Comparative Study of Fluoroscopy and Intracardiac Echocardiographic Guidance for the Creation of Linear Atrial Lesions

Laurence M. Epstein, MD; Mark A. Mitchell, MD; Timothy W. Smith, PhD, MD; David E. Haines, MD

Background—Recently, attempts have been made to cure atrial fibrillation by creating multiple linear atrial lesions with radiofrequency energy. Intracardiac echocardiography (ICE) offers imaging of endocardial anatomy and the ablation electrode–tissue interface not available with standard fluoroscopy. This study sought to prospectively compare fluoroscopic with ICE guidance for the creation of linear atrial lesions in a canine model.

Methods and Results—The creation of 3 linear atrial lesions was attempted in each of 10 dogs, half guided by fluoroscopy alone and half by ICE. Coil-tissue contact was prospectively graded. After ablation, animals were euthanized, and the location and continuity of lesions were evaluated. ICE guidance led to a higher percentage of successful applications (P<0.02) and mean achieved temperature (P=0.004). The contact scores of excellent, fair, and poor correlated well with successful energy delivery, mean temperature, and efficiency of heating (P<0.0001). In 25% of the blinded energy deliveries, the location, as determined by the ablation operator, differed from that of ICE. Pathological evaluation revealed improved lesion formation in the ICE-guided compared with the ICE-blinded group. Lesions were found outside the target areas in the ICE-blinded but not the ICE-guided group.

Conclusions—Compared with fluoroscopy, ICE guidance improved targeting, energy delivery, and lesion formation in this canine model. This study suggests that ICE guidance improves lesion formation and prevents energy delivery to potentially dangerous sites. (Circulation. 1998;98:1796-1801.)

Key Words: echocardiography • catheter ablation • atrial fibrillation
adult mongrel dogs. The dogs were premedicated with ketamine and morphine and intubated. Anesthesia was maintained with 1% halothane, and animals were continuously ventilated. The level of anesthesia and surface ECG were monitored throughout the procedure. Via cutdowns, an 8F vascular sheath was placed in the right femoral vein and a 10F long vascular sheath was placed in the left femoral vein for the introduction of the ablation and ICE catheters, respectively.

Linear lesions were created with a multielement ablation catheter (MECA ablation system, EP Technologies, Inc). These steerable 7F catheters contain 2 to 6 flexible 12.5-mm stainless steel coil electrodes with 2 thermocouples embedded in each coil. The coils can be activated simultaneously, but for this study, each was activated individually. After positioning, radiofrequency energy was delivered via a radiofrequency generator capable of delivering up to 150 W (XP-1000, EP Technologies, Inc). The generator was set to deliver energy for up to 60 seconds and achieve a temperature of 70°C. The power draw was regulated by feedback from the 2 thermocouples mounted on opposite sides of each ablation coil. Temperature, impedance, and power were monitored for each energy delivery. To avoid charring, especially at the electrode edges, energy delivery was conservatively set to automatically terminate if the current required to achieve the preset temperature exceeded 0.9 A.

Intracardiac ultrasound imaging was performed with a 9F9-MHz catheter (Boston Scientific). These catheters have a tip-mounted mechanical ultrasound transducer connected to a motor unit by a flexible driveshaft. Images were viewed in real time on a Sonos ultrasound imaging console (Hewlett Packard) and recorded on flexible drives. Images were viewed in real time on a Sonos ultrasound imaging console (Hewlett Packard) and recorded on flexible drives. Images were viewed in real time on a Sonos ultrasound imaging console (Hewlett Packard) and recorded on flexible drives. Images were viewed in real time on a Sonos ultrasound imaging console (Hewlett Packard) and recorded on flexible drives.

The multicoil ablation catheter was positioned across the desired cardiac region with an attempt to have as many coils in contact with the endocardium as possible. Linear lesions were created by applying energy to the ablation coils sequentially. In some regions, the linear lesion could not be completed with a single catheter placement. In these cases, the catheter was repositioned, under either fluoroscopic or ICE guidance, to extend lesion formation from the location of the previous energy applications. There was no preset number of energy applications per lesion set. Attempts were continued until the ablation operator thought the lesion was completed. Blinded and guided experiments were alternated to avoid any effect of a learning curve on the outcome of the study.

Before each radiofrequency energy delivery, the ICE operator scored the quality of coil-tissue contact as poor, fair, or excellent as defined below. In the ICE-blinded procedures, the ablation operator and the ICE operator independently recorded the expected location of the energy application on the basis of the fluoroscopic and ICE images, respectively.

For each radiofrequency delivery, mean achieved temperature, efficiency of heating (temperature/power), and occurrence of automatic termination of energy delivery due to excessive current draw were monitored. These variables were compiled for all procedures and compared with the ICE assessment of quality of coil-tissue contact.

After completion of the procedure, the animals were euthanized, and the hearts were excised for dissection and examination of the ablation lesions formed. The right atrium was opened, and the endocardial lesions were identified. The atrium was stained with nitro blue tetrazolium (0.5 mg/mL, 0.2 mol/L Sorensen’s buffer) to better identify nonviable myocardium. Lesions were bisected longitudinally to assess the depth of lesion formation and to determine whether they were transmural. Each linear lesion was assessed for continuity, completion, and location. The percent completion of each linear lesion, as defined below, was compared for ICE-blinded and ICE-guided ablations.

**Definitions**

A radiofrequency energy application was considered successful if energy was delivered for the full 60 seconds and a tissue temperature of ≥60°C was attained.

Coil-tissue contact was defined as follows: poor, <50% of the ablation coil in contact with the endocardium throughout the entire cardiac cycle; fair, between 50% and 90% of coil electrode in contact with the endocardium throughout the cardiac cycle; and excellent, >90% of the coil in contact with the myocardium throughout the cardiac cycle.

For each linear lesion, the percent completion was defined as follows: 100%, transmural lesion completely traverses the desired area; ≥90%, transmural lesion almost complete, with single gap accounting for ≤10% of the total lesion; ≥75%, transmural lesion with ≥1 gap accounting for 10% to 25% of total lesion; and <50%, transmural lesion formation over <50% of desired area.

**Statistical Analysis**

Values are represented as mean ± SD. Variables were compared by ANOVA and χ² analysis as indicated. Differences were considered significant if the P value was < 0.05.

**Results**

Right atrial endocardial anatomy was well visualized in all animals, and the ablation coils were easily identified. With ICE imaging, coil-tissue contact was easily evaluated for each operator used the ICE images (in addition to fluoroscopy) to guide placement of the ablation coils and optimize coil-tissue contact. In this group, energy was not delivered if the coil/tissue contact was thought to be poor on the basis of the ICE image. In addition, ICE was used to optimize completion of each linear lesion by ensuring that a successful energy delivery was made along the entire endocardial length of the desired target region.
of the 328 attempted energy applications. Of the total energy deliveries, 161 were in the 5 dogs in which the ablation operator was blinded to the ICE images, and 167 were in 5 dogs in which lesions were attempted with ICE guidance in addition to fluoroscopy (P = NS).

ICE guidance resulted in a higher rate of successful energy application compared with fluoroscopic guidance alone. Overall, 61% (102/167) of ICE-guided attempts were successful, whereas only 48% (78/161) of the ICE-blinded attempts were successful (P = 0.02). The mean temperature achieved in ICE-guided ablation attempts (60.3 ± 9.8°C) was also significantly higher than that achieved without ICE guidance (56.8 ± 11.1°C) (P = 0.004). Although the difference in efficiency of heating did not reach significance, there was a trend toward a higher value in ICE-guided procedures (1.8 ± 0.9°C/W versus 1.6 ± 1.0°C/W).

On the basis of ICE imaging, a coil-tissue contact score was assigned prospectively for all 328 energy deliveries. The contact score proved to be an excellent predictor of successful energy application (Table 1). None of the ablation attempts with poor contact were successful, 43% of fair contact attempts were successful, and 92% of the attempts with excellent contact were successful (P < 0.0001). In addition, the mean temperature achieved and efficiency of heating were well correlated with the ICE assessment of contact score. As can be seen in Table 2, the excellent predictive value of ICE imaging was universal among the 3 lesion sets. An example of ICE images representing excellent and poor contact during attempts to create the isthmus lesion can be seen in Figure 2.

There were 118 attempts for which contact was deemed excellent. These accounted for a higher percentage of applications in the ICE-guided (58%, 69/118) than in the ICE-blinded (42%, 49/116) procedures. There were 166 attempts for which the contact was scored fair. Again, these accounted for a higher percentage of applications in the ICE-guided (59%, 98/166) than in the ICE-blinded (41%, 68/161) procedures. There were 44 attempts when coil-tissue contact was scored poor. All of these applications were in ICE-blinded procedures (27%, 44/161), because no energy deliveries were attempted in the ICE-guided group if contact was deemed poor.

Pathological evaluation revealed that ICE guidance improved the continuity, completion, and placement of the

<table>
<thead>
<tr>
<th>Contact Score</th>
<th>Poor</th>
<th>Fair</th>
<th>Excellent</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success rate, % (n)</td>
<td>0 (0/44)</td>
<td>43 (71/166)</td>
<td>92 (109/118)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>45.1 ± 5.7</td>
<td>56.8 ± 10.3</td>
<td>66.1 ± 4.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Efficiency of heating, °C/W</td>
<td>1.1 ± 0.4</td>
<td>1.5 ± 0.7</td>
<td>2.2 ± 1.1</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Table 1. Correlation Between Coil-Tissue Contact Score and Parameters of Radiofrequency Energy Delivery

<table>
<thead>
<tr>
<th>Contact Score</th>
<th>Intercaval lesions</th>
<th>Anterior Lesions</th>
<th>Isthmus lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success rate, % (n)</td>
<td>0 (0/16)</td>
<td>0 (0/15)</td>
<td>0 (0/13)</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>45.2 ± 5.6</td>
<td>41.7 ± 4.8</td>
<td>48.8 ± 4.6</td>
</tr>
<tr>
<td>Efficiency of heating, °C/W</td>
<td>1.2 ± 0.7</td>
<td>1.0 ± 0.1</td>
<td>1.2 ± 0.1</td>
</tr>
</tbody>
</table>

Table 2. Correlation Between Coil-Tissue Contact Score and Parameters of Radiofrequency Energy Delivery for Each Linear Atrial Lesion
linear right atrial lesions. Three linear lesions (anterior, transvalvular, and flutter) were attempted in each animal for a total of 30 lesions (15 in each group). Figure 3 shows the percent completion of the lesions produced in the ICE-blinded and ICE-guided procedures. All of the ICE-guided linear lesions had >75% completion, and 8 of 15 lesions (53%) were ≥90% complete. This differed significantly from the ICE-blinded group, in which only 1 lesion was ≥90% complete (7%) and 7 of 15 (47%) were <50% complete ($P=0.002$). The most striking difference between the ICE-guided and ICE-blinded lesions was in the flutter isthmus (from the IVC to the tricuspid annulus). In the ICE-guided procedures, 5 of 5 of the lesions were 100% complete, whereas 0 of 5 of the flutter lesions without ICE guidance were complete with this ablation system.

Compared with fluoroscopic guidance alone, ICE guidance improved positioning of the ablation coils. In 25% (40/161) of energy applications in the ICE-blinded group, the location of the ablation coil, according to the ablation operator, differed significantly from ICE assessment. The mean percentage of such applications for each animal was 24±15%, with a range of 12% to 50%. The most common misplacements of the ablation coil were as follows: across the tricuspid valve into the right ventricle (14), in the IVC or SVC instead of the right atrium (10), in the right atrial appendage (9), and on the crista terminalis (5). One ablation attempt, seen to be high on the crista terminalis by ICE, resulted in sinus arrest. In Figure 2B, an ablation coil can be seen crossing the tricuspid valve into the right ventricle during an attempt to create an isthmus lesion. On the basis of fluoroscopy, the distal ablation coil was thought to be on the right atrial side of the annulus by the ablation operator. These differences were also seen at pathological evaluation. In none of the animals that underwent ICE-guided procedures were individual ablative lesions found outside of targeted areas. In contrast, ablation lesions were found outside of targeted areas in all animals in which fluoroscopy alone was used for guidance. These included lesions within the right ventricle in 2 animals and on the crista terminalis in 2 animals.

**Discussion**

The present study prospectively compared intracardiac echocardiographic with fluoroscopic guidance for the creation of linear atrial lesions. In this animal model, ICE was clearly superior to fluoroscopy in assessing coil-tissue contact and anatomic location.

ICE evaluation of coil-tissue contact was an excellent predictor of successful energy delivery and directly correlated with achieved temperature and efficiency of heating. The assessment of contact as poor, fair, and excellent used in the present trial was modified from that used by Kalman et al.\textsuperscript{17} In a canine model, they evaluated the correlation between ICE assessment of electrode-tissue contact, efficiency of heating, and lesion formation. Although their ablation electrode was smaller (4 mm) and the ICE catheter different (10F/10 MHz), their findings were similar to ours. There was a significant correlation between ICE evaluation of tissue contact, parameters of tissue heating, and lesion size. They also speculated that ICE could be used prospectively to improve the percentage of good contact applications during ablation procedures. This proved to be true in our study. In the ICE-blinded group, ablation attempts were made with poor contact 25% of the time and with excellent contact <33% of the time. The higher percentage of successful energy applications in the ICE-guided group was due to improved tissue contact made possible by directly visualizing the coil/tissue interface.

Although there was a higher percentage of successful energy applications overall, slightly more than 33% of applications were still unsuccessful in the ICE-guided group. These were almost all confined to the applications in which contact was deemed fair. Many of these applications might have been successful if not for the conservative energy delivery system used, which limited the current draw to 0.9 A. Suboptimal contact can sometimes be overcome with higher energy output. The radiofrequency energy generator used in this study was capable of an output of up to 150 W. However, it has been shown that high-energy delivery with a high current can result in charring, especially at the edge of electrodes, due to a high current density.\textsuperscript{18} We thought it better to terminate energy delivery than to risk charring. Therefore, with the ablation system used, excellent contact along the entire length of the coil must be sought and can only be assessed with ICE.

Incomplete linear lesions not only may lead to procedure failure but also may be proarrhythmic.\textsuperscript{19} ICE guidance clearly improved the ability to create continuous lesions in this animal model. With the ablation system used, half of the linear lesions were <50% complete and only 1 was >90% complete in the ICE-blinded group. This was most likely a result of a combination of inadequate lesion formation and poor localization of target sites. This was most apparent in the isthmus region. Although the coils in these catheters were flexible, it was difficult to gain contact along the complex architecture of the IVC–tricuspid valve isthmus.\textsuperscript{20–22} ICE imaging allowed excellent contact and lesion formation in all animals in the flutter region as opposed to the inability to create lesions in this region with fluoroscopy alone.

One of the most striking findings in this study was how often the assessment of location by the ablation operator differed from that of the ICE operator. In the ICE-blinded group, 25% of all energy applications and 50% of the
applications in 1 animal were to unintended sites. Although not all of the applications resulted in lesion formation, lesions were found outside of target areas in all animals of this group. These are not only inefficient but possibly dangerous. The safety of creating multiple lesions throughout the atrium is unknown. Lesions outside intended areas can only add to the potential deleterious effects, unnecessarily increasing the mass of atrial tissue ablated or unintentionally damaging important structures. For example, in this study, 1 energy application unintentionally placed high on the crista terminalis resulted in sinus arrest, and others created lesions in the right ventricle.

Other Studies

Other studies have demonstrated the utility of ICE imaging as an adjunct to fluoroscopy for guiding radiofrequency catheter ablation procedures in animals and humans. Chu et al14 used ICE to help guide the ablation of a variety of arrhythmic substrates in the right atrium: anatomic structures such as the crista terminalis, tricuspid annulus, coronary sinus ostium, eustachian ridge, fossa ovalis, and remnants of prior surgical procedures. Successful ablations of atrial flutter, atrial tachycardia, sinus node reentry, AV nodal reentrant tachycardia, and sinus node reentry were assisted by ICE guidance. Assessment of electrode-tissue contact was possible for only 60% of energy applications in this study. This was most likely due to the limited maneuverability of the “over-the-wire” ICE catheter used. In a study of sinus node ablation or modification for the treatment of inappropriate sinus tachycardia, Lee et al23 found ICE imaging very useful in identifying the superior aspects of the crista terminalis at the superior vena cava–right atrial junction. In 1 patient, ICE imaging identified unsuspected significant narrowing of the SVC due to multiple ablation attempts, preventing further damage. Olgin et al24 recently used ICE to create linear lesions in the right atrium in an animal model. With a 10F/10-MHz ICE catheter and a 4-coil ablation catheter, linear lesions were created in the right atrium of pigs. Before radiofrequency energy application, ICE imaging of the coil/tissue interface was used to optimize contact and direct anatomic placement. After tissue contact was optimized, all energy applications were successful, and lesions were found to be within 0.3 mm of target sites. The coils in this trial were significantly smaller (5 mm) than those used in the present study (12.5 mm), and there was no limitation on current. This most likely resulted in the higher success rate of energy applications. These trials demonstrate the utility of ICE guidance for a variety of catheter ablation procedures. To the best of our knowledge, however, the present trial is the only study to prospectively compare ICE with fluoroscopic guidance for the creation of linear atrial lesions.

Limitations

The goal of this trial was to evaluate the use of ICE guidance to create linear atrial lesions. Although the ultimate goal of any such ablation procedure is to prevent atrial fibrillation, this was not evaluated in this trial. Animals were not in atrial fibrillation. Therefore, no conclusions concerning the utility of ICE for curing atrial fibrillation can be drawn from the present study. However, if percutaneously created linear atrial lesions can prevent atrial fibrillation, then any modality that can improve lesion creation should improve the success and safety of the procedure. In addition, patients with atrial fibrillation may have much larger atria than the normal dog. The ICE catheter used in this study offered excellent resolution with a field of view of up to 10 cm, which should be more than adequate to visualize even the largest atria. Because of these limitations, the findings in this study cannot be directly translated to human atrial fibrillation therapy, and further study is warranted.

Although some reports suggest that atrial fibrillation can be prevented with ablation in the right atrium alone, it appears that most patients will require lesions in the left atrium. Current ICE technology offers only limited views of the left atrium from the right atrium. Advances in ICE technology will be required to guide left atrial ablation attempts in the future.

Conclusions

Intracardiac echocardiography was superior to fluoroscopy for the guidance of linear lesion creation in the right atrium in this canine model. Compared with fluoroscopy, ICE guidance improved targeting, energy delivery, and lesion formation. This study suggests that ICE guidance may be an important component of clinical procedures designed to cure atrial fibrillation by improving lesion formation and preventing energy delivery to potentially dangerous sites.

References


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