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Journal Review
Journal of Atrial Fibrillation

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Intracardiac Echocardiography in Catheter Ablation for Atrial Fibrillation: It Is Better to See What You Are Doing?

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Abstract

Current advanced technology allows the accurate three-dimensional reconstruction of cardiac structures using multiple images from two-dimensional intracardiac echocardiography (ICE). This technology is applicable to atrial fibrillation (AF) ablation and provides real-time anatomical information on relevant atrial structures and myocardial thickness as well as suitable sites for transseptal puncture. ICE allows radiofrequency to be delivered away from structures resistant to ablation and the monitoring of possible complications during AF ablation. Visualization of the inside of both atria during the procedure may contribute to safe and effective AF ablation. The purpose of this review was to elucidate the utility of ICE in AF ablation.

Introduction

As target sites of atrial fibrillation (AF) ablation have expanded to broader areas of both atria, more detailed information about cardiac anatomy has become necessary. Traditionally, electrophysiologists have used fluoroscopy with contrast medium to visualize the cardiac structure. However, this technique provides images with poor resolution, and it also exposes patients and healthcare providers to radiation.

The merging of three-dimensional electro-anatomical mapping systems, such as EnSite Velocity/NavX (St. Jude Medical, St. Paul, MN, USA) or Carto (Biosense Webster, Diamond Bar, CA, USA), with computed tomography (CT) or magnetic resonance imaging (MRI) can produce high-resolution images and reduce radiation exposure during the ablation procedure. Nonetheless, due to changes in intravascular volume, patient position, and/or cardiac rhythm, the CT or MR images may not always accurately reflect the actual cardiac anatomy, resulting in misleading catheter manipulation.

Intracardiac echocardiography (ICE), on the other hand, provides real-time information on cardiac structure intraoperatively without harmful effects, such as radiation exposure, on patients and healthcare providers. Phased-array ICE (SoundStar and AcuNav catheter, Biosense Webster, Diamond Bar, CA, USA)[1,2] has some particular advantages, including a larger depth of field, Doppler color flow imaging, and steerability, compared with conventional mechanical ICE. The purpose of this review was to describe the application of the phased-array ICE catheter to AF ablation and to clarify its effectiveness.

Disclosures:
None.

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Exclusion of Thrombi in the Left Atrial Appendage: Intracardiac versus Transesophageal Echocardiography

While previously ICE considered to be less sensitive than transesophageal echocardiography (TEE) for identifying atrial thrombi in the left atrial appendage (LAA),[3] ICE has been shown to be a good alternative to TEE for this purpose prior to the AF ablation procedure.[4–6] The disagreement in visualization sensitivity seems to be related to the location where the ICE probe was placed. ICE has been shown to provide 100% visualization of the LAA when the ICE probe is advanced to the pulmonary artery (PA) and not reserved to the right atrium (RA).[5,6] The LAA is located closer to the PA than to the esophagus, with no obstacle between the LAA and PA, and thus, images of the LAA produced by ICE are of a higher quality than are those produced by TEE (Figure 1).

Anter et al.[5] examined 71 patients to assess thrombi in the right atrial appendage (RAA) and LAA with the simultaneous use of TEE and ICE. RAA and LAA could be viewed in all 71 patients using ICE but in only 69 patients using TEE because of the inability to intubate the esophagus in some cases. A total of four thrombi were diagnosed (3 LAA, 1 RAA). ICE detected all four thrombi, but TEE detected only one. Diagnostic imaging of the LAA was achieved in 71 patients (100%) with ICE and in 62 patients (87.3%) with TEE ($P < .002$). Thus, ICE used in the PA was superior to TEE in detecting LAA thrombi, and it seems especially applicable for patients in whom TEE probe insertion is difficult.

However, as the ICE catheter is not as flexible as are mapping catheters, the advancement of the ICE probe to the PA may be difficult in some patients and may even cause the complication

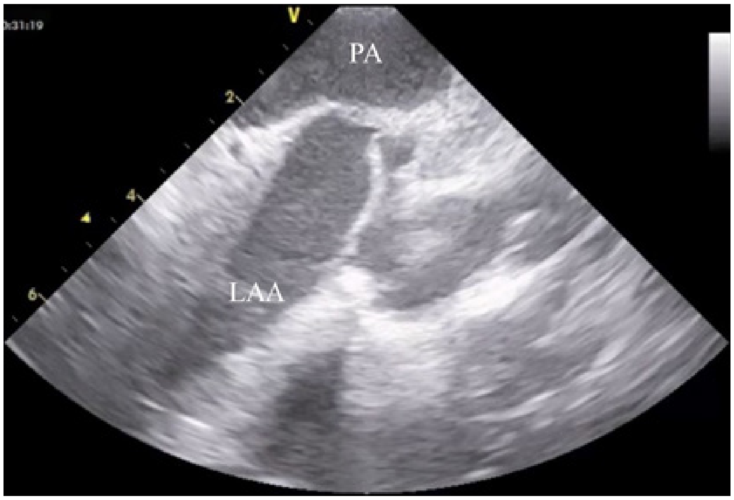

Figure 1: An intracardiac echocardiogram of the left atrial appendage from the pulmonary artery. LAA = left atrial appendage, PA = pulmonary artery

of cardiac tamponade. In such cases, the ICE catheter should be carefully manipulated, or a mapping catheter advanced to the PA may serve as a landmark to guide the ICE catheter to the PA.

Transseptal Puncture

ICE has greatly increased the safety of the transseptal puncture. A target site for puncture in AF ablation is usually the foramen ovale (FO), because subsequent procedures would be easier in the left atrium (LA). For transseptal puncture, the ICE probe should be placed at the sites from which the FO is clearly visible. The lateral site of the RA is preferable for this purpose (Figure 2), and the ICE probe should be moved there with a long sheath with a curved tip, such as the SL0 (St. Jude Medical, St. Paul, MN, USA). To visualize more anterior or posterior parts of the FO, operators should rotate only the ICE shaft.

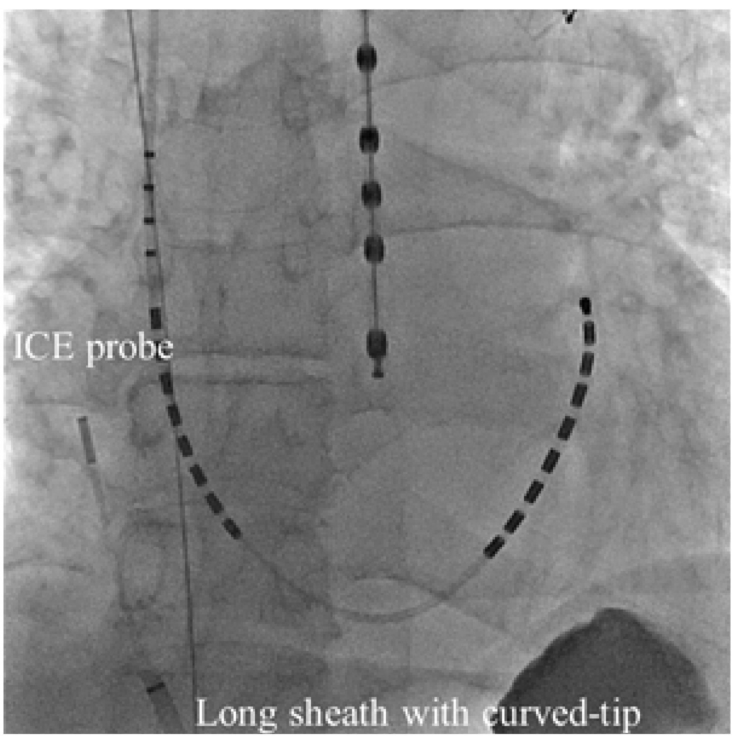

Figure 2: Standard position of intracardiac echocardiography probe to observe the foramen ovale. ICE = intracardiac echocardiography

The long sheath should be fixed in order to maintain the ICE probe's spatial position. These methods allow operators to understand easily the orientation of the relevant cardiac structures. Since the PV and mitral isthmus are located more posteriorly and anterior-inferiorly relative to the FO, the posterior and anterior-inferior parts of the FO are suitable as puncture sites for pulmonary vein isolation (PVI) and mitral isthmus ablation, respectively, for the procedure thereafter. The point at which the transseptal needle contacts the FO is detectable on ICE. If no tenting of the FO is visible, then the needle tip is not attached to the FO. In such a situation, the direction or the curve of the transseptal needle tip should be adjusted to cause tenting of the FO.

ICE enables transseptal puncture even in patients with an atrial septal defect closure device.[7] Transseptal access can be obtained in portions of the native septum in the majority of cases. Direct transseptal puncture with the device is feasible and safe but requires a longer amount of time for each transseptal access.

ICE has also been shown to prevent cardiac tamponade related to the transseptal puncture. Aldhoon et al. reported that the incidence of cardiac tamponade was as low as 0.25% in 1192 consecutive AF ablation procedures.[8] They performed ICE-guided transseptal puncture in all procedures and suggested that the low incidence of cardiac tamponade might be attributed to the sole use of ICE during the transseptal puncture. Similarly, a study conducted by Lee et al. also showed no cardiac tamponade during the ablation procedure,[9] although TEE was used instead of ICE. Thus, visualization of the relevant atrial structures during transseptal puncture helps reduce complication rates.

Utility of Intracardiac Echocardiography for Challenging Cavo-tricuspid Isthmus Ablation

Despite a high success rate, radiofrequency ablation of the cavo-tricuspid isthmus (CTI) can be unusually challenging in some cases. Bencsik et al.[10] assessed the efficacy of ICE vs. that of fluoroscopy alone for CTI ablation in 102 patients. Compared to the fluoroscopy group, the group in which ICE alone was employed, procedural and fluoroscopic times were significantly shortened, and the radiofrequency energy required for creating the CTI conduction block was reduced. Seven patients (13%) from the fluoroscopy-only

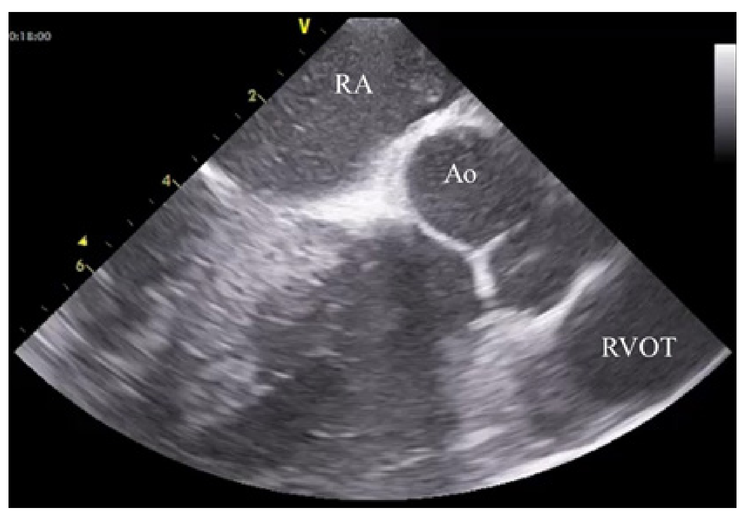

Figure 3: An intracardiac echocardiogram acquired at the home view position. Ao = aorta, RA = right atrium, RVOT = right ventricular outflow tract

group crossed over to the ICE-guidance group because of prolonged unsuccessful radiofrequency ablation (RFA), and all were treated successfully. The authors concluded that the primary reason for the difficulty in achieving the CTI conduction block in these cases was the highly variable and complex anatomy of the CTI, such as pouches near the Eustachian ridge or the concave morphology of the CTI. However, ICE may have enabled visualization of the suitable sites for ablation in order to create the successful conduction block.

Morton et al.[11] assessed CTI morphology before and after the ablation of a typical atrial flutter in 15 patients. A pouch or recess (n = 11) and trabeculations (n = 10) were seen among the 15 patients. The septal CTI was more likely to have pouches than was the lateral CTI, but the latter had more prominent trabeculations. Anterior, mid-, and posterior CTI thicknesses pre-RFA were 4.1 ± 0.8, 3.3 ± 0.5, and 2.7 ± 0.9 mm, respectively, and post-RFA were 4.8 ± 0.8 mm (P = NS vs. pre-RFA), 3.8 ± 0.8 mm (P = 0.05 vs. pre-RFA) and 3.8 ± 0.8 mm (P = 0.02 vs. pre-RFA), respectively. ICE allowed operators to guide ablations away from deep recesses and prominent trabeculations and to observe the changes in diffuse atrial swelling by RFA.

Utility of Intracardiac Echocardiography for Pulmonary Vein Isolation

Three-dimensional ICE images of the left atrium (LA) and pulmonary vein (PV) guide the appropriate placement of the ablation catheter and enable operators to monitor tissue contact during the AF ablation procedure. Moreover, ICE allows the reduction of the fluoroscopic time for PVI. Pratola et al.[12] have examined different image integration modalities with the Carto electro-anatomical mapping system to guide AF ablation, and they concluded that ICE image integration with Carto significantly reduced fluoroscopy time and the time spent in the LA in comparison to those seen for MRI and Carto integration.

In addition to ICE, the integration of CT images with three-dimensional electroanatomical information is helpful for AF ablation. Kimura et al.[13] reported the usefulness of CT image integration with ICE images for PVI. Through matching both the respiratory phase and the cardiac cycle during CT and ICE image acquisition, the distance of corresponding sites between both images was 1.08 ± 0.14 mm, significantly smaller than that between the CT image and electroanatomical data.

How to Visualize the Left Atrium

The CartoSound™ module (Biosense Webster, Diamond Bar, CA, USA) can create a three-dimensional echocardiographic image from multiple two-dimensional images.[14] Although the acquisition of the LA image from the LA itself allows for more detailed LA geometry,[15] most two-dimensional images of the LA can be obtained from the RA. To obtain these images, the ICE tip is first advanced to either the high RA and/or the low RA, adjusted to which part of the LA is the region of interest (ROI). The basic position to identify each relevant region of the LA is the so-called “Home view” position (Figure 3), in which the RA, right ventricular outflow tract, and aorta are observed. Clockwise rotation of the ICE from the “Home view” position provides visualization of the FO, LA body, mitral annulus (MA), and LAA as well as of the left ventricle (LV) (Figure 4 A). The left superior pulmonary vein (LSPV) is visualized with a little further clockwise rotation (Figure 4 B). In some cases, it might be difficult to distinguish the LSPV from the LAA, because they are located very close to each other. However, an observation of the LAA continuing to the MA and of the LAA morphology could help differentiate the LSPV from the LAA; therefore, careful manipulation of the ICE probe is essential. The left inferior pulmonary vein (LIPV) is seen just after or simultaneously with the LSPV (Figure 4 C), usually at around the “6 o’clock” position on the wedged-shape image when the ICE probe is placed in the RA. Next, the LA main body or the esophagus is visualized (Figure 4 D) before the right superior and inferior pulmonary veins are finally visualized (Figure 4 E). The pulmonary artery is observed next to the right superior pulmonary veins. As shown in figure 4F, once the access to the LA is achieved, the LSPV is also a suitable site for visualizing the LAA.

How to Visualize the Right Atrium

As in the LA, a basic position for the ICE probe to reconstruct the RA geometry is also the “Home view” position, and the height of the ICE probe should be adjusted to the ROI. The coronary sinus ostium, an important structure for AF ablation, appears with the ICE probe moved a little downward from the “Home view” position (figure 5A). Counterclockwise rotation shows the RAA, CTI, and crista terminalis (figures 5B–D). While observing the CTI from the inferior vena cava-RA junction, the Eustachian ridge might produce some acoustic shadow, which can be misinterpreted as the bottom of the CTI. In such cases, the ICE probe should be moved to above

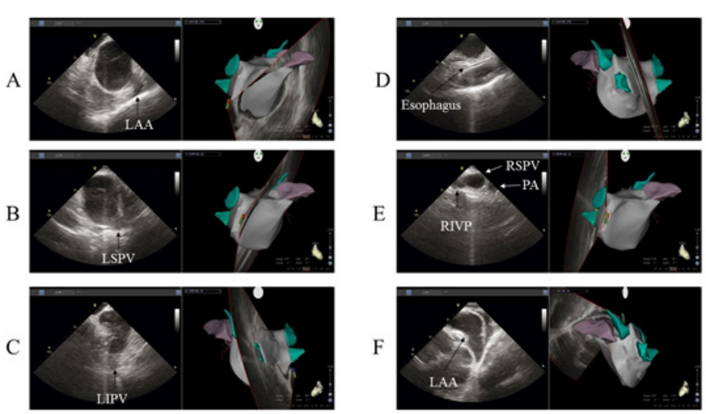

Figure 4: Three-dimensional reconstruction images of the left atrium. LAA = left atrial appendage, LIPV = left inferior pulmonary vein, LSPV = left superior pulmonary vein, PA = pulmonary artery, RIPV = right inferior pulmonary vein, RSPV = right superior pulmonary vein

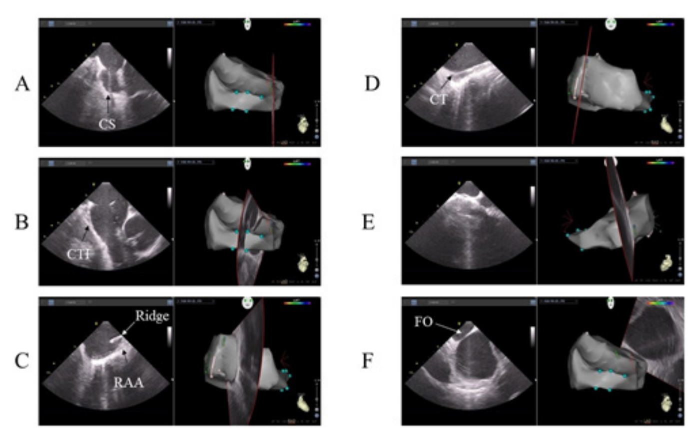

Figure 5: Three-dimensional reconstruction images of the right atrium. CT = crista terminalis, CTI = cavo-tricuspid isthmus, CS = coronary sinus, FO = foramen ovale, RAA = right atrial appendage

the CTI to direct the echo beam perpendicularly to the CTI. As the RAA has unique anatomical characteristics, its identification is easy, and the superior ridge of the RAA can be a good marker for identifying the crista terminalis (Figure 5C, D) because they connect to each other and develop a thick myocardial bundle. With the placement of the ICE probe along the body's long axis, the sagittal plane of the crista terminalis is shown on the ICE image (Figure 5D). Since the crista terminalis is one of the major sites of AF foci, it is crucial that the operators performing AF ablation know its exact location or its anatomical information, such as myocardial thickness. ICE is currently the only modality that can provide such information during the procedure. Further counterclockwise rotation of the ICE probe from the crista terminalis plane visualizes the RA posterior wall (Figure 5E). The RA septal aspect is obtained from the images of the FO (Figure 5F).

Utility of Intracardiac Echocardiography for Cryoballoon Ablation for Atrial Fibrillation

Cryoballoon PV ablation has become a standard option to treat drug-resistant AF.[16] ICE has been used to facilitate decisions about adequate balloon size, assessment of full ostial occlusion in the PV, prediction of acute ablation success, and exclusion of acute narrowing of the PV ostia.[17] A loss of color Doppler reflow or echo contrast back-flow to the LA after saline injection reflects full ostial occlusion and predicts successful PVI.[16,17]

Monitoring Potential Complications

ICE can allow intraprocedural detection of potential complications, such as cardiac tamponade or thrombosis. The ICE probe is advanced from the RA into the right ventricle with the anteriorly deflected ICE tip across the tricuspid annulus, and clockwise rotation of the ICE toward the interventricular septum permits visualization of the posterior-inferior aspect of the LV or LA (Figure 6), where cardiac effusion firstly accumulates. ICE also allows operators to evaluate the change in volume of the cardiac effusion and to determine the timing of the cardiocentesis. However, ICE might cause cardiac effusion to be underestimated or even overlooked, because ICE images only reflect one cross-section of the heart; global evaluation of cardiac effusion can be difficult with ICE. Therefore, fluoroscopic images showing the posterior-inferior aspect of the LV or LA, such as from the left anterior oblique view, should also be monitored for early diagnosis of cardiac tamponade.

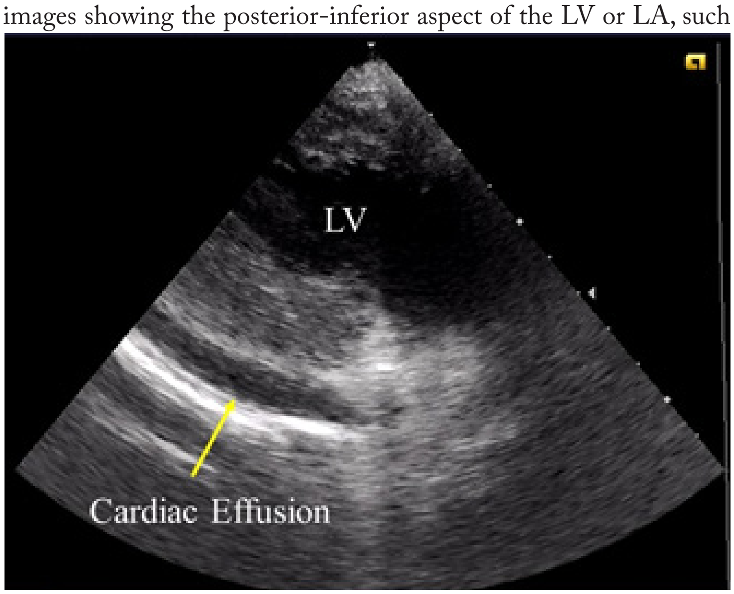

Figure 6: Cardiac effusion during AF ablation procedure. LV = left ventricle

ICE can detect thrombosis occurring in the AF ablation procedure. Information of the thrombi obtained from the images could help determine how to treat them. There have been a few case reports in which ICE revealed thrombosis during AF ablation. In one case, a thrombus as long as 8 cm was found in the LA and was treated with 25 mg alteplase, and it completely disappeared within 20 minutes.[20] In another case, ICE detected a serpiginous atrial thrombus (23 × 2 mm). It was aspirated with a 10 mL syringe attached to the proximal end of the fixed-curve sheath. ICE imaging confirmed complete removal of the thrombus.[21] As noted above, ICE is the only way to detect thromboses during the ablation procedure; therefore, early detection and early intervention of the thrombosis by ICE might reduce the incidence of thromboembolic complications related to AF ablation.

Phrenic nerve paralysis is the most frequently observed complication during cryoballoon ablation, occurring in roughly 7 to 9% of cases.[22] Monitoring of diaphragmatic motion with ICE during phrenic nerve pacing may help reduce the risk of phrenic nerve palsy.[23]

Limitations of Intracardiac Echocardiography

Rordorf et al. examined the dimensional accuracy of ICE image reconstruction using a multislice CT (MSCT) three-dimensional image as a gold standard.[24] Despite an agreement of latero-septal LA diameter between the ICE and MSCT images, the anterior-posterior and superior-inferior LA diameter were shorter in ICE than those in MSCT. ICE underestimated the LA dimension, as MSCT showed. This discrepancy was probably due to some "blind" areas in the LA that were overlooked by ICE. If the observation of the LA occurs only from the RA, the echo beam is directly parallel to the LA anterior wall, resulting in a blind side there. Advancement of the catheter to the coronary sinus, right ventricular outflow tract, or the LA itself would resolve this problem, but it may also result in complications or increased time consumption. The extent of ultrasound exploration should be determined based on the risks and benefits in each individual case.

Furthermore, there may be some discrepancies between the interpolated surface of the atria created by the CartoSound module and the real atrial endocardial surface, which could make the tip of the ablation catheter appear seemingly outside of the atrial shell; this might be attributed to the algorithms of the CartoSound module or to a hard push of the ablation catheter.

Conclusion

Detection of thrombi in the LAA is superior with ICE than with TEE. ICE enables the guidance of relevant atrial structures during transseptal puncture and contributes to safe access to the LA. Three-dimensional reconstruction ICE images may facilitate the deployment of the ablation catheter to the ROI and the monitoring of its contact on the atrial surface. Lastly, ICE has contributed to the early diagnosis of some complications during the AF ablation procedure. Thus, ICE has become an indispensable tool for AF ablation.

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