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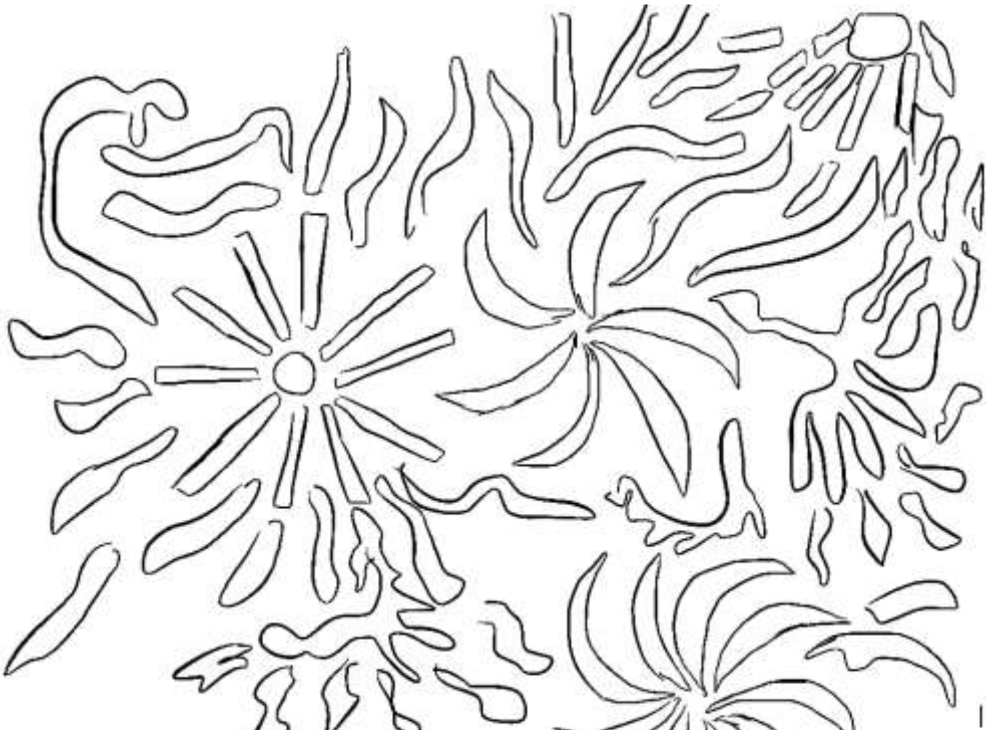
Part II

Imaging to facilitate ablation of complex arrhythmias



Chapter 8

Intracardiac Echocardiography

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Introduction

In the past years intracardiac echocardiography (ICE) has emerged as a valuable imaging tool for interventional and electrophysiological procedures. Intracardiac echocardiography allows real-time visualization of important anatomical structures that cannot be visualized on fluoroscopy, and is not associated with radiation exposure to the patient and operator. This imaging modality is used to guide and monitor interventional procedures and for early detection of complications. Importantly, as an alternative to transesophageal echocardiography (TEE), ICE can be performed without general anesthesia. In this chapter, the basic principles and clinical applications of ICE will be discussed.

Anatomic considerations

Intracardiac echocardiography is generally performed from within the right atrium or the right ventricle. The images acquired with ICE should therefore be interpreted from that perspective. Depending on the position and direction of the ultrasound catheter, all large cardiac structures, including the atria, ventricles, atrioventricular and semilunar valves, coronary sinus and pericardium can be visualized with ICE. Awareness of the orientation of the scanning plane and a good understanding of the 3-dimensional (3D) cardiac anatomy are essential for a correct interpretation.

Equipment

Currently, two different ICE technologies are available. The first approach utilizes a mechanical ultrasound tipped catheter which can also be used for endovascular echocardiography. The second uses an electronic ultrasound catheter that is equipped with a phased array transducer at its tip. Both are introduced using a retrograde femoral venous approach after the application of local anesthesia. The mechanical or rotational system uses a 9 French catheter equipped with a 9 MHz single-element transducer incorporated at its tip (Ultra ICE™, Boston Scientific, San Jose, CA). A piezoelectric crystal inside the transducer is rotated at 1800 rpm in the radial dimension and provides a 2-dimensional (2D) 360º scanning plane, oriented perpendicular to the catheter shaft. To adjust the imaging plane, the catheter can be withdrawn or advanced inside the heart. To prepare the catheter for use, the system has to be filled with 3-5 ml sterile water and connected to a dedicated ultrasound machine (iLab™ System, Galaxy® System, Galaxy2™ system or Clearview® Ultra™ system, Boston Scientific).

The electronic system uses an 8, 9 or 10 French ultrasound catheter equipped with a 64-element phased array transducer located at its tip (ACUSON Acunav™, Siemens Medical Solutions, Mountain View, CA and ViewFlex™, St. Jude Medical, West Berlin, NJ) that generates a 90º wedge shaped 2D scanning plane, oriented parallel to the catheter shaft. The high resolution transducer can be used at multiple frequencies (5-10 MHz) thereby allowing depth control and enhancement of tissue penetration to a maximum of 15 cm. The flexible catheter can be rotated around its axis, and the tip of the catheter can be deflected by manipulating the steering mechanism at the handle of the catheter. The flexibility and maneuverability of the catheter enable the operator to position it inside the right ventricle or coronary sinus. In this way, additional views can be obtained, that cannot be acquired from the right atrium. The phased array catheter is connected to a dedicated ultrasound machine (Sequoia™, Cypress™, CV70™, Siemens Medical Solutions and ViewMate®, St. Jude Medical).

Several important differences between the two ICE technologies exist. The phased array catheter allows adjustment of the ultrasound frequency, thereby enabling depth control. Furthermore, the phased array catheter has Doppler capabilities, allowing measurement of hemodynamic and physiologic variables, and has superior flexibility compared to the rotational catheter. The advantages of rotational ICE include a 360º scanning plane instead of 90º and the considerably lower costs. In daily clinical practice, phased array ICE is the most commonly used technology in the cardiac catheterization laboratory. The focus of the present chapter will be on phased array ICE, while, mechanical intravascular ultrasound is reviewed in Chapter 28.

Fundamentals

Intracardiac echocardiography can be used to visualize nearly all cardiac structures.[1] However, unlike for transthoracic echocardiography and TEE, there are no widely accepted standard views for ICE. In the following paragraphs, a clinically oriented guide for catheter manipulation and visualization of the various cardiac structures is provided.

Intracardiac echocardiography is generally performed under conscious sedation. Using local anesthesia and a femoral vein approach, the ultrasound catheter is inserted through the inferior vena cava into the right atrium. While standing at the right side of the patient, the operator can change the orientation of the ultrasound beam by advancing or withdrawing the catheter and by rotating it around its axis. In this chapter, rotation of the ultrasound catheter away from the operator is called clockwise rotation, whereas rotation towards the operator is referred to as counter-clockwise rotation. The orientation of the ultrasound beam can also be altered by deflecting the tip of the ultrasound catheter in two orthogonal planes (anterior-posterior, left-right) through manipulation of the two steering knobs at the handle of the catheter.

Even though images acquired with ICE are quite similar to TEE, the large freedom of ultrasound beam orientation can easily cause a sense of disorientation to the inexperienced operator. In order to gain and regain orientation, a ‘home view’ position is defined which can be used as the starting point for all catheter manipulations. In this chapter ‘home view’ position is used as the starting point from which all catheter manipulations are described. To reach this position, the ultrasound catheter is positioned in the mid-right atrium with the control knobs in a neutral position. The resulting image shows the right atrium, tricuspid valve and right ventricle (Figure 1, panel A). The operator can use these and other anatomical landmarks to maintain orientation during catheter manipulation. To further improve the operator’s orientation, a marker is present on the ultrasound screen corresponding to the inferior portion of the ultrasound beam.

Figure 1. Panel A: ‘Home view’ position: right atrium (RA), right ventricle (RV), tricuspid valve (TV) and vena cava inferior (VCI). Panel B: aortic valve (AoV), cavotricuspid isthmus (*), Eustachian ridge/valve (EuV), right ventricular outflow tract (RVOT). Panel C: interatrial septum, left atrium (LA), coronary sinus (CS) and mitral valve (MV).

Right-Sided Structures

Starting from ‘home view’ position and slightly withdrawing the catheter into the inferior right atrium, the Eustachian ridge can be visualized (Figure 1, panel B). The tissue between the Eustachian ridge and the tricuspid valve is known as the cavotricuspid isthmus which is targeted during catheter ablation for atrial flutter. By advancing the catheter back in ‘home view’ position and rotating it counter-clockwise the crista terminalis and right atrial appendage are visualized. Clockwise rotation will first bring back ‘home view’ and will then reveal the right ventricular outflow tract, the pulmonary artery and the ascending aorta (Figure 1, panel B).

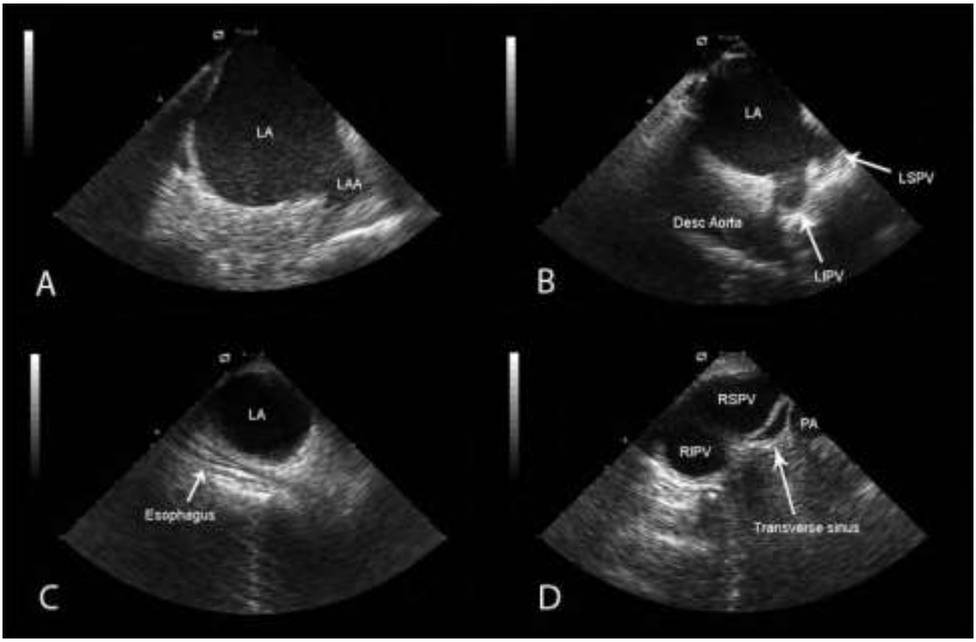

Figure 2. Panel A: Left atrium (LA) and left atrial appendage (LAA). Panel B: Descending aorta (Desc Aorta), LA, left superior pulmonary vein (LSPV) and left inferior pulmonary vein (LIPV). Panel C: Esophagus and posterior LA wall. Panel D: Pulmonary artery (PA), right inferior pulmonary vein (RIPV), right superior pulmonary vein (RSPV) and transverse sinus.

Left-Sided Structures

Clockwise rotation of the ultrasound catheter from 'home view' position, past the right ventricle and right ventricular outflow tract, provides a view on the left atrium, mitral valve, the interatrial septum and the coronary sinus (Figure 1, panel C). By gently deflecting the catheter tip in the left direction, the left atrial appendage can be seen (Figure 2, panel A). From this view, clockwise rotation will reveal the left-sided pulmonary veins (Figure 2, panel B). The left inferior pulmonary vein is visualized at the inferior portion of the ultrasound beam and the left superior pulmonary vein at the superior portion. In case of difficulty to distinguish between the left superior pulmonary vein and the left atrial appendage, Doppler flow measurements can be used to differentiate between the two structures. When further rotating clockwise, the posterior left atrial wall and the esophagus can be visualized (Figure 2, panel C). Eventually, continued clockwise rotation will provide a cross-sectional view of the right-sided pulmonary veins and the right pulmonary artery (Figure 2, panel D). Similar to the left pulmonary veins, the right inferior pulmonary vein is visualized at the inferior portion of the ultrasound beam and the right superior pulmonary vein at the superior portion.

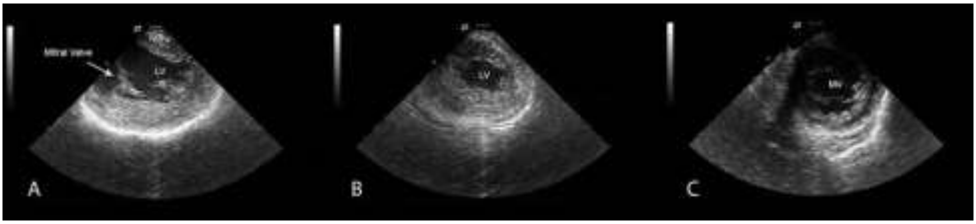

Figure 3. Panel A: Long axis view of the left ventricle (LV): interventricular septum (IVS), mitral valve (MV). Panel B: Short axis view at the apical level. Panel C: Short axis view at the basal level.

To acquire a long axis view of the left ventricle and mitral valve from 'home view', the catheter is withdrawn slightly into the inferior right atrium and the tip of the catheter is deflected in the anterior direction. By advancing the catheter through the tricuspid valve into the right ventricle and rotating the catheter clockwise, the interventricular septum and left ventricle appear (Figure 3, panel A). This long axis view can be very useful to detect pericardial effusion during interventional procedures. From the long axis view, a short axis view of the left ventricle can be acquired by deflecting the tip of the catheter in the left or right direction (Figure 3, panel B). Advancing or withdrawing the catheter will result a more apical or basal short axis views (Figure 3, panel C).

Indications and clinical applications

Intracardiac echocardiography can be used in a wide variety of diagnostic and interventional procedures. These procedures are summarized in Table 1 and will be reviewed in the following paragraphs.

Table 1. Applications of Intracardiac Echocardiography during Interventional and Electrophysiological Procedures

- Detection of intracardiac thrombus
- Closure of atrial septal defect
- Transseptal puncture
- Electrophysiological procedures
    - Atrial fibrillation ablation
    - Complex atrial flutter ablation
    - Ventricular tachycardia ablation
    - Left ventricular lead placement in cardiac resynchronization therapy
- Other interventional procedures
    - Biopsy of an intracardiac tumor
    - Left atrial appendage closure
    - Closure of ventricular septal defect
    - Alcohol septum ablation in hypertrophic obstructive cardiomyopathy
    - Mitral valve balloon valvuloplasty
    - Percutaneous valve procedures

Detection of Intracardiac Thrombus

Patients undergoing a left-sided interventional procedure are at a high risk for systemic embolism.[2,3] Intracardiac echocardiography can facilitate a safe left-sided procedure by excluding intracardiac thrombus inside the left atrial appendage, left atrium and left ventricle.[4] Furthermore, ICE can be used to assess the presence of spontaneous contrast, thereby identifying patients at a high risk for thrombus formation.[5] Furthermore, ICE can help to detect the formation of thrombi at an early phase and allow for treatment prior to the occurrence of embolic events.[6,7]

The efficacy of TEE to detect intracardiac thrombus has been established by the ACUTE trial (Assessment of Cardioversion Using Transesophageal Echocardiography).[8] Even though ICE provides high quality images comparable to TEE, only few studies have compared the sensitivity of the two imaging modalities for the detection of intracardiac thrombus. The ICE-CHIP study (IntraCardiac Echocardiography guided Cardioversion to Help Interventional Procedures) was designed to address this issue.[9] The preliminary results of the ICE-CHIP study show that ICE has a similar sensitivity for the detection of spontaneous contrast, as compared to TEE.[10] In 100 patients with atrial fibrillation, spontaneous contrast of the left atrium was seen in 50% on ICE and in 55% on TEE (p=NS) whereas spontaneous contrast of the left atrial appendage was seen in 24% on ICE and in 34% on TEE (p=NS). However, the results on thrombus detection from the ICE-CHIP study are not yet available. Therefore, more studies are needed to determine the exact value of ICE for the detection of intracardiac thrombi.

Closure of Atrial Septal Defect

Percutaneous transcatheter device closure of atrial septal defect or patent foramen ovale has proven to be a safe and effective alternative to open heart surgery.[11,12] While percutaneous closure of patent foramen ovale may be performed under fluoroscopy guidance only, closing procedures of atrial septal defect are typically guided by TEE and fluoroscopy. However, ICE does not require general anesthesia, and may provide similar images as TEE.[13,14] It has been shown that the use of ICE during transcatheter device closure may result in a reduction of fluoroscopy time (9.5 ± 1.6 minutes vs. 6.0 ± 1.7 minutes, $p<0.0001$),[13] procedure length (47 ± 8 minutes vs. 35 ± 6 minutes, $p<0.001$) and catheterization laboratory occupation (92 ± 18 minutes vs. 50 ± 12 minutes, $p<0.001$) compared to TEE guided interventions.[15] Importantly, the high costs of an ICE catheter may be balanced by the need for general anesthesia during TEE guided procedures.[16]

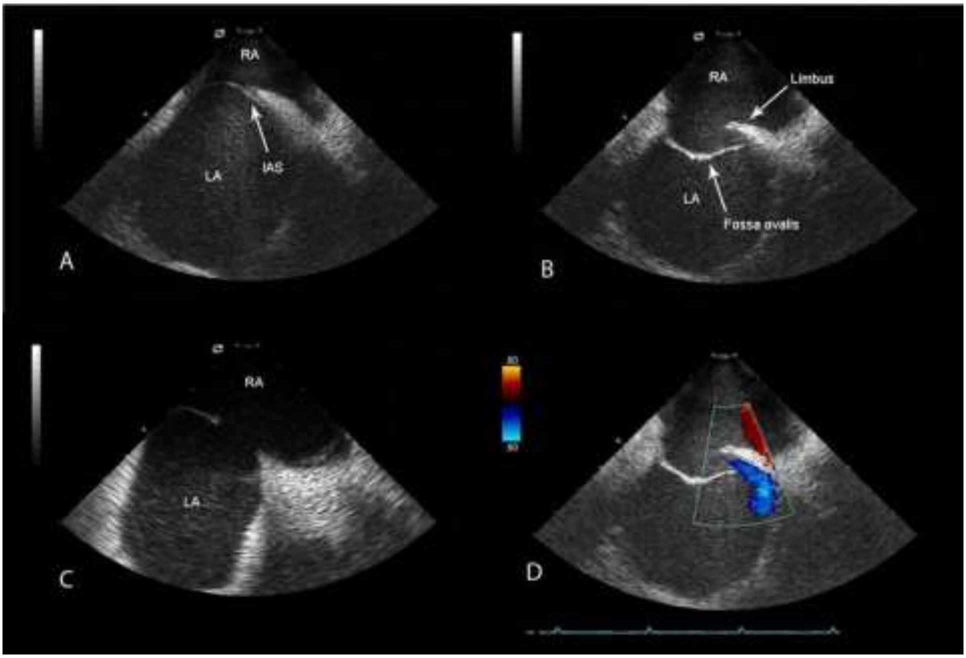

Figure 4. Panel A: Interatrial septum (IAS), left atrium (LA) and right atrium (RA). Panel B: During a Valsalva maneuver the patent foramen ovale (PFO) is revealed. Panel C: A large type II atrial septal defect (delineated by the two markers). Panel D: Doppler flow delineates the flow across PFO during a Valsalva maneuver.

To guide the placement of a transcatheter closure device, the ultrasound catheter is positioned in the 'home view' position and is rotated clockwise to visualize the interatrial septum and fossa ovalis (Figure 4, panel A, B and C). By using Doppler capacities, the flow between the left and right atrium can be visualized and quantified (Figure 4, panel D). A guiding wire is then placed through the atrial septal defect and inside the left atrium. Subsequently, the catheter that contains the closure device is advanced through the atrial septal defect and the left-sided portion of the occluder is deployed. After this step, the position of the device against the interatrial septum is carefully evaluated before deploying the right-sided portion of the occluder in order to avoid malposition and the associated risk of migration of the device (Figure 5, panel A). Once the operator is convinced that the position is correct, the right-sided portion of the occluder is deployed (Figure 5, panel B). Once again the position and the stability of the device are checked and subsequently the occluder is released.

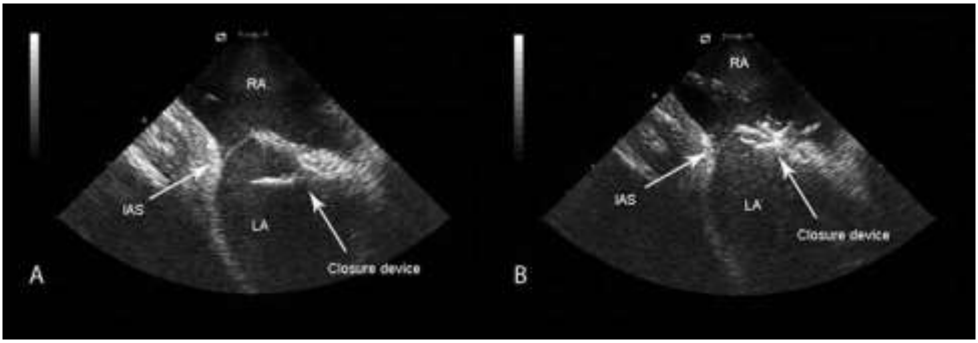

Figure 5. Panel A: A biodegradable closure device is inserted across the interatrial septum (IAS) inside the left atrium (LA). Subsequently, the left-sided occluder is deployed. (RA = right atrium). Panel B: After confirmation of the position of the device, the right-sided occluder is also deployed.

Transseptal Puncture

A transseptal puncture provides antegrade access to the left atrium and left ventricle during left-sided interventional procedures as an alternative to a retrograde approach through the aortic valve and mitral valve. However, a transseptal puncture can result in serious complications, such as aortic perforation, pericardial tamponade and perforation of the inferior vena cava.[17] The fossa ovalis is considered to be the safest site to perform a transseptal puncture in order to avoid these complications. Intracardiac echocardiography allows excellent visualization of the fossa ovalis and can be used to detect a patent foramen ovale or monitor the transseptal puncture.[18] At present, no prospective studies have addressed the question whether ICE may improve the safety of transseptal punctures.

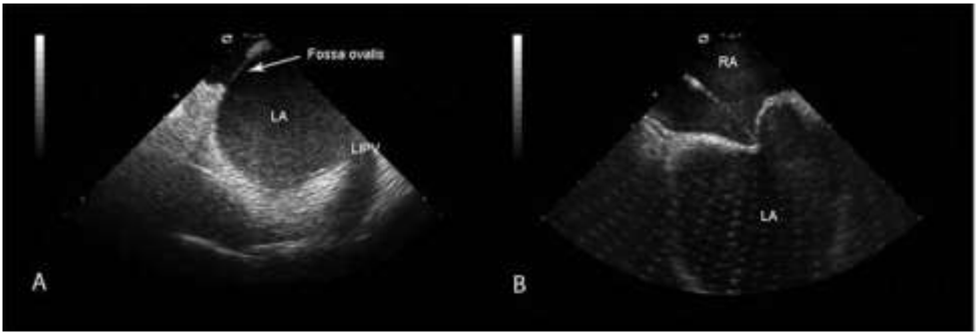

Figure 6. Panel A: Fossa ovalis, left atrium (LA), left inferior pulmonary vein (LIPV). Panel B: Tenting of the transseptal sheath against the fossa ovalis. (RA = right atrium).

To visualize the interatrial septum, the catheter is gently rotated clockwise from 'home view' position. The interatrial septum consists of a thicker part (limbus) and thin part (fossa ovalis) (Figure 6, panel A). To detect a patent foramen ovale, saline/contrast is injected through the femoral vein inside the right atrium and the patient is instructed to perform the Valsalva maneuver (Figure 7, panel A). In the presence of a patent foramen the contrast will cross the interatrial septum, into the left atrium (Figure 7, panel B). In the absence of a patent foramen ovale, a transseptal sheath with a concealed Brockenbrough transseptal needle is inserted through the femoral vein inside the right atrium. Using fluoroscopy and ICE, the transseptal sheath is positioned against the fossa ovalis. In case of a stable position of the sheath against the fossa ovalis, a 'tenting' phenomenon can be seen on ICE (Figure 6, panel B). The transseptal puncture can now be performed by pushing the needle out from the sheath, through the fossa ovalis. Successful transseptal puncture can be confirmed on ICE by injecting saline/contrast through the needle inside the left atrium.

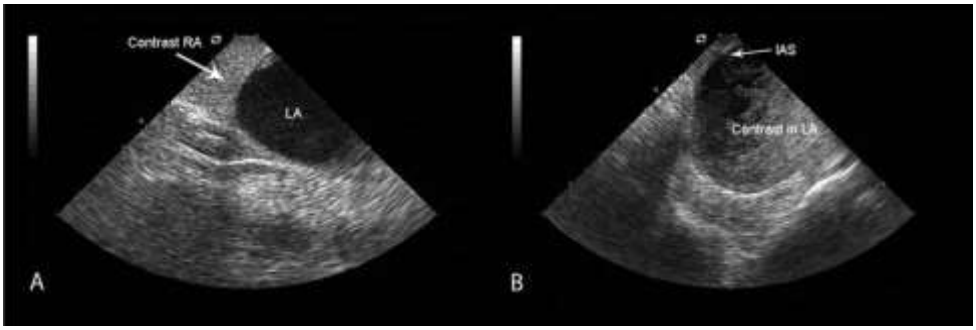

Figure 7. Panel A: Contrast inside the right atrium (RA) during Valsalva, in a patient with a closed foramen ovale. Panel B: Contrast crosses the interatrial septum (IAS) from the RA to the left atrium (LA) during Valsalva in a patient with a patent foramen ovale.

Electrophysiological Procedures

Intracardiac echocardiography has become an important imaging tool during electrophysiological procedures. In addition to thrombus detection and guidance of a transseptal puncture, ICE can be used to identify key anatomical structures to facilitate complex procedures like atrial fibrillation ablation and atrial flutter ablation.[19-21] Intracardiac echocardiography can visualize the exact location of the mapping catheter and confirm stable contact of the catheter against the myocardium. Moreover, ICE can be used to visualize morphological changes in the myocardium, such as increased echo density, wall thickening and crater formation as a sign of effective lesion formation,[22] and the development of micro bubbles as a sign of tissue heating and potential char formation.[23,24] In the following paragraphs, the specific role of ICE in various electrophysiological procedures will be reviewed.

Atrial fibrillation ablation

Radiofrequency catheter ablation targeting the pulmonary veins is a potential curative treatment option for patients with drug-refractory atrial fibrillation.[25,26] However, it is associated with long procedure times and a small risk for severe complications, including pulmonary vein stenosis, systemic embolism, cardiac tamponade and esophagus injury.[2] Intracardiac echocardiography can facilitate these complex procedures by visualization of the pulmonary veins and monitoring of the location of the ablation catheter, and may help in avoiding complications by visualization of the esophagus and other important surrounding structures.[19,23,27]

Several studies have shown that pulmonary vein anatomy is highly variable.[28-30] Application of radiofrequency current inside a pulmonary vein ostium may cause pulmonary vein stenosis and pulmonary hypertension.[31] Accurate visualization of the pulmonary vein region is therefore of utmost importance to safely and effectively perform catheter ablation. A head-to-head comparison between ICE and multi-slice computed tomography (MSCT) demonstrated that ICE enables accurate assessment of pulmonary vein anatomy and mean ostial diameters (ICE 1.51 ± 0.22 mm vs. MSCT 1.45 ± 0.29 mm, p=NS). However, less additional pulmonary veins were detected using ICE, as compared with MSCT (ICE 2 (8%) vs. MSCT 5 (21%)).[29] This was confirmed by Jongbloed et al who detected less additional pulmonary veins with ICE, as compared with MSCT (ICE 7 (17%) vs. MSCT 13 (32%)).[30] In addition, an underestimation of the ostial diameter on ICE compared to the ostial diameter in superior-inferior direction on MSCT was noted (14.9 ± 4.0 mm vs. 18.4 ± 3.4 mm, $p<0.01$).[30] This finding suggests the need for 3D imaging to accurately visualize the shape and dimensions of the pulmonary vein ostia. Nevertheless, in a group of 259 patients, Marrouche et al demonstrated that anatomical guidance of radiofrequency catheter ablation with ICE is both safe and effective.[23] Importantly, the use of ICE in addition to a circular catheter resulted in an improved outcome compared to a circular catheter alone.[23]

The esophagus and left atrial posterior wall are very closely related. With the use of ICE, Ren and colleagues demonstrated that the mean distance between the left atrial posterior wall and the esophagus was 5.8 ± 1.2 mm (range 3.2-10.1 mm) and that the left atrial posterior wall and the esophagus were contiguous over a mean length of 36.0 ± 7.7 mm (range 18-59 mm).[27] As a consequence, the temperature inside the esophagus may increase significantly during left atrial ablation.[32] Heating of the esophagus can result in esophageal injury varying from transient erythematous changes to tissue necrosis and the development of an atrioesophageal fistula.[27,33,34] While monitoring the relation between the esophagus and the ablation catheter with ICE, the ablation power and duration can be adjusted in order to reduce esophageal damage.[27] Monitoring lesion development and the occurrence of micro bubbles as an indication of an increased esophageal temperature, allows the operator to perform additional energy titration, thereby further minimizing the risk of esophageal damage.[27,32]

As an alternative to anatomical guidance with ICE, image integration with MSCT or magnetic resonance imaging integration is commonly used to guide radiofrequency catheter ablation for AF.[35] A 3D image of the left atrium can be integrated with an electroanatomical map by performing a semi-automatic registration process. However, the validity of this technique is largely dependent on the quality of the registration.[36-38] An inaccurate registration process can result in a large shift of landmark points up to of 5-10 mm, thereby compromising the safety and efficiency of lesion placement.[36,37] Adjunctive real-time imaging with ICE can be used to confirm the accuracy of the registration process in order to ensure an accurate delivery of radiofrequency energy.[37]

Recently, an electroanatomical mapping system (CARTO Sound, Biosense Webster, Diamond Bar, CA) has been released that allows the integration of ICE and electroanatomical mapping.[39] By integrating ICE and electroanatomical mapping, an accurate 3D anatomical shell of the left atrium and pulmonary veins can be acquired without performing a registration process.[40] A modified phased array ultrasound catheter with an imbedded navigation sensor at its tip (Soundstar, Biosense Webster) is positioned inside the right atrium. The mapping system can detect the position and direction of the ICE catheter, thereby enabling the projection of the scanning plane inside its 3D environment. By gently rotating the ultrasound catheter, ECG-gated images of the left atrium and pulmonary veins are acquired. On each image, the endocardial borders (contours) are traced manually and are thereafter assigned to a designated map (Figure 8, panel A). Separate maps are created for the left atrial body and each of the pulmonary veins. All contours within a map are used to create a 3D shell of the structure (Figure 8, panel B). By combining all maps, the 3D geometry of the whole left atrium and pulmonary veins is visualized, which can be merged with a MSCT image in order to facilitate the ablation procedure (Figure 8, panel C).

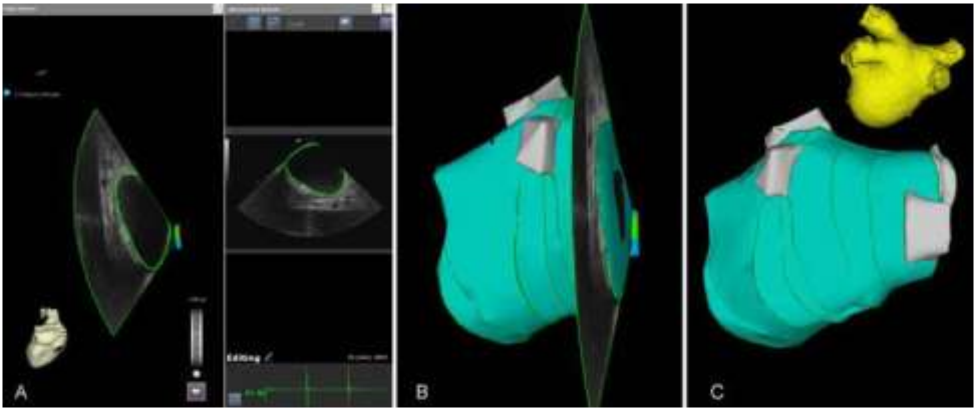

Figure 8. Panel A: After acquisition of an ECG-gated ultrasound image, the endocardial contours (green) of the left atrium (LA) and pulmonary veins are manually traced and are thereafter assigned to a corresponding map. Panel B: By systematically collecting images of the whole LA and marking the endocardial borders, a registered three-dimensional (3D) reconstruction of the LA anatomy is created. Panel C: The acquired 3D geometry can be used to guide radiofrequency catheter ablation for atrial fibrillation.

Complex atrial flutter ablation

A common atrial flutter is an organized tachycardia with a reentry circuit inside the right atrium and a protected isthmus between the tricuspid valve and the inferior vena cava (cavo-tricuspid isthmus).[20] Ablation of a common flutter is performed by creating a linear line of block across the cavo-tricuspid isthmus.[41] Even though it is considered unnecessary to use special imaging or mapping during a standard procedure, during complex cases ICE may be used to facilitate the procedure.[21] Intracardiac echocardiography can identify the cavo-tricuspid isthmus and other anatomical structures that can act as electrical barriers during atrial flutter, like the crista terminalis and Eustachian ridge.[20] Ablation of an atrial flutter can be complicated by complex anatomy, for example in patients previously operated for congenital heart disease. Particularly in these patients, ICE can facilitate the ablation procedure by visualizing important anatomical structures and guiding catheter placement.[42]

Ventricular tachycardia ablation

Ablation of ventricular tachycardia is usually limited to inducible and tolerated arrhythmias.[43,44] Techniques to identify the arrhythmogenic substrate without inducing the tachycardia are being developed in order to treat patients who do not meet these criteria. Intracardiac echocardiography allows identification of akinetic and dyskinetic (aneurysmatic) myocardial segments in patients with ischemic ventricular tachycardia, thereby visualizing the exact location and extent of the substrate.[45,46] Furthermore, ICE can be used to visualize small aneurysms of the right ventricle in patients with (suspected) arrhythmogenic right ventricular dysplasia, thereby detecting the arrhythmogenic substrate in these patients.[46]

Recently, the feasibility of the integration of ICE and electroanatomical mapping to guide ischemic ventricular tachycardia ablation was demonstrated.[47] By creating a 3D geometry of the left ventricle and marking the akinetic and dyskinetic segments as seen on ICE, the ischemic substrate could be mapped and the ablation procedure could be performed successfully.

Left ventricular lead placement in cardiac resynchronization therapy

Cardiac resynchronization therapy (CRT) has a beneficial effect on clinical symptoms, exercise capacity and left ventricular systolic function in selected patients with drug-refractory heart failure.[48-50] Moreover, CRT is associated with an increased survival and a reduction in the number of re-hospitalizations for heart failure, as compared to optimal medical treatment.[48] However, implantation of a CRT device — usually performed under fluoroscopic and angiographic guidance — can be challenging due to venous anatomy, resulting in a failure to place the left ventricular pacing lead in up to 8% of the patients.[48-50] A number of case studies report on the use of ICE to visualize the coronary sinus in order to guide left ventricular lead placement.[51,52] However, at present no prospective studies have reported a beneficial effect of ICE guidance on the success rate for left ventricular lead placement.

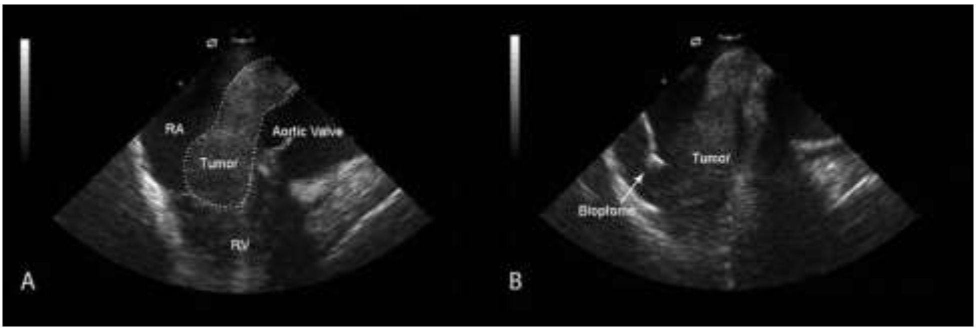

Figure 9. Panel A: An intracardiac mass originating from the superior vena cava is extending into the right atrium (RA) and tricuspid valve. (RV = right ventricle). Panel B: Intracardiac echocardiography is used to monitor and guide the biopsy by visualizing both tumor and bioptome.

Other Interventional Procedures

Biopsy of intracardiac mass. Intracardiac echocardiography can be used to visualize the origin and extent of an intracardiac mass (Figure 9, panel A). Therefore, ICE may be used to guide biopsies (Figure 9, panel B) and to monitor associated complications such as perforation or bleeding as suggested by few preliminary reports.[53,54]

Left atrial appendage closure. Implantation of a left atrial appendage occlusion device has been advocate as strategy to reduce the risk for systemic embolism in patients with atrial fibrillation and contraindications for anticoagulation and the procedure is typically guided by TEE. Recently, in a small group of patients the feasibility of ICE guidance as an alternative to TEE was reported.[55] Intracardiac echocardiography provided similar visualization of the left atrial appendage and similar assessment of the left atrial appendage orifice diameter compared to TEE (ICE 22.6 ± 3.4 mm vs. TEE 19.5 ± 1.5 mm, p=NS). Importantly, the degree of accuracy with respect to exclusion of a thrombus inside the left atrial appendage, the exact positioning of the delivery sheath and the verification of the location and stability of the occlusion device using ICE were was comparable to TEE.

Ventricular septal defect closure. Intracardiac echocardiography can be used to guide transcatheter closure of a perimembranous ventricular septal defect.[56] This imaging modality allows identification and visualization of the defect and monitoring the placement of a guiding wire through the defect and the deployment of the left sided occluder. Subsequently, ICE is used to confirm the correct position of the left sided occluder against the interventricular septum before the deployment of the right sided occluder. After deployment of the second occluder, ICE can be used to assess any residual shunt and valvular regurgitation that may have resulted from the procedure. In 12 patients, Cao et al documented that ICE may be used as a safe and effective alternative for TEE to guide closure of a ventricular septal defect.[56]

Alcohol ablation in hypertrophic obstructive cardiomyopathy. Alcohol septal ablation is an effective treatment to reduce the intraventricular gradient in patients with hypertrophic obstructive cardiomyopathy.[57] However, the efficacy and safety of the procedure is dependent on the identification of the correct septal artery. In order to identify this branch, echocontrast is commonly injected into a septal artery at the time of coronary angiography and transthoracic echocardiography is used to detect the extent and localization of the corresponding myocardial territory. Intracardiac echocardiography allows high quality visualization of the entire interventricular septum and may be a useful tool to guide alcohol septal ablation.[58] In 9 patients, Pedone et al demonstrated that the use of ICE to guide the procedure was feasible .[59] However, more studies are needed to define the role of ICE in alcohol septal ablation in patients with hypertrophic obstructive cardiomyopathy.

Mitral valve balloon valvuloplasty. Percutaneous balloon valvuloplasty is an accepted alternative to surgical commissurotomy in selected patients with symptomatic mitral stenosis. In this setting, ICE can be used to exclude thrombus formation at the level of the left atrium, assess the morphology and function of the mitral valve, guide the transseptal puncture, monitor the positioning of the balloon and assess any residual valvular gradient or postprocedural mitral regurgitation.[60] In addition it may allow an early detection of complications such as cardiac tamponade.

Percutaneous valve procedures. Intracardiac echocardiography may provide online anatomical information useful to guide percutaneous valve repair or replacement.[61,62] Accordingly, this imaging modality may be used to determine the appropriate size and site of deployment of the percutaneous valve as well as to monitor the anatomical and functional result of the procedure.[62] Studies are needed to define the role of ICE during percutaneous valve procedures.

Intrapericardial use of intracardiac echocardiography. Positioning the ICE catheter inside the pericardium has the potential to provide valuable information during complex ablation procedures. Recently, the safety and feasibility of this approach was demonstrated in both experimental and clinical setting.[63,64] In 10 patients, endocardial structures could be visualized in great detail from various angles.[64] The ability to visualize cardiac anatomy from different angles could benefit catheter navigation. However, this invasive approach is limited to patients undergoing epicardial access for catheter ablation.[63,64]

Limitations

Although phased array ICE enables adjustment of the ultrasound frequency, tissue penetration remains a limiting factor in visualizing cardiac anatomy. The use of a lower ultrasound frequency would result in a higher degree of tissue penetration allowing visualization of structures further away from the transducer, but at the cost of a lower image resolution. In addition, the costs of phased array ICE are relatively high as compared to TEE and these expensive catheters are for single use only. However, the costs of ICE are somewhat balanced by the need for general anesthesia and an echocardiographist during TEE. Moreover, intracardiac echocardiography provides 2D monoplane images.

This limitation can be partially overcome by the flexibility of the catheter enabling to visualize the same structure from another angle. Nevertheless, operators who are used to multiplane TEE may still have difficulty obtaining the same views. Finally, there are no widely accepted standard views for ICE, in contrast to TEE and transthoracic echocardiography. This may be difficult, in particular for the inexperienced operator. Standard manipulation of the ultrasound catheter starting from 'home view' position as well as recognition of landmark structures may be helpful.

Special issues

Intracardiac echocardiography is an invasive imaging modality and its use is usually confined to patients undergoing a percutaneous interventional procedure. In general, the contraindications for ICE are similar to other right-sided cardiac catheterization procedures using a transfemoral access. In pediatric patients, the use of ICE is limited by the respective diameters of the femoral vein and the ultrasound catheter.

Conclusions

Intracardiac echocardiography is a valuable imaging tool for a wide variety of interventional and electrophysiological procedures. This imaging modality allows real-time visualization of anatomical structures, catheters and devices thereby enabling the monitoring and guidance of complex procedures like catheter ablation for atrial fibrillation and placement of a transcatheter closure device for atrial or ventricular septal defects. Since it provides images of quality comparable to TEE, ICE may be used — in the hands of an experienced operator — as an alternative to TEE during closure of an atrial septal defect or ventricular septal defect and during percutaneous occlusion of the left atrial appendage.

In addition, ICE is a potentially safe alternative for TEE to detect an intracardiac thrombus.

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