Intracardiac echocardiography during catheter ablation of atrial fibrillation

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Introduction
Since the initial observation that triggers responsible for the initiation of atrial fibrillation (AF) arise from within the pulmonary veins (PVs), catheter-based ablation has emerged as an effective therapy for patients with symptomatic AF. This includes among others, electrical isolation of the PV’s. This anatomically based approach has led to a need to better visualize atrial anatomy, beyond traditional fluoroscopy. The gross anatomy of the left atrium (LA) and the PV’s is more complex and variable than it appears. The concept that the PV’s are mere cylindrical structures with well-defined openings that enter a spherical LA has been shown to be rather naive and simplistic. Therefore, accurate ablation at the ‘PV–LA junction’ for the purpose of electrical isolation is better served with ‘real-time’ imaging to define this variable anatomy for each individual case. In our experience, intracardiac echo (ICE) has been a great help to guide catheter-based PV antrum isolation. Specifically, it has helped in the identification of the anatomic structures relevant to the ablation, is a complementary tool to fluoroscopy to guide safe transseptal access, and has guided accurate placement of the circular mapping catheter and allowed safe and effective titration of the delivered energy and allowed for early recognition of complications. This has led to an improvement in success rate and a decrease in complications when compared with earlier approaches.

ICE uses high-frequency ultrasound to image the heart. It represents an evolution from intravascular ultrasound, which used mechanical rotation of a single piezoelectric crystal to produce a two-dimensional image extending radially in a plane perpendicular to the catheter. While useful for examination of the coronary arteries, its limited field of view makes it difficult to define the more complex anatomy of heart. In contrast, the standard ICE catheter utilizes a linear array of crystals arranged longitudinally along the catheter to produce a fan-shaped image radiating coplanar to the long-axis of the catheter.

In typical clinical use, the ICE catheter is introduced via the femoral vein and advanced into the right atrial cavity; alternatively, it can be introduced via the internal jugular vein and advanced via the superior vena cava (SVC) to the right atrium (RA).

Identification of anatomic structures
For our AF ablation procedures, we routinely introduce the ICE catheter through the femoral vein and advance into the RA. An initial quick scanning view in each patient allows a delineation of the overall left atrial anatomy, interatrial septum (IAS), and PVs (Figure 1). In the ‘home view’, the long-axis of the RA is visualized together with the right ventricle (RV) and the tricuspid valve. In this view the posterior cavitricuspid isthmus can be well-seen which can help in ablation of typical atrial flutter along the posterior corridor. Gradual slow clockwise motion of the ICE probe visualizes the aortic valve, portion of the left ventricle in long-axis and the right ventricular outflow tract/pulmonic valve. Further rotation shows the mitral valve (MV) in its long-axis, the LA and the left atrial appendage (LAA). In most cases, ICE can be used to confirm the presence of a clot in the LAA; however, it has not been
validated for this purpose in a prospective trial against transoesophageal echocardiography, which remains the gold standard for this purpose. Continuing a small clockwise rotation, the left PVs are visualized along their long-axis together with the body of the LA and the IAS. The use of colour Doppler and pulsed wave Doppler can help to characterize and confirm flow across the PV’s and help differentiate them from the LAA. In most cases, both left-sided veins can be seen in the same view, yet other cases require further manoeuvring of the probe, whereby the left superior PV (LSPV) is seen first (immediately after visualizing the LAA), followed by the LIPV which appears as a vertical structure. With more clockwise rotation, a progressively smaller portion of the body of the LA is seen as the scanning plane moves more posteriorly and the oesophagus can be seen coursing over the posterior aspect of the LA. The oesophagus has a variable relationship to the left (LPV) and right PV’s (RPV). Visualization of the oesophagus can be enhanced by the ingestion of small amounts of carbonated beverage or by observing peristaltic waves during swallowing. Some groups have reported shifting of the oesophageal location during the procedure after administration of barium paste, a finding which has not been confirmed in our experience (Figure 1E). Next, the RPV’s are visualized in their cross-sectional plane at the level of the antrum. This view is also known as the ‘owl-eye’ view and colour Doppler can confirm typical PV flow. It is more important to visualize the RPV’s in their longitudinal axis to better delineate the antrum and positioning of the mapping catheter. For that purpose, the transducer probe is retroflexed posteriorly and clocked against the IAS. Unlike the LPV’s, it is unusual to visualize both RPV’s in their longitudinal axis in the same frame. Gentle clockwise rotation, while the probe is still retroflexed, will shift from the more posteriorly and inferiorly located right inferior PV (RIPV), which is shorter and more tubular than the more funnel-shaped right superior PV (RSPV). In this view, the right PA is seen in proximity to the RSPV and can help in differentiating this vein from the RIPV (Figure 4C). With further clockwise rotation, right atrial anatomic structures can be identified such as the crista terminalis, which is important during ablation of certain atrial tachycardias and persistent atrial fibrillation. With further rotation, we go back to the ‘home view’, completing a 360° rotation. Our ablation strategy includes also isolation of the SVC. ICE is used to identify the SVC–RA junction, located 1–2 cm below the opening of the azygos vein and posterior to the lower border of the right pulmonary artery. This initial scanning allows to build a three-dimensional (3D) reconstruction of the atrial anatomy in our mind and facilitate catheter navigation. More recently, newer CartoSound™ technology allows near real-time reconstruction of such geometry. An electromagnetic sensor placed on the tip of the ICE probe allows for precise localization of the scanning transducer in space. Multiple scanning planes are obtained by rotating the probe and the atrial endocardial surface is traced manually or by edge enhancement technology. This forms a series of atrial rings which are then connected together and provides a 3D reconstruction of the LA allowing for easier navigation with potentially less fluoroscopy time (Figure 2).

ICE can easily detect some anatomic variations such as those seen in the IAS and PV anatomy and may help plan and facilitate the procedure. Approximately 10–15% of patients have an easily appreciable common ostium on the left PVs (Figure 4A) and a short common confluence is not uncommon and can be seen in roughly 85%. A common ostium of the RPV’s is less common, occurring in <25% of the patients and is invariably of shorter length. The right middle PV is usually a tributary of the RSPV, but can drain through a separate ostium into the LA. Recognition of

Figure 1 Initial scanning sweep. The various planes of interest are shown (A). The home view (B) shows the tricuspid valve and right ventricle with the right ventricular outflow tract superiorly. (C) The left atrial appendage and short axis of the mitral valve are seen. (D) Long-axis view of the left pulmonary veins. (E) The oesophagus is seen running along the posterior wall of the left atrium. (F) The right pulmonary veins are seen in their short axis. Manoeuvring of the intracardiac echocardiography catheter is needed to visualize the right pulmonary veins along their long-axis.
these variations is important to guide placement of the circular mapping catheter and ensure isolation of all PV's. Additional variations such as false tendons in the LA, pouches, etc. have also been reported.

**Guidance of transseptal puncture**

The use of ICE has facilitated transseptal access to the LA in several ways. It helps visualize the IAS and some of the related anatomic variations and devices that could complicate transseptal puncture (TSP) (Figure 3). This includes the presence of a thick septum, aneurysmal septum, double membrane septum, patent foramen ovale, atrial septal defect (ASD), or other closure and repair devices. It also helps in determining the exact position of the tip of the transseptal sheath by looking for tenting of the IAS and confirms access to the LA via injection of saline through the needle and visualization of bubbles in the LA. The goal of TSP is to cross the septum in the posterior region of the fossa ovalis. The more anterior portions of the septum are depicted by the views that display the aortic root. An anterior puncture is not only less safe but also directs the catheters more anteriorly towards the mitral annulus, left ventricle, and the LAA. While this approach might be helpful for procedures such as LAA occlusive devices, LA ablation, and MV procedures, it can make the manipulation of catheters difficult for an AF ablation procedure, as the sheaths would face against the posteriorly placed PVs. Gentle clockwise rotation of the ICE catheter

Figure 2 Three-dimensional intracardiac echocardiography image creation. The endocardial edge contours of the left atrium are marked as green loops. Multiple loops are obtained via intracardiac echocardiography catheter rotation, which is tracked in space by Carto sensor located in the catheter tip. The rings are joined via an interpolation algorithm to create a complete nearly real-time geometry of the left atrium. Seen in this figure is the integration of the three-dimensional computed tomography scan which shows a good match of the volume obtained by the three-dimensional echo.

Figure 3 Transseptal puncture. (A) Tenting of the mid portion of the interatrial septum by the Brockenbrough needle. (B) An example where the septum is aneurysmal. In this situation, it is important to visualize the distance from the needle tip to the roof of the left atrium. Note that the puncture site is performed within the plane of the left pulmonary veins. (C) An example of a double layered septum after the needle punctured the first part and tenting is seen on the second layer. (D) In this case ASD closure (Amplatzer device), a small rim of interatrial septum is visualized inferiorly. Intracardiac echocardiography was used to guide the location for transseptal puncture to access the left atrium.
from that anterior position will display the more posterior portion of the IAS, which faces the left PVs. This is our plane of choice for crossing the septum to the left side in AF procedures. In our experience, we administer heparin even before the transseptal access, to minimize the risk of formation of clots on the sheaths or catheters. We also prefer to do a double transseptal access to prevent interference between the mapping and ablation catheters and to achieve greater mobility and manoeuvrability in the LA. Overall, ICE allows a safer approach for TSP even in less-experienced hands.

Monitoring of catheter positioning

Intracardiac echo has been instrumental in allowing adequate placement of the circular mapping catheter (CMC). We seek antrum isolation, which requires abolition of all electric potentials that extend to the PV antrum proximal to the tube-like portion of the PV. Therefore, the CMC is placed in various positions along the antra of the right and left PV’s, and serves as a visual as well as an electric guide when applying radiofrequency energy to isolate the PV’s. In many situations, the definition of the ostium on ICE is more proximal than that defined by PV angiogram. Furthermore, while minor movements of the CMC and its different locations around at the antrum of a PV are not well-appreciated fluoroscopically, these are accurately tracked and visualized by ICE (Figure 4). This is important as it helps to deliver lesions proximally, resulting in higher efficacy and lower risk of complications. This is particularly useful during isolation of the LSPV. In this vein, the CMC is positioned under ICE guidance and the anterior segment appears slightly deeper into the antrum. This area corresponds to the end of the tube-like portion of the PV. Usually at this position energy is applied only at the roof, the carina, and the anterior segments, which correspond to the ridge of tissue between the appendage and the LSPV, and ablation in this area can be challenging. Isolation of the LSPV antrum is completed by flipping the CMC 180° from that position so that it lays over the posterior wall immediately posterior to the LSPV and ablating the atrial potentials in that location. This minimizes the risk of PV stenosis. ICE is also useful in assuring adequate tissue contact of the CMC in areas that are sometimes hard to reach such as the region of the RIPV, to confirm isolation of the antrum in that location. In our experience, isolation of the PV antrum is essential for complete and effective isolation of most of the triggers of atrial fibrillation.6

Monitoring of energy titration and delivery

Traditionally, adequate tissue contact of the ablation catheter has been monitored by looking for catheter stability on fluoroscopy and the stability of the electrical recording.
In that regard, ICE can be used not only to help positioning of the CMC and assuring tissue contact but also real-time monitoring of the catheter-tissue interface of the ablation catheter during energy delivery without the need for intermittent fluoroscopy. Poor contact reduces resistive heating through the desired site and increases convective heat loss into the circulating blood. This could result in diminished heat delivery, inefficient lesion formation, and increases the risk of coagulum formation. Kalman et al.\(^7\) have reported that ICE can be used to improve the number of lesions with good contact during energy delivery resulting in an increase in procedural success.

ICE is also useful as a monitoring tool while titrating energy delivery during radio frequency (RF) applications. Conventionally, temperature, power, and impedance are monitored during RF energy delivery. In our initial experience using ICE and an 8-mm ablation catheter, we noted that impedance rise during RF energy delivery was preceded by a sudden dense shower of microbubbles (Figure 5). This is thought to be due to 'steam' formation, a manifestation of tissue overheating. Following these observations, we have devised a RF energy delivery protocol during which power is titrated progressively upward in a gradual step up fashion.\(^8\) When scattered micro-bubbles (MBs) are seen by ICE, the power is maintained at ~5 W below this level and is kept constant. Ablation is terminated immediately if a sudden brisk shower of MB is observed. By guiding our ablation using MB formation to titrate power output, we have seen improved success rates and reduced risk of complications. By using transcranial Doppler, we have established a relation between MB formation and the risk of symptomatic and asymptomatic thrombo-embolic episodes. We have also noted that there may be a relation between the incidence of MB formation and temperature rise in the oesophagus during ablation over the posterior wall. Hence, monitoring for MB formation and titrating energy delivery

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**Figure 5** A brisk shower of microbubbles during delivery of radio-frequency energy with an 8 mm tip ablation catheter along the inferior border of the LIPV os. The microbubbles originate for the catheter tissue interface and spread into the LA cavity. In this situation, radio frequency energy is immediately terminated.

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**Figure 6** Complications detected by intracardiac echocardiography. (A) Early detection of pericardial effusion during the ablation procedure, before the development of hemodynamic compromise or echocardiographic suggestions of cardiac tamponade such as right atrium or right ventricle diastolic collapse. (B) Transseptal sheath in the LA with a mobile thrombus on its tip. This occurred in a patient with an activated coagulation time below 350 s. (C) Intramural hematoma along the inferoseptal border of the RIPV, following transseptal puncture and ablation. The size of these hematomas may become large enough to occlude the drainage of the PV or impinge of the filling of the LA resulting in hemodynamic compromise requiring surgical intervention.
accordingly may be helpful in reducing the potential risk of left atrial–oesophageal fistulas as well as embolic complications. Interestingly, the formation of microbubbles has a highly variable pattern and is not necessarily related to specific power settings or temperature readings. Obviously, MB monitoring is not useful with the use of an open irrigated ablation catheter. All in all, ICE is useful in assuring adequacy of tissue contact and in guiding titration of energy delivery, thus reducing potential complications and improving ablation efficiency.

Early detection of complications

Complications related to the use of ICE are rare. Nevertheless, the probe is relatively stiff and its advancement could result in vascular injury and/or perforation, and hence the need for caution cannot be overemphasized. ICE imaging is a valuable tool for early detection of complication during AF ablation procedure and consequently allows for earlier intervention. Moreover, the recognition of certain complications has paved the way to changes in anticoagulation and power titration protocols. Examples of such complications include (Figure 6):

(1) Cardiac perforation and impending tamponade: ICE allows detection of early pericardial effusion. This is usually detected along the inferior border of the RV and posterior LA. Early detection allows early intervention with pericardiocentesis and continuous monitoring of reaccumulation during the drainage process.

(2) Thrombus formation: These usually form on the transseptal sheath, and less commonly on the CMC or ablation catheter. They are most often noted when the activated coagulation time is <350 s. While such a finding may not affect specific acute intervention, it has led to a change in anticoagulation protocol during the procedure. We administer heparin before the double TSP, the sheaths are flushed continuously with heparinized saline, and ACT is maintained >400 s throughout the procedure.

(3) Char formation on the CMC: This is usually observed in association with frequent MB formation. This material is firmly adherent to the catheter and is less likely to embolize spontaneously. However, when noted, catheter should be pulled carefully into the sheath while maintaining continuous negative suction to minimize embolization.

(4) Monitoring of PV flow velocity with Doppler: Mild to moderate rate increase in PV flow velocity has been reported following PV ostial ablation procedure. This appears to be well tolerated, and tends to return toward baseline by 3 months follow up. Therefore, acute changes in PV flow immediately after ostial PV isolation do not appear to be a strong predictor of chronic PV stenosis.

(5) Other reported complications seen with ICE during AF ablation include the formation of adherent clot onto the atrial myocardial wall, crater formation in the atrial wall following brisk MB formation and intramural hematoma.

Conclusion

Intracardiac echo plays a valuable role during percutaneous catheter ablation for atrial fibrillation. It provides real-time imaging of the complex anatomy of the LA and PVs. It helps in quickly identifying anatomic variations and helps in planning for the ablation procedure. It provides online visualization for placement of the mapping and ablation catheters and monitoring their position, potentially reducing fluoroscopy time. It also allows for titration of energy delivery, therefore improving safety and efficacy of the ablation. The use of ICE has been critical in allowing early detection of procedural complications so that they can be managed timely and effectively. In addition, it has helped in developing safer anticoagulation and energy delivery protocols.

Conflict of interest: none declared.

References