

Featured Review





www. jafib.com

The Role of Intracardiac Echocardiography in Atrial Fibrillation Ablation

Elad Anter, MD, Mathew D. Hutchinson, MD, David J. Callans, MD

Cardiovascular Division, Department of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania.

Abstract

Radiofrequency catheter ablation of pulmonary veins has emerged as an effective therapy for patients with symptomatic atrial fibrillation. Advances in real-time intracardiac echocardiography with 2D and Doppler color flow imaging have led to it integration in atrial fibrillation ablation procedures. It allows imaging of the left atrium and pulmonary veins, including identification of anatomic variations. It has an important role in guiding transseptal catheterization, imaging the pulmonary vein ostia, assisting in accurate placement of mapping and ablation catheters, monitoring lesion morphology and flow changes in the ablated pulmonary veins, hence allowing titration of energy delivery. Importantly, it allows instant detection of procedural complications.

Introduction

Atrial fibrillation (AF) is the most common arrhythmia encountered in clinical practice, accounting for approximately one third of hospitalizations for cardiac rhythm disturbances .1 AF is characterized by seemingly disorganized atrial electrical activity without effective atrial contraction. It was once thought that all AF was caused by a single mechanism of multiple wavelets propagating in random fashion throughout the atria. According to the multiple-wavelet hypothesis, fractionation of wavefronts propagating through the atria results in self-perpetuating "daughter wavelets." Simultaneous recordings from multiple electrodes supported the multiple wavelet hypothesis in human subjects.² However, it has become apparent that there are likely other mechanisms underlying AF. In many patients, AF is caused by a focal discharge at rapid rates. A focal origin of AF was originally supported by experimental models of aconitine

and pacing-induced AF, in which the arrhythmia persists only in isolated regions of atrial myocardium. ³This theory received minimal attention until the important observation that a focal source for AF could be identified in humans and ablation of this source could extinguish AF. ⁴The observation that AF could be initiated by ectopic beats originating in the pulmonary veins (PVs) sparked new interest in the focal catheter-based techniques to isolate the PVs from the surrounding left atrium. ⁴Initial attempts to identify and ablate the PV foci directly were only moderately successful and were associated with frequent re currences of AF and a significant risk of PV stenosis. The efficacy and safety have improved using PV electrical isolation coupled with the use of three-dimensional electro-anatomic mapping systems, intracardiac echocardiography (ICE) and special mapping catheters .5 ICE imaging has become an important player in AF ablation. It guides transseptal catheterization, confirms

Corresponding Address :David J. Callans, MD, Hospital of the University of Pennsylvania, Cardiovascular Division, 9 Founders Pavilion, 3400 Spruce St, Philadelphia, PA 19104. E-mail: david.callans@uphs.upenn.edu,

Figure: 1 ICE-guided transseptal puncture.

These ICE images, with the transducer placed in the right atrium (RA), show (a) a transseptal needle (arrow) tenting the interatrial septum at the fossa ovalis; (b) Advancement of the transseptal needle tip to the left atrium (LA) was then performed. After confirmation of optimal position in the LA, a sheath (arrow) was advanced over a wire to the LA.



Figure: 1B



the accurate placement of mapping and ablation catheters, images the PV ostia, and assists in the early detection of procedural complications.

Intracardiac Echocardiography

Over the past 30 years, electrophysiological pro-

cedures have been performed almost exclusively under fluoroscopic guidance. Although, two-dimensional "cardiac silhouette" imaging correlates reasonably well with cardiac anatomy, it requires substantial operator experience. Moreover, the increased complexity of some ablative procedures requires more accurate imaging tools. Although,

Figure: 2 ICE images of the pulmonary veins. ICE images with the transducer placed in the right atrium, showing: (a) right upper (RUPV), middle (RMPV), and lower (RLPV) pulmonary veins; (b) separate left upper (LUPV) and lower pulmonary vein (LLPV) ostia; (c) color flow directed to the left atrium from the separate left pulmonary vein ostia; (d) Pulsed Doppler spectrum recording of the left upper pulmonary vein ostium with systolic and diastolic components.



Figure: 2B



Figure: 2C

Figure: 2D



transesophageal echocardiography has been used for such cases, it carries major disadvantages, including prolonged placement requiring heavy sedation, and the risk of vagal nerve stimulation. ICE allows visualization of the heart from within the cardiac chambers or from within the great vessels. Catheter-based ICE has advanced from devices bearing single-element transducers and M-

mode transducers to current technology, which allows for higher resolution two -dimensional imaging with wave Doppler and color flow evaluation of blood vessels and intracardiac structures. This technology was initially limited due to the large size of the lower frequency ICE cateters. Over the past 20 years, technology has progressed with the advent of low frequency (12.5-9 MHz, 9 Fr) transducers allowing enhanced tissue penetration and higher resolution. More recently, a 5.5-10MHz, 9 Fr electronic phase-arrayed ultrasound catheter with pulsed/continuous-wave Doppler and color flow imaging has been developed. This ultrasound catheter has a flexible tip that provides higher resolution and deeper penetration of the left side of the heart from the right atrium.

Transseptal Catheterization

Mapping and ablation in the left atrium are performed through a transseptal approach. Intracardiac echocardiography provides the best available imaging tool for guiding transseptal catheterization. Patients undergoing AF ablation typically need dual transseptal catheterization (8Fr sheaths). Knowledge of the septal anatomy and its relation ship to adjacent structures is essential for safe and effective access to the left atrium. The true interatrial septum is limited to the floor of the fossa ovalis, flap valve, and anteroinferior rim of the fossa .⁶ Many apparent septal structures are not truly septal, and inadvertent puncture of some septal structures can lead to perforation of the lateral wall of the left atrium or aortic root. These potentially lethal complications can occur even with the most experienced operator. The challenge for a successful atrial septal puncture is positioning the Brockenbough needle at the thinnest aspect of the atrial septum. ICE provides excellent views of the fossa ovalis and of the transseptal apparatus. Utilization of ICE in conjunction with fluoroscopy allows the electrophysiologist to clearly identify the interatrial septum and adjacent structures. When advanced in the right atrium, the catheter provides a cross-sectional view of the fossa ovalis. It allows checking the position of the Brockenbough needle and the Mullins sheath in the middle of the fossa ovalis and tenting of the membranous septum at the time of fossa ovalis puncture [figure 1]. ^{7, 8}

Imaging the Pulmonary Vein Ostia

Ablation of AF requires accurate anatomical information of the PVs. The PVs can have variable anatomy, with most heart examined found to have four PVs with discrete ostia, however the remainder (approximately 25%) having a common ostium, either on the left or on the right. The right PV generally has upper, middle, and lower pulm nary veins, with the right upper and middle PVs sharing a common ostium separated from the lower right PV by a carina. The PV ostia in patients with AF tend to be ellipsoid with longer superoinferior dimension, and funnel-shaped ostia.⁹ICE provides detailed imaging of the pulmonary veins including ostial diameter, which can assist in selection an appropriately-sized circular multipolar mapping catheter [figure 2].

Guiding Position of Catheters at the PV Ostia

After successful transseptal catheterization, the circular multipolar mapping catheter and the mapping/ablation catheter are advanced through the sheaths into the different PV ostia. ICE helps to optimally position the catheters in place. Based on the size measured with ICE Doppler color flow imaging, an appropriate circular multipolar catheter is placed on either an individual ostium or a common one. When the common ostial diameter is larger than that of the circular mapping catheter used, the latter can be positioned at the upper portion of the ostium and then moved to the lower portion under ICE imaging guidance. ICE imaging also confirms that delivery of radiofrequency energy via the ablation catheter occurs proximal to the multipolar mapping catheter and not inside the PV.

Changes in Ostial PV flow Velocity

Doppler color flow imaging has been effectively used for monitoring pulmonary vein ostial narrowing during AF ablation. ¹⁰ Peak flow velocity at the pulmonary vein ostium is measured at systole and diastole before and after ablation [figure 2D]. The ultrasound beam should be within 1 cm of the PV ostium, and the pulsed Doppler sampling gate should be parallel to the PV ostium. The peak pressure gradient can be estimated us-

ing the simplified Bernoulli equation ($\Delta P = 4V2$).¹¹ An increase in flow velocity greater than 100 cm/ sec warrants redirection of the ablation lesions to a more a proximal zone. In our early experience, radiofrequency energy was deployed at a total of 219 PV ostia and changes in PV ostial peak flow velocities and pressure gradients were measured.¹⁰ The peak velocity of PV ostial flow measured 56 ± 12cm/sec (range 21-98) before and 101 ± 22cm/sec

(range 47-211) after ablation (p<0.001). Turbulent flow features with spectral broadening of Doppler signal recorded at the ablated PV has been observed when the peak velocity was greater than 130 cm/ sec [figure 3]. Patients with an acute rise in PV flow velocities following ablation were followed for a period of six to eighteen months. Periodic clinical evaluations for symptoms of PV steno sis (dyspnea, exercise intolerance) were cor-

Figure: 4A Pericardial effusion. These ICE images with the transducer placed near the tricuspid valvular orifice in the right ventricle , showing the interventricular septum (IVS), left ventricular (LV) wall and pericardium (arrow); (b) ICE image of a moderate pericardial effusion (arrow, echo-free space) surrounding the LV free wall



Figure: 4B

roborated with magnetic resonance imaging (MRI) or contrast-enhanced computed tomography. The study showed that an acute increase in the PV ostial peak flow velocity of up to 158 cm/sec (estimated pressure gradient \geq 10 mmHg) appears to be well tolerated .¹⁰ It is our practice to conduct ablation lesions when the peak PV flow velocity change is less than 100 cm/sec. However, a flow velocity change of more than 100cm/sec will warrant a more proximal approach to lesion deployment. Interestingly, in the majority of patients, the acute rise in PV ostial velocities probably reflects tissue edema, as we noted almost complete reversibility in PV velocities in the subset of who returned for a second ablation procedure. ¹⁰

Monitoring ostial flow velocity during repeated ablation at previously ablated pulmonary veins is also critical. We have previously reported the outcome of our first 13 patients undergoing repeat AF ablation procedure.¹⁰ There were two patients with PV flow velocities >100cm/sec before subsequent ablation. Following subsequent ablation, in three PV, velocities greater then 158 cm/sec were recorded. In one patient, the left upper PV flow velocity increased from 116 to 194 cm/sec. In another patient, the left upper PV flow velocity increased from 118 to 172 cm/sec and the left lower PV from 83 to 176 cm/sec. In these two patients, MRI was performed at 2 and 4 months after ablation, demonstrating mild to moderate PV stenosis (50–60%). The patient with two PV velocities greater than 158 cm/sec developed exertional dyspnea at 4 months. The second patient had no symptoms or progression of PV stenosis with late MRI imaging. No patient with PV flow velocity < 158 cm/sec has been found to develop symptoms consistent with PV stenosis after a repeat ablation procedure.¹⁰

The typical Doppler color flow imaging in PV stenosis is characterized by increased ostial PV peak flow followed by a blunted systolic velocity and prolonged and elevated diastolic velocity, resulting in a fused systolic and diastolic components and long pressure half-time .¹⁰⁻¹³

Isoproterenol infusion is one of the most useful provocative maneuvers for potentiating firing of both PV and non-PV triggers of AF. The effect of isoproterenol on PV flow before and after AF ab ablation has been studied using ICE with Doppler

color flow imaging.14 This study showed that isoproterenol increases ostial peak flow velocity of both pre-ablated and ablated PVs. Moreover, this effect of isoproterenol appears to be independent of the heart rate effect since atrial pacing at similar rates had no effect on PV flow velocities. However, although isoproterenol leads to higher peak velocity, the pulsed Doppler imaging shows separate systolic and diastolic velocity components with normal pressure half-time. These isoproterenol effects are important to recognize, especially when the peak velocity of PV flow is used as an index of ostial PV stenosis. The clinical implication is that an "isoproterenol effect" on PV ostial flow could potentially be misinterpreted as clinically significant PV stenosis. 14, 15

Morphological changes of ablation lesions

ICE provides tissue imaging of morphologic changes induced by radiofrequency energy. These changes include tissue swelling, dimpling, crater formation, accelerated bubbles before poppingcrater like lesion development, and increased echogenicity during or immediately after lesion deployment. The left atrial wall thickness can also be assessed with 2D or M-mode imaging. Based on real-time ICE monitoring of lesion development, titration of energy power and/or duration can control lesion formation and prevent tissue overheating or structural perforation. The ligament of Marshall is occasionally an important trigger for AF, and may therefore be a target for ablation. The thickness of the ligament of Marshall is usually greater than the surrounding tissue, and therefore has greater echogenicity, enhancing its identification with ICE.

Monitoring for Complications

ICE imaging is a valuable tool for early detection of complication during AF ablation procedures and consequently allows earlier intervention. Moreover, the recognition of certain complications has paved the way to changes in anticoagulation and power titration protocols. Potential complications include those occurring during transseptal catheterization and left heart mapping and ablation. The major potential complications detected by ICE during left heart ablation include:

Featured Review

Damage to Cardiac Structures

Inadvertent manipulation of the catheter during transseptal catheterization or mapping/ablation may cause damage to adjacent non-targeted structures, such as aorta, left atrial appendage, mitral valve, and left atrial wall. As mentioned above, ablation radiofrequency energy may cause intramural superheating and a "crater" lesion during ablation.

Pericardial Effusion and Tamponade

Pericardial effusion is one of the most serious complications associated with catheter ablation for AF. It may occur immediately after transseptal catheterization, during catheter manipulation and ablation and after withdrawal of a coronary sinus catheter. ICE allows early detection of pericardial effusion [figure 4]. This is usually detected along the inferior border of the RV and posterior LA. Early detection allows early intervention with pericardiocentesis and

Figure: 5A I. Visualizing Thrombi ICE images of the left atrium, showing: (a) a thrombus (arrow) formed at the superior aspect of the right upper pulmonary vein following an ablation lesion; (b) a large thrombus is visualized at the left atrium, extending from the pulmonary valve to the septal leaflet of the tricuspid valve.



Figure: 5B



continuous monitoring of re-accumulation during the drainage process.

Left atrial Thrombus Formation

Atrial thrombus formation has been recognized as one of the major complications during atrial ablation procedures .16 These thrombi are usually single, linear, and mobile, and are typically attached to the transseptal sheath, and less commonly to the circular mapping or ablation catheters [figure 5]. The incidence of left atrial thrombus formation during left atrial ablation has been reported as high as 10.3% when anticoagulation is maintained at a target activated clotting time of 250-300 sec .16 In 90% of patients with ICE detected left atrial thrombus, successful withdrawal of the thrombusattached catheter/sheath from the left atrium into the right atrium has been reported to prevent serious systemic embolic consequences. Increased anticoagulation with an activated clotting time ≥350 sec reduces the risk of left atrial thrombus formation during ablation procedures for AF.

Pulmonary Vein Stenosis

One of the most serious complications of AF ab-

lation is the development of PV stenosis. ICE Doppler and color flow imaging are used to accurately evaluate and monitor the flow velocities and pressure gradients before and after ablation lesions [figure 3]. As mentioned above, significant ostial PV stenosis is morphologically characterized by swelling and enhanced echogenicity. Color Doppler may demonstrate turbulence flow, and spectral Doppler shows increased ostial PV peak flow followed by a blunted systolic velocity and prolonged and elevated diastolic velocity, resulting in a fused systolic and diastolic components and long pressure half-time. ¹⁰⁻¹³

Esophageal Injury

The esophagus is contiguous with the thin posterior wall of the left atrium. With the advance in catheter design and higher energy delivery, esophageal injury, with or without left atrioesophageal fistula, has been described and associated withhigh mortality rate.¹⁷⁻¹⁹ Radiofrequency lesions in the posterior and lateral aspect of the right lower PV or posterior and medial aspect of the left PV are within immediate proximity to the esophagus. ICE real-time imaging monitoring of the posterior atrium and esophagus during radiofrequency energy delivery may reduce the risk of

Figure: 3 Pulsed Doppler recorded peak flow velocity of the left superior pulmonary vein (LSPV) ostium shows the maximal velocity measured 50 cm/s with two systolic components (S) as well as early diastolic (D) before ablation (a). Following ablation, the ostial peak flow velocity increased to 134 cm/s (b).



injury.

Conclusions

ICE has emerged as an extremely useful tool during electrophysiology procedures. In particular, ICE plays a valuable role in left heart mapping and ablation procedures, and has become standard in AF ablation procedures. It provides realtime imaging of the complex anatomy of the left atrium and PVs, guides transseptal catheterization, assists in accurate placement of mapping and ablation catheters, and monitors lesion morphology and flow changes in the ablated PV. ICE allows early detection of procedural complications, facilitating timely and effective therapy

References

1. Fuster V, Ryden LE, Cannom DS, Crijns HJ, Curtis AB, Ellenbogen KA, Halperin JL, Le Heuzey JY, Kay GN, Lowe JE, et al. Acc/aha/esc 2006 guidelines for the management of patients with atrial fibrillation: Full text: A report of the american college of cardiology/american heart association task force on practice guidelines and the european society of cardiology committee for practice guidelines (writing committee to revise the 2001 guidelines for the management of patients with atrial fibrillation) developed in collaboration with the european heart rhythm association and the heart rhythm society. Europace 2006;8:651-745.

2. Moe GK, Abildskov JA. Atrial fibrillation as a self-sustaining arrhythmia independent of focal discharge. Am Heart J 1959;58:59-70.

3. Scherf D, Schaffer AI, Blumenfeld S. Mechanism of flutter and fibrillation. AMA Arch Intern Med 1953;91:333-352.

4. Jais P, Haissaguerre M, Shah DC, Chouairi S, Gencel L, Hocini M, Clementy J. A focal source of atrial fibrillation treated by discrete radiofrequency ablation. Circulation 1997;95:572-576.

5. Marchlinski FÊ, Callans D, Dixit S, Gerstenfeld EP, Rho R, Ren JF, Zado E. Efficacy and safety of targeted focal ablation versus pv isolation assisted by magnetic electroanatomicmapping. J Cardiovasc Electrophysiol 2003;14:358-365.

6. Anderson RH, Brown NA, Webb S. Development and structure of the atrial septum. Heart 2002;88:104-110.

7. Daoud EG. Transseptal catheterization. Heart Rhythm 2005;2:212-214.

8. Johnson SB, Seward JB, Packer DL. Phased-array intracardiac echocardiography for guiding transseptal catheter placement: Utility and learning curve. Pacing Clin Electrophysiol 2002;25:402-407.

9. Zipes DP, Jalife J. Cardiac electrophysiology : From cell to bedside. Philadelphia: Saunders; 2004.

10. Ren JF, Marchlinski FE, Callans DJ, Zado ES. Intracardiac doppler echocardiographic quantification of pulmonary vein flow velocity: An effective technique for monitoring pulmonary vein ostia narrowing during focal atrial fibrillation ablation. J Cardiovasc Electrophysiol 2002;13:1076-1081.

11. Feigenbaum H. Echocardiography. Philadelphia: Lea & Febiger; 1994.

12. Samdarshi TE, Morrow WR, Helmcke FR, Nanda

NC,Bargeron LM, Jr., Pacifico AD. Assessment of pulmonary vein stenosis by transesophageal echocardiography. Am Heart J 1991;122:1495-1498.

13. Seshadri N, Novaro GM, Prieto L, White RD, Natale A, Grimm RA, Stewart WJ. Images in cardiovascular medicine. Pulmonary vein stenosis after catheter ablation of atrial arrhythmias. Circulation 2002;105:2571-2572.

14. Ren JF, Marchlinski FE, Callans DJ. Effect of heart rate and isoproterenol on pulmonary vein flow velocity following radiofrequency ablation: A doppler color flow imaging study. J Interv Card Electrophysiol 2004;10:265-269.

15. Ren J-F. Practical intracardiac echocardiography in electrophysiology. Malden, Mass.: Blackwell Pub.; 2006.

16. Ren JF, Marchlinski FE, Callans DJ. Left atrial thrombus associated with ablation for atrial fibrillation: Identification with intracardiac echocardiography. J Am Coll Cardiol 2004;43:1861-1867.

17. Gillinov AM, Pettersson G, Rice TW. Esophageal injury during radiofrequency ablation for atrial fibrillation. J Thorac Cardiovasc Surg 2001;122:1239-1240.

18. Mohr FW, Fabricius AM, Falk V, Autschbach R, Doll N, Von Oppell U, Diegeler A, Kottkamp H, Hindricks G. Curative treatment of atrial fibrillation with intraoperative radiofrequency ablation: Short-term and midterm results. J Thorac Cardiovasc Surg 2002;123:919-927.

19. Pappone C, Oral H, Santinelli V, Vicedomini G, Lang CC, Manguso F, Torracca L, Benussi S, Alfieri O, Hong R, et al. Atrioesophageal fistula as a complication of percutaneous transcatheter ablation of atrial fibrillation. Circulation 2004;109:2724-2726.