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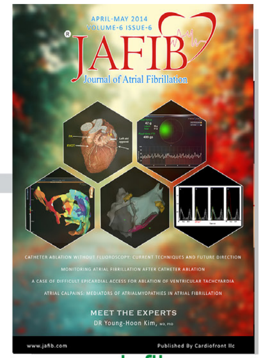

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The Evolving Utility Of Intracardiac Echocardiography In Cardiac Procedures

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Abstract

Intracardiac echocardiography (ICE) has gained increasing use in electrophysiology due to the need to visualize key anatomic structures. Precise guidance for transseptal puncture and visualization of the pulmonary veins are common essential uses for ICE, but many operators adept at ICE imaging have developed additional and specific uses. With heavy use of ICE guidance, electrophysiologists demonstrated feasibility of left atrial ablation with minimal use of fluoroscopy. With the advent of 3D mapping-integrated ICE, rendering of contours for the left atrium, aortic cusps, and left ventricular structures such as the papillary muscles have become possible. Improved understanding of the anatomy of these areas can facilitate mapping and ablation of these structurally complex sites. Additional uses of scar-visualization and integration into voltage maps have been explored. Left atrial appendage imaging has been an area of interest in the ICE community, although technological improvements are likely needed to make this more reliably complete. A new real-time 3D ICE catheter has also been developed, and work is in progress to delineate potential uses for this new frontier. Increasingly routine use of ICE has led to improved real-time guidance of all percutaneous cardiac procedures.

Imaging in Electrophysiology

As the field of cardiac electrophysiology continues to mature, it has become increasingly recognized that arrhythmias have unique relationships with anatomic structures of the heart and great vessels. Haissaguerre and colleagues made the seminal observation that atrial fibrillation (AF) was often triggered from the pulmonary veins (PVs).[1] Atrial arrhythmia foci are also frequently found at the crista terminalis, superior vena cava (SVC), coronary sinus (CS), and the tricuspid and mitral valve annuli. Idiopathic ventricular arrhythmias commonly arise from the right ventricular outflow tract (RVOT), the aortic cusps, and papillary muscles. Ventricular tachycardias in cardiomyopathy tend to involve areas of myocardial scar, which may be endocardial, epicardial, or intramural. Accordingly, it is essential for physicians who perform electrophysiology procedures to gain precise knowledge of cardiac anatomy, and real-time imaging of these structures and their variations among individuals is a fundamental skill to achieve safe and effective ablation procedures.

Key Words:
Intracardiac Echocardiography, Cardiac Mapping, Catheter Ablation.

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Since its initial development for facilitating device closure of atrial septal defects,[2] intracardiac echocardiography (ICE) has seen a significant adoption by electrophysiologists as an important tool to reduce dependence on fluoroscopy. Importantly, ultrasound allows identification of soft tissue structures that are invisible with fluoroscopy. Thus, the fossa ovalis can be visualized and transseptal puncture can be more precisely directed toward the left pulmonary veins – thereby avoiding an anterior trajectory (to reduce risk of aortic perforation) and facilitating catheter stability in the pulmonary veins (to improve the efficacy of ablation). In the beating heart with respiratory motion, maintaining optimal catheter-tissue contact is essential to achieve successful ablation of any arrhythmia, and ICE provides live visualization of catheter positioning and tissue contact. Finally, routine use of ICE allows the immediate recognition and expedited management of complications such as pericardial tamponade and thrombus formation on catheters and sheaths.[3-5]

Comparison of Intracardiac vs. Transesophageal Echocardiography

Prior to the advent of ICE catheters, live ultrasound guidance of percutaneous cardiac procedures was limited to transesophageal echocardiography (TEE). TEE remains the sole ultrasound imaging method in many electrophysiology laboratories due to the higher cost of ICE catheters, which has diminished with reprocessing of

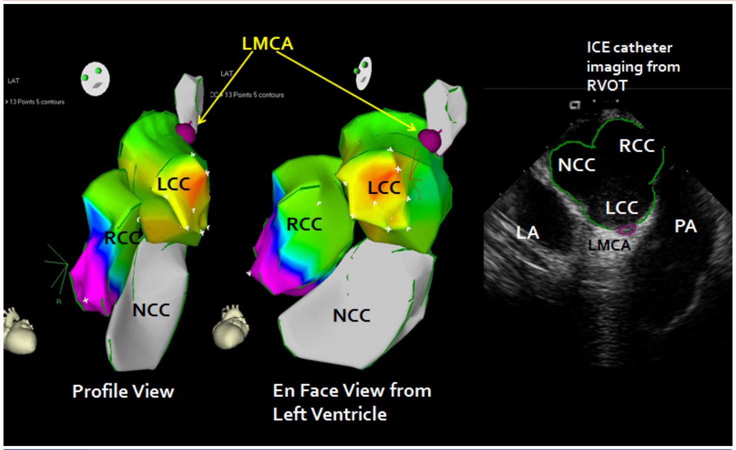

Figure 1: ICE-defined aortic cusps integrated into 3D electroanatomic map. Left: 3D contours and activation map of PVC focus at base of left coronary cusp (red color denotes early activation). Right: Corresponding ICE view with ICE catheter positioned in right ventricular outflow tract (RVOT) imaging the aortic valve. RCC = right coronary cusp; LCC = left coronary cusp; NCC = noncoronary cusp; LMCA = left main coronary artery ostium; LA = left atrium; PA = pulmonary artery.

these sterile catheters. With regard to imaging capability, TEE continues to have the advantage of multiplane imaging – where an electrical mechanism rotates the imaging plane up to 180o to provide a continuum of imaging planes with a single probe position. More recently, the advent of 3D TEE probes has allowed real-time 3D imaging of complex structures such as the pulmonary veins, left atrial appendage, and valves. However, TEE entails a different risk profile due the requirement for moderate sedation, so that patients with sedation risk, compromised airways, or known oral or esophageal abnormality are at increased risk of complications including oropharyngeal trauma, esophageal perforation, and aspiration pneumonitis. Furthermore, intra-procedural TEE-guidance requires general anesthesia due to lengthy duration of imaging, and requires the presence of a TEE specialist which adds to the cost of the procedure even though there is no incremental cost for use of the TEE equipment.

ICE catheters contain imaging elements (piezoelectric crystals) arranged either in circumferential fashion (radial ICE) or in linear fashion (phased array ICE). Most electrophysiology laboratories have adopted the phased array ICE catheters, in which the imaging plane is parallel to the catheter orientation. Simple manual rotation of the catheter can rotate/sweep the imaging plane 360o to provide circumferential view of the catheter proximity. Since the heart is a relatively small structure, relatively small movements of the ICE catheter can provide basic imaging of nearly all cardiac structures, although experience is needed to place the ICE catheter in more difficult locations for more comprehensive imaging of some structures. Ultimately a significant advantage of ICE is the control provided to the electrophysiologists performing the procedure, besides obviating the need for an additional TEE physician. Furthermore, since ICE imaging is done with standard venous access, this can be performed safely with local anesthesia and minimal sedation, even during prolonged imaging, with minimal patient discomfort.

Emerging Uses of ICE

Physicians adept at ICE have demonstrated that transseptal puncture and left atrial ablation can be performed with little to no fluoroscopy.[6] Besides the common uses listed above, other uses of ICE have evolved in electrophysiology and non-electrophysiology procedures.

Integration of ICE into the 3D Mapping System

A major technological advance in this field was the development of an ICE catheter integrated into a 3D mapping system. The SoundStar® catheter contains a location sensor embedded within the ICE catheter, which allows the ultrasound image to be displayed and integrated into the electroanatomic mapping system. This CartoSound® module then allows tagging of structures visualized on the projected ICE image to be displayed on the 3D map.[7] This breakthrough has bridged the gap between the aforementioned critical understanding of anatomy and electrophysiologic targets. For AF ablation, drawing contours of the left atrium and pulmonary veins creates a shell of the left atrium without the additional need for preoperative imaging or even transseptal access. Tagging the esophagus provides additional appreciation for its proximity to certain aspects of the posterior wall. For VT ablation, with the ICE catheter placed in the right ventricle, anatomic contours can be obtained for the left ventricle and papillary muscles to facilitate catheter movement with reduced need for fluoroscopy. Given the tilted position of the aortic cusps, mapping and ablation of arrhythmias in this region has been greatly simplified by the use of 3D mapping-integrated ICE, which allows tagging of the individual cusps and essential appreciation for the precise location of the mapping/ablation catheter relative to the commissures (Figure 1). Just as importantly, visualization

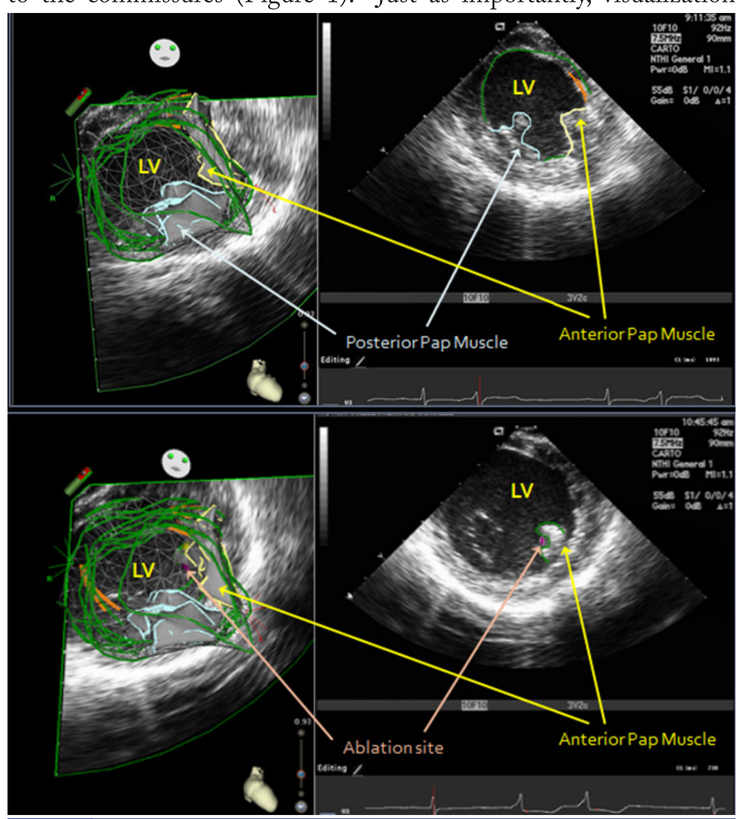

Figure 2: ICE-defined papillary muscles integrated into 3D electroanatomic map. Top Left and Right: 3D contours and ICE view of anterior and posterior papillary muscles of left ventricle (ICE catheter imaging from right ventricular outflow tract; yellow contours used to define anterior papillary muscle; blue contours used to define posterior papillary muscle. Bottom Left and Right: Site of successful ablation of PVC at tip of anterior papillary muscle. LV = left ventricle.

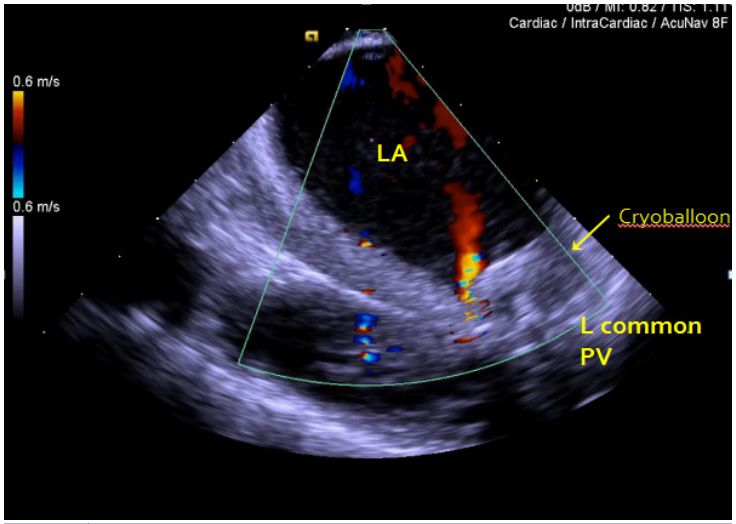

Figure 3: ICE imaging from the right atrium shows cryoballoon occluding most of the large common antrum of the left pulmonary veins, but with a small inferior leak detected by color Doppler (red flow from pulmonary vein into left atrium. LA = left atrium; PV = pulmonary vein.

and tagging of the coronary artery ostia helps the operator avoid unintended catheter advancement and ablation without need for additional arterial access or repeated contrast angiography. Mapping and ablation on the papillary muscles are also greatly facilitated by 3D-mapping integrated ICE due to the complexity of these structures (Figure 2). Routine tagging of the pulmonic valve annulus has demonstrated that many presumed RVOT arrhythmias in fact originate from pulmonary artery myocardium beyond the valve.[8]

In an attempt to localize scar and provide the critical link between substrate and ablation target, Bunch and colleagues demonstrated a novel use for 3D mapping-integrated ICE.[9] Areas of wall motion abnormality on ICE were tagged in the 3D map, and were found to correlate with areas of low voltage by catheter mapping. This provides a potentially powerful tool to localize potential targets of VT ablation prior to even entering the left ventricle.

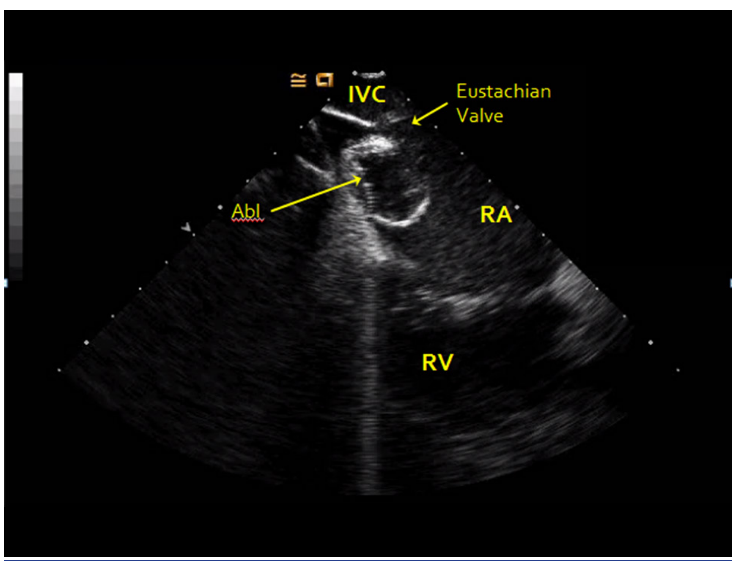

Figure4: ICE catheter positioned in low right atrium imaging the cavotricuspid isthmus. Due to the prominent Eustachian valve, the ablation catheter (Abl) must be curved to achieve effective ablation of the pouch near the base of the Eustachian valve. IVC = inferior vena cava; RA = right atrium; RV = right ventricle.

ICE in Specific Ablation Procedures

As cryoballoon PV isolation is increasingly adopted, additional tools have been sought to guide the fundamental technique of this procedure: balloon occlusion of the pulmonary veins. Color Doppler from ICE imaging provides a relatively simple and effective method of assessing for leaks without the need for radiocontrast or fluoroscopy (Figure 3). Cavotricuspid isthmus ablation can be difficult due to anatomic variants such as a large pouch or a prominent Eustachian valve; these can be visualized on ICE and appropriate catheter adjustments can be made (Figure 4). Although no comparative studies are available, expeditiously making these necessary adjustments likely reduces ineffective ablation lesions and thereby may reduce complications such as perforation and injury to the right coronary artery.

ICE Imaging of the Left Atrial Appendage

Given the routine need in electrophysiology to assess for thrombus in the left atrial appendage (LAA), there has long been interest in utilizing ICE for this purpose in lieu of the gold standard TEE. However, due to proximity of the esophagus to the left atrium and the aforementioned power of multiplane imaging provided by TEE, it has been difficult to achieve similarly clear and complete imaging of

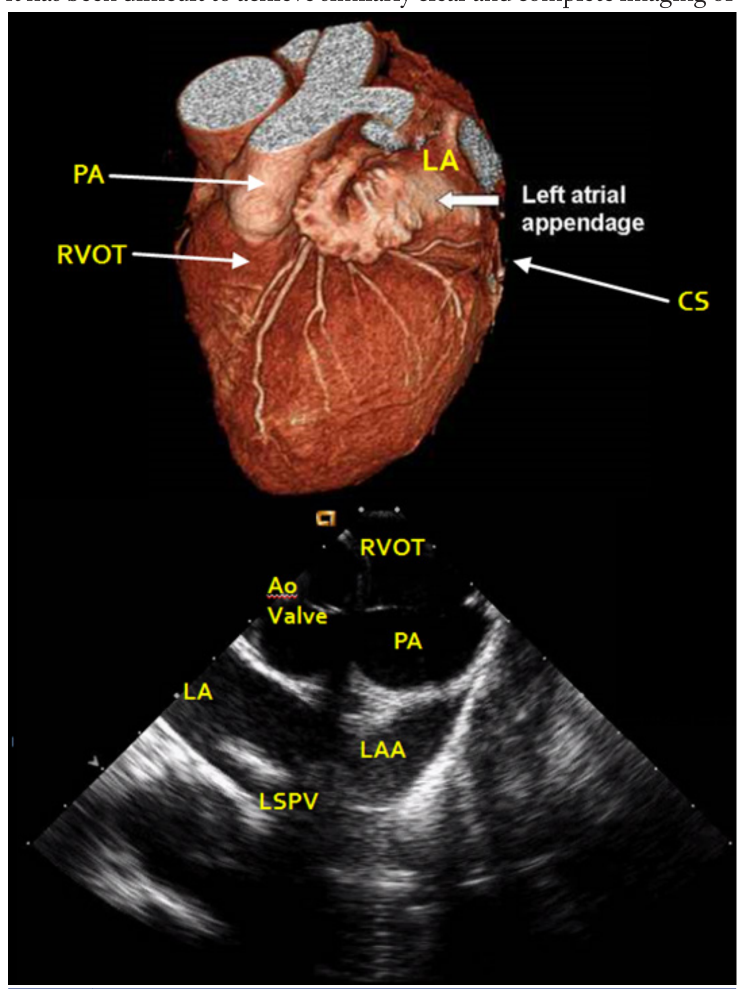

Figure 5: Left atrial appendage imaging. Top: CT representation of a typical left atrial appendage with adjacent structures approachable with ICE. Bottom: Image of left atrial appendage (LAA) obtained with ICE catheter placed in RVOT. LA = left atrium; CS = coronary sinus; PA = pulmonary artery; RVOT = right ventricular outflow tract.

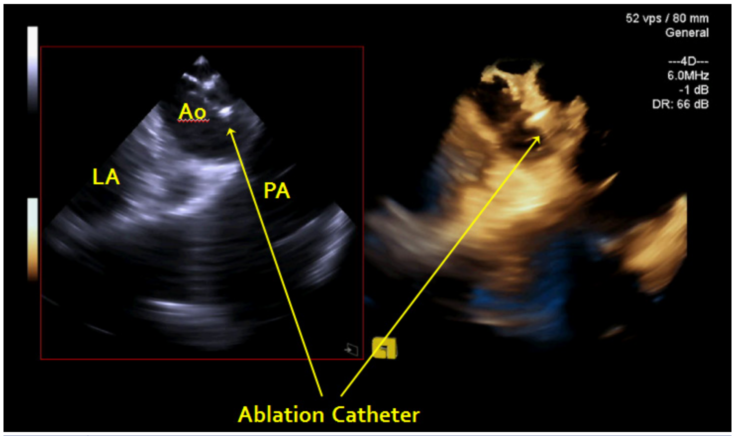

Figure 6: Real-time volumetric 3D ICE of the aortic valve from the right ventricular outflow tract. Left: 2D view of the aortic cusps (Ao) with ablation catheter tip at commissure of right and left coronary cusps. Right: Corresponding 3D view. LA = left atrium; PA = pulmonary artery.

the LAA with ICE, since ICE imaging depends heavily on operator skill. The high stakes nature of stroke prevention also increases the threshold for replacing the standard approach in this regard.[10]

Detailed scanning of the LAA from the right atrium is usually not possible due to intervening structures including the interatrial septum, aortic root, and pulmonary artery – all of which progressively attenuate the ultrasound beam and thereby cause reduction of the image resolution. In the ICE-CHIP study, ICE imaging of the LA body was excellent, but imaging of the LAA was overall inferior to TEE.[11] Therefore, clear visualization of the LAA – particularly the distal portions where thrombus usually resides – requires placement of the ICE catheter in a structure adjacent to it: the left atrium proper (and left superior pulmonary vein), the coronary sinus, the right ventricular outflow tract, or the pulmonary artery (Figure 5).[12] When transseptal access is already obtained, ICE imaging from the left atrium is relatively simple.[13] However, ICE placement in the mid coronary sinus can be difficult and requires experience in order to avoid perforation with the relatively stiff ICE catheter. On the other hand, ICE placement into the RVOT is relatively simple, and clockwise rotation of the imaging plane leftward and superiorly provides excellent views of the distal LAA (Figure 5 bottom), although parts of the LAA neck may be obstructed from view by the aortic root. Finally, comprehensive scanning of the LAA is most reliably obtained with the ICE in the proximal pulmonary artery, but this position is difficult to reach with the current generation of stiff ICE catheters due to concern for perforation of the anterior RVOT. Again, in order to compensate for the lack of mechanized multiplane imaging, multiple manual scans of the imaging plane through the complex anatomy of the LAA is required with ICE, and a combination of the aforementioned approaches may be necessary in order to image the entire length of the LAA to definitively rule out thrombus. Further improvement in the technology of ICE catheters – including miniaturization, improvement in steering mechanisms, and 3D imaging – should increase the feasibility of complete LAA imaging in the future.

ICE in Non-Electrophysiology Procedures

With the growth of percutaneous interventions for structural heart disease, ICE has also found a natural fit for procedures besides ASD closures which require prolonged real-time imaging guidance. Bartel and colleagues reported a randomized study comparing ICE with TEE for guidance of transcatheter aortic valve replacement (TAVR).[14] ICE provided continuous visualization of the area of interest with less need for repositioning, since it does not obstruct fluoroscopic views. Both coronary ostia were more frequently visualized by ICE than by TEE. Measurements made with ICE correlated well with pre-procedural TEE measurements. They concluded that ICE guidance for TAVR is feasible and probably equivalent to TEE. Similar to electrophysiologists before them, there will likely be increasing motivation for interventional cardiologists to gain comfort with using ICE as percutaneous structural heart interventions become more routine.

Real-Time 3D ICE

Since the introduction of matrix array probes, 3D TEE has become standard practice in assessing valves and guiding structural heart procedures. A volumetric 3D ICE catheter has been developed for clinical use as well,[15] but the 3D imaging sector (22o x 90 o) is relatively narrow compared with 3D TEE, and with added cost, introduction into clinical use has been slow. Potentially, real-time 3D ICE would provide better perception of depth while visualizing pulmonary veins, aortic cusps, and papillary muscles, as well as better appreciation of catheter orientation (Figure 6). If the 3D imaging frame rate is high enough, it could even allow efficient real-time guidance of catheter manipulation.

Conclusions:

Intracardiac echocardiography (ICE) has unique advantages for real-time use during electrophysiology and other percutaneous cardiac procedures. ICE provides the operator independence and flexibility with regard to structural and functional characteristics, which are essential to guide the procedure as well as monitor the patient. Integration of ICE into the 3D mapping system has improved electrophysiologists' appreciation for anatomical correlates to various arrhythmias. Increased dexterity with catheter manipulation to achieve desired views creates evolving roles for ICE, including assessing the left atrial appendage and guiding TAVR. Emerging technological progress such as volumetric 3D ICE imaging will improve real-time visualization and potentially reduce need for fluoroscopy even further.

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