Intracardiac Echocardiography
Ultrasound technology has progressed rapidly over the past several years, leading to significant miniaturization of transducer design. The original catheter-based transducers, known as intravascular ultrasound (IVUS) catheters, are high frequency (20 to 40 MHz) and are used to image the walls of coronary arteries and other small vessels. They contain a single ultrasound crystal that rapidly rotates in the end of the catheter, offering a circumferential, 2-dimensional image. Although this high-frequency transducer provides excellent near-field spatial resolution, its acoustic depth is limited to several millimeters, thus making it suitable for intracoronary imaging.

Transducers with lower frequencies (5 to 12 MHz) have been developed to apply catheter-based echocardiography to intracardiac imaging, which requires greater ultrasound penetration than intravascular imaging. Two types of ultrasound catheters are currently in use. The first is a mechanical echo catheter, which is similar to IVUS catheters, with a rotating ultrasonic transducer driven by a motor unit at the opposite end of a braided drive shaft, which results in a 360-degree view perpendicular to the catheter. The second type is a fixed or phased array echo catheter that uses electronically controlled multiple transducers affixed to one side of the catheter shaft, which results in a wedge-shaped image sector similar to that of a transesophageal echo probe.

Both types of catheters provide high resolution, real-time images of anatomic structures and of other intracardiac devices and catheters. Echo catheters are currently 6 to 10 French, and are typically introduced through a sheath in a femoral vein. Phased array catheters offer a large depth of field and the possibility of Doppler imaging, whereas mechanical catheters offer better near-field resolution.

Catheter-Based Treatment of Atrial Fibrillation
Two catheter-based techniques are being investigated to treat atrial fibrillation.1 Inspired by the results of the surgical Maze procedure,2 the first strategy attempts to modify the ability of the atrial substrate to sustain reentrant circuits. Linear ablation lesions are made in the left and/or right atria in anatomically defined locations with the intent of producing local conduction block. Ablation lines are created with either a single electrode used to make a series of contiguous focal lesions or by a multi-electrode catheter positioned against the atrial wall in the desired orientation. The efficacy and safety of the various techniques for performing a catheter-based Maze procedure have been disappointing to date. Although right-sided lesions alone appear to be inadequate, the correct “lesion set” has not been determined. With current technology, continuous transmural lesions cannot be created uniformly. Lastly, significant complications have been reported with this approach, including pericardial effusion, sinus node dysfunction, cerebral embolization, phrenic nerve injury, and pulmonary vein stenosis.

The second strategy targets ectopic atrial foci that can trigger bouts of atrial fibrillation. Such foci can be located in the left or right atrium but are found in the pulmonary veins in the majority of cases.3 Because multiple ectopic foci are frequently present in the pulmonary veins, the most commonly used ablation strategy is to electrically isolate 3 or all 4 pulmonary veins from the left atrium. This approach prevents spontaneous signals that originate within pulmonary vein myocardial fibers from reaching the left atrium. Electrical disconnection can be achieved with either circumferential ablation around the pulmonary vein ostia or by using a circular, multi-electrode sensing catheter to target specifically only sites of electrical continuity between atrial and venous tissue.4 The success of this strategy has been encouraging but quite variable, with significant recurrence of atrial fibrillation necessitating repeat procedures. The most common compli-
cations include pulmonary vein stenosis, pericardial effusion, and cerebral embolization.

**Intracardiac Echocardiography Can Improve Atrial Fibrillation Ablation**

It is likely that intracardiac echocardiography (ICE) can facilitate atrial fibrillation ablation by reducing complications and increasing efficacy. Ultrasound is vastly superior to fluoroscopy with respect to cardiac imaging, giving it multiple advantages, including the following: (1) the definition of cardiac anatomy, including variation from normal; (2) direction of catheter position to discrete anatomic locations; (3) identification of proper electrode-tissue contact; (4) detection of electrogram migration during ablation; (5) detection of pericardial effusions before they are hemodynamically significant; (6) recognition of pulmonary vein stenosis; (7) visualization of microbubble formation during ablation; and (8) visualization of coagulum formation during ablation.

In addition to its imaging advantages, ICE can reduce fluoroscopic exposure for both patient and operator. Investigations of the utility of ICE during atrial ablation have uniformly reported distinct advantages of ultrasound guidance at each step of the procedure.

**Transseptal Puncture**

For ablation procedures in the left atrium, access through the interatrial septum is the route of choice. Safe puncture of the septum with a Brockenbrough needle requires precise localization of the fossa ovalis, which traditionally is done with fluoroscopy. Because fluoroscopy does not visualize atrial tissue, this procedure requires the combined use of visual landmarks and subtle catheter sensations. Puncturing a small structure that cannot be seen can be a challenge for even the most experienced operator, especially in the setting of atrial enlargement, ascending aortic dilation, or other anatomic variations. Potential complications include aortic root and atrial perforation, either of which could prove fatal.

The use of transseptal puncture in the cardiac catheterization laboratory has diminished over time. With the recent expansion of procedures in which access to the left atrium is required, transseptal puncture is experiencing a resurgence. Many electrophysiologists, however, have limited training in transseptal puncture, which led Baim et al to state, “The relative infrequency with which the procedure is needed has made it difficult for most laboratories to maintain operator experience and to train cardiovascular fellows in transseptal puncture and has given the procedure an aura of danger and intrigue.”

An ICE catheter positioned in the right atrium provides clear visualization of the interatrial septum and fossa ovalis. ICE guidance can remove the “aura” and allow safe transseptal puncture, even in the anticoagulated patient. The transseptal sheath can be positioned adjacent to the thin, membranous portion of the septum, which is seen to tent as the needle is advanced. Rebound of the fossa demonstrates needle penetration into the left atrium, and the sheath can then be safely advanced (Movie I). Even in relatively inexperienced hands, ICE can be used to guide transseptal puncture repeatedly without complications.

**Catheter Position**

Both atrial fibrillation ablation strategies (linear atrial ablation and focal ablation of triggers) are based on cardiac anatomy. Linear lesions are designed to produce conduction block between specific anatomic structures, thus making correct catheter positioning critical in achieving the desired substrate modification. Ectopic atrial foci that trigger atrial fibrillation are most frequently found in the pulmonary veins, which are the cardiac structures with the greatest anatomic variability. Because ectopic foci can occur near the ostia of the pulmonary veins, ablation lesions are ideally placed on the cuff of atrial tissue that leads into each vein. ICE imaging allows direct visualization of the pulmonary veins and precise localization of the atrio-venous junction (Movie II). Other sites of ectopic foci appear to have characteristic anatomic locations as well, such as the crista terminalis, ostium of the coronary sinus, superior vena cava, and the ligament of Marshall.

Ablation catheter positioning is traditionally guided by fluoroscopy and electrical recordings from the catheter tip. Fluoroscopic imaging provides very little information about cardiac anatomy and can be misleading with respect to catheter position. One study demonstrated that the perceived location of an atrial catheter based on fluoroscopy differed significantly from ICE confirmation 25% of the time. Incorrect lesion placement is inefficient and could be harmful if critical structures such as sinus nodal tissue are inadvertently ablated. ICE can provide continuous anatomic information, which increases accuracy of ablation catheter placement and reduces fluoroscopy time. The fluoroscopic images and electrograms from an ICE-guided ablation can be seen in Figure 1.

In addition to guiding ablation catheter positioning, ICE can be helpful in confirming the location and orientation of diagnostic catheters. Circular, multi-electrode catheters are frequently used to search the circumference of pulmonary veins for points of electrical continuity. ICE has been shown to visualize pulmonary vein ostia better than angiography. ICE can be used to document anatomic variation of the pulmonary veins, to confirm a perpendicular orientation of the circular electrode array to the venous wall, and to accurately demonstrate the distance between the diagnostic catheter and the venous ostium.

**Electrode Contact**

Radiofrequency energy creates an endocardial lesion by direct resistive heating and conductive heating of deeper tissue. Poor contact between ablation electrode and endocardium reduces heat transfer to the tissue and allows convective heat loss into the circulating blood. Reduced heat delivery to myocardial tissue results in increased power output, poor lesion formation, and increased risk of coagulum formation. Good perpendicular contact between ablation electrode and endocardium is therefore important in achieving proper lesion formation.

Electrode contact is typically evaluated by documenting a stable electrical recording from the catheter tip and looking for catheter movement fluoroscopically before the application of radiofrequency energy. As with catheter positioning, flu-
oroscopy provides very limited information regarding contact between electrode and myocardium. Fluoroscopy is unable to detect perpendicular electrode orientation, cannot detect catheter movement during the cardiac cycle, and is not used to image catheter position throughout lesion formation. The local electrogram that is recorded from the ablation catheter occurs at end diastole, when the catheter is at its most stable position. Significant catheter migration can occur (without being detected) during the period of mechanical contraction but electrical silence. One study used ICE to visualize the ablation electrode after it was deemed to be in good contact by traditional positioning criteria. Fewer than half of these radiofrequency lesions were placed with good perpendicular contact, and more than 5 mm of lateral electrode sliding was observed in almost 20% of cases.

ICE can be used to ensure proper electrode contact and stability before the application of radiofrequency energy. Good contact results in better energy delivery and larger lesion formation. ICE also demonstrates proper contact of a multi-electrode array with the atrial wall, resulting in more effective creation of a continuous ablation line. Incomplete linear lesions not only reduce the likelihood of successful treatment of atrial fibrillation, but may also be proarrhythmic.

Ablation Monitoring
During a radiofrequency energy application, only temperature and electrical parameters such as power and impedance are typically monitored. Energy delivery is terminated after either a predetermined amount of time or the observation of an impedance rise that suggests excessive tissue heating with gas bubble production and endocardial surface disruption.

The introduction of ICE monitoring during lesion formation has provided new insights into the events that occur at the electrode-tissue interface during radiofrequency application. Microcavitations or “bubbles” are frequently seen in both the myocardium and the atrium before an impedance rise, and coagulum at the catheter tip may also be seen. These findings have been reported to occur with much greater frequency when catheter contact is

![Image of Ablation Monitoring](image-url)
suboptimal. Given the earlier visual findings with ICE compared to terminate suboptimal energy delivery. With better electrode contact and ablation monitoring under ICE visualization, it is possible that microcavitation, coagulum, and char formation will be reduced, which might result in a reduction in embolic events.

**Complications**

Another advantage of using ICE during atrial fibrillation ablation is the ability to promptly detect undesired effects of ablation. Even small pericardial effusions can be seen and monitored during the procedure, allowing early treatment if warranted. Ablation inside or near venous structures can result in venous narrowing, which is immediately detected by ICE. The use of ICE catheters with Doppler capabilities can determine the physiological effects of venous narrowing (Figure 2). The ablation procedure is thus modified to minimize such complications.

**Conclusion**

As therapeutic electrophysiological strategies improve through technological advances and new insights into atrial pathophysiology, so too must imaging modalities. The ability to visualize cardiac anatomy and intracardiac events precisely before, during, and after electrophysiological procedures will increase efficacy and decrease complications. In addition to affecting procedure outcome, ICE has the potential to decrease fluoroscopic exposure, benefiting both patient and operator.

**References**


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