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Review Article

Intracardiac Echocardiography: Technique and Role in Interventional Cardiology

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Abstract

Peri-interventional echocardiographic monitoring and guidance is of paramount importance in the current interventional era. Intracardiac echocardiography (ICE) complements and has in part replaced transoesophageal echocardiography (TEE, including real-time three-dimensional (RT-3D) imaging. In contrast to TEE, ICE represents a purely intraprocedural guiding and imaging tool unsuitable for diagnostic purposes. Accurate imaging of the particular pathology, its anatomic features and spatial relation to the surrounding structures is critical for catheter and wire positioning, device deployment, evaluation of the result and for ruling out complications. This review describes the peri-interventional role of ICE, outlines the basic principles of intracardiac echocardiography and examines its applications in the different settings of invasive cardiology.

Keywords: *Peri-Interventional; Intracardiac Echocardiography; Invasive Cardiology*

Introduction

The limitations of standard fluoroscopy have led to the development of improved imaging techniques to guide noncoronary cardiac interventions. Noninvasive cardiac imaging tools include ultrasound, computed tomography and magnetic resonance imaging can generate high-resolution images of the heart and are increasingly being used to guide cardiac interventions. Despite these advances, there remains a strong role for invasive imaging tools include transesophageal echocardiography, intracardiac echocardiography, intracardiac endoscopy and electroanatomic mapping systems. Despite the risks inherent to the invasive nature of these tools, these modalities can provide excellent real-time, detailed images that can be invaluable in guiding certain cardiac interventions. Intracardiac echocardiography (ICE) is a promising technique for accurate visualisation of intracardiac anatomical structures with an ultrasound catheter placed exclusively in the right side of the heart.

History

The introduction of ICE in clinical medicine began in the 1960s. Early models were limited by the mechanical and rotational imaging of a single piezoelectric crystal on the tip of a 6F or 10F catheter [1]. Availability of only higher frequencies additionally limited imaging depth. By 1969, Bom., *et al.* had developed a 32-element phased array coil in Rotterdam [2]. During the 1980s, the advent of intracoronary ultrasound led to its first clinical use in cardiology [3]. Glassman and Kronzon presented the successful use of ICE in aiding the transseptal puncture, a fundamental technique for structural heart interventions [4]. The subsequent development of lower-frequency transducers, which allowed for greater imaging depth with visualization of cardiac chambers and soft tissue structures, led to some of the earliest investigations in intracardiac anatomy during the 1990s [5].

Technology

ICE is an imaging modality in evolution. There are five commercially available ICE catheters:

1. The Ultra ICE (Boston Scientific; Natick, MA, United States) is a mechanical tipped, 9F single element, rotational ultrasound transducer that rotates at 1800 rpm with a fixed frequency of 9 MHz. It provides a large 360-degree field of view with 3D reconstruction capabilities, but at a radial depth restricted to 5 cm, limiting its utility for imaging of left-sided structures and for the transseptal puncture. Emerging applications involve crossing the septum to aid in left-sided evaluation but given the lack of Doppler capabilities and reduced steerability they are largely utilized for electrophysiologic procedures.
2. The AcuNav (Biosense Webster, Diamond Bar, CA, United States) is a 8 or 10F, 90 - 110 cm long catheter that has 64 elements phased-array transducer used to scan in a longitudinal monoplane at frequencies ranging from 5 to 10 MHz. It provides 90° imaging sector, similar to transthoracic echocardiography (TTE) or TEE with tissue penetration up to16 cm, allowing visualization of left-sided structures from the right heart. The catheter is able to deflect in four planes, each at an angle of 160 degrees, offering the acquisition of multiple study planes. Furthermore, the device has Doppler capabilities and is positioned under fluoroscopic guidance without necessitating guide wire support. Other features are represented by optimal maneuverability, with the possibility of anterior/posterior and left/right deflection of the catheter and a locking system holding the probe in the desired position during the procedure.
3. The ViewFlex PLUS (St. Jude Medical, St. Paul, MN, United States) the ViewMate Z ultrasound system
4. (EPMedSystems, Inc., Berlin, NJ) has a 9F 64 element, phased-array transducer operating at frequencies ranging from 4.5 to 8.5 MHz and a penetration depth up to 21 cm. It has a large curvature radius and an Agilis-designed handle that provides full maneuverability with steering angles in two planes up to an angle of 120 degrees. The two phased-array catheters provide greater frequency range, field depth and steerability.
5. The ClearICE device (St. Jude Medical, Inc) has a 64-element phased-array transducer with a highly steerable catheter and bidirectional steering up to 140º. It works with the Vivid system (GE Healthcare Technologies, Wauwatosa, WI). It has two sets of electrodes for integration of 3D localization with NavX. Apart from grayscale and tissue Doppler, it also allows for synchronization mapping and 2D speckle tracking.
6. The SoundStar Catheter system (Biosense-Webster) has the same characteristics like AcuNav catheter but with CARTO magnetic sensor in the tip (Figure 1).

Figure 1: *AcuNav Catheter. The control handle has three knobs: first to move the tip in posterior/anterior directions, second to move the tip in right/left directions, and the last knob is a locking one that will fix the tip in the desired orientation.*

ICE catheter insertion techniques

The catheter can be introduced percutaneously by femoral vein or internal jugular vein. However, the femoral vein approach is the most popular among most of the interventionalists because it is closer to the table, allowing easier manipulation of the control handle. The 8F AcuNav catheter is carefully advanced from the groin to the heart under continuous fluoroscopic guidance because of its rigidity (stiffness) and possible advancement of the catheter into side branches with potential vessel injury before reaching the right atrium (RA). It is recommended to use a long 8F sheath (30 cms) in either femoral vein in order to avoid vascular complications or possibly entanglement below the level of the IVC. This approach offers easy accessibility and allows fairly free movement of the catheter inside the heart. In adult patients, the catheter can be introduced in the same vein used for the device delivery while for patients with weight below 35 kg, access in the opposite femoral vein is recommended.

Views

The ICE catheter is introduced through the femoral vein and advanced via the inferior vena cava (IVC) into the RA. ICE protocol starts with obtaining first the home view followed by septal view, long axis view and short axis view in combination with fluoroscopic image.

1. **Home view**: This view can be obtained by advancing the ICE catheter to the mid right atrium. Catheter is parallel to the spine with the transducer portion facing the tricuspid valve. Subtle counter clockwise movements in the knob of the catheter can be done to obtain the home view image. Right atrium, the tricuspid valve, the right ventricle, right ventricular inflow and outflow and a portion of the aortic valve in short axis view are seen. The anterior portion of the septum can be occasionally visualized as well (Figure 2A) [6].
2. **Septal view**: After the home view image is obtained, slight movements of the anterior-posterior knob posteriorly and the right-left knob rightward will make the transducer face the atrial septum. In this view entire length of the atrial septum is seen. The image closer to the ICE catheter (superior) is the RA and distal to the image (inferior) is the left atrium (Figure 2B).
3. **Long axis view**: This view can be obtained after having the catheter in the septal view, followed by slight superior advancement of the ICE catheter in the RA towards the SVC. The catheter can either face the atrial septum, the SVC or both; it depends on the position of the catheter. Advancing the flexed catheter in the direction of the SVC can profile much better the SVC and the respective superior rim. Withdrawal of the flexed catheter towards the IVC will profile the inferior part of the atrial septum and the inferior rim as well. This view is good for measurements of an atrial septal defect as well. The right and left pulmonary venous drainage can be seen just rotating the catheter clockwise or counterclockwise as well as with flexion/anteflexion (Figure 2C).
4. **Short axis view**: The catheter is still flexed in its locked position; the entire catheter should be moved from the sheath hub in a clockwise manner in order to place it inferior to the aortic valve and near the tricuspid valve. This is followed by slight adjustments in the posterior anterior knob with less posterior flexion and more leftward rotation on the right/left knob. Fluoroscopy image shows the position of the catheter. This view is the opposite of the short axis view that can be obtained using TEE with the near field image being the right atrium and the far field image being the left atrium. The anterior rim and posterior rim can be obtained as well (Figure 2D).
5. **Additional views**:
    a. Turning 60° - 70°clockwise from the home view, without deflection, it is possible to view the interatrial septum, left atrium (LA) and left atrial appendage (LAA), mitral valve (MV) and left ventricle (Figure 3A) [7].
    b. From septal view, a further clockwise rotation of 90° - 100°, without deflection, the left pulmonary veins (PVs) are visualized (Figure 3B). The view is completed with the display of the right PVs obtained by shifting and rotating the catheter 150° - 180°clockwise (Figure 3C): a longitudinal view of the PVs is obtained by deflecting the probe on a left/right plane.
    c. From the home view in the middle right atrium, it is possible to deflect anteriorly and move the catheter forward in the right ventricle, then turn clockwise to show the interventricular septum (Figure 3D) and further deflect the probe to change from a long-axis to a short-axis view (Figure 3E).

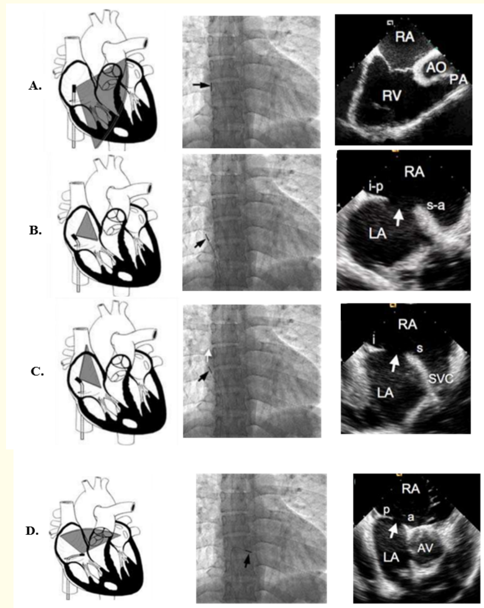

Figure 2: *Left, heart diagram with the position of the ICE catheter, shaded area represents structures seen in that view. Middle, A-P Fluoroscopic image of the ICE catheter (black arrow). Right, ICE 2-D image. (A) Home view, (B) Septal view, (C) Long-axis 'caval view', (D) Short-axis view. [Right atrium (RA), left atrium (LA), left upper and lower pulmonary veins (LUPV, LLPV), superior vena cava (SVC), Right ventricle (RV), Aortic valve (AV), Pulmonary artery (PA)]. ASD rims: superoanterior (s-p), inferoposterior (i-p), superior (s), inferior (i), anterior (a), posterior (p). Atrial septal defect (ASD- white arrow).*

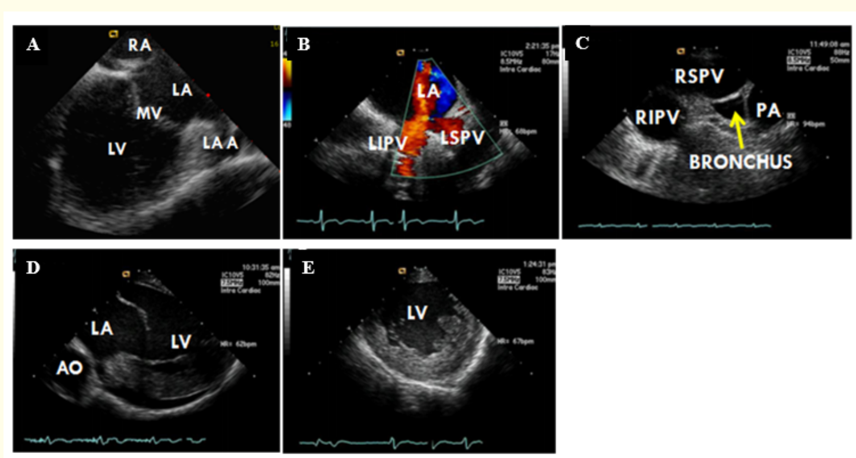

Figure 3: *[A] view for left atrial appendage (LAA), left atrium (LA), mitral valve (MV), left ventricle (LV). [B] view for left superior and inferior pulmonary veins (LSPV, LIPV). [C] View for right superior and inferior pulmonary veins (RSPV, RIPV). [D]LV long axis view. [E] LV short axis view.*

Uses during intervention

1. Transseptal puncture
2. Atrial Septal Defect and Patent Foramen Ovale Closure
3. Ventricular Septal Defect Closure
4. Left Atrial Appendage Occlusion
5. Aortic Valvuloplasty and Valve Implantation
6. Mitral Valvuloplasty and Valve Repair
7. Pulmonic Valvuloplasty and Valve Replacement
8. Ablation of complex arrhythmias
9. Lead extraction and device-related endocarditis
10. Endomyocardial biopsy.
11. Miscellaneous Interventional Procedures

Transseptal puncture

Transseptal access to the LA is a prerequisite for several procedures: atrial fibrillation (AF) ablation, MV valvuloplasty and LAA closure. ICE has been demonstrated to be particularly useful to achieve a safe transseptal puncture (especially in the presence of anatomical anomalies of the interatrial septum). Transseptal puncture is best performed with the ICE catheter in the mid RA and flexed posteriorly to show "tenting effect" of the IAS with advancement of the puncture needle [8].

Atrial septal defect and patent foramen ovale closure

TEE has provided excellent imaging and assessment of the interatrial septum (IAS) to guide device closure; however, the necessity of general anesthesia and a separate echocardiographic operator have made it less favorable than ICE. Mullen., *et al.* found similar efficacy between TEE and ICE in assessing percutaneous closure of ASDs [9].

In percutaneous ASD or PFO closure, the ICE catheter is advanced into the RA to display the "home" view. In this view, accurate assessment of the TV for any substantial regurgitation is important in determining the suitability of percutaneous closure [10]. Slight posterior rotation and rightward movement of the probe brings the IAS into view to assess the ASD or PFO. Advancing the probe toward the superior vena cava, while facing the septum, visualizes the IAS in a superoinferior plane. Specific maneuvers identifying the location and size of the defect, adequacy of surrounding rims, normal pulmonary vein insertion and confirmation of interatrial shunting by Doppler imaging and agitated saline assist in the appropriate selection of patients, sizing of the defect and positioning of percutaneous device.

Ventricular septal defect closure

Muscular VSDs can be difficult to delineate with ICE and TEE may need to be used for complete assessment. However, membranous VSDs are readily visible with the ICE catheter positioned in the RA. The ICE catheter, positioned in the mid RA in a neutral position facing the TV, shows the RV inflow and the perimembranous portion of the interventricular septum (IVS). Long-axis, short-axis and 4-chamber views can be obtained by manipulation of the catheter within the RA. If the patient has an ASD or PFO, the ICE catheter can be advanced through the defect into the left atrium (LA) and VSD interrogation can be performed with images similar to those of TEE. Alternatively, the ICE catheter can be flexed and advanced across the TV into the RV and rotated anteriorly to image the IVS and VSD for measurements and device deployment. One smaller study of 12 patients, comparing TEE and ICE, found that ICE provided similar anatomic views and measurements to safely guide membranous VSD closure [11].

Left atrial appendage occlusion

The LAA can be readily imaged by rotating the ICE catheter clockwise from the mid RA at the level of the TV past the aorta until the LAA appears at the level of the mitral annulus. ICE allows accurate assessment of the size and shape of the LAA as well as guide device placement. Complications of LAA occlusion such as MV or pulmonic vein obstruction, pericardial effusion and a suboptimal device position can also be expeditiously recognized using ICE guidance.

Aortic valvuloplasty and valve implantation

Transesophageal echocardiography remains the echocardiographic modality of choice currently for TAVI. However, ICE may offer advantages of avoiding general anesthesia and a separate echocardiographer while providing sufficient imaging data for evaluation of the valve and performance of aortic valvuloplasty and valve implantation. A recent study randomizing 50 TAVI procedures to ICE or TEE for imaging guidance found ICE to be a suitable alternative, with adequate imaging and hemodynamics assessment along with continuous visualization without the need for probe repositioning during the procedure [12].

Mitral valvuloplasty and valve repair

Percutaneous mitral valvuloplasty and mitral clip edge-to-edge repair are performed under fluoroscopic and TEE guidance; however, ICE can be performed to evaluate the MV during these procedures. Clockwise rotation of the transducer with slight posterior flexion from the home view allows visualization of the MV. Positioning the catheter within the RV provides an additional view of the MV. Intracardiac echocardiography from within the CS provides exceptional views of the MV and LA. Intra-CS ICE has been used to delineate the mitral isthmus, atrioventricular groove vessels, intra-CS muscle bundles and MV apparatus. Protocols for ICE imaging continue to be developed to guide precise deployment of sutures into the A2-P2 scallops of the MV to confirm the final result before release of the clip [13].

Pulmonic valvuloplasty and valve replacement

ICE enables the assessment of valvular gradients and regurgitation both before and after valvuloplasty [11].

Ablation of complex arrhythmias

In AF ablation in particular, ICE allows real-time direct imaging of the FO, posterior atrial wall and aorta, helping the operator to choose with more precision the puncture site (e.g. posterior region of the FO) in order to achieve maximum catheter maneuverability during mapping and ablation. Usually integrated to other imaging techniques, ICE can give further information about the individually variable anatomy of PVs, permitting identification of their number, position and size, as well as the presence of a common ostium and evaluation of the position, dimensions and shape of the LAA, as well as its spatial relationship with the left PVs [14].

It also allows precise real-time visualization of the mapping/ablating catheter position in relation to these structures and can be used in addition to electrophysiological indices such as impedance monitoring to identify sites that are safe for energy delivery to obtain PV isolation [15,16].

Furthermore, titration of radiofrequency energy based on visualization of microbubbles by ICE has been demonstrated to improve long-term outcome and reduce PV stenosis after AF ablation. Finally, ICE plays an important role in monitoring for possible intraprocedural complications, the most threatening being cardiac perforation with consequent pericardial effusion and tamponade, thromboembolism and esophageal injury. In all these cases, an early detection warranted by ICE will lead to a prompt intervention resulting in a better final outcome [17,18].

ICE is also used during other supraventricular arrhythmia ablations, especially in disorders for which the ablation approach is typically anatomically based, like atrial tachycardias originating from the crista terminalis or challenging atrial flutters, for example, in the presence of prominent pectinate muscles and subeustachian pouches or in patients with complex anatomy due to congenital heart disease [19,20].

The contribution of ICE can be appreciated as well in ventricular arrhythmia ablations: the ability to visualize precise catheter position has proven to be very useful in the ablation of ventricular tachycardia (VT) originating close to delicate cardiac structures such as coronary ostia (in idiopathic VTs from Valsalva sinuses) or arteries (in epicardial ablations) or from areas in which getting a stable catheter-tissue contact can be challenging, like papillary muscles (Figure 4) [7]. Continuous monitoring provided by ICE is very useful to prevent or rapidly treat potential complications in VT ablations too. However, the peculiar contribution of ICE in VT ablation procedures is represented by its role in the identification of the arrhythmic substrate, especially if combined with electroanatomic mapping techniques. Most VTs originate from myocardial scars secondary to ischemia and infarction or from the border zones between scars and adjacent tissue. Thus, the identification of these akinetic areas as arrhythmogenic substrate is a useful endpoint for a successful ablation. The identification of the akinetic and diskinetic areas or aneurismatic dilatation by ICE could give additional information compared to traditional electroanatomic mapping system, defining not only the relevant arrhythmogenic myocardial areas but also the wall thickness before ablation [21-23]. This imaging tool could be helpful also in the context of epicardial ablation of VT [24-26].

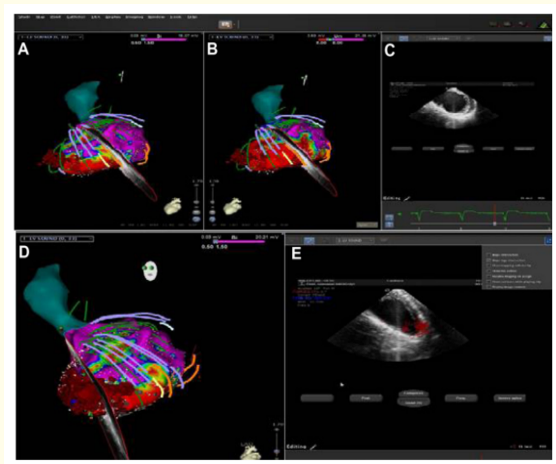

Figure 4: *Integration of intracardiac echocardiography with ventricular electronanatomic mapping. (A, B, D) integration of intracardiac echocardiography with bipolar and unipolar left ventricular electroanatomic mapping. (C, E) intracardiac echocardiographic views of all left ventricular layers. ICE gives an important support during ablation procedures with information about the contact between the mapping/ablating catheter and the myocardial tissue, indicating the sites where RF energy has been delivered (red tags). Comparison with electroanatomic maps may show the anatomical features of areas of potential interest and provide a real time continuous monitoring and surveillance of potential procedural complications. (ICE, intracardiac echocardiography; RF, radiofrequency).*

Lead extraction and device-related endocarditis

ICE plays a key role in the diagnosis and treatment of device-related infections, providing an excellent imaging of right-sided PM/ICD leads, prosthetic valves and cardiac structures, proven to be superior to TEE in detecting signs of infectious involvement, guiding the procedures of lead extraction and monitoring for complications [27,28].

Endomyocardial biopsy

In regard to endomyocardial biopsy, ICE is an optimal imaging tool to guide the procedure, with direct visualization of the biopsy zone and real-time monitoring of potential adverse effects. ICE is of remarkable importance if the procedure involves high-risk structures like papillary muscle and/or cardiac wall affected by pathological processes that reduce thickness and modify tissue architecture. Moreover, directing a bioptome to an intracardiac mass is extremely difficult with fluoroscopic or echocardiographic guidance. The use of ICE facilitates biopsies of such lesions and, also imaging them with high resolution, plays a fundamental role in the differential diagnosis of intracardiac neoplasms [27].

Miscellaneous interventional procedures

In addition to the above-mentioned interventions, ICE may also assist in patent ductus arteriosus closure, perivalvular leak closure for prosthetic valves, alcohol septal ablation for hypertrophic obstructive cardiomyopathy [28-30].

Safety and feasibility

Two major limitations of ICE are its cost and invasive nature. Operator experience is a prerequisite for successful performance of ICE. In two series conducted by Earing., *et al.* and Hijazi., *et al.* there were no reported vascular complications in more than 100 ICE procedures. The most common complication was atrial tachycardia, in up to 4% of patients, during ICE catheter manipulation within the right atrium (RA) [31,32].

Future directions

Intracardiac echocardiography is the most commonly used non fluoroscopic imaging tool in the interventional laboratory. The advancements of ICE will include enhanced image quality and resolution, as well as smaller, more flexible and stable transducers, which may allow for radial access intracardiac imaging. Forward-looking ICE catheters, primarily being developed in conjunction with radiofrequency ablative devices, will provide an alternative view of cardiac anatomy [10]. Real-time 3D ICE is currently being developed and has the potential to enhance image acquisition, measurement of ventricular volumes and peak flow velocities during valvular interventions [33,34]. 3D ICE will also be useful for leads extraction, direct visualization of the anatomical relationship between electrocatheters and tricuspid leaflets, identification of lead and/or valvular vegetations.

Summary

Intracardiac echocardiography, an evolving echocardiographic modality has proven useful in conducting safe and efficient interventional procedures in various diagnostic and therapeutic areas. As structural heart disease interventions continue to evolve, ICE appears poised to complement these therapeutic procedures (Figure 5).

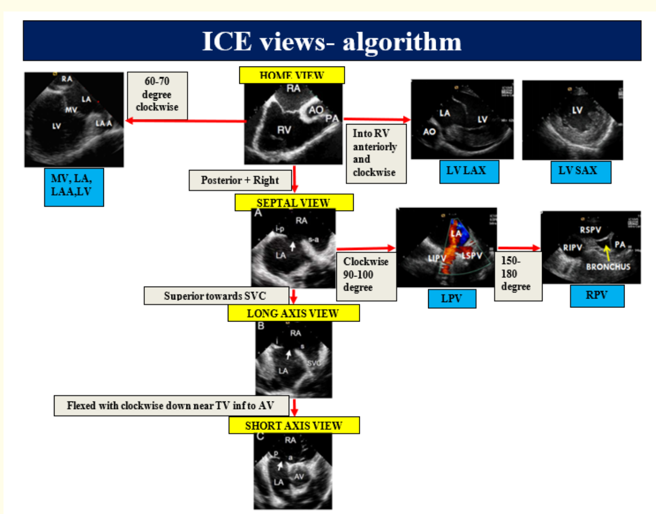

Figure 5

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