Saline-Cooled Versus Standard Radiofrequency Catheter Ablation for Infarct-Related Ventricular Tachycardias

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Background—Saline cooling of the electrode during radiofrequency (RF) ablation increases lesion size in animal models. If cooled RF also increases lesion size in human infarcts, it should facilitate the termination of ventricular tachycardia (VT).

Methods and Results—In 66 patients with VT due to prior infarction, 366 ablation sites, which were classified by entrainment and isolated potentials followed by ablation during VT with either standard RF energy (247 sites) or cooled RF (119 sites), were retrospectively reviewed to compare the efficacy for terminating VT. RF energy was applied at 259 isthmus sites, 62 bystander sites, 28 inner loop sites, and 17 outer loop sites. Compared with standard RF, cooled RF terminated VT more frequently at isthmus sites where an isolated potential was present (89% versus 54%, \(P=0.003\)), isthmus sites without an isolated potential (36% versus 21%, \(P=0.04\)), and at inner loop sites (60% versus 22%, \(P=0.04\)). Termination rates were similarly low for cooled and standard RF at bystander sites (14% versus 9%, \(P=0.56\)) and outer loop sites (13% versus 11%, \(P=0.93\)).

Conclusions—Greater efficacy of cooled RF for terminating VT is consistent with the production of a larger lesion in human infarctions, which should facilitate successful ablation. *(Circulation. 2001;103:1858-1862.)*

Key Words: tachycardia • ablation • reentry

Ablation of ventricular tachycardia (VT) associated with myocardial infarction can be challenging. The reentry circuits can be large, and portions of the reentry path can be located deep to the endocardium.\(^1\)\(^-\)\(^3\) Multiple radiofrequency (RF) lesions are often required, and inadequate lesion size likely contributes to failures. For any given electrode size and tissue contact area, RF lesion size is a function of RF power and duration of application. These parameters are limited when the tissue electrode interface reaches 100°C and denatured proteins form a coagulum on the electrode catheter, increasing impedance. Cooling the electrode by saline irrigation helps to prevent coagulum formation and allows the creation of deeper and larger lesions in animal models. If saline-cooled RF ablation increases lesion size in human infarcts, it should facilitate termination of VT during RF ablation. The 2 methods of ablation have not been directly compared for VT ablation in humans.

Termination of sustained VT by an RF application indicates that conduction has been interrupted through a portion of the reentry circuit.\(^3\)\(^-\)\(^4\) We hypothesized that if saline-irrigated ablation produced larger lesions in vivo in human infarct regions, it would be more effective in interrupting VT compared with standard RF ablation. Therefore, the effect of cooled RF ablation and standard RF ablation on induced, sustained VT was compared in patients undergoing VT ablation after infarction. The location of the RF site relative to the reentry circuit was characterized by entrainment and analysis of isolated potentials; therefore, the 2 types of ablation were compared at similar types of sites, including isthmus sites where termination is often achieved and in reentry circuit loops and bystander regions, where termination of VT is more difficult.

Methods

A retrospective analysis of data from a total of 66 patients with recurrent VT after myocardial infarction who were referred for catheter ablation was performed. Patients had to meet the following criteria: (1) sustained, monomorphic VT was present or inducible in the electrophysiology laboratory, and (2) pacing for entrainment was performed at a mapping site followed immediately by application of RF current for ablation, allowing assessment of whether VT terminated during the RF application.\(^3\)\(^-\)\(^4\) Patient characteristics are shown in Table 1.

Mapping and ablation using the investigational ablation systems were performed according to protocols approved by the institutional review boards of Brigham and Women’s Hospital, Boston, Mass, after informed consent was obtained. The mapping and ablation approach has been previously described.\(^3\)\(^-\)\(^4\) Access to the left ventricle was achieved with a retrograde aortic or trans-septal approach. Systemic anticoagulation was maintained with the intravenous administration of heparin. Bipolar electrograms were filtered at 30 to 500 Hz and recorded along with the 12-lead ECG of all induced VTs (Prucka Engineering Inc). After introducing the catheters, the area of

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infarction was identified on the basis of the location of abnormal electrograms. If VT was not incessant, tachycardia was then initiated and mapping continued during monomorphic VT, if tolerated. If VT was poorly tolerated, repeated initiation and termination were used to allow limited mapping during tachycardia. We initially sought reentry circuit isthmus sites for ablation.

When RF application terminated VT at a site, additional lesions were applied to the region within 1 cm of the termination site until unipolar pacing at the stimulus strength initially tested (usually 10 mA, 2 ms pulse width) failed to capture at the site. When isthmus sites were not identified, RF lesions were placed at outer loop or bystander sites. Programmed stimulation was then used to induce VT for further mapping and ablation of other circuits. The end point of the procedure was the absence of inducible VT, no reentry circuit sites identified on the endocardium, or only rapid, poorly tolerated, inducible VT that was different in rate and morphology than the VT sites were not identified, RF lesions were placed at outer loop or bystander sites. Programmed stimulation was then used to induce VT for further mapping and ablation of other circuits. The end point of the procedure was the absence of inducible VT, no reentry circuit sites identified on the endocardium, or only rapid, poorly tolerated, inducible VT that was different in rate and morphology than the VT induced at the beginning of the procedure.

Standard RF ablation was performed using an 8-French catheter with a 4-mm tip electrode (EPT, Boston Scientific or Biosense Webster) in 46 patients. RF energy application was initiated at 20 to 30 W, and the power was gradually increased to achieve a measured electrode tip temperature of 60 to 65°C, an impedance fall of 6 to 10 Ohms, or a maximum power of 50 Watts. The electroanatomical mapping system was used to track catheter position in 7 patients with the external irrigation system and in 19 patients with standard RF.

Cooled RF ablation was performed using 1 of 2 systems in 20 patients. In 7 patients, an external irrigation system was used (Chilli Cool Catheter, Cardiac Webster). This 8 French catheter has an electrode 3.5 mm in length with 6 holes in the tip through which saline flows at 30 mL/min during RF application. In 13 patients, an internal irrigation system was used (Chilli Cool Catheter, Cardiac Pathways). Saline flows at 36 mL/min through the electrode and returns through a second lumen to be discarded outside the patient. For both cooled RF systems, application was initiated after saline irrigation decreased the measured electrode temperature to 28 to 32°C. Initial power was 20 to 30 W, and the power was gradually increased to achieve a fall in impedance of 5 to 10 Ohms or a maximal measured electrode tip temperature of 40 to 45°C. Energy application was continued for a minimum of 30 seconds and a maximum of 2 minutes. RF current application was discontinued if measured impedance increased by >10 Ohms, the catheter changed position, or VT failed to terminate after 30 to 60 seconds.

Before RF current application, entrainment was used to determine the relation of the site to the reentry circuit.1 Entrainment used unipolar stimuli at a stimulus strength of 10 mA and 2 ms pulse width, which increased to pulse widths of 5 or 9 ms if needed for capture. Sites were designated as being in the reentry circuit if the postpacing interval was within 30 ms of the tachycardia cycle length or if the S-QRS interval during entrainment with concealed fusion was within 20 ms of the electrogram to QRS interval. Isthmus sites are defined as those that are in the circuit where entrainment occurs with concealed fusion and with a stimulus to the QRS (S-QRS) interval that was ≤70% of the tachycardia cycle length. Outer loop sites are circuit sites where entrainment occurs with QRS fusion. Inner loop sites are in the circuit but have a S-QRS >70% of the VT cycle length during entrainment with concealed fusion. Bystander sites are outside the circuit.3 Sites were further grouped into those with and without an isolated potential present during VT.5,6

At the end of the procedure, programmed stimulation was used to determine the early results of ablation. Stimulation included burst pacing and 1 to 3 extrastimuli after drive trains of 2 different cycle lengths from 2 different right ventricular sites. Early results were defined as no inducible VT, modified VT (a faster new VT is induced), and failure to abolish inducible VTs that were targeted for ablation. Previously ineffective antiarrhythmic agents were continued (in the absence of toxicity) before and after ablation when required by investigational device protocols or when amiodarone had been administered long-term before ablation. Follow-up was obtained for all patients in May 2000.

Statistics
Results are expressed as mean±SD. Unpaired t tests and χ² tests were used for comparisons with the null hypothesis discarded at P<0.05. Time-to-event survival curves were constructed using the Kaplan-Meier method and compared with the Mantel-Cox method.

Results
Short-Term Effects
Data from a total of 366 sites evaluated during 89 different VTs that met the inclusion criteria were analyzed. There were 259 isthmus sites, 62 bystander sites, 28 inner loop sites, and 17 outer loop sites. RF termination was more frequent at isthmus sites (36%) than at other types of sites (18%), and it was more frequent at isthmus sites where an isolated potential was also present (67%) than at isthmus sites without isolated potentials (24%, P<0.0001).

Standard RF current application terminated VT at 62 sites (25%), and cooled RF current application terminated VT at 51 sites (43%, P=0.0006). At isthmus sites, cooled RF terminated VT more frequently than standard RF ablation (Table 2). For isthmus sites where an isolated potential was present, cooled RF terminated VT more frequently than standard RF (89% versus 54%, P=0.003). Cooled RF was also more effective than standard RF at isthmus sites where an isolated potential was absent (36% versus 21%, P=0.04) and at inner loop sites (60% versus 22%, P=0.04). At outer loop (13% versus 11%, P=0.93) and bystander sites (14% versus 9%, P=0.56), cooled RF and standard RF had a similarly low efficacy (Table 2).

Table 3 compares the average maximal power achieved. As anticipated, the maximal power achieved was greater with cooled than with standard RF (Figure 1). Within the cooled RF group, maximal power was similar for sites where RF application terminated VT and for sites where RF failed to terminate VT (Table 3). Similarly, in the standard RF group, similar power was applied to the sites where termination of
VT occurred and in those where RF failed to terminate VT. In the cooled RF group, ablation at an isthmus site with the external irrigation catheter (Thermocool) resulted in termination more frequently than with the internal saline irrigation catheter (Chilli Cool Catheter) (16 of 17 sites [94%] versus 27 of 55 sites [50%), \( P = 0.0026 \)). This difference could be related to the greater maximal power applied (40.2\( \pm \)4.2 versus 37.7\( \pm \)4.6 W with external versus internal irrigation, \( P = 0.05 \)) and longer total duration of RF application with the external irrigation catheter compared with the internal irrigation catheter (115.4\( \pm \)14.9 versus 74.5\( \pm \)31.8 s, \( P \leq 0.0001 \)). However, at sites with termination, the time to termination of VT was shorter with external irrigation than with internal irrigation (28.1\( \pm \)34.0 versus 51.9\( \pm \)29.0 s, \( P = 0.01 \)).

In the standard RF group, power delivery was guided by a fall in impedance in 56 applications using catheters without temperature sensors and by temperature monitoring in 253 applications using temperature-controlled RF application. With both temperature monitoring and impedance monitoring, the frequency of impedance rises (6 of 253 sites [2.4%] versus 2 of 56 sites [3.6%], \( P = 0.62 \)) and the incidence of VT termination (61 of 253 sites [24.1%] versus 16 of 56 sites [28.6%], \( P = 0.49 \)) were similar.

A total of 26.3\( \pm \)20.4 standard RF applications and 20.8\( \pm \)12.1 cooled RF applications were applied per patient. Standard RF ablation abolished all inducible, monomorphic VTs in 21 of 46 patients (46%), modified inducible VT in 14 patients (30%), and failed to abolish an inducible targeted VT in 11 patients (24%). Cooled RF ablation abolished all inducible monomorphic VTs in 9 of 20 patients (45%), modified inducible VT in 8 patients (40%), and failed to abolish a targeted VT in 3 patients (15%). The early success rate (abolished inducible VT or modified inducible VT) for cooled RF was 85%, and for standard RF, 76\% (\( P = 0.85 \)).

Complications occurred in 4 patients in the standard RF group (2 femoral artery dissections, 1 small peripheral arterial embolism that did not require therapy, and 1 retroperitoneal hematoma that required transfusion) and in 2 patients with cooled RF (1 femoral artery dissection that did not require intervention and 1 aortic valve injury with aortic insufficiency discovered at coronary artery bypass surgery).

### Follow-Up

During follow-up, previously ineffective antiarrhythmic agents were continued in 55\% of the standard ablation and 65\% of the cooled ablation groups. All but 10 patients had an implanted cardioverter defibrillator. During a mean follow-up of 530\( \pm \)495 days (range, 4 to 1916 days), VT recurred spontaneously in 35\% of the standard RF ablation patients and in 10\% of the cooled RF ablation patients (\( P = 0.07 \), Figure 2). Average time to VT recurrence was 93\( \pm \)159 days (range, 1 to 294 days). Mortality was similar in the 2 groups.

### TABLE 2. Termination Rate of Cooled RF Versus Standard RF

<table>
<thead>
<tr>
<th>Location</th>
<th>Standard RF</th>
<th>Cooled RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isthmus</td>
<td>259</td>
<td>187</td>
</tr>
<tr>
<td>IP 1</td>
<td>73</td>
<td>46</td>
</tr>
<tr>
<td>IP 2</td>
<td>186</td>
<td>141</td>
</tr>
<tr>
<td>Inner loop</td>
<td>28</td>
<td>18</td>
</tr>
<tr>
<td>Outer loop</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>Bystander</td>
<td>62</td>
<td>33</td>
</tr>
<tr>
<td>Total</td>
<td>366</td>
<td>247</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Termination Sites, n (%)</th>
<th>Nontermination Sites, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isthmus</td>
<td>259</td>
<td>187</td>
</tr>
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</tr>
<tr>
<td>Total</td>
<td>366</td>
<td>247</td>
</tr>
</tbody>
</table>

*IP indicates isolated potential. \( P < 0.05 \) vs standard RF.

### TABLE 3. Comparison of Average Power at Termination and Nontermination Sites

<table>
<thead>
<tr>
<th>Location</th>
<th>Standard RF</th>
<th>Cooled RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isthmus</td>
<td>32.8( \pm )9.8</td>
<td>31.6( \pm )9.6</td>
</tr>
<tr>
<td>Inner Loop</td>
<td>26.9( \pm )10.2</td>
<td>32.5( \pm )9.4</td>
</tr>
<tr>
<td>Bystander</td>
<td>29.4( \pm )8.3</td>
<td>32.9( \pm )9.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration, s</th>
<th>Standard RF</th>
<th>Cooled RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isthmus</td>
<td>84.7( \pm )37.7</td>
<td>75.6( \pm )37.9</td>
</tr>
<tr>
<td>Inner Loop</td>
<td>105.8( \pm )28.5</td>
<td>76.7( \pm )41.4</td>
</tr>
<tr>
<td>Bystander</td>
<td>70.0( \pm )45.8</td>
<td>77.3( \pm )32.0</td>
</tr>
</tbody>
</table>

Significantly higher power was delivered with cooled RF ablation catheters.
In the cooled RF group, 3 patients (15%) died (from pulmonary embolism after hip fracture, cancer, and pneumonia, respectively) and 1 patient underwent cardiac transplantation. In the standard RF group, 11 patients (28%) died (7 of congestive heart failure, 1 of stroke, 2 of sepsis, and 1 of liver failure, respectively) and 3 patients underwent cardiac transplantation.

**Discussion**

This is the first study comparing saline-cooled RF ablation with standard RF ablation in patients with VT due to prior myocardial infarction. Cooled RF ablation was more effective in terminating VT in the short-term, which is consistent with the production of a larger lesion, as seen in prior studies in animal models, in vitro preparations, and anecdotal observations. Ablation was most effective at sites identified as likely isthmuses on the basis of entrainment and the presence of an isolated potential, as was previously reported. In the present study, the termination rate at isthmus sites was significantly higher in the cooled RF group, suggesting that these reentry circuit isthmuses often exceed the width and depth of a standard RF lesion.

The ideal comparison of cooled and standard RF ablation would be a prospective, randomized study. Our patients who received cooled RF were enrolled in US Food and Drug Administration–approved studies when this technology was investigational. A randomized trial was not possible. Subsequently, one of these systems (Chilli Cool Catheter, Cardiac Pathways) was approved by the agency, and ongoing investigation of the other system is continuing. To reduce confounding factors in our retrospective analysis, we took several precautions. Termination of VT during RF application was used as the end point for assessing effect, as described previously. The efficacy of VT during RF application was compared for identical types of sites, as identified by entrainment and the presence of isolated potentials. The duration of RF application at sites without termination was analyzed and found to be similar for the cooled and standard RF applications.

During follow-up, the incidence of recurrent VT tended to be lower, although statistical significance was not reached. Comparison of early success rates with previous studies is difficult because success is often reported as the ablation of a "targeted" or "clinical" VT, without regard to the presence of other inducible VTs. The efficacy of standard RF was similar to that observed in a previous study of 52 patients from our group. Standard RF abolished all inducible VT in 40% of patients and modified inducible VTs in 31% of patients; recurrence rate after 3 years of follow-up was 33% and the survival rate was 70%. In the present study, 85% of patients were rendered free of inducible VT or had modified VT with cooled RF ablation. During follow-up, the recurrence rate was 35% in the standard RF group and 10% in the cooled RF group. The Cooled RF Multicenter Investigators group, which included 10 of the patients reported in this study among their 146 total patients, reported a 75% success rate of cooled RF and a recurrence rate during follow-up of 40%.

**Limitations**

There are a number of limitations to this study. The protocols for cooled RF systems precluded randomization of patients or lesion sites. A number of differences between RF ablation systems makes comparison of power and energy between different ablation systems difficult. The power reported by the generator indicates only a fraction of the power that is dissipated as heat in the tissue due to variations in system impedance, loss along the cables, and other factors. Our system for internal saline irrigation stored only the maximal power, impedance, and temperature for later retrieval. Therefore, we compared only the maximal values among systems, recognizing that this is only a crude indication of the energy applied. Methods for standard RF energy application guided by temperature or impedance monitoring have been well defined, and both methods yielded similar effects in the present study. The optimal manner of energy titration for cooled RF application has not been clearly defined. Whether the systematic method used in this study is the optimal method of energy delivery for maximizing lesion size is not known. We also applied the same methods of RF current application with both the internal and external saline irrigation systems, despite the differences between the 2 systems. Finally, we do not have anatomic, histological documentation of lesion size with the different methods.

**Conclusions**

Cooled RF ablation terminates reentrant VT more effectively than standard RF, which is consistent with the production of larger lesions in human infarctions. Saline-cooled RF ablation is a promising technology for facilitating the ablation of large reentry circuits.
Acknowledgment
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References
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