0.0001). Only 46% of applications at 20 and 30 W produced temperatures ≥48°C, the minimum temperature associated with permanent interruption of accessory pathway conduction (Figure 6). At 40 W, 63% of applications resulted in steady-state temperatures in excess of 48°C.

Discussion

Main Findings

Temperature monitoring at the tip of the ablation catheter during radiofrequency ablation of accessory pathways reveals the following: 1) temperature at the catheter–tissue interface rises exponentially to reach a steady state within a few seconds; 2) because of marked variability between sites in the efficiency of heating, power output does not predict temperature; 3) at any given site, however, there is a clear-cut dose–response relation between power and temperature; 4) radiofrequency energy applications on the atrial side of the tricuspid annulus produce lower temperatures than do applications on the ventricular side of the mitral annulus; 5) characteristics of the ablation site electrogram, including stability and amplitude, do not correlate with temperature; 6) applications of radiofrequency energy that cause transient block in the accessory pathway have a mean temperature of 50±8°C, whereas those that permanently eliminate accessory pathway function are associated with a significantly higher mean temperature of 62±15°C; 7) at a power output of 20 or 30 W, a majority of sites have sufficiently poor coupling between the ablating electrode and adjacent tissue to prevent temperatures from exceeding 48°C, the minimum temperature associated with permanent accessory pathway block.

Figure 5. Graphs of time and temperature during radiofrequency (RF) energy application. Panel A: Temperature recorded during RF energy application that produced transient (approximately 30 seconds) elimination of accessory pathway function. Note that the delta wave disappears at a temperature of 44°C. Panel B: Application that permanently eliminated accessory pathway function is associated with a steady-state temperature of 60°C.

Figure 6. Bar graph shows percentage of radiofrequency energy applications at each power level that were associated with steady-state temperatures ≥48°C, the minimum that produced permanent block of accessory pathways. Note that at 20, 30, and 40 W, only a minority of sites were sufficiently well coupled to result in adequate heating.
Comparison With Previous Studies

Temperature monitoring has been used to titrate radiofrequency ablation in the central nervous system for over three decades.12 In the present study, temperature correlated with the electrophysiological effect of radiofrequency energy application. Previous studies in animals have shown that tip-temperature monitoring predicts lesion volume more accurately than applied power or the duration of energy application.6,8 Accessory pathway conduction was permanently interrupted at a mean of 62°C. Interestingly, several studies in intact animals have shown 62°C as the threshold temperature, below which detectable lesions are not consistently produced.6,13

The higher temperatures associated with ablation of left-sided accessory pathways compared with those on the right are probably due to differences in the technique used for positioning the catheter. Greater contact pressure can be applied at the base of the left ventricle than on the atrial side of the tricuspid valve. The force of contact is directly proportional to temperature and lesion volume during radiofrequency ablation in animals.3,5 In addition, the cavitary blood flow is likely to be greater on the atrial side of the tricuspid annulus than between the mitral leaflet and left ventricular endocardium. Thus, convective heat loss may also contribute to the inefficiency of right-sided radiofrequency energy applications.

Abrupt impedance rise in this study was invariably associated with temperatures between 95 and 100°C and did not occur at lower temperatures. This probably reflects the behavior of water at the phase transition (boiling point). The electrode–tissue interface would be expected to stay at the boiling point as long as some moisture remained. Because the power supply discontinued radiofrequency current delivery 1–2 seconds after impedance rise, further increases in temperature were not observed. Haines and Verow14 made similar observations in a study of radiofrequency ablation in canine ventricular myocardium, with impedance rise due to coagulum formation occurring only at temperatures approaching 100°C.

The rate of temperature rise was considerably faster in this clinical study than with previous studies in vitro.6,8 This probably reflects the substantial convective heat loss engendered by intracavitary blood flow. The time required for temperature to approach steady state (2.2±3 seconds) is in remarkably close agreement with the time to initial accessory pathway block reported in a series of 195 patients (2.9±3.4 seconds).15

A recent study has identified several characteristics of the ablation site electrogram that are predictive of successful interruption of accessory pathway conduction.16 However, even at optimal sites, the probability of success was only 57%. Results of the current study suggest that inadequate heating may often be responsible for inefficacy despite ideal electrogram characteristics at the ablation site.

Limitations

The temperature measured during radiofrequency energy application may have been affected by catheter orientation and contact pressure. Convective cooling by cavitary blood is more likely to artificially lower temper-


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