Radiofrequency Catheter Ablation Guided by Intracardiac Echocardiography

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Background Radiofrequency catheter ablation requires precise positioning of the ablation electrode. Fluoroscopically guided catheter manipulation has limitations, and there are risks of radiation exposure. The purpose of this study was to examine the feasibility of guiding catheter ablation within the right atrium with catheter-based intracardiac echocardiography.

Methods and Results A 10F, 10-MHz intracardiac imaging catheter was used to direct an ablation electrode at four or five anatomic landmarks in the right atrium. Thirty-eight radiofrequency energy applications were performed in nine anesthetized dogs, and 38 lesions were identified on pathological examination. Lesions were created a mean of 1.9±2.1 mm from the ultrasound-guided site. Twenty-six of 38 lesions (68%) were less than 2.2 mm from the imaged site. Intracardiac echocardiography was also used to confirm stable electrode-endocardial contact in 37 energy applications (97%) and identified catheter movement in 9 energy applications (24%).

Radiofrequency (RF) catheter ablation has revolutionized the treatment of patients with a variety of clinical tachycardias.1,2 Discrete lesions created by RF energy applied to the endocardium can sever reentrant pathways and abolish foci of automaticity. As currently practiced, ablation catheter positioning is guided by fluoroscopy, and target sites are based on an analysis of intracardiac electrograms, although in some arrhythmias such as atrial flutter, target sites may be anatomic.3 There are limitations to the use of fluoroscopy, including failure to identify the endocardium and the anatomic detail required for catheter positioning. Ablation electrode-endocardial contact and lesion formation cannot be assessed directly with fluoroscopy. In addition, ionizing radiation exposure can potentially increase the risk of malignancy to the patient and the operator.4 We hypothesized that intracardiac echocardiography (ICE) can overcome the limitations of fluoroscopically guided catheter ablation.

Catheter-based, two-dimensional ultrasound has been applied primarily to intravascular imaging, but the development of low-frequency transducers now can be applied to imaging of cardiac chambers.5 Preliminary reports have demonstrated the use of intracardiac imaging during catheter ablation to assist in identifying endocardial contact and lesion formation6,7; however, ICE has not been validated as an accurate guide to anatomic based lesion placement.

The purpose of this study was to test the hypothesis that ICE can accurately guide lesion placement in the canine right atrium.

Methods

Nine adult mongrel dogs (Canis familiaris) weighing 26.5±5.2 kg were premedicated with Innovar-vet (0.1 mL/kg SC) and anesthetized with sodium pentobarbital (7 to 15 mg/kg IV). After intubation, the dogs were mechanically ventilated, and the ECG and anesthetic tone were continuously monitored. Venous access was obtained with 8F and 10F sheaths by femoral cut-down technique. All studies conformed to the "Position of the American Heart Association on Research Animal Use" adopted November 11, 1984, and the University of California, Committee on Animal Research, in an approved protocol.

The Intracardiac Echocardiographic System

The imaging system comprised a 10-MHz ultrasound transducer mounted on the tip of a 10F, 120-cm-long, over-the-wire catheter (CVIS, Cardiovascular Imaging Systems, Sunnyvale, Calif). The outer diameter of the catheter was 0.131 in (0.333 cm), which is passed through a 10F intravascular sheath with an internal diameter of 0.136 in (0.345 cm). At a focal depth of 4 cm, the axial resolution is 450 μm and the lateral resolution is 750 μm. The imaging plane is orthogonal to the catheter, with a radial field of view of 4 cm. Images are acquired at 28 frames per second and recorded on a 0.5-in (1.27 cm) super VHS videotape for review. For comparisons at different times during the procedure, images were selected with the same anatomic landmarks and at the point during the cardiac cycle of maximum chamber volume.
Catheter Ablation and Imaging Procedures

The intracardiac imaging catheter was placed into the right atrium, without fluoroscopic guidance, and continuous imaging was performed. A 7F, tip-defecting catheter (EP Technologies, Mountain View, Calif) with an 8F, 4- or 5-mm electrode tip then was placed in the right atrium under fluoroscopic guidance. Further catheter manipulations were guided with ICE. In the interest of safety, with the first three study animals, standard fluoroscopic confirmation of catheter tip position was performed after ICE guidance. In the subsequent studies, the catheter position did not require fluoroscopic confirmation. Fluoroscopic exposure times were logged.

RF energy was applied to spatially disparate anatomic landmarks that were identified by ICE: (1) the junction of the superior vena cava (SVC) with the right atrium (RA), (2) the junction of the inferior vena cava (IVC) and the RA, (3) the fossa ovalis, (4) the coronary sinus ostium, and (5) the orifice of the RA appendage (identified by visualization of pectinate muscles). Gentle manipulation of the imaging catheter was required to identify the ablation tip, which was echoreflective and had a characteristic fan-shaped acoustic shadow (Fig 1). RF energy (500 kHz) was applied between the distal electrode and a large surface area skin patch, with a mean RF power of 43±17 W for 60 seconds.

Ultrasound Pathological Correlation

After intravenous injection of a myocardial histochemical stain, triphenyl-tetrazolium chloride, the dogs were euthanized with high-dose sodium pentobarbital (200 mg/kg IV) followed by bolus potassium concentrate (20 mL IV). The heart and proximal great vessels were immediately removed.

Ablation targets, determined by ICE, were localized on a right atrial schematic. This schematic was used by an investigator, blinded to intracardiac images, to measure the error between the anatomic target defined by ICE and the site of the lesion directly visualized on postmortem examination, relative to local landmarks. The distance to the lesion center and the lesion edge, rounded to the nearest 0.5 mm, was measured. In addition, for circular structures such as the superior or IVC, targets were also assigned a location on an imaginary clock face around the structure to distinguish anterior, posterior, medial, or lateral positions. Approximate lesion volumes were calculated using the formula for the volume of one half of a prolate ellipsoid \( \frac{1}{2} \cdot \pi \cdot a \cdot b \cdot c \) or for transmural lesions, the formula for the volume of a coin \( \pi \cdot r_1 \cdot r_2 \cdot d \), where \( r_1 \) and \( r_2 \) are one half the major and minor widths, and \( d \) is lesion depth.

Statistical Analysis

Data are presented as mean±SD. ANOVA was used to compare lesion volume for RF energy applications with and without ICE-visualized movement. Values of \( P<.05 \) were considered statistically significant.

Results

High-resolution images were obtained in all studies, although during the RF energy application, background artifact was seen to slightly degrade image quality. The following major anatomic landmarks of the RA were identified in every animal: the SVC, the orifice of the RA appendage, the fossa ovalis of the interatrial septum, the coronary sinus ostium, the tricuspid valve, the eustachian valve, and the IVC. The imaging catheter did not interfere with the maneuverability of the ablation catheter.

No arrhythmias or hemodynamic changes were observed during the procedure, and there was no damage to cardiac structures on pathological examination.

ICE Targeting of Catheter Ablation

Under ICE guidance, RF energy was applied to four sites in seven dogs and five sites in two, for a total of 38 applications. Thirty-eight lesions were identified on pathological examination and were sharply demarcated from viable myocardium, which was stained deep red (Fig 2). The mean lesion volume was 56±63 mm³.

The measured error between the center of the predicted ICE target and the lesion identified on pathological examination was 1.9±2.1 mm to the lesion center and 0.7±1.3 mm to the lesion edge (Fig 3). The centers of 13 of 38 lesions (34%) were without measurable error to the ICE-guided site. An additional 13 lesions had an error of 2 mm or less. Eight of the 12 lesions (67%) with a measured error greater that 2.2 mm occurred with the first three study animals. In addition, the edge of 28 of 38 lesions (74%) encompassed the ICE-directed target.
Fig 2. After radiofrequency energy applications, pathological examination was performed. This specimen was dissected from the superior vena cava (SVC), to the left, to the inferior vena cava (IVC), to the right, and through the right ventricular free wall, exposing the right atrium, the septal leaflet of the tricuspid valve (TV), and the right ventricle (RV), both to the upper right. Lesions were targeted and can be identified at the SVC–right atrial junction (1), the posterior lip of the coronary sinus (CS) ostium (2), the fossa ovalis (3), and the posterolateral IVC–right atrial junction (not seen).

In Vivo Observations

We recorded endocardial–catheter tip continuity in 37 of 38 (97%) RF energy applications. During videotape review, the ablation catheter shaft was misidentified as the distal electrode in one application. In nine applications (24%), the catheter was observed to move during RF energy application, occurring with the respiratory and the cardiac cycles. This movement was frequently of the order of 2 to 4 mm and was usually manifest as sliding of the electrode without loss of

Fig 3. Radiofrequency catheter ablation guided by intracardiac echocardiographic imaging. Left panel, The imaging catheter, identified as a central black circle, was placed into the high right atrium and in a coronal plane visualizes the superior vena cava (SVC), the proximal aorta (Ao) and aortic valve, and the tricuspid valve (TV, in center panel). Center panel, The distal ablation electrode is directed at the SVC–right atrial junction (arrow). Right panel, After a radiofrequency energy application, adherent thrombus and a lesion can be identified (arrow). On pathological examination, the lesion center was 2 mm from the anatomic SVC–right atrial junction, and the lesion edge encompassed this junction.
endocardial contact. These lesions did not have significantly different morphology or lesion volume \((66\pm67 \text{ mm}^3)\) compared with applications without observed movement \((53\pm63 \text{ mm}^3)\).

Discrete lesions were clearly identified in 13 of 38 (34%) RF energy applications and could be seen as a defect or dimple in the endocardial continuity not present before RF application (Fig 4). The tissue beneath these lesions appeared to have an increased echodensity.

Microcavitations or bubbles were seen during 23 (61%) RF energy applications and frequently occurred in a cyclic manner, in phase with respiratory motion. Movement of the catheter was associated with bubbles in seven of nine (77%) applications. Thrombus could be identified in 19 applications (50%), typically remaining adherent to the lesion edge after removal of the catheter (Fig 5). In all cases of thrombus formation, microcavitations were present during the energy application, but an impedance rise causing automatic RF energy shutdown did not occur.

Fluoroscopy

The fluoroscopic exposure time was 23 minutes for the first case, 4 and 3 minutes for the next two cases, and less than 2 minutes for each of the last five cases.

Discussion

At present, catheter ablation requires fluoroscopy for the manipulation and placement of the ablation electrode, which is associated with significant radiation exposure.\(^4\) Previous studies have examined the role of echocardiography in guiding ablation procedures. However, localization by transthoracic echocardiography is limited by catheter shaft artifact and proper identification of the catheter tip.\(^8\) In an animal model, a transponder catheter system using transesophageal echocardiographic guidance demonstrated precise localization of an electrode catheter,\(^9\) but this technique has not been performed in humans. Transesophageal echocardiography has been used to assist in the positioning of catheters and to monitor for complica-
tions such as thrombus formation and damage to valves. However, transesophageal echocardiography requires a second operator, and airway management presents a major concern with the combination of heavy sedation, supine positioning, and lengthy electrophysiological studies. Catheter-based, two-dimensional intracardiac imaging has the potential to guide catheter ablation without these limitations if it can demonstrate accurate and reliable lesion localization.

In this study, we have demonstrated that ICE can be used to accurately guide anatomically based RF lesion placement within the right atrium. Importantly, when fluoroscopy was not used to confirm positioning of catheters, we were able to create four or five distinct lesions in under 2 minutes of fluoroscopy time. Lesions were accurately placed less than 2 mm from an anatomically based target in the majority of cases (68%). The edge of the lesion encompassed the ICE-determined target in 74% of RF energy applications, which might be expected to result in clinically successful ablation of an arrhythmic substrate.

ICE can be used to identify endocardial detail and anatomic structures not seen on fluoroscopy including the border between the SVC-RA, IVC-RA, coronary sinus ostium–tricuspid valve annulus, and right atrial appendage–RA. Identification of anatomic borders and the ability to direct RF energy to them has become increasingly important. Several investigators have successfully targeted for ablation an anatomic corridor defined by the coronary sinus ostium, the tricuspid valve annulus, and the IVC in patients with type I atrial flutter. Anatomically based RF catheter ablation of atrial flutter and, potentially, other arrhythmias such as reentrant atrial tachycardia, sinus, and AV nodal tachycardias might be accomplished under ICE guidance.

We have demonstrated the ability to visualize atrial lesions using ICE. Technical advances are likely to improve our ability to identify and confirm lesion formation in situ. This may be especially important when the goal of ablative therapy is to create block with a line or ring of sequential lesions. Anatomically based ablation, where electrophysiological findings are not the only end point, also might require confirmation of successful lesion formation.

Catheter movement during energy application occurred despite attempts by the operator to maintain stability. Although no differences were found in mean lesion volume, further studies may find that different catheter movements were associated with various lesion morphology and volume. Unanticipated findings included the observation that microcavititation formation predicted thrombus formation and that thrombus formation was a frequent event.

We identified several limitations of ICE. A 10F venous sheath is necessary, which may lead to difficulties and potential complications, especially when multiple catheters are required. Currently, the RA is the only chamber that is easily imaged using a venous approach. Fluoroscopy is still required for safe positioning of catheters in the heart; however, the requirements during the procedure could be potentially reduced by complementary ICE.

Conclusions

ICE accurately guides RF ablation catheter placement at anatomic targets in the RA. ICE confirms stable endocardial contact, potentially confirms lesion forma-

References


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