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Contemporary Use of Intracardiac Echocardiography in the Electrophysiology Laboratory

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ABSTRACT. Intracardiac echocardiography (ICE) is increasingly being used in percutaneous electrophysiology procedures. Standard ICE views are commonly used during electrophysiology procedures to define the anatomy of the right atrium, intra-atrial septum, left atrium, and pulmonary venous structures. During transseptal puncture for left atrial access and catheter manipulation during the ablation of complex arrhythmias, the ability of ICE to visualize these procedures is invaluable to ensure their correct performance and prevent complications. Early detection of ablation complications such as pericardial effusion, atrial-esophageal fistulae and intracardiac thrombus is also possible and an additional benefit of ICE. This article reviews the ICE catheter technology currently available along with standard ICE views commonly obtained through their use, and the current clinical applicability of ICE in the electrophysiology laboratory.

KEYWORDS. ablation, electrophysiology, intracardiac echocardiography.

Introduction

Catheter-based invasive ablation therapies have become the treatment of choice for a variety of dysrhythmias, and intracardiac echocardiography (ICE) has become an integral part of this treatment modality. ICE has been under development since the mid-1950s with initial ICE catheters consisting of single-element crystal probes whereas today’s ICE catheters are made of multi-element phased arrays, with enhanced imaging capabilities. In this article we review the benefits and limitations of currently available ICE catheters, the standard views obtained through their use, and their utility in the electrophysiology laboratory.

ICE catheters

There are two types of ICE catheter designs: 1) rotational ICE; and 2) phased array ICE. A rotational ICE catheter uses a motor unit that rotates the transducer providing a 360 degree view of the near field in a perpendicular fashion to the ICE catheter (Figure 1a,b). The ability of rotational ICE to image the near field is particularly useful in imaging the interatrial septum when performing a transseptal puncture. Phased array ICE catheters have multiple piezoelectric elements that allow for detailed intracardiac imaging. These catheters are steerable and have the ability to acquire Doppler and color flow imaging (Figure 1c).

UltraICE (Boston Scientific, San Jose, CA) is a 9 Fr, 9 Mhz rotational non-steerable ICE catheter that is commonly used to image the interatrial septum during transseptal punctures. (Figure 1b) Placement of the UltraICE Catheter in the right atrium (RA) allows for identification of “tenting” of the interatrial septum when performing a transseptal puncture. Outside of its use for accessing the left atrium (LA) this ICE catheter has limited use, although it may be used to identify the
formation of thrombus on the catheter and/or sheath. The major advantage of the UltraICE catheter is its low cost and ease of use.

AcuNav (Siemens Medical Solutions USA, Inc., Mountain View, CA) is a steerable 64-element parallel drive, phased array ICE catheter that comes in either 8 or 10 Fr sizes with a frequency range of 5–10 MHz. The AcuNav catheter allows for pulsed wave and continuous wave Doppler imaging as well as color flow imaging, which is often useful in determining pulmonary vein (PV) flows during ablation of atrial fibrillation (AF). When using the AcuNav catheter the typical “home view” represents the neutral position of the ICE catheter in the RA, and through a series of maneuvers the entire right and left heart can be readily imaged as discussed in the following section.

ViewFlex PLUS (St. Jude Medical, Inc., St. Paul, MN) is a steerable (anterior-posterior ±120-degree flexion) 9-Fr 64-element phased array ICE catheter with a 90 degree viewing sector that has a maximum viewing depth of 21 cm. The ViewFlex PLUS ICE catheter along with the ViewMate II Ultrasound viewing system allows for color flow Doppler, pulsed and continuous wave Doppler imaging, as well as advanced options including tissue Doppler imaging.

Standard ICE views

Initial/home view
The initial or home ICE view is achieved with the ICE probe in the mid-RA and the scan plane directed anteriorly. This provides an excellent view of the RA, right ventricle and tricuspid valve (Figure 2). From this view, withdrawing the catheter brings the Eustachian ridge, the remnant of the Eustachian valve, and the tricuspid valve isthmus into view.

Interatrial septum
From the home view, slight advancement of the catheter with flexion and clockwise rotation brings the interatrial septum and fossa ovalis into view (Figure 3). A small amount of left to right manipulation may be required to open up the septum. From this view it is possible to accurately direct the transseptal puncture and minimize the risk of damage to surrounding structures such as the aorta and aortic root. During septal puncture, ICE visualization of tenting in the interatrial septum provides the location of the puncture and visual confirmation of successful access into the LA.

Pulmonary veins
When visualizing the interatrial septum, increasing the field depth will reveal the left superior and inferior PVs (Figure 4). Often, when performing pulmonary venous isolation for AF, this view is utilized to avoid ablation within the pulmonary venous structures by targeting the LA antrum. Pulse wave and color Doppler can be performed to examine flow from the PVs to determine if any stenosis is present from previous ablation procedures. Clockwise rotation and advancing of the ICE catheter brings the right PVs into view. Often, secondary to difficult visualization of the right PVs, advancing into the superior vena cava may be required to identify them.

Additional views
Advancing the catheter towards the atrial septum with clockwise rotation from the home view brings the left atrial appendage and mitral valve apparatus into view (Figure 5). Further clockwise rotation allows visualization of the coronary sinus ostium, also displayed in Figure 5. Small adjustments in this view will typically allow visualization of the LV and papillary muscles, which is often necessary for the ablation of ventricular arrhythmias.

ICE in atrial fibrillation ablation
Ectopic foci in the PVs have been identified as potential triggers for AF. Radiofrequency (RF) ablation and
isolation of these foci through PV isolation may improve AF burden. During AF ablation, ICE plays an integral role in performing the transseptal puncture, in mapping of the LA–PV junction, in monitoring of catheter placement, and in examining for any potential procedural complications.

ICE can be useful in visualizing the fossa ovalis and its variants when performing a transseptal puncture to gain access into the LA (Figure 3). ICE provides views of the interatrial septum that allows the electrophysiologist to adapt to the variations in this anatomy. Needle tenting of the interatrial septum can be seen, marking the point of puncture into the LA (Figure 6). Once the needle tip is within the LA, saline or contrast can be injected and visualized by ICE to confirm left atrial access. When a thick interatrial septum is visualized by ICE, the operating electrophysiologist may decide to proceed with a RF transseptal needle to cross the septum. In addition, ICE can help position the transseptal needle in the anterior-posterior dimension so that access into the LA can be achieved in an optimum angle that will allow for easy manipulation and steering of the ablation catheter.

The anatomy of the LA and PV can show significant variability, and a good understanding and intraprocedural visualization of this anatomy is important in
performing a successful and safe AF ablation procedure.\textsuperscript{11} Ablation within the PV may result in PV stenosis, and hence care is given to ablate in the PV antrum. ICE can be used to accurately delineate the PV ostia as well as PV with common ostia and can help identify PV antral sites for safer ablation (Figure 4). Rates of moderate and severe PV stenosis have been shown to be lower in patients in whom ICE was used during PV isolation.\textsuperscript{12}

Good endothelial contact between the ablation catheter and the endocardial surface is a key step in ensuring delivery of adequate ablation lesions. ICE can assist in maneuvering the ablation catheter and in the identification of appropriate catheter–endothelial contact. Kaykin et al\textsuperscript{13} showed that the PV antrum isolation procedure using ICE is more likely to result in freedom from AF than circumferential PV ablation supplemented by complex fractionated electrogram ablation in selected

Figure 4: Two-dimensional phased array intracardiac echocardiography (ICE) image of the left atrium and left superior pulmonary vein (red/dashed arrow). The antrum of the left atrium is noted on either side of the pulmonary vein (white arrows). Of note, the farfield resolution with phased array ICE is noticeably better than that of the rotational ICE images already presented.

Figure 5: Phased array intracardiac echocardiography (ICE) image of the mitral valve (solid white arrows), coronary sinus OS (solid red arrow) and left atrial appendage (white dashed arrow). Within the far field of this image the left ventricle (LV) can be visualized, albeit with typically low resolution.
patients. Verma et al\textsuperscript{14} also showed that ICE was effective in guiding the PV antrum isolation for AF. In another study by Marrouche et al\textsuperscript{12} ICE was shown to improve the outcome of cooled-tip PV isolation with a reduction in fluoroscopy time and procedure time, and a decreased recurrence rate of AF. The positive impact of ICE in these studies can be in part attributed to better visualization of the cardiac landmarks\textsuperscript{15} and a clearer understanding of PV anatomy.

**ICE for detection of left atrial thrombus**

RF ablation procedures are associated with the risk of systemic arterial thromboembolism. Transesophageal echocardiography (TEE) has been shown to be very sensitive and specific for identifying left atrial thrombi and is considered the gold standard.\textsuperscript{16} The use of ICE for detecting left atrial thrombus was recently studied in a porcine model and was similar to detection by TEE.\textsuperscript{17} A recent prospective study in humans compared the ability of ICE and TEE in detecting left atrial and left atrial appendage thrombus in patients with persistent AF undergoing right heart catheterization. Left atrial appendage imaging was achieved in 85\% with ICE (Figure 5) and 96\% with TEE. The concordance for the presence or absence of thrombus was 97\% in the LA and 92\% in the left atrial appendage, but the latter was detected more frequently with TEE (p=0.11).\textsuperscript{18} However, at this time TEE remains the gold standard for routine imaging of the left atrial appendage and for definitive evaluation of left atrial thrombus.

**ICE in early detection of complications**

Use of ICE during an ablation procedure provides real-time monitoring for any potential complications. ICE-guided ablation allows for closer monitoring of factors that are associated with stroke, such as thrombus formation on catheters and/sheaths, and thrombus formation at lesion sites. Thrombi identified on sheaths by ICE may be withdrawn into the RA safely under ICE guidance, reducing the risk of stroke.\textsuperscript{19} Rates of embolic events including transient ischemic attacks have been found to be lower in patients when ICE was used during PV isolation.\textsuperscript{12} PV stenosis is a serious complication seen after ablation for AF and it can lead to respiratory symptoms; it is frequently misdiagnosed and mistreated.\textsuperscript{20} The incidence of PV stenosis in different studies has been reported in the range of 3\% to 42\%.\textsuperscript{5,20–25} Studies have shown that the rates of moderate and severe PV stenosis are lower in patients in whom ICE was utilized for PV isolation.\textsuperscript{12,26,27} More specifically, Marrouche et al\textsuperscript{12} studied 315 patients randomized to either circular mapping (CM), CM and ICE imaging, and CM, ICE, and RF ablation titration utilizing microbubbles visualized on ICE. In the CM-only group, 3.5\% of patients experienced severe (>70\%) PV stenosis compared with 1.8\% (p<0.05 compared with the CM only group) for the ICE and zero in the ICE ablation titration groups. The lower incidence of PV stenosis when ICE is used is likely due to a clearer understanding of the LA–PV anatomy, minimizing the chance of RF ablation within the PVs directly (Figure 4).

Life-threatening procedure-associated complications of left atrial ablation include atrial-esophageal fistula formation and chamber perforation followed by tamponade. Ablation in the posterior LA may rarely be complicated by full thickness thermal injury of the wall of the atrium into the esophagus resulting in left atrial-esophageal fistula formation, cardiac perforation, and potentially life-threatening tamponade (Figure 7). ICE has been shown to be useful in the identification and prevention of these increasingly rare yet morbid complications.
complications.28–31 The esophagus is in close proximity to the posterior LA–PV junction. ICE can accurately determine the distance of the ablation sites form the esophagus, which can then be used to titrate power and duration of ablation in this sensitive area.28 Common methods used to label and avoid injury to the esophagus during posterior LA ablation include the use of intra-procedural esophageal temperature monitoring,32 marking of the esophagus with barium,33 and integration of pre-ablation acquired images of the LA and esophagus with electroanatomic mapping systems.34 Even though ICE can be used to accurately denote the course of the esophagus during ablation there are no data to suggest its use has resulted in a reduction in the incidence of left atrial-esophageal fistula formation.35

Pericardial effusion and tamponade occurs in about 1–6% of ablation procedures and is the most common potentially life-threatening complication associated with ablation procedures.29,30 ICE has demonstrated its utility in the early detection of pericardial effusions before the onset of significant hemodynamic instability.31 With early detection of impending tamponade, anticoagulation can be discontinued and reversed, and a pericardiocentesis and/or a pericardial window can be performed.

ICE in ventricular tachycardia ablation

Ventricular tachycardia (VT) frequently develops from anatomical substrate such as scar tissue following myocardial infarction or myocarditis, or from focal sites due to automaticity or triggered activity, or can be idiopathic in normally structured hearts. VT ablation in select patients may not only improve the burden VT but may also be a potentially curative therapeutic modality. ICE provides accurate visualization of the ventricles and can facilitate catheter steering and placement into regions of interest. ICE has been used to guide ablation of VT from other etiologies including arrhythmogenic right ventricular cardiomyopathy, hypertrophic cardiomyopathy, outflow tract VTs, and VT arising from the papillary muscles (Figure 7).36

Other applications of ICE

ICE imaging within the coronary sinus provides unique views of the mitral valve and clear views of the LA. ICE catheters can characterize the mitral isthmus,37 atrioventricular groove vessels, intracoronary sinus muscle bundles,38 coronary arterial tree, and mitral valve apparatus. ICE has also been used to gain access into the coronary sinus in patients undergoing implantation of a left ventricular lead as part of cardiac resynchronization therapy.39 Recently, percutaneous intrapericardial cardiac echo (PICE) has been performed in patients undergoing epicardial catheter ablation. PICE images provide views of the heart from the pericardial sinuses. PICE provides high-resolution images of endocardial structures, not very well seen with conventional ICE or other imaging modalities.3

Innovations in ICE

Recent advances in catheter design and image processing have allowed for the rapid integration of real-time
three-dimensional (3D) ICE images with electroanatomic mapping systems, specifically CARTO (Biosense Webster, Diamond Bar, CA). A 10-French SOUNDSTAR 3D ICE catheter along with the CARTOSOUND module is used to create a 3D map of the cardiac chamber of interest. From the RA, a 3D map of the LA and LV can be created, and this information can then be used during subsequent ablation (Figure 8). This feature has the potential to decrease the time required to generate an accurate 3D map and the overall ablation procedure time.

Conclusions

ICE is increasingly being used in the catheter ablation of various arrhythmias. It provides real-time imaging, aids in transseptal puncture, and makes these procedures safer and more effective. The boundaries of the use of ICE are being extended to include imaging from within the coronary sinus and epicardial space and in the creation of accurate 3D maps during electroanatomic mapping. There is a variety of available ICE catheters, and each serves a purpose, whether it be for simple and affordable imaging of the interatrial septum with a rotational ICE catheter to more extensive and expensive imaging capabilities with phased array ICE catheters.

References


