

# Deep Myocardial Ablation Lesions Can Be Created with a Retractable Needle-Tipped Catheter

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**SAPP, J.L., ET AL.: Deep Myocardial Ablation Lesions Can Be Created with a Retractable Needle-Tipped Catheter.** *RF catheter ablation of ventricular tachycardia is sometimes limited by inadequate lesion depth. This study investigated the use of a retractable needle-tipped catheter to create deep RF lesions in vivo in porcine myocardium. An 8 Fr electrode catheter with an extendable 27-gauge needle at the tip was modified for RF ablation by embedding a thermocouple and attaching a pin connector. In three swine (32–58 kg) the left ventricle was entered via the femoral artery and endocardial contact was made. The needle was advanced 10 mm and 13 RF applications were made under a controlled temperature (90°C × 120 s). Nine control lesions were made using a standard 4-mm tip catheter (60°C × 120 s). The lesions were fixed, serially sectioned from the endocardium, digitally imaged, and quantified. Needle ablation lesions were deeper (10.15 ± 0.77 vs 5.67 ± 0.37 mm, P < 0.001) and more likely to be transmural (77 vs 11%, P = 0.008) than control lesions. The volume of control lesions, however, was larger (358.4 ± 56.2 vs 174.7 ± 18.6 mm<sup>3</sup>, P = 0.002) due to a significantly larger cross-sectional area at the endocardium (0.548 ± 0.04 vs 0.151 ± 0.01 cm<sup>2</sup>, P < 0.001). At depths > 6 mm, the needle electrode lesions had a greater cross-sectional area (0.136 ± 0.01 vs 0.005 ± 0.004 cm<sup>2</sup>, P < 0.001). Catheter-based needle ablation is feasible and allows creation of deeper lesions that can be transmural. Although deep, the lesions had a small cross-sectional area such that precise targeting would be required for success. (PACE 2004; 27:594–599)*

**catheter ablation, tachyarrhythmias, ventricles, ablation**

## Introduction

Ablation of ventricular tachycardia associated with a myocardial scar is often challenging, in some cases because significant portions of the reentry circuit are deep to the endocardium, beyond the limits of catheter ablation using standard techniques.<sup>1–3</sup> Even saline-cooled ablation catheters, which can create significantly larger ablation lesions,<sup>4,5</sup> fail to interrupt some reentry circuits.<sup>6</sup> Strategies to increase myocardial ablation lesion size and depth are of great interest.

Deep radiofrequency (RF) ablative energy can be delivered in noncardiac tissue with the use of an electrically active needle electrode,<sup>7</sup> effectively creating lesions of homogeneous necrosis with distinct borders. Needle electrodes have also

been evaluated in experimental preparations in which they were inserted from the epicardium,<sup>8,9</sup> to create ablation lesions. To this point, a catheter-based (percutaneous) needle electrode has not been available. This article reports the feasibility of using a retractable needle-tipped catheter for the creation of deep myocardial RF ablation lesions.

## Methods

### Catheters

Retractable needle-tipped catheters (Biosense-Webster, Inc. Diamond Bar, CA, USA) originally designed for intramyocardial drug delivery were modified. The catheters have an 8 Fr, 4-mm tip containing an electroanatomic sensor compatible with the CARTO mapping system (Biosense Webster, Inc.) and an extendable/retractable 27-gauge nitinol needle. The needle was modified by affixing a connector pin to the proximal end and by embedding a thermocouple in the distal tip of the needle (Fig. 1).

### Animals

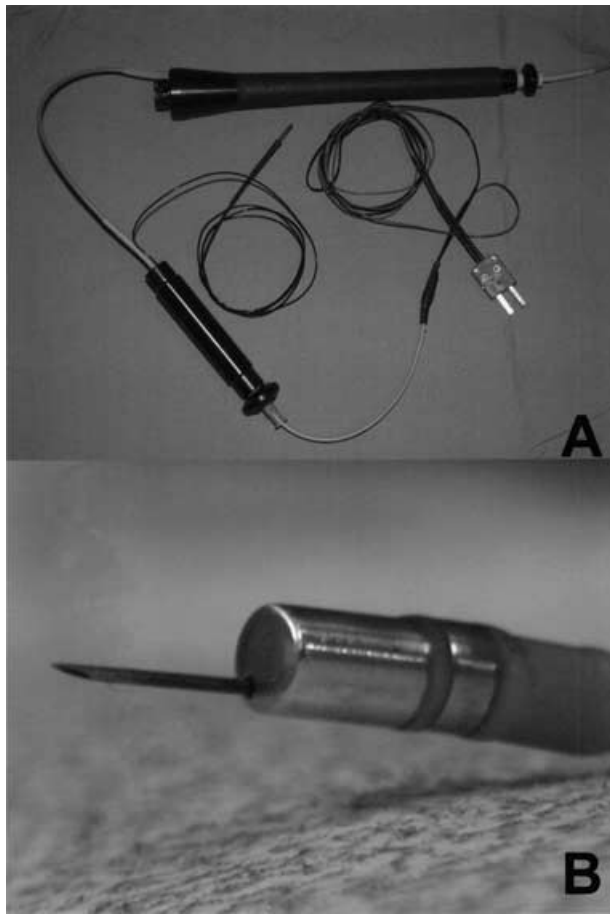
Three male swine (32–58 kg, 7–9 months of age) were anesthetized with tiletamine and zolazepam (telazol) 4.4 mg/kg, intubated, and ventilated with 0.1–5% isoflurane in a protocol

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**Figure 1.** The modified ablation catheter is shown. (Panel A) The catheter has a standard handle and connection cable with a second portion for extension and retraction of the needle. The second portion of the handle has a screw-adjustable thumb control that can be used to limit the depth of needle penetration. The needle is extended or retracted by sliding the knob. A separate wire with a connector pin allows radiofrequency energy delivery through the needle. A thermocouple has been inserted within the lumen of the needle and extends to the tip. (Panel B) The catheter tip is shown with the needle extended. The tip of the shaft contains a (Biosense) location sensor and an extendable 27-gauge needle embedded with a thermocouple. The maximal extendable length of the needle is 12–14 mm.

approved by the Harvard Animal Research Committee. Xylazine (2.2 mg/kg), atropine (0.05 mg/kg), and acetylsalicylic acid (325 mg) were administered according to the authors' laboratory protocol. Catheters were inserted into the femoral vessels.

### Ablation

The catheter was navigated using a combination of fluoroscopy and electroanatomic mapping.

The left ventricle was entered using the retrograde aortic approach. A baseline electroanatomic map of the ventricle was created and used for positional reference. The catheter tip was positioned in contact with, and perpendicular to, the endocardium. Sites were selected for ablation when the catheter could be securely positioned and the site appeared to be >2 cm from the nearest RF lesion. The needle was extended 10 mm. RF energy (500 kHz, Stockert-70 RF Generator, Freiburg, Germany) was delivered between the needle and a skin patch electrode for 2-minute applications. The power was manually adjusted to maintain the tip temperature at or below 90°C, starting at 9–10 W and adjusting output in response to temperature. The position was monitored continuously using the Biosense mapping system. The needle was fully retracted prior to repositioning. The catheter was replaced with a standard 4-mm thermistor-tipped catheter, which was advanced via the retrograde aortic approach to the left ventricle. The catheter tip was positioned in contact with and parallel to the endocardium to maximize the contact area. RF power was initiated at 2–10 W and manually titrated to maintain a tip temperature at or below 60°C for 2-minute applications. The position was continuously monitored using the Biosense electroanatomic mapping system. With both catheters, lesion sites were tagged on the electroanatomic map allowing accurate assessment of lesion location and the placement of lesions a minimum of 2 cm apart.

### Lesion Analysis

At the end of the procedure, the animal was euthanized with intravenous KCl. The heart was rapidly excised, and the coronary arteries were isolated and perfused with 10% formalin. The ventricle was dissected to expose the endocardium. Lesions were identified and excised in full thickness with a 3–5 mm margin. A careful comparison of the electroanatomic map with the endocardium was made to accurately identify each lesion. Lesions were included for analysis if they could be identified with confidence, did not overlap with other lesions, and were completed according to protocol. The tissue was fixed in formalin for 48 hours. The lesions were then serially sectioned in 1-mm sections from the endocardium using a tissue matrix and microtome blade. Each section was then digitally photographed through a zoom macroscope (Wild Heerbrug, Heerbrug, Switzerland) and digitally photographed (SV Micro, SoundVision, Wayland, MA, USA). Lesion dimensions and surface areas were analyzed using computer graphics programs (Adobe Photoshop V 4.0.1, Adobe Systems Inc, San Jose, CA, USA, Scion Image V 4.0.2, Fredrick, MD, USA). Lesion volume was calculated

by summing the products of the surface area at each section and section thickness (1 mm). Statistical analysis was performed using SigmaStat V.2.03 (Jandel Scientific, San Rafael, CA, USA); Student's *t*-test and Fisher Exact tests were used as appropriate.

### Results

Fourteen needle ablation lesions and 12 control lesions were created, of which 13 and 9, respectively, were available for analysis. Two control lesions were censored for inadvertent overlap; one could not be definitely identified. One needle ablation lesion was censored because of failed needle deployment. The catheter was readily manipulated within the left ventricle, and no mechanical complications were observed.

Needle ablation lesions had a characteristic appearance on the endocardial surface: there was minimal endocardial disruption, no adherent thrombus or char, and a  $3.3 \pm 0.5$  mm diameter area of pallor. In some cases the needle entry point could be visualized. Serial sections through the lesions revealed long narrow lesions along a needle track with a uniform diameter (mean  $4.4 \pm 0.1$  mm). The maximal diameter of these lesions was  $7 \pm 0.4$  mm. Lesions extended the full depth of the needle track.

In contrast, control (standard endocardial) ablation lesions had an ovoid area of pallor on the surface, which had a mean diameter of  $7.2 \pm 0.7$  mm. Serial sections of control lesions revealed widening of the lesion within the first 2 mm followed by rapid tapering such that the lesion could no longer be seen by 5-8 mm depth. The overall mean diameter of the lesions was  $8.5 \pm 0.2$  mm, while the maximal diameter of the lesions was  $12 \pm 0.7$  mm (Fig. 2).

Needle lesions were significantly deeper than control lesions, but control lesions had greater volumes. Needle lesions had a mean depth of  $10.2 \pm 0.8$  mm, while control lesions reached  $5.7 \pm 0.4$  mm depth ( $P < 0.001$ ). Needle lesions were also more likely to be transmural than standard lesions. Ten (77%) of 13 needle lesions, but only 1 (11%) of 9 control lesions extended to the epicardium ( $P = 0.008$ ). Despite greater depth, lesions created by using the needle ablation catheter had significantly smaller volume ( $175 \pm 18$  mm<sup>3</sup>) in comparison with control lesions ( $358 \pm 56$  mm<sup>3</sup>,  $P = 0.02$ ).

Needle lesions were deep and narrow, while control lesions were wide and shallow. The maximal cross-sectional area of the needle lesions was observed at a mean depth of 5.4 mm (range 2-9) while the maximal cross-sectional area of control lesions was observed at a mean depth of 3.1 mm (range 2-5 mm,  $P = 0.027$ ). The cross-sectional

area of needle lesions was significantly less than the control lesions at all depths from endocardium to 5 mm ( $15.1 \pm 1$  vs  $54.8 \pm 4$  mm<sup>2</sup>,  $P < 0.001$ ), but was significantly greater than control lesions at all depths  $> 6$  mm ( $13.6 \pm 1$  vs  $0.5 \pm 0.4$  mm<sup>2</sup>,  $P < 0.001$ ) (Fig. 3).

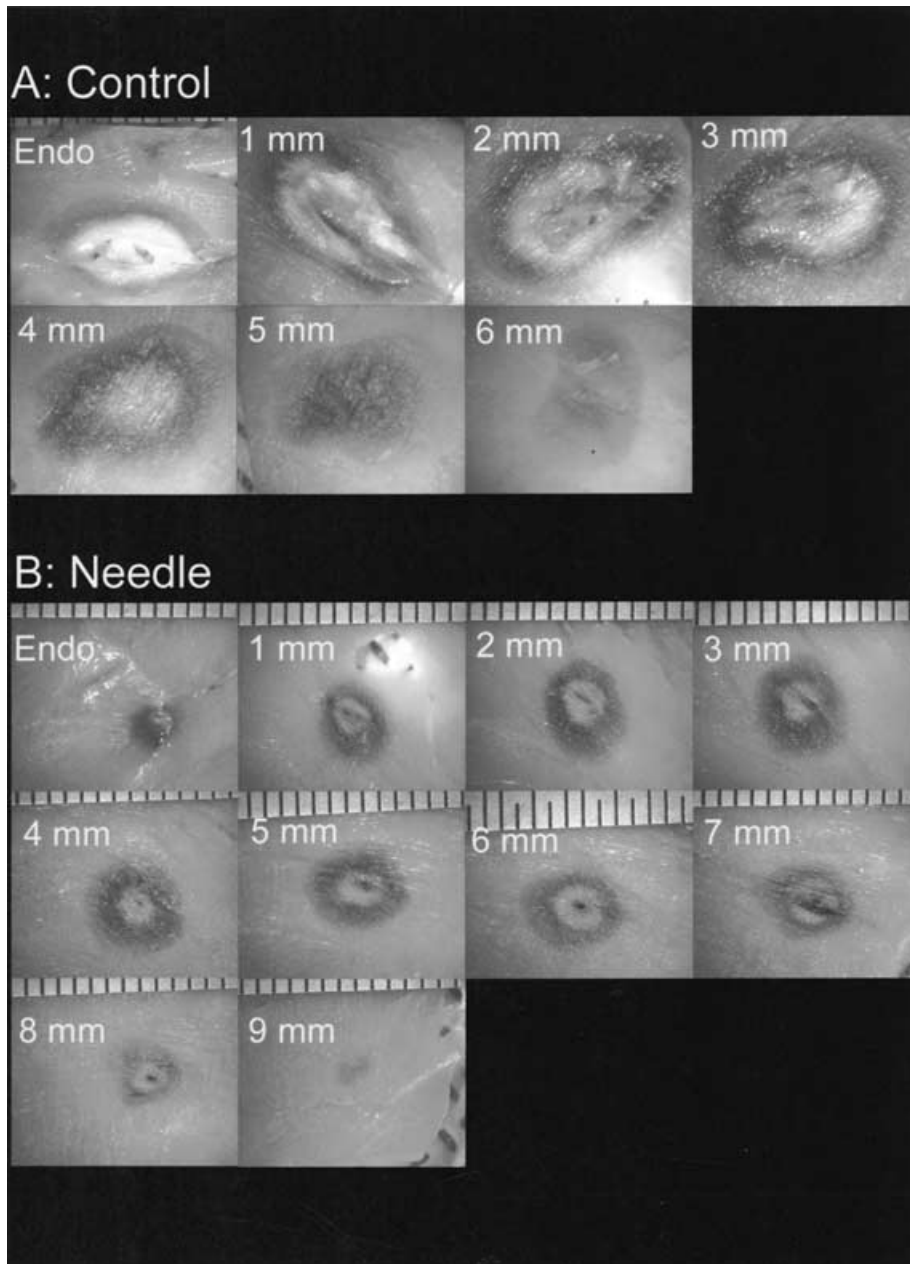
One animal developed pericardial tamponade after perforation with a full thickness needle ablation at the thin left ventricular apex. A second animal had a small hemopericardium without tamponade.

### Discussion

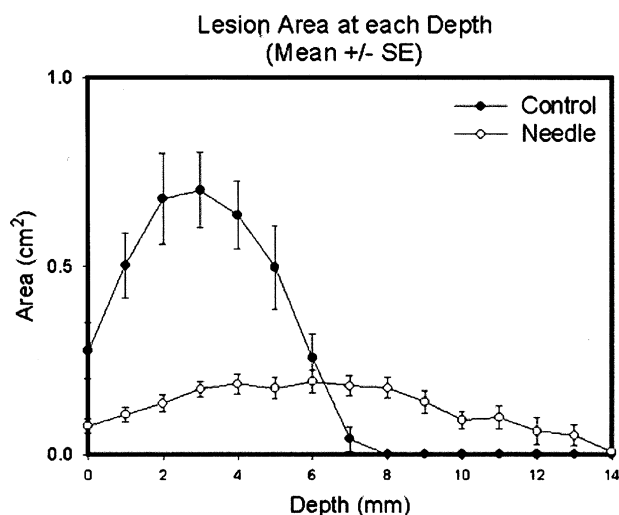
The authors have demonstrated that RF ablation lesions can be created with the use of a retractable needle-tipped catheter *in vivo*. Lesions created are deep but narrow and of smaller volume when compared to standard endocardial ablation using a 4-mm tip catheter. The greater depth achieved by this method is attributable to extension of the electrode deep within the myocardium, with the creation of a homogeneous, nearly cylindrical lesion surrounding it, and extending through the full depth of needle penetration. Despite the greater depth achieved, lesion volume was relatively small and standard ablation lesions had much greater cross-sectional areas at shallow depths.

Lesion formation by RF ablation depends on heating of the tissue. Resistive heat generation within tissue immediately adjacent to the ablating catheter depends on energy absorption, which varies with the square of voltage, and inversely with the fourth power of the radius from the energy source.<sup>10</sup> This results in a small zone of "resistive heating" that conducts heat to a larger zone of "conductive heating." Lesion size is critically dependent on the size of the ablating electrode. It is likely that the small size of the needle electrode embedded within tissue results in a small area of resistive heating with power titrated to 90°C and consequently small lesions. This is the likely explanation for the diminished lesion volume in comparison with standard 4-mm ablation catheters.

The authors chose an upper temperature limit of 90°C because their earlier *in vitro* work in bovine myocardial slabs (data not shown) suggested that temperatures  $> 90^\circ\text{C}$  were associated with boiling at the tissue surface and within the tissue, and on some occasions with "steam pops," which could result in perforation *in vivo*. The authors hypothesized that temperature inhomogeneity and blood coagulum associated with standard ablation catheters was less likely to occur with the needle electrode, which is not exposed to flowing blood, and therefore did not limit temperature to



**Figure 2.** (Series A) A representative example of a standard (control) radiofrequency ablation lesion is shown (temperature controlled, 60°C, 120-s application duration) in serial section. Section thickness is 1 mm; plane of section is parallel to the endocardial surface. The first section (“Endo”) is the endocardial surface, depth of each section is labeled in millimeters (mm). The lesion consists of a central area of pallor, surrounded by an area of dense hemorrhage. Lesion diameter is typically greatest at 1–2 mm depth, and no lesion is apparent beyond 6 mm depth. Maximal diameter is approximately 12 mm. Millimeter markers are shown in the first panel. (Series B) Serial sections of a needle ablation lesion are shown (temperature-controlled, 90°C, 120-s application duration). Millimeter markers are shown, and the scale and labels are the same as in Series A. In this example, a central area of pallor surrounds the slightly charred needle track, and is itself surrounded by an area of hemorrhage. The maximal diameter of the lesion is approximately 6 mm. The lesion morphology is relatively cylindrical and of near-uniform diameter through most of its depth. The needle track can be seen beyond 8 mm depth. Tissue changes are present throughout and slightly beyond the full depth of needle penetration.



**Figure 3.** The mean cross-sectional surface areas ( $\pm$  SE) of control lesions and needle ablation lesions at each depth are shown. Mean cross-sectional area of control lesions is significantly greater than needle lesions at all depths  $<$  6 mm. The mean cross-sectional area of needle ablation lesions is significantly greater than control at all depths  $>$  6 mm. The mean volume of each series of ablation lesions is represented by the area under the curves. The profile of ablation lesions is reflected in the shape of the curve. Needle ablation achieved deep narrow lesions, of approximately cylindrical shape. Control lesions were of larger volume, shallower, and had a bulbous shape.

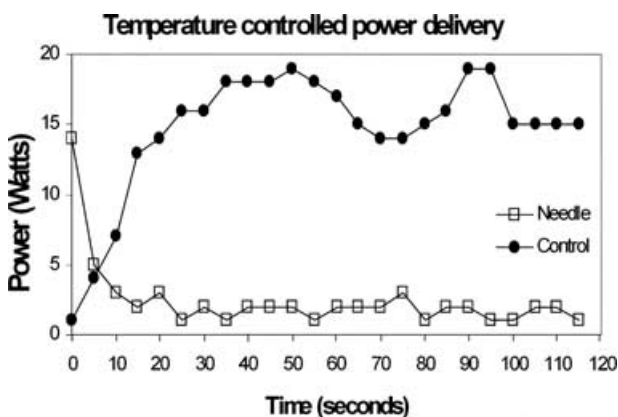
60°C–65°C as is commonly done clinically. Standard ablation catheter RF applications were limited to an electrode temperature of 60°C to replicate clinical practice and to avoid coagulum formation. Despite allowing needle electrode temperatures to reach higher temperatures, power delivery was significantly less than was observed in standard ablation controls. Mean power was only  $2.9 \pm 0.3$  W in the needle ablation group, which was far less than  $16.7 \pm 4$  W in the control group. Compared to standard RF in which a significant portion of current may be shunted through blood rather than the target tissue, current loss is probably minimal with the needle electrode. The efficient heating combined with lack of cooling from circulating blood flow reduced the power requirement to achieve the target temperature. Ablation using the needle electrode resulted in an early power peak, followed by rapid tapering to low power to avoid overheating. This was distinct from the typical power profile of a standard ablation (Fig. 4).

Adapting the extendable needle for RF delivery allowed recording of intramyocardial potentials and cardiac pacing from deep within the myocardium. Intramyocardial mapping was not

evaluated in this study in normal myocardium, but could potentially be helpful in locating the source of an arrhythmia deep to the endocardium.

Needle ablation lesions were much more likely to be transmural than control lesions. The authors' preliminary in vitro work (results not shown) suggested that the depth of needle ablation lesions is limited only by the length of the needle and the thickness of the myocardium. They arbitrarily chose a 10-mm insertion depth for this feasibility study in an effort to maximize lesion size without regard for safety. On one occasion, RF application delivered at the thin (5 mm) left ventricular apex was followed by hemopericardium and tamponade. Clinical application of this technique would require a method of avoiding perforation and hemopericardium by limiting needle depth or by individually assessing myocardial thickness at each site prior to needle deployment. A maximum temperature of 90°C was chosen to maximize lesion size. While only one impedance rise and no "pops" were seen with this approach, clinical use may require a lower temperature to avoid excessive tissue heating and intramyocardial steam pops.

The limited volume of tissue destruction with the use of needle ablation in the heart may limit its



**Figure 4.** Representative examples of power delivered during RF ablation using a standard (control) ablation catheter under temperature-control, limited to 60°C (closed circles), and using the needle ablation catheter under temperature-control, limited to 90°C (open squares). Power was manually titrated to achieve the specified temperature. For needle ablation, power was initiated at 10 W and had to be rapidly decreased as tip temperature quickly approached 90°C; only 2–3 W was required to maintain this target temperature thereafter. Standard ablation was initiated at 2–5 W and power was gradually increased to achieve 60°C. Power could typically be increased to approximately 17 W for the rest of the 2-minute application.

clinical applicability. Precise positioning would be required to achieve therapeutic success, and interruption of broad reentry circuits may not be possible. Investigations into methods to take advantage of the depth that can be achieved by this technique and to increase lesion size are warranted.

### Conclusions

Deep myocardial ablation is feasible using a percutaneous catheter with a retractable active

needle tip. Temperature-guided RF delivery using the currently available modified catheter results in deep narrow lesions. Investigation into methods to increase lesion size to avoid perforation are warranted.

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