Temperature-Guided Radiofrequency Catheter Ablation With Very Large Distal Electrodes

Jonathan J. Langberg, MD; Marsha Gallagher; S. Adam Strickberger, MD; and Omar Amirana, MD

**Background.** Previous studies have shown that the size of lesions produced by radiofrequency catheter ablation correlates with the temperature and surface area of the electrode-tissue interface. The purpose of the present study was to compare the effects of ablation using very large distal electrodes (8F, 8 and 12 mm long) with those made by a conventional radiofrequency ablation catheter (distal electrode 8F, 4 mm long).

**Methods and Results.** Each catheter had a thermistor in the tip of the distal electrode. Radiofrequency energy (500 kHz) was supplied by a generator that continuously monitored temperature and produced up to 100 W. In 10 dogs, each of the three ablation catheters were introduced percutaneously and positioned under fluoroscopic guidance at disparate left ventricular endocardial sites. Radiofrequency power output was titrated to achieve a temperature of 80°C for 60 seconds at each ablation site. The power required to produce a steady-state temperature of 80°C was directly proportional to electrode size (15±7, 46±15, and 62±32 W using the 4-mm-, 8-mm-, and 12-mm-long electrodes, respectively). Lesions produced by the 8-mm electrode were nearly twice as deep (11±2.4 versus 6±1.2 mm, P<.001) and four times as large (905±410 versus 210±100 mm³, P<.001) as those made with a conventional 4-mm electrode. Lesions produced by the 12-mm electrode were intermediate in size (depth, 8±1.2 mm; volume, 465±225 mm³) and sometimes were associated with charring and crater formation. Ablation with the larger electrodes caused a drop in arterial pressure and more ventricular ectopy than ablation using a 4-mm distal electrode.

**Conclusions.** Thermistor-equipped elongated ablation electrodes coupled to high-power outputs can reproducibly produce lesions approximately 1 cm in diameter. This system may prove useful for ablation of ventricular tachycardias in patients with coronary artery disease. (*Circulation* 1993;88:245-249)

**Key Words** • catheter • ablation • ventricular tachycardia • radiofrequency

During radiofrequency catheter ablation, endocardial lesions are formed primarily through resistive heating of the endocardium. Previous studies have shown that lesion volume correlates directly with the temperature and surface area of the electrode-tissue interface. Radiofrequency ablation using "conventional" catheters with distal electrodes 4 mm long produces lesions approximately 5 to 7 mm in diameter. These lesions have proven very effective for ablation of accessory atrioventricular connections and for treatment of atrioventricular nodal reentry tachycardia. However, larger lesions may be useful for ablation of other arrhythmias, particularly ventricular tachycardia due to reentry in patients with a history of myocardial infarction.

The purpose of the present study was to assess the effects of ablation using a new system incorporating distal electrodes 8 and 12 mm long and to compare these effects with the results achieved using a conventional radiofrequency ablation system.

**Methods**

**Experimental Preparation**

The protocol was approved by the University of Michigan Committee on Use and Care of Animals. Ten mongrel dogs of either sex weighing between 15 and 25 kg were used in this study. Animals were anesthetized with 3 mg acepromazine i.m., followed by 10 to 30 mg/kg sodium pentobarbital i.v. General anesthesia was maintained with supplemental doses of sodium pentobarbital as needed. The animals had endotracheal intubation and were mechanically ventilated. Arterial blood gases were periodically checked, and ventilation was adjusted to maintain arterial pH between 7.35 and 7.45. Hemostatic sheaths were introduced into the left internal jugular vein and left common carotid artery. The left femoral artery was cannulated for continuous monitoring of blood pressure. The surface ECG and intracardiac electrograms were displayed and recorded on a multichannel recorder (Electronics for Medicine VR16, Pleasantville, NY).

**Apparatus Used for Ablation**

A radiofrequency power supply (EP Technologies, Mountain View, Calif) was modified to deliver an output of up to 100 W. This device produced a continuous,
unmodulated signal at 500 kHz. Via an interface with a microcomputer, the power supply continuously monitored and recorded current, voltage, power, impedance, and temperature during each energy application. Power delivery was shut off automatically if measured impedance exceeded 300 Ω. The onset and offset of radiofrequency energy application were not synchronized to the cardiac cycle. Current was applied between the distal electrode of the ablation catheter and a large adhesive skin electrode placed over the left anterior chest.

Each ablation catheter had a thermistor embedded in the tip of the distal electrode (Fig 1). This thermobead was exposed to the surface and thermally insulated from the surrounding electrode by a plastic sleeve to measure more accurately the temperature of the endocardium adjacent to the electrode. Each catheter was calibrated individually and found to be accurate to within ±0.5°C in the range of 37 to 100°C. All ablation catheters used in this study were bipolar, with 2-mm interelectrode spacing, and had a deflectable shaft that was 7F in diameter.

Control lesions were produced with a catheter that had a platinum electrode that was 8F in diameter and 4 mm long. Experimental lesions were made with identical catheters that had distal electrodes 8 and 12 mm long (Fig 1).

Ablation Procedure

One of the three types of ablation catheters (4-, 8-, or 12-mm distal electrode lengths) was chosen at random and introduced via the carotid sheath. It then was advanced under fluoroscopic guidance into the apex of the left ventricle. A calibrated bipolar endocardial electrogro was recorded using minimal filtering (0.05 to 1000 Hz). Heart rate and arterial blood pressure immediately before ablation also were recorded. Radiofrequency energy application at each site was 60 seconds in duration. Power output was titrated manually to achieve a steady-state temperature of 80°C during each ablation (Fig 2). There was no difference in the mean temperature achieved during energy application through the 4-, 8-, and 12-mm distal electrodes. The surface ECG was monitored continuously during each radiofrequency energy application. Immediately after ablation, repeat recordings were made of heart rate, arterial pressure, and the ablation site electrogro.

This process was repeated with the other two ablation catheters positioned at widely disparate sites at the inferior base and midanterior wall of the left ventricle to allow unambiguous postmortem identification of the lesion sites.

Two hours after completion of the procedure, triphenyl tetrozolium chloride, a stain that highlights the demarcation between normal and necrotic myocardium, was infused, and the animals were killed. The hearts were removed, and the individual lesions were identified through inspection of the endocardium. Blocks of tissue encompassing each lesion were excised and fixed in 10% formalin solution. The fixed lesions were sliced into sections 1 to 3 mm thick, and both sides of each section were traced onto acetate. The lesion outlines were scanned digitally (Macintosh Apple scanner, Sunnyvale, Calif), and the surface area was calculated using a microcomputer. Lesion volume then was calculated according to the equation:

$$V_L = \sum T_N \times \left[ (A_1 + A_2)/2 \right],$$

where $V_L$ is lesion volume, $T_N$ is the thickness of the given slice, $A_1$ is the planimetered surface area of the lesion on one side of the slice, and $A_2$ is the surface area of the lesion on the opposite side of the slice.

Characteristics of the target site electrogram and hemodynamic parameters before and after ablation...
were compared using Student's \( t \) test for paired data. Lesion dimensions produced by the large electrodes were compared with those associated with the control (4 mm) electrode using Student's \( t \) test for unpaired data. The relation between electrode surface area and radiofrequency energy delivery parameters was evaluated using simple regression analysis. \( P<.05 \) was considered statistically significant.

**Results**

Thirty lesions were produced in 10 dogs with the three different ablation catheters. There were no changes in heart rate after radiofrequency ablation. There was a slight but significant rise in mean arterial pressure immediately after ablation using the control (4 mm) catheter, from 120±24 to 123±22 mm Hg (\( P=.002 \)). Conversely, there was a fall in mean arterial pressure after ablation using catheters with an 8-mm distal electrode (122±23 to 99±18 mm Hg, \( P=.0001 \)). There was a comparable fall in mean arterial pressure after ablation with the 12-mm distal electrode (141±25 to 125±22 mm Hg, \( P=.004 \)).

Premature ventricular contractions occurred during 6 of 10 ablations using the control catheter and during all of the radiofrequency energy applications using the larger 8- and 12-mm distal electrodes. No tachycardia was observed during control ablations, whereas 5 of 10 and 6 of 10 radiofrequency energy applications with the 8- and 12-mm distal electrodes produced nonsustained ventricular tachycardia. Ventricular fibrillation occurred 3 seconds after offset of radiofrequency energy during one ablation with the control catheter and during another ablation using a 12-mm distal electrode. Both animals were defibrillated and subsequently remained stable.

The amplitude of the endocardial electrogram did not change significantly as the result of ablation using the control catheter with a 4-mm distal electrode (8±4.7 before versus 8±4.8 mV after ablation, \( P=NS \)). In contrast, the ventricular electrogram amplitude decreased significantly at sites ablated using the 8-mm electrode (9±7.6 versus 5±8 mV, \( P=.004 \)). Interestingly, target sites electrograms recorded with the 12-mm distal electrode were smaller and did not change significantly after ablation (5±4.5 before versus 5±2.1 mV after ablation, \( P=NS \)).

**Energy Delivery Parameters During Catheter Ablation**

Typically, the radiofrequency power required to produce a temperature of 80°C initially was relatively high and then declined to a steady state after 10 to 20 seconds (Fig 2). There was a direct correlation between the surface area of the distal electrode and the steady-state power required to maintain 80°C (\( R^2=.954 \); Fig 3). A mean power of 15.7±8.9 W was used to produce a tip temperature of 80°C with the 4-mm electrode, 46.8±14 W with the 8-mm electrode, and 60.5±26.3 W with the 12-mm electrode.

There was an inverse relation between the distal electrode surface area and the impedance during ablation (\( R^2=.90 \); Fig 3). Mean impedance was 113±17 \( \Omega \) with the 4-mm distal electrode, 90±18 \( \Omega \) with the 8-mm electrode, and 84±16 \( \Omega \) with the 12-mm electrode.

**Lesion Characteristics**

None of the animals had pericardial bleeding at the time of death. Four of the 10 lesions made at the apex of the left ventricle were transmural (3 of these were made using an 8-mm distal electrode and one with a 12-mm electrode). All 30 applications of radiofrequency energy resulted in lesions that were visible by gross inspection of the left ventricular endocardium and that could be identified unequivocally based on the fluoroscopic position of the ablation catheter. Charring and crater formation were seen at the center of 3 of 10 lesions made with the 12-mm catheter but not with any of the other lesions. (Representative examples of ablative lesions are shown in Fig 4.)

Mean maximum lesion depth and lesion volume for each of the three types of ablation catheter are shown in Fig 5. Lesions formed with the 8-mm distal electrode had a maximal depth of 11±2.4 mm compared with 6±1.2 mm for lesions made with the standard 4-mm distal electrode (\( P<.001 \)). Mean lesion volume was 905±410 mm\(^3\) with the 8-mm tip electrode compared with 210±100 mm\(^3\) for control lesions (\( P<.001 \)). Lesions made with the 12-mm distal electrode were 8±1.2 mm deep and had a volume of 465±225 mm\(^3\) (\( P<.001 \) for both values versus control lesions).

**Discussion**

**Summary of Main Findings**

Thermistor-tipped radiofrequency ablation catheters with distal electrodes 4, 8, and 12 mm long were used to make left ventricular endocardial lesions. All energy applications were titrated to produce a steady-state temperature of 80°C. There was a direct correlation between distal electrode surface area and the power required to produce a temperature of 80°C. In contrast, impedance was related inversely to electrode size. Lesions produced by the 8-mm electrode were fourfold larger than those made by a "conventional" 4-mm distal electrode. Lesions produced by the 12-mm electrode.
were intermediate in size and sometimes were associated with charring and crater formation.

**Comparison to Previous Studies**

The clinical benefits of increasing electrode length from 2 to 4 mm were characterized in two studies of patients undergoing radiofrequency catheter ablation of the atrioventricular junction. Langberg et al.\(^\text{15}\) noted an increased success rate of 92% when a large-tipped ablation catheter was used compared with a 50% success rate in historic controls treated with a 2-mm distal electrode. Jackman et al.\(^\text{16}\) reported that the use of 4-mm distal electrodes reduced the number of energy applications required to cause atrioventricular block from a mean of 46±22 to 4.7±4.6.

A study in animals showed that increasing the length of the distal electrode from 2 to 4 mm more than doubled the lesion size achieved during radiofrequency catheter ablation.\(^\text{5}\) The incidence of impedance rise due to coagulum formation also was significantly less, suggesting that the larger electrode was able to couple more power to the endocardium without excessive temperature elevation. In contrast to the present study, a significant decrease in lesion volume was observed when electrodes 6 to 10 mm long were used. This disparity most likely is the result of differences in the radiofrequency energy delivery strategies used. In the earlier study, a fixed power output of 15 W was used for all electrode sizes. Results of the present study suggest that this power output would be inadequate to heat the endocardium in contact with an electrode with a very large surface area. The present study has shown that when sufficiently high power is used to heat the electrode-tissue interface to 80°C, very large electrodes do, in fact, produce bigger lesions than those formed by a 4-mm electrode.

Lesions resulting from ablation with the electrode 12 mm long were smaller than the lesions produced by the 8-mm electrode. This may have been the result of inconsistent endocardial contact along the surface of this very elongated electrode. The presence of charring in some of the lesions made with the 12-mm electrode is consistent with this hypothesis. Charring and crater formation most likely are the result of localized superheating to temperatures above 100°C despite the fact that the temperature at the tip of the electrode remained at 80°C.

The effects of electrode surface area on impedance and power requirements are consistent with previous observations. The primary determinants of total impedance during ablation are the resistivity of the tissue in contact with the ablation electrode and the surface area of contact. The steady-state temperature of the endocardium adjacent to the ablation electrode is directly proportional to power density (radiofrequency power per unit surface area). To maintain the same power density, the total applied power would need to be increased commensurate with increasing electrode surface area.
Study Limitations

A thermistor exposed to the surface of the electrode tip was used to measure endocardial temperature. Although this measurement probably would be an accurate reflection of heating around the distal end of the ablation electrode, it is possible that variation in contact more proximally would have caused significant fluctuation in temperature along the 8- and 12-mm electrodes. However, such variation would tend to decrease the overall efficiency of lesion formation using these very large electrodes. Therefore, it is unlikely that inaccuracies in temperature monitoring accounted for the dramatic increase in lesion volume seen with the larger electrodes. It is possible that the temperature recorded from the tip of the 12-mm electrode overestimated the average temperature of the electrode-tissue interface more than the measurements from the 4- or 8-mm electrodes. Thus, the smaller lesions produced with the 12-mm electrode may have been due, in part, to artificially elevated temperature readings.

Radiofrequency catheter ablation using the 8- and 12-mm distal electrodes was associated with a higher incidence of nonsustained ventricular tachycardia and with moderate decreases in mean arterial pressure. These adverse effects probably are a manifestation of the larger volume of myocardial necrosis associated with the elongated electrodes. Additional studies are required to characterize long-term hemodynamic and arrhythmia effects of ablation with these large electrodes.

Clinical Implications

Radiofrequency catheter ablation using "conventional" technology has been used to treat ventricular tachycardia in the setting of coronary artery disease. Its use has been restricted to a select subset of patients with hemodynamically stable ventricular tachycardia of relatively few morphologies. Some of the difficulties encountered with radiofrequency catheter ablation of ventricular tachycardia probably are due to the nature of the arrhythmia substrate. Intraoperative mapping during ventricular tachycardia in patients with a history of myocardial infarction has shown that the zone of slow conduction critical to the maintenance of the tachycardia may occupy several square centimeters. Some foci may be located in the midmyocardial or subepicardial regions. Therefore, lesions produced with a 4-mm electrode often may be inadequate to ablate ventricular tachycardia in the setting of coronary artery disease.

This study has shown that thermistor-equipped elongated ablation electrodes coupled to high-power outputs can reproducibly produce lesions approximately 1 cm in diameter. Additional studies will be required to determine if this system will enhance efficacy of ventricular tachycardia ablation or shorten procedure durations.

References
