

# Convective Cooling Effect on Cooled-Tip Catheter Compared to Large-Tip Catheter Radiofrequency Ablation

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**Background.** Both actively cooled-tip and large-tip catheters are currently available clinically to create large endomyocardial lesions during application of radiofrequency (RF) energy. The purpose of this study was to compare the effect of convective cooling at physiologic flow rates on RF lesion size using both actively cooled and large-tip catheters.

**Methods.** Porcine hearts were sectioned into 72 pieces and placed in a temperature-controlled saline bath (37°C) with varying directed flow rates (0, 1, 2, and 3 L/min). Cooled-tip RF ablation (4 mm tip) was performed for 1 minute on 36 tissue sections with power manually titrated to keep tip temperature below 40°C. Large-tip catheter ablation (10 mm tip) was performed at 65°C target temperature for 1 minute on 36 tissue sections. For each catheter, flow rates were randomized between applications. The tissue pieces were sectioned and measured to determine lesion depth, width, and volume.

**Results.** Lesion dimensions were independent of the flow rate for the cooled-tip catheter (mean volumes:  $382.0 \pm 121.6$ ,  $419.9 \pm 133.4$ ,  $375.9 \pm 169.1$ , and  $346.7 \pm 173.4$  mm<sup>3</sup> for 0, 1, 2, and 3 L/min flow rate, respectively,  $P = 0.78$ ). For the large-tip catheter, lesion size varied significantly with flow, such that higher flow rates produced larger lesions (mean volumes:  $120.7 \pm 50.7$ ,  $256.5 \pm 97.9$ ,  $393.4 \pm 149.9$ , and  $548.9 \pm 157.0$  mm<sup>3</sup> for 0, 1, 2, and 3 L/min flow rate respectively,  $P < 0.001$ )

**Conclusion.** During RF ablation, blood flow rate significantly affects lesion size for large-tip but not cooled-tip catheters. At low flow rates (0–1 L/min) cooled-tip catheters create larger lesions, while at high flow rates (3 L/min) large-tip catheters create larger lesions. (PACE 2006; 29:1368–1374)

**ablation, convective cooling, lesion size, large-tip catheter, cooled-tip catheter**

## Introduction

Radiofrequency (RF) catheter ablation is now the treatment of choice for many supraventricular and ventricular arrhythmias. Standard sized ablation catheters (7-Fr and 4-mm tip electrode length) are sufficient for destruction of most arrhythmia substrates that are located a few millimeters below the endocardial surface of the heart, such as atrio-ventricular accessory pathways. However, for some arrhythmias, a larger lesion size is required to achieve successful destruction of the arrhythmia substrate. For example, some ventricular tachycardias arise from damaged myocardium that may extend for several square centimeters and be at locations significantly deeper than can be reached with standard RF catheter technologies.<sup>1,2</sup> Similarly, intraatrial reentrant tachycardia in patients with repaired congenital heart disease arises from areas of surgical scarring. Often this scarring

occurs in hypertrophied atrial myocardium which is distant from the endocardium.<sup>3,4</sup> Currently, both actively cooled and large-tip catheters are available clinically for production of larger myocardial lesions. Clinical studies suggest that by way of the larger lesions, ablation with these catheters has a greater success rate than ablation with standard catheters for arrhythmia substrates that are large or deep within the myocardial tissue.<sup>5</sup>

This study was designed to compare the effects of convective cooling on RF lesion size for large-tip and cooled-tip ablation catheters. We hypothesized that the additive cooling effects of regional blood flow, while significant for large-tip ablation catheters, would be negligible for cooled-tip ablation catheters at physiologic flow rates.

## Methods

### Experiments

A local meat processor provided freshly removed porcine hearts. The hearts were infused with chilled physiological saline within an hour of excision and transported to the laboratory. Upon arrival the hearts were sectioned into block shaped pieces with the endocardial surface exposed (20 × 20 mm, 15 mm depth). Areas of myocardium that

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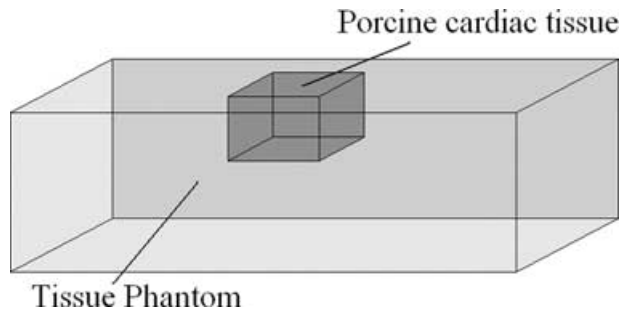


Figure 1. Schematics of tissue and phantom setup.

were not at least 15-mm thick were not used. The tissue pieces were then placed in saline solution maintained at a temperature of 37°C and allowed to equilibrate. The temperature was checked using a thermometer (Omega HH506RA, Stanford, CT, USA). For each ablation a tissue piece was placed in an Agar-Water gel block. The gel block had same electrical conductivity (0.54 S/m at 500 kHz, where  $1 \text{ S} = 1 \text{ ohm}^{-1}$ ) as myocardium<sup>6</sup> and simulated surrounding myocardium (Fig. 1). The gel block was placed in a temperature-controlled 0.3% saline bath with similar thermal and electrical properties to blood (0.67 S/m at 500 kHz and 37°C).<sup>7</sup> The bath temperature was maintained at 37°C using temperature-controlled water bath (Haake C1, Thermo Electron Corp., Waltham, MA, USA). The tissue piece was positioned flush with the lower edge and 2 cm from a rigid polyethylene tube (20-mm diameter) which directed flow across the tissue piece and gel block. A pump (Mag Drive WMD-20RLT-115, IWAKI, Tokyo, Japan) and flow meter (Model 7200, King Instrument, Garden Grove, CA, USA) were used to maintain and adjust saline flow across the tissue piece. Plastic tubing was used to supply the pump with saline from the bath and connect the pump to the outflow tube. Figure 2 illustrates the experimental apparatus. The flow meter and pump were calibrated by injecting a droplet of dye at the inlet of the rigid tube. The wavefront maximum flow velocity was recorded at 30 frames/s using a digital camera (Canon Powershot A510, Tokyo, Japan). At 3L/min a maximum flow velocity of 15.5 cm/s was calculated, corresponding to maximum flow velocities measured by Doppler echocardiography in a beating heart.<sup>8</sup>

Ablation was performed using either a large-tip catheter (Blazer II XP, Boston Scientific, Natick, MA, USA) or a catheter actively cooled using an internal closed loop system (Standard Chilli, Boston Scientific). The catheter was positioned perpendicular to the endocardial surface and placed at the center of the tissue piece. A 10-g piece of copper was attached to the catheter to provide consistent tissue contact pressure. RF power was supplied to

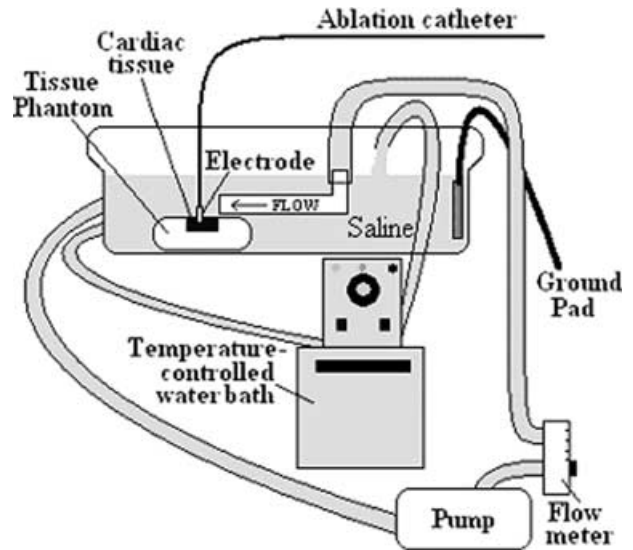
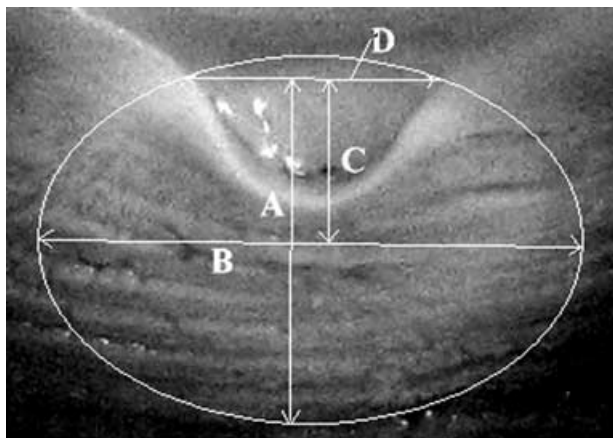


Figure 2. Schematics of experimental apparatus.

the catheters by a commercial cardiac ablation generator (EPT-1000XP, Boston Scientific). The electrode of the large-tip catheter (Blazer II XP, Boston Scientific) was 10 mm long and 8 FR (2.7 mm) in diameter. The electrode of the cooled-tip catheter (Chilli, Boston Scientific) was 4-mm long and 7 FR (2.3 mm) in diameter. A piece of aluminum foil (15 × 10 cm) was placed in the saline bath more than 20 cm from the ablation catheter for electrical grounding. A single large-tip catheter and cooled-tip catheter were used for all ablations.

### Ablation Protocol

For the actively cooled-tip catheter, the RF generator was used in power control mode. Power was manually controlled starting at an initial power level of 10 W, and was manually titrated up to a maximum of 50 W to achieve a desired tip temperature of 39–40°C,<sup>9</sup> for a total of 60 s.<sup>5,9</sup> Deionized water at room temperature was used as the internal coolant at a flow rate of 30 mL/min. While for clinical application 5% Dextrose solution (D5W) is used as coolant for safety reasons; we opted for water to prevent any clogging of the catheter after prolonged use. This would not affect the results as heat capacity of water and D5W are similar.<sup>10</sup> For the large-tip catheter temperature-controlled ablation was performed for 60 seconds at a target temperature of 65°C; target temperatures of 65–70°C have been clinically used for large-tip catheters in several recent studies.<sup>11–14</sup> External flow rate (0, 1, 2, and 3 L/min) was selected randomly before each application and nine ablations were performed for each flow rate. After ablation was complete, the tissue sample was removed and sectioned perpendicular to the endocardium through the center of the lesion. Each lesion was



**Figure 3.** Lesion example with the dimensions measured and the equation of volume for a partial oblate ellipsoid.

photographed with a digital camera, and the image was downloaded to a computer. Image processing software (Paint Shop Pro 5.0) was used to approximate the lesion boundary by drawing an ellipsoid over the lesion image (Figure 3). Lesion dimensions were then measured using software available from the National Institutes of Health (Bethesda, MD, USA; Image J) and lesion volume was calculated using the equation of volume for a partial oblate ellipsoid (Equation 1).

$$V = \frac{\pi}{12}(2AB^2 + CD^2) \quad (1)$$

### Data Analysis

Student's *t*-test was used to compare lesion dimensions (depth, width, and volume) and average power at different flow rates. Student's *t*-test was also performed to compare lesion dimensions (depth, width, and volume) for the two types of catheters at each flow rate. Analysis of variance (ANOVA) analysis was performed for both catheter types to determine if there is an effect of flow rate on lesion dimensions or average power. For all tests a  $P < 0.05$  was considered significant.

### Results

A total of 72 lesions were produced. Popping occurred during two cooled-tip ablations. These lesions were discarded and repeated at the same flow rate. All lesions measured underwent ablation for the full 1-minute application time. Statistical significance in difference of lesion dimensions and power is indicated in Figures 4–7.

**Width (Figure 4).** For the large-tip catheter, lesion width increased with flow rate ( $P < 0.05$ ) for all flow comparisons except 1 and 2 L/min ( $P = 0.13$ ). For the cooled-tip catheter, lesion width was not statistically different between any of the flow

rates (ANOVA  $P = 0.72$ ). Lesion width was significantly larger for the cooled-tip catheter at flow rates of 0 and 1 L/min ( $P < 0.01$ ), significantly smaller at 3 L/min ( $P < 0.05$ ), and there was no significant difference at 2 L/min ( $P = 0.98$ ).

**Depth (Figure 5).** Lesion depth was also larger ( $P < 0.05$ ) with increasing flow rate when created by the large-tip catheter except between 2 and 3 L/min ( $P = 0.26$ ). Lesion depth was not different between the four flow rates for the cooled-tip catheter (ANOVA  $P = 0.53$ ). Lesion depth was significantly larger for the cooled-tip catheter at flow rates of 0 and 1 L/min ( $P < 0.05$ ), significantly smaller at 3 L/min ( $P < 0.05$ ), and there was no significant difference at 2 L/min ( $P = 0.36$ ).

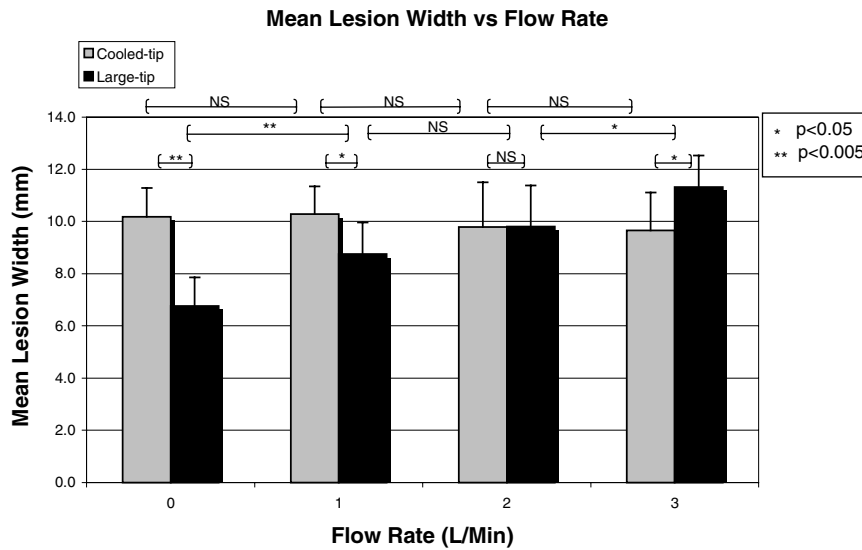
**Volume (Figure 6).** Calculated lesion volume was progressively larger for each higher flow rate for the large-tip catheter (ANOVA  $P < 0.001$ ), but did not vary by flow rate for the cooled-tip catheter (ANOVA  $P = 0.78$ ). When lesion volumes from the two catheter types were compared, volumes were larger for the cooled-tip catheter at low flow rates (0 and 1 L/min) ( $P < 0.01$ ), the same for both catheters at a flow rate of 2 L/min ( $P = 0.82$ ), and larger for the large-tip catheter at a flow rate of 3 L/min ( $P < 0.05$ ).

**Power (Figure 7).** Average applied power increased with increasing flow rate for the large-tip catheter (ANOVA  $P < 0.001$ ), but did not differ by flow rate for the cooled-tip catheter (ANOVA  $P = 0.51$ ).

### Discussion

During RF ablation, the myocardium is heated by resistive heating and a lesion is created when tissue temperature exceeds about 50°C.<sup>15</sup> The region of cell death spreads into the myocardium as heat is conducted away from the area of resistive heating. A significant rise in electrical impedance is encountered when the tissue temperature reaches approximately 100°C due to boiling, charring, and coagulum formation.<sup>16</sup> Two methods of creating larger lesions are increasing the size of the catheter tip to allow contact with more tissue and cooling of the catheter-tip. Convective cooling by blood flow has been shown to affect RF ablation lesion size in both *ex vivo* experiments<sup>17,18</sup> and computer models.<sup>8, 19</sup> Further, it has been demonstrated in a porcine animal model that larger lesions are created in areas of higher velocity blood flow.<sup>18</sup>

The larger the ablation tip, the greater the catheter-tissue contact surface area and the larger the heated region. Further, large-tip catheters have a greater surface area in contact with the blood resulting in augmented convective cooling effect. All of these features increase lesion size, where large-tip catheters may create four times as large lesion volumes as standard 4 mm electrode catheters.<sup>20</sup>

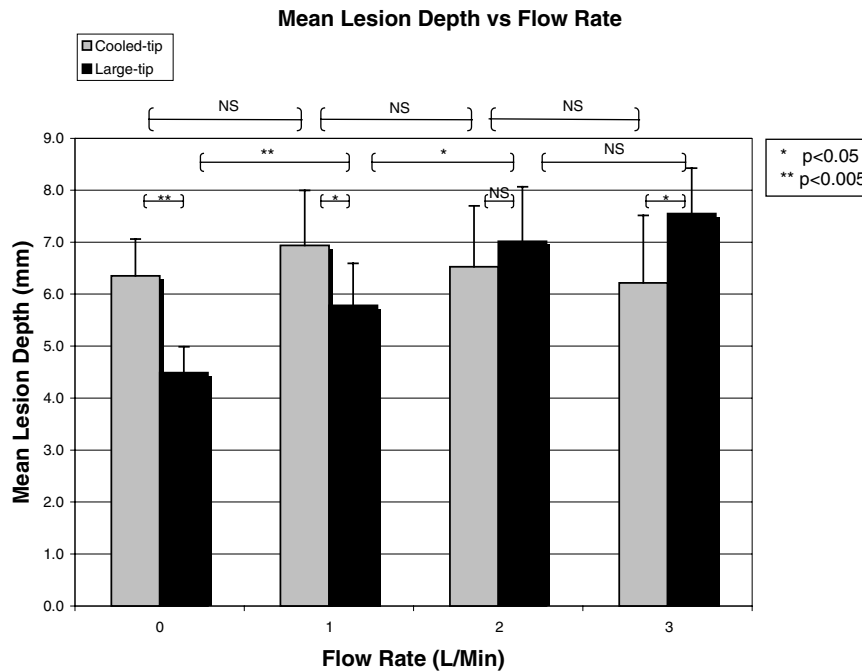


**Figure 4.** Relationship between mean lesion width and flow rate for both catheter types. Highest flow rate (3 L/min) corresponds to a flow velocity of 15.5 cm/s.

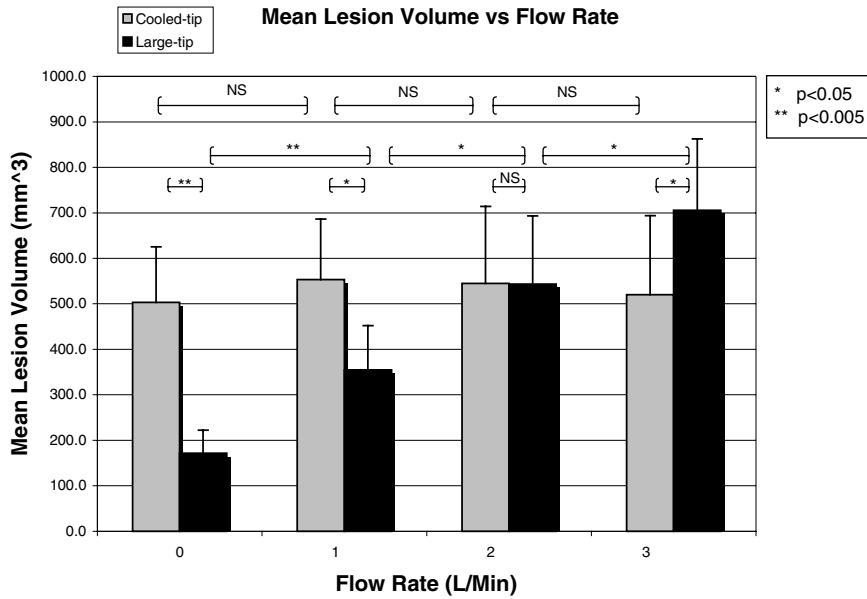
Cooled-tip ablation catheters use an active cooling system to control the temperature at the catheter-endocardial contact surface. Both internally closed loop and open loop actively cooled electrode tip systems are now available clinically.<sup>21,22</sup> This active cooling prevents the electrical impedance rise associated with high tissue temperatures near the catheter tip, as occurs with

standard catheters. Cooling, whether active, passive, or through external convective factors moves the location of maximum temperature further into the tissue, thereby increasing lesion size.<sup>23-28</sup>

The effect of varying amounts of convective cooling using different perfusate flow rates was evaluated for two clinically available catheter types, large tip and actively cooled tip.



**Figure 5.** Relationship between mean lesion depth and flow rate for both catheter types. Highest flow rate (3 L/min) corresponds to a flow velocity of 15.5 cm/s.

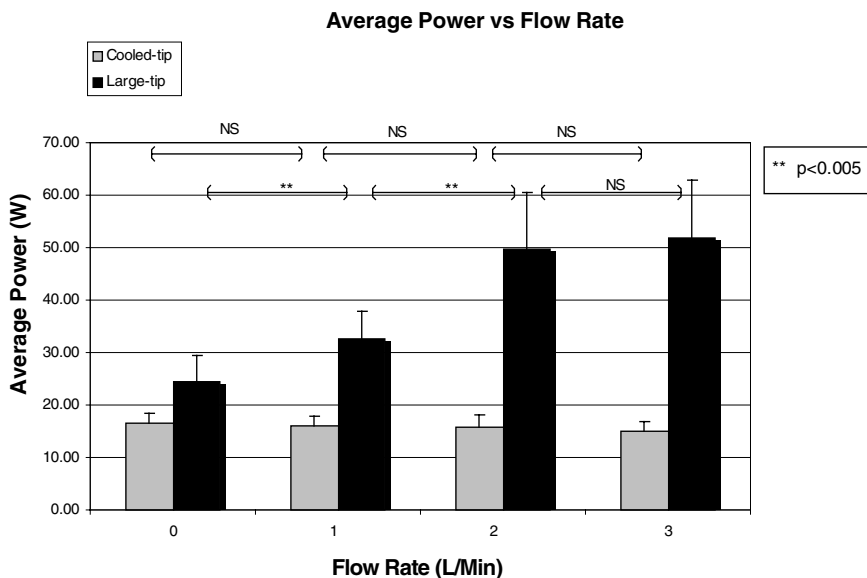


**Figure 6.** Relationship between mean lesion volume and flow rate for both catheter types. Highest flow rate (3 L/min) corresponds to a flow velocity of 15.5 cm/s.

The most important findings of this study are that the lesion sizes for the large-tip catheter are affected significantly by convective cooling, whereas the lesion sizes for the cooled-tip catheter were independent of the amount of convective cooling. Consistent with these findings, applied power varied with the rate of convective cooling for the large-tip catheter, but not the actively cooled-tip catheter. Finally, when the lesion sizes were com-

pared between the large and cooled-tip catheters as a function of flow rate, the cooled-tip catheter created a larger lesion under low flow conditions (0 and 1 L/min), while the large-tip catheter created larger lesions under high flow conditions (3 L/min).

Other studies have demonstrated that higher convective cooling is associated with larger RF lesion size.<sup>8,17-19</sup> The findings of this study add to



**Figure 7.** Average applied power of each catheter type for different flow rates.

the previous ones by assessing these effects in a highly controlled setting and demonstrating that the effects of regional convective cooling are lost with the active internally cooled catheter evaluated in this study. The results of this study suggest that the heat conducted away from the ablation site of the cooled-tip catheter is relatively maximized by the internal coolant flow at room temperature. Therefore, physiologic blood flow velocities do not have significant additional convective cooling effect. However, further improved cooling may be obtained by decreasing the internal coolant temperature, or by increasing the surface area of the catheter tip. This study also demonstrates that large-tip passively cooled catheters may create bigger lesions under high flow conditions compared to cooled-tip catheters. This is likely due to the larger surface being in contact with the tissue compared to cooled-tip catheters.

Our findings have several clinical implications. In regions where high blood flow velocities are expected (near the atrioventricular groove or right ventricular outflow track), and when a larger lesion is desired, a large-tip catheter may be a better choice. However, when large lesions are desired in locations of low velocity blood flow (e.g. right atrial appendage, ventricular apex, or trabeculae in any location), the cooled-tip catheter may be superior. Furthermore, since cooled-tip catheter lesions are independent of flow rate, the lesion size is more predictable which may be an advantage in some cases. Although in general, blood flow velocity can be deduced from the position of the catheter tip in the heart and measured by Doppler echocardiography, a method to directly quantify convective cooling at the ablation catheter tip would be helpful in deciding which catheter to use to produce larger lesions.

### Study Limitations

The study was performed using an *ex vivo* model at constant flow rates. In clinical ablation settings the cardiac cycle produces pulsatile blood flow. It is unclear how significant *in vivo* pulsatile flow would be when averaged over an ablation time of approximately 1 minute. Catheter tissue contact was controlled in this study by application of a consistent tip pressure and angulation. *In vivo*, the catheter tip pressure and angulation

may be highly variable, depending on many factors, some of which might affect the consistency of lesion dimensions produced by any catheter or technique. Endocardial perfusion also acts as a convective cooling source *in vivo* and may affect lesion size. In addition, saline was used in our experiment to simulate blood flow. This prohibited monitoring for blood boiling, charring, and coagulum formation, all of which are serious concerns during RF ablation.<sup>13</sup> To control for this, we used ablation settings that are slightly less aggressive than a recent *in vivo* study by McGreevy et al. that report a charring rate of 6–11% while using a target temperature of 70°C for large-tip catheters<sup>12</sup>; the same target temperature was used in a recent multicenter prospective trial by Feld et al.<sup>11</sup> Another recent study used target temperatures of 60–65°C with coagulum formation in 0.9% of the ablations.<sup>14</sup> A similar study as presented here using an animal model would help clarify these issues.

### Conclusions

Convective cooling due to varying perfusate flow rates significantly affects RF lesion size for large-tip but not cooled-tip catheters. At low flow rates cooled-tip catheters create larger lesions than large-tip catheters, but at high flow rates large-tip catheters create larger lesions than cooled-tip catheters. The results of this study may be helpful in deciding between large-tip and cooled-tip catheters based on the anticipated local blood flow characteristics in the area of ablation. When lesion size predictability independent of location in the heart is desired, the cooled-tip catheter may be a better choice. Likewise, in areas of expected or documented low flow with arrhythmia substrate that requires large ablation lesions, the cooled-tip catheter may be superior. When a large lesion is desired in a high flow rate region the large-tip catheter may be more efficacious. It should be noted that the operator must be aware of the potential complications as well as the benefits of large ablation lesions.

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