CHAPTER

15

How I Do It: ICE-Guided Technique for Percutaneous PFO Closure

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OUTLINE

INTRODUCTION

In order to close a patent foramen ovale (PFO) safely and effectively, it is important to understand the septal anatomy as it relates to surrounding structures (Chapter 1). Ultrasound imaging plays a central role in defining the PFO or atrial septal defect anatomy. It may also help in crossing the septum, deploying the septal occluder, and assessing the device position [1]. Some operators prefer to use the Amplatzer PFO Occluder (Abbott, St. Paul, MN, USA) or devices derived from it, and deploy these devices with or without a prescreening transesophageal echocardiogram using only fluoroscopic guidance at the time of implantation (Chapter 16). Other operators prefer the Cardioform Occluder (W.L. Gore and Associates, Flagstaff, Arizona) due to its conformation to the contours of the atrial septal anatomy and pliability, which makes it well tolerated by most patients [2]. There are reports of nickel allergy with the Amplatzer PFO Occluder, but we are not aware of any reports of nickel allergy with the Cardioform device or with other occluders; the Cardioform device is covered instead with Gore-Tex (e-PTFE). Many operators believe it is preferable to have ultrasound imaging guidance during the deployment of the Cardioform device, or PFO devices in general. This chapter will describe the technique of using intracardiac echocardiography (ICE) for PFO closure and provide examples of difficult cases where special techniques are required [1].

The initial imaging modality of choice to study the septum is transthoracic echocardiography (TTE). However, TTE is not very sensitive for identifying PFOs and does not show the fossa ovalis or the interface between the septum primum and septum secundum due to its relationship with the axis of the chest where the TTE probe is applied

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(Chapter 2) [3]. In comparison, transesophageal echocardiography (TEE) is more accurate as the probe is placed in the esophagus, directly behind the left atrium in close proximity to the septum; TEE operates at a higher frequency of 5−10 MHz, which provides a more detailed image at the cost of depth penetration [4]. With improvement in TEE probes and processing technology, it is now routine to define the septal defect in 3 dimensions and identify adjacent anatomical variations, such as multifenestrations or a septal aneurysm, which may not have been seen on TTE. Furthermore, TEE prior to PFO closure is used to assess for a left atrial appendage (LAA) thrombus, valvular pathologies, intracardiac masses, anomalous pulmonary veins, and other defects such as adjacent or distant atrial septal defects. This, in combination with other diagnostic studies, is important before committing to percutaneous PFO closure as a therapeutic procedure [5]. Fluoroscopy by itself is helpful but not deemed sufficient for a safe and reliable PFO closure by most operators [6]. However, in order to use TEE during the implantation procedure, the patient is usually intubated or at least deeply sedated, which in contrast to intubation carries a risk of bronchial aspiration, and the TEE imaging procedure is invasive in itself. An alternative is to use ICE during the procedure. The advantages of ICE are that the entire closure can be done with the patient fully conscious and the operator is able to adjust the probe without the need for an imaging specialist being present and subjected to substantial radiation [7]. The ICE catheter operates at a higher frequency of 8−12 MHz, which limits depth penetration but provides detailed imaging of cardiac structures with improved spatial resolution.

ICE catheters were first used in the 1980s. They are simple to manipulate but require additional training for image interpretation and optimal visualization of the cardiac anatomy. Addition of phased array transducers on the tip provides Doppler and color-flow imaging. The addition of matrix transducers, without significantly increasing the catheter size, allows for acquisition of volumetric 3D imaging, although with a limited window width and penetration compared to TEE. An adult-size TEE probe measures just over 5 mm for the shaft and about 10 mm for the imaging tip [8]. The ICE catheter measures 2.7 or 3 mm, which fit into an 8 or 9 French sheath respectively. The 2 most common probes are the Siemens Acuson (Siemens Healthcare, Erlangen Germany) and Abbott (St. Jude Medical, St. Paul, MN, USA) probes. The tip houses a 64-element transducer, scanning vertically along the probe to provide a 90 degrees sector image (Fig. 15.1) [9].

As the atrial septum is oriented superiorly and medially to where the inferior vena cava (IVC) enters the right atrium, it is fairly straightforward to place the ICE probe in the right atrium such that it faces the septum and visualizes the anatomy around the fossa ovalis during procedures. Simple maneuvers can then be used to study the adjacent anatomy and device deployment. We recommend using a 9 French 24 cm long sheath, which extends beyond the posterior bend of the iliac vein; this avoids any risk of inducing pain or perforation when passing the ICE probe from the femoral vein. In comparison, TEE has both a wider field of view and a rotating omniplane to show the anatomy and septal rims from any aspect (Fig. 15.2). ICE is not able to fully define the inferior borders in relation to the defect, especially in cases where there is a deficient IVC rim. Use of an ICE catheter adds additional direct costs to the procedure and requires operator familiarity with manipulating the probe to obtain the necessary images. The cost of an ICE catheter can be mitigated by use of a resterilized probe and performing the procedure under conscious sedation, obviating the need for an anesthesiologist or requiring a postoperative unit for patient recovery [10]. A comparison study assessed the costs between TEE and ICE imaging techniques and showed them to be similar [11]. Additionally, the operator using ICE has to be comfortable controlling the probe and sedating the patient while performing PFO closure. Obtaining that skill requires some training and an appreciation of the limits of ICE imaging.

FIGURE 15.1 The Acuson intracardiac echocardiography imaging catheter requires an 8F sheath.

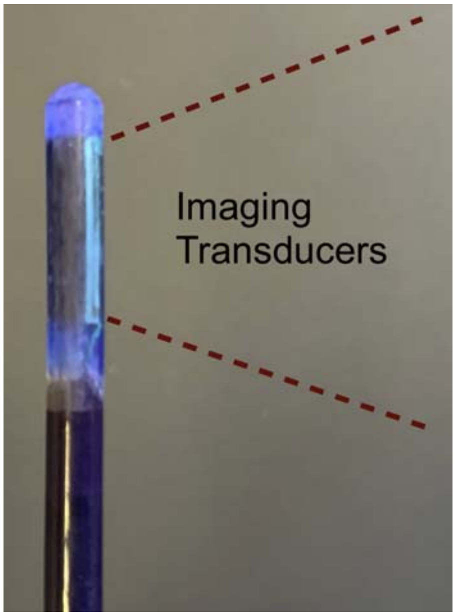

FIGURE 15.2 The tip of an intracardiac echocardiography imaging catheter. The transducer array is radioopaque and lines up along the end of the catheter to generate an image with the field of view vertical in the same axis as the catheter.

ANATOMIC CONSIDERATIONS

The Chiari network shunts blood from the IVC into the right atrium and toward the PFO. In utero, this serves to direct the flow of blood across the interatrial septum to the left atrium during gestation, thus bypassing the fluid-filled lungs (Chapter 1). A large Chiari network can become an obstacle to crossing into the right atrium from the IVC, diverting the ICE catheter to variable unwanted directions. Since an ICE catheter cannot be guided over a wire, it is prudent to stop when encountering any resistance and gently turn the catheter to navigate it into the right atrium with minimal force [12]. A review of the basic anatomy can then be done using the views described below. A septal aneurysm can occur in the septum primum and is defined as either a septal deflection into either atrium of >10 mm beyond the plane of the atrial septum or a total septal deflection for both chambers of >15 mm (Fig. 15.3).

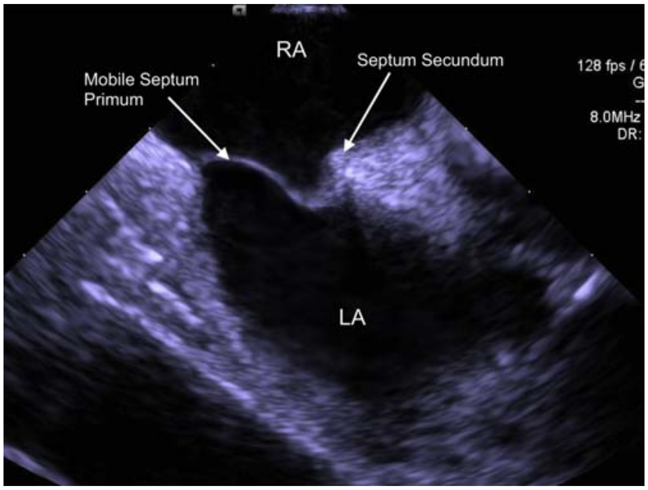

FIGURE 15.3 Aneurysmal mobile septum primum and thicker more stable septum secundum seen with intracardiac echocardiography imaging.

If the PFO flap is open, it may be visualized as left-to-right shunting of blood between the atria by color flow Doppler [13]. This is expected as baseline left atrial pressure is physiologically slightly higher than right atrial pressure [14]. During a Valsalva maneuver, straining, coughing, certain phases of breathing, or in those with pulmonary hypertension, right-to-left shunting may be seen by color flow Doppler. Right-to-left shunting is also seen in the presence of hypoxemia, due to shunting of deoxygenated blood to the left atrium across the PFO [15]. Pointing the ICE imaging transducer to bring the anatomy of interest into view is done by deflecting the ICE catheter anterior-posterior or right-left, advancing and retracting it, and with gentle catheter rotation as described below (Fig. 15.4).

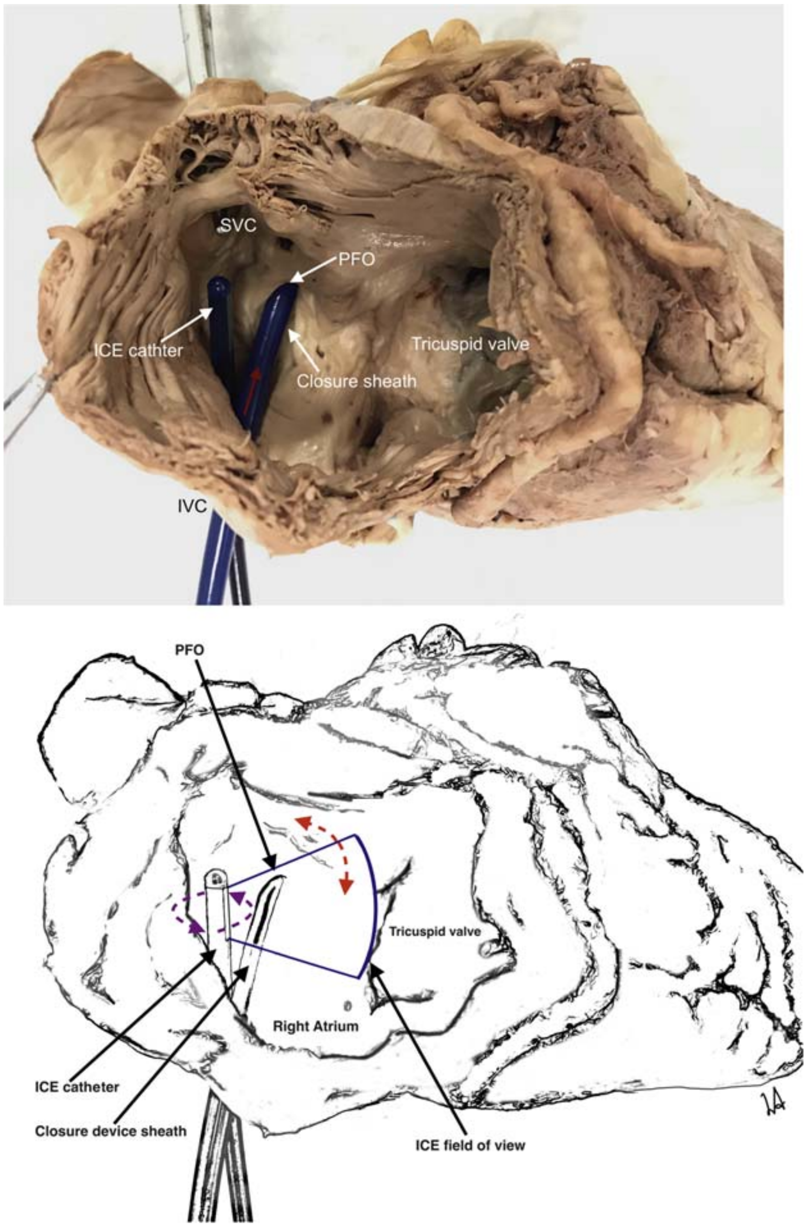

FIGURE 15.4 (Top) Image of the right atrium showing the location of a PFO within the fossa ovalis, and position of the intracardiac echocardiography (ICE) imaging catheter and closure device in relation to the septum, superior vena cava (SVC), and inferior vena cava (IVC). The red arrow indicates the flow of blood from the IVC toward the PFO. (Bottom) Depiction of the right atrium and location of the ICE catheter imaging field of view as it is used to scan across the different anatomical planes of the right atrium.

INSERTING THE INTRACARDIAC ECHOCARDIOGRAPHY CATHETER

To insert the ICE catheter, venous access is obtained from the right femoral vein, but the left femoral vein could be used as well. In patients with small femoral veins, it may be advantageous to have the ICE catheter on the contralateral side of the PFO closure catheter. If on the same side, the 2 venous punctures can be placed 5 mm apart to limit the interaction between the closure sheath and the ICE catheter. We recommend watching the ICE catheter under fluoroscopy as it exits the sheath, making sure it is unlocked. It is important to follow the tip and avoid pushing when there is resistance or if the tip appears to bend [16]. Existence of an IVC filter is not a contraindication to performing the procedure under ICE guidance. However, if an IVC filter is observed, it is prudent to first perform a venogram of the femoral vein and watch the flow up through the IVC filter to the right atrium prior to advancing the ICE catheter, sizing balloon, or closure device in order to avoid displacing clots, damaging, or embolizing the filter (Fig. 15.5) [17].

The imaging edge on the tip of the ICE catheter is radioopaque and so, when uncertain of the anatomy and location of the catheter, it is useful to look under fluoroscopy at both the position of the ICE catheter and the direction it is facing (Fig. 15.6) [18].

MANIPULATING THE INTRACARDIAC ECHOCARDIOGRAPHY CATHETER

Once the ICE catheter is in the right atrium, it can be positioned while unlocked or with a 20 degree posterior bend to obtain the "home view" of the right atrium, tricuspid valve, and right ventricle. The operator's right hand is positioned on the device handle and the left hand on the probe shaft itself, just outside the sheath hub. With gentle clockwise rotation of 10–15 degrees, the aortic valve will come into view, followed by the mitral valve and LAA. Additional clockwise rotation will bring the interatrial septum into view (Fig. 15.7).

Slight right and left angulations along with clockwise and counterclockwise rotations are done to scan across the PFO and image different sections of the septum [19]. It is important to remember that only slight movements are needed. If the operator is uncertain of the anatomy, visualizing the position of the probe under fluoroscopy and returning to the home view is advisable. Use of the ICE probe by an experienced operator is safe, resulting in a 99.8% success rate [20]. Avoiding excessive manipulation and overdeflecting the probe is important as the stiff tip

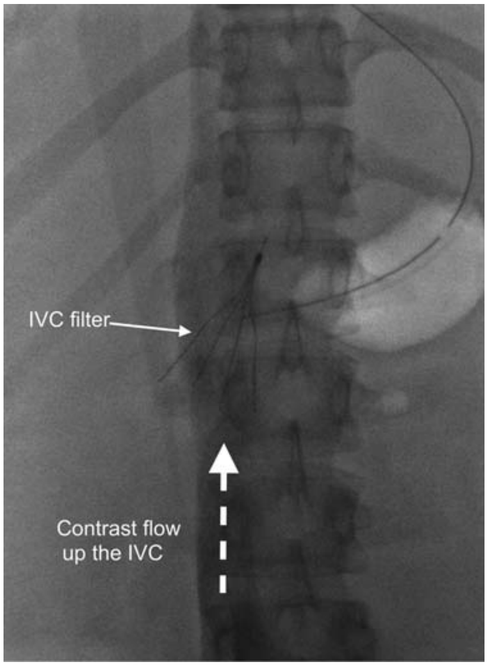

FIGURE 15.5 A patient with deep vein thrombosis and recurrent cerebrovascular accidents. A venogram of the intracardiac echocardiography (ICE) showing flow through the inferior vena cava (IVC) filter. An ICE catheter was advanced carefully through the filter and the PFO closure was performed.

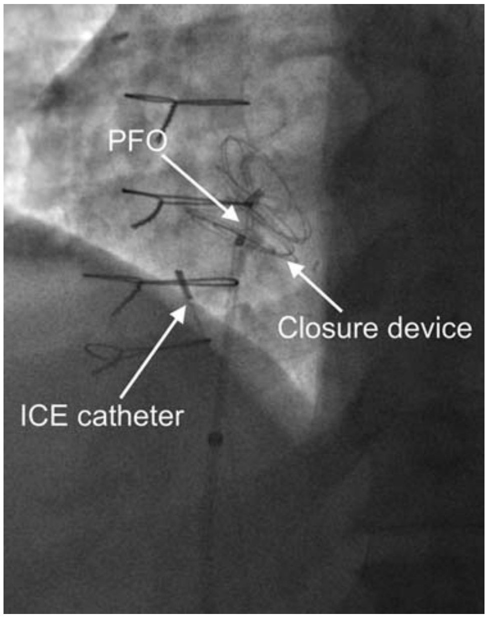

FIGURE 15.6 Position of the intracardiac echocardiography (ICE) catheter in relation to the interatrial septum and the closure device. Note the slight posterior tilt on the ICE catheter allowing it to visualize more of the septum. *PFO*, patent foramen ovale.

can cause injury or perforation, especially if the probe is advanced into the right atrial appendage. The probe is advanced or retracted to show more of the superior and inferior parts of the septum respectively [21].

Slight right and left tilting, along with gentle rotation, will visualize more of the LAA in the 4–5 o'clock position on the screen. This is a good view to confirm that the wire is not in the LAA after it crosses the PFO. Depending on the variable anatomy of the left atrium, there is a tendency for the wire to deflect off the top of the septum and enter the fragile LAA. To avoid the risk of perforation, especially when the operator is obliged to push the delivery catheter through a long PFO tunnel, it is best to either place the guidewire in the pulmonary veins or use a coiled wire such as the Safari (Boston Scientific, Marlborough, MA, USA), the Confida (Medtronic, Minneapolis, MN, USA), or the TorayGuide (Toray, Tokyo, Japan) wire. These wires coil in the left atrium and help reduce the risk of perforation by preventing the devices from entering the LAA or traumatizing the left atrial surface.

Additional clockwise rotation brings the fossa ovalis and the thinnest part of the septum into view, including the interface between the septum primum and secundum (Fig. 15.7). This is the best view for watching deployment of devices and checking for apposition, especially in the left atrium. Adding a posterior tilt on the ICE catheter pulls the transducer away from the septum, showing more of the septum and surroundings including any aneurysmal septum primum. Subtle right-left manipulation of the dial and advancing-retracting the catheter lets the operator scan across the septum in its entirety. Rotating further clockwise points the imaging tip toward the posterior atrium and one can observe the pulmonary veins entering into the left atrium. From here, the operator can visualize higher up on the septum secundum, imaging apposition of the device posteriorly in the right atrium. Withdrawing the probe and adding further posterior tilt points the imaging tip upward toward the superior vena cava (SVC). With careful manipulation, the retro-aortic rim can be visualized in profile (anteriorly) along with the SVC [22]. Although unusual, an occasional PFO cannot be closed from the IVC due to anatomic issues, thrombosis, or instrumentation. It is possible to close a PFO from the SVC with ICE imaging guidance. Closure from the SVC may be facilitated by a deflectable sheath entering the right atrium, which turns superiorly to enter the PFO.

With careful manipulation, the ICE catheter can be advanced across the tricuspid valve, the atrial septum, or up the SVC to visualize additional anatomy. This should only be attempted when the operator is familiar with the device and appreciates the risk of injury and perforation.

CLOSING THE PFO

When advancing a sizing balloon or a closure device delivery sheath, it is common for the catheter shaft to interact with the ICE catheter. Placing a wet towel on the ICE catheter weighs it down and prevents the image from shifting

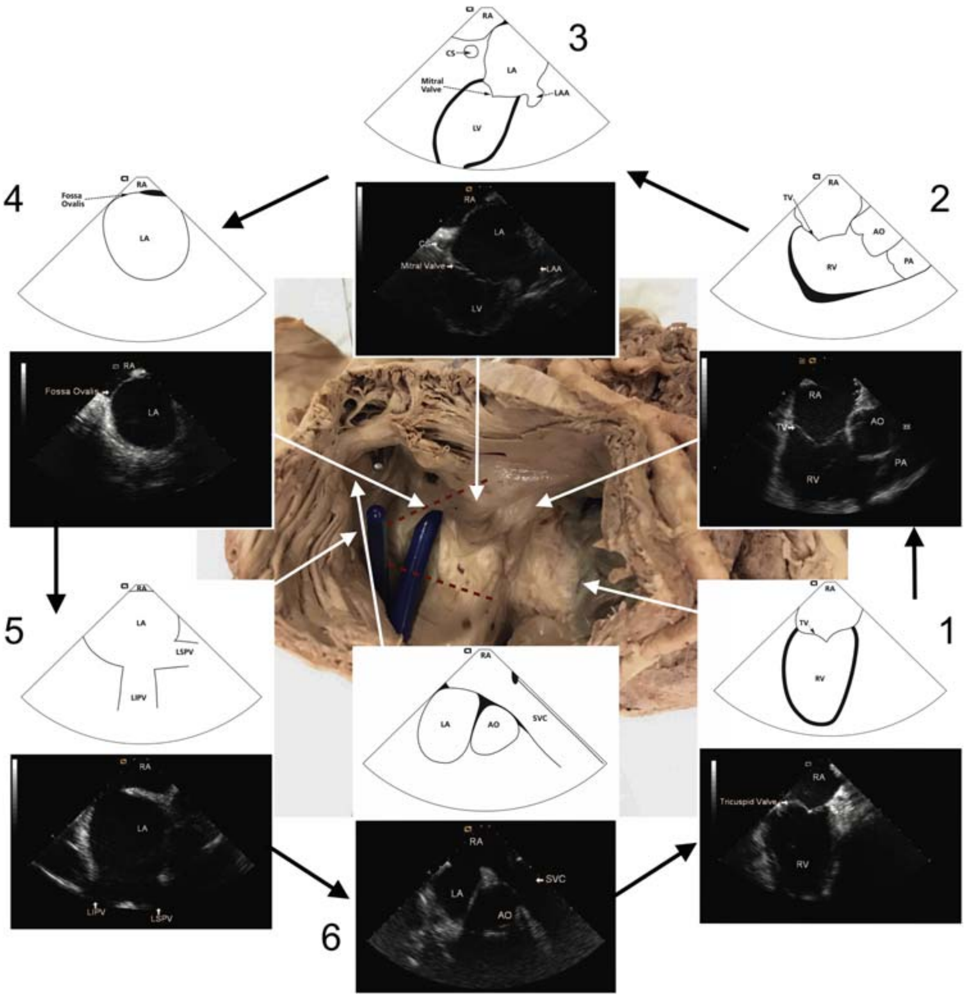

FIGURE 15.7 A composite image showing the position of the intracardiac echocardiography catheter in the right atrium (RA) and the echocardiographic images generated from pointing the imaging tip toward the different aspects of the atrium. Each white arrow indicates the corresponding image obtained at that position. The home view is typically obtained at position 1 and clockwise rotation cycles through the subsequent images. *AO*, ascending aorta; *CS*, coronary sinus; *LA*, left atrium; *LAA*, left atrial appendage; *LIPV*, left inferior pulmonary vein; *LSPV*, left superior pulmonary vein; *LV*, left ventricle; *PA*, pulmonary artery; *RV*, right ventricle; *SVC*, superior vena cava; *TV*, tricuspid valve. *Courtesy: Biosense-webster, ©2017. All rights reserved.*

during the procedure. As part of assessing the PFO, an agitated saline bubble study may be performed. Since the IVC anatomically shunts blood into the PFO, it is best to perform this test from the femoral vein. This can be done via the sheath intended for the closure device. During the injection of bubbles, the patient (who is typically awake) is asked to perform a Valsalva, coughing, or a sniffing (Mueller) maneuver. The ICE catheter may be switched to color Doppler mode, allowing assessment of blood flow across the PFO tunnel [23].

To cross the PFO, we use a multipurpose (MP) tip diagnostic 6Fr catheter and a standard J wire. If the PFO is smaller than 6 mm, the J wire tip may be too large to cross the PFO. In cases where it is difficult to pass the guidewire, we place the MP catheter into the fossa ovalis and inject iodinated contrast medium to visualize the PFO. Occasionally, the PFO will be closed or have a cul-de-sac pouch despite the fact that a preliminary TTE or TEE is interpreted as showing a patent foramen. If the PFO is small and will not admit a J curve wire, the wire tip can be straightened or a straight wire can be used with caution to cross the PFO. The operator can then advance the wire with the PFO in view on ICE at the thinnest part of the septum, until the wire passes across the septum and into the left atrium (Fig. 15.8). More precise sizing of the PFO can be accomplished by using the Amplatzer 24 mm sizing balloon filled with diluted contrast medium. Once the delivery sheath is across the septum, some fine adjustments of the ICE catheter may be needed to bring the septum into view again prior to device deployment. In the mid-right atrial view, pointing the ICE catheter toward the fossa ovalis and showing the left atrial side, the left atrial disc of the closure device is deployed. The device is then

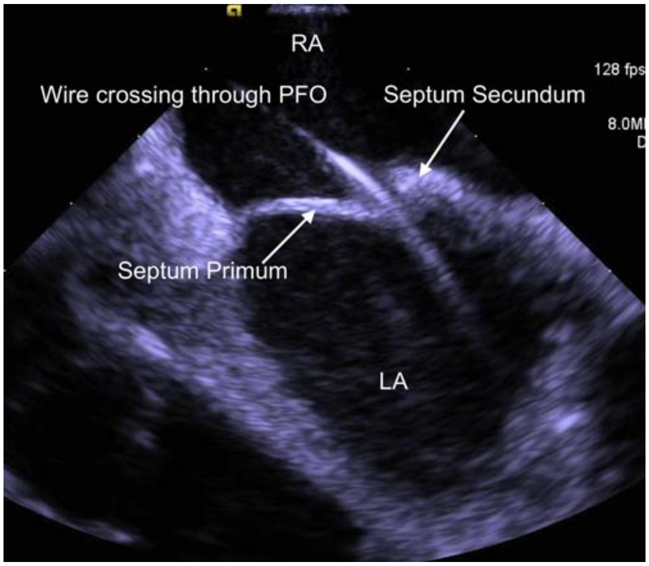

FIGURE 15.8 Intracardiac echocardiography image showing the guidewire crossing from the inferior vena cava through the patent foramen ovale (PFO) and into the left atrium (LA). *RA*, right atrium.

pulled against the septum and, while observing on ICE, the right atrial disc is deployed. It is important at this point to look at the septum secundum (superior to the device) and septum primum (inferior to the septum secundum), to ensure the right atrial disc covers the lip of the septum secundum (Pacman sign), so that the disc will remain on the right atrial side and not slip into the PFO tunnel (Fig. 15.9). This is more likely to occur in patients with a thick septum secundum or a large PFO with a mobile septum primum. The ICE catheter is then used to study the edges of the closure device and ensure it has accomplished appropriate capture of the septum, sandwiching it and attaining a stable position. While tethered to the delivery cable, the closure device may show a fair amount of traction in the inferior direction (Fig. 15.9). Inferior traction on the device creates "cupping" of the right atrial disc, and the tension on the delivery catheter should be released prior to setting the locking wire. The ICE catheter is then rotated to ensure that the device edge does not impinge on the pulmonary veins, the SVC, tricuspid valve, or coronary sinus; this is especially important in patients with smaller atria or when using large devices. Although unlikely to occur with PFO occluding devices, it is more of a concern with atrial septal defect closures. Attention should also be paid to the rhythm to ensure the patient has not developed a conduction block or atrial arrhythmia [24].

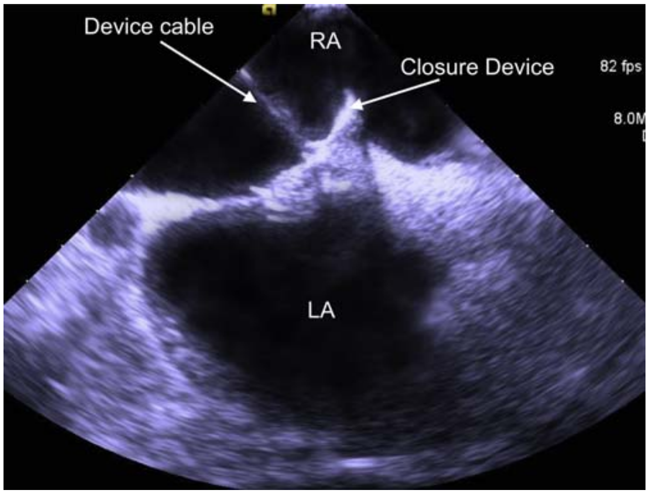

FIGURE 15.9 Intracardiac echocardiography (ICE) image showing the closure device "sandwiching" the septum primum on the left and septum secundum on the right. The ICE image is shown from the point of view of the probe in the right atrium (RA), but it is rotated 90 degrees from the true anatomic position so that the septum primum points in the inferior plane and the septum secundum is superior. There is tension from the delivery cable causing the device to tilt into the RA and toward the inferior vena cava. *LA*, left atrium.

POST DEPLOYMENT AND INTRACARDIAC ECHOCARDIOGRAPHY CATHETER WITHDRAWAL

Once the device is released and the delivery sheath is withdrawn, the ICE catheter is used to scan across the deployed device and assess the PFO closure. Color-flow and agitated saline bubble studies may be repeated. At this point, it is important not to allow the ICE catheter to interact with the closure device. This is done by keeping the device in view, and not manipulating the imaging catheter when unable to see the septum. If the operator loses sight of the septum or closure device, fluoroscopy is helpful in positioning the imaging catheter without interfering with the closure device. Once satisfied with the closure, the ICE catheter is unlocked and withdrawn through the sheath. We use heparin to obtain an activated clotting time of 250–300 s during the procedure and reverse the heparin with protamine prior to removal of the sheaths. A pressure bandage can be applied, or a figure-of-eight suture suffices for hemostasis after sheath removal.

CHALLENGES

ICE imaging can be a challenge in patients with an abnormal or rotated cardiac anatomy. In those situations, fluoroscopy and a familiarity with the anatomy from a preprocedural TEE are valuable. A tortuous IVC and other anatomic barriers may prevent easy advancement of the ICE catheter. Using a wire-guided long sheath, to deliver the ICE catheter into the right atrium, can be done. Interaction between the ICE catheter and other devices in the right atrium or IVC is not a major concern and can be controlled with a second operator handling the ICE catheter, or anchoring the handle of the catheter on the table. Of greater concern is the ICE catheter interacting with recently implanted pacemaker or defibrillator leads. The operator should be especially cognizant of the leads and avoid excessive angulations when manipulating the imaging catheter to avoid displacement. An IVC filter is not a barrier to using ICE, as described above, provided the operator has taken the precaution to check for IVC patency and free blood flow through the filter (Fig. 15.5). If there is concern, a long sheath can be used to bypass the filter and deliver the ICE catheter.

UNUSUAL CASES: TIPS AND TRICKS

When the PFO width is >7 mm, the procedure is usually straightforward with little variation or need for secondary techniques. However, some cases may have unexpected imaging results or present challenges in crossing the septum and choosing an appropriate closure device based on the anatomy. This section will review several cases that highlight these hurdles and how to manage them. It is important to note how preprocedure imaging and detection of a PFO may be inconsistent or reveal the presence of additional pathology.

One difficulty that can be encountered with closing a PFO comes when there is trouble crossing the septum with the guidewire. A MP 1 catheter angled toward the septum usually allows a standard 0.038″ J-tipped guidewire to push open the fossa ovalis under the septum secundum and deflect the septum primum toward the left atrium. The guidewire slips easily across the septum and is positioned into the left upper pulmonary vein.

It can be difficult to engage the septum, often because of an unexpected heart rotation or position. ICE can be invaluable in assessing for anatomical variations such as significant posterior rotation of the heart or a septal aneurysm. Based on the maneuvers needed to appropriately align the ICE transducer with the septum, the operator can adjust the initial attempts to engage the fossa ovalis, such as a greater clockwise rotation for a rotated heart. Real-time ICE imaging allows visualization of the wire so that adjustments in the position and rotation of the MP1 catheter can be continuously made until the wire is seen in the appropriate location. This can be performed predominantly with ultrasound guidance to decrease radiation exposure. If there is significant difficulty engaging the fossa ovalis, the guidewire can be advanced into the SVC, followed by the MP 1 catheter; the wire is then withdrawn. Next, the catheter is slowly moved caudally along the septum, eventually "jumping" across the limbus into the fossa ovalis, similar to the technique used in performing a transseptal puncture. ICE is used to ensure the guidewire is engaged and crosses the septum. However, when the guidewire will not cross, there are a variety of maneuvers that can be employed.

In Case #1, a 55-year-old man experienced a stroke 3 h after completing an intense race. An extensive neurologic workup revealed no obvious etiology for the stroke and a diagnosis of cryptogenic stroke was made. Transcranial Doppler (TCD) bubble study showed a Spencer grade I right-to-left shunt at rest, which increased to a grade 4 shunt

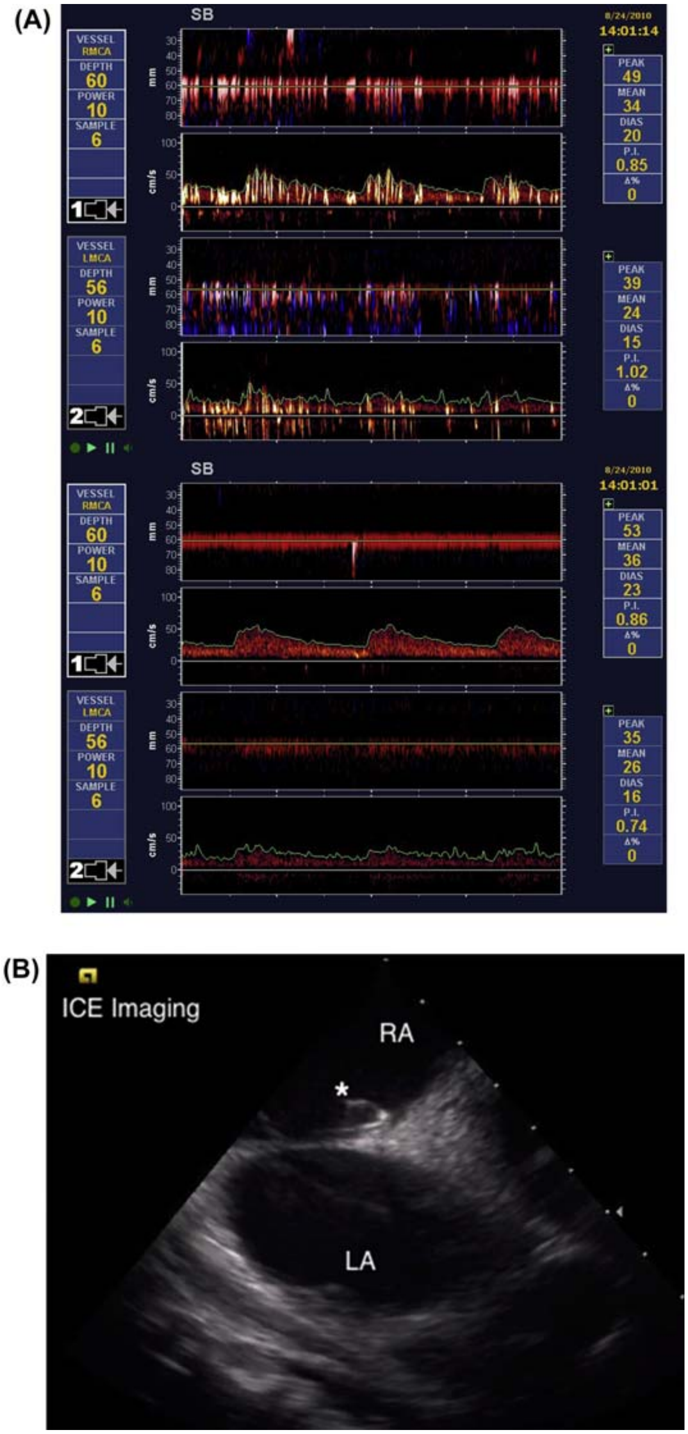

FIGURE 15.10 (A) Transcranial Doppler of the bilateral middle cerebral arteries shows a grade 1 right-to-left shunt at rest (bottom) which increases to grade 4 with Valsalva (top), indicating a PFO or transpulmonary shunt. (B) An intracardiac echocardiography (ICE) image of a 0.038″ J-tipped guidewire (marked with an asterisk), which is echo bright at the top of the image, slides along the septum, but will not cross between the septum primum and secundum. (C) Balloon sizing of the PFO confirms a small PFO. The white arrow shows the small waist on the balloon. *RA*, right atrium, *LA*, left atrium.

with Valsalva (Fig. 15.10A). An initial attempt to cross the PFO was made with a 5F MP 1 catheter and standard J-tipped guidewire as seen in the ICE images (Fig. 15.10B). The wire engaged the limbus of the septum, but would not cross, which may be due to a variety of reasons including a small PFO, a narrow tunnel-like PFO, or that there is no PFO present. The standard J-tipped guidewire, indicated by an asterisk in Fig. 15.10B, has a diameter of 6 mm

(C)

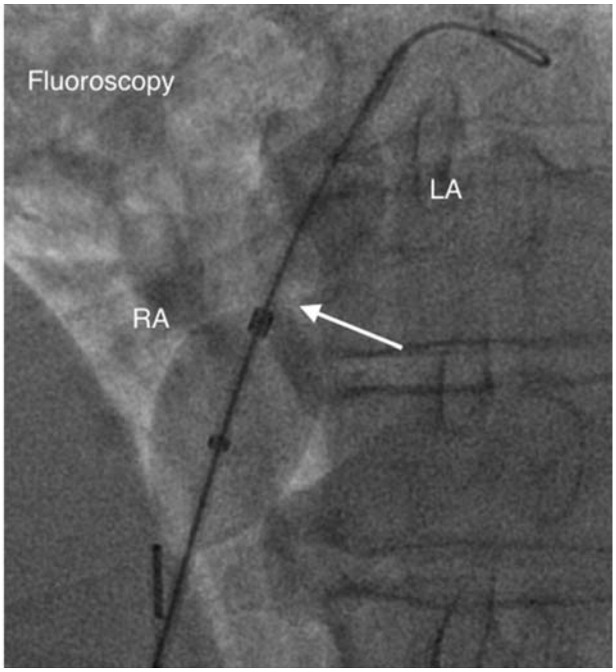

FIGURE 15.10 cont'd.

when the tip is allowed to assume its J shape, which may be larger than the PFO width. One option is to straighten the guidewire tip or change the J-tipped guidewire for a floppy straight tip 0.035″ wire, which has a diameter less than 1 mm and should pass through a small PFO (Fig. 15.10C). Care must be exercised as the straight tip, although floppy, can damage cardiac structures or cause a perforation. If the straight wire cannot pass, a hydrophilic coated wire such as the 0.035″ straight Glidewire (Terumo, Somerset, NJ) can be used as it will more easily pass between the septa and through the PFO with the reduced resistance between the wire and the tissue. Once the straight tipped wire has crossed the septum and is in the left atrium, it should be held in the atrium and the catheter should be advanced through the PFO, and the straight wire withdrawn. A safer J-tipped wire can then be advanced into the pulmonary vein followed by the catheter. In some cases, more support is needed to cross the septum. In this case, once the J-tipped guidewire is engaged at the septum, the catheter can be advanced against it. Using a counterclockwise rotation of the catheter while applying forward pressure will cause it to slide up and through the PFO into the left atrium. At this point the J-tipped guidewire can be advanced into the pulmonary vein. In Case #1, while the J-tipped wire would not cross, advancing the 5F MP 1 catheter with counterclockwise rotation was successful in crossing the septum.

In Case #2, a 68-year-old man suffered sudden onset vertigo and vomiting. He subsequently had a magnetic resonance imaging (MRI) brain study, which showed a cerebellar stroke. During the ensuing workup, a TCD revealed a grade 4 right-to-left shunt with Valsalva. A subsequent TEE did not clearly show any color flow or evidence of agitated saline contrast crossing the septum; however, the diagnosis of a PFO based on color flow across the septum has a poor sensitivity of 28% [25]. While TEE with agitated saline contrast is highly sensitive for a PFO, studies have found that 61%–65% of patients cannot adequately perform the Valsalva maneuver that is necessary to raise right atrial pressure over left atrial pressure and unmask right-to-left shunting [26,27]. One group of investigators examined the effect of external IVC compression during a TEE, to a depth of 5 cm for 30 s followed by release when the agitated saline contrast first reaches the right atrium [27]. This technique had the highest rate for identifying a PFO during TEE, even more than the Valsalva maneuver.

In most patients receiving a TEE or TTE with agitated saline contrast, the saline is given via a peripheral intravenous line in the upper extremity. In one study, performing agitated saline contrast medium injections from the femoral vein resulted in detecting a greater degree of shunt compared with brachial vein injections [28], including 8% of patients who would have been incorrectly classified as having no shunt with brachial injections. One possible explanation for this may be the presence of a residual Eustachian valve. When a Eustachian valve, which is present in-utero to direct oxygen-rich blood from the IVC across the foramen ovale, persists after birth, it continues to direct lower body blood toward the septum. This preferential flow pattern creates an echolucent or "negative" space

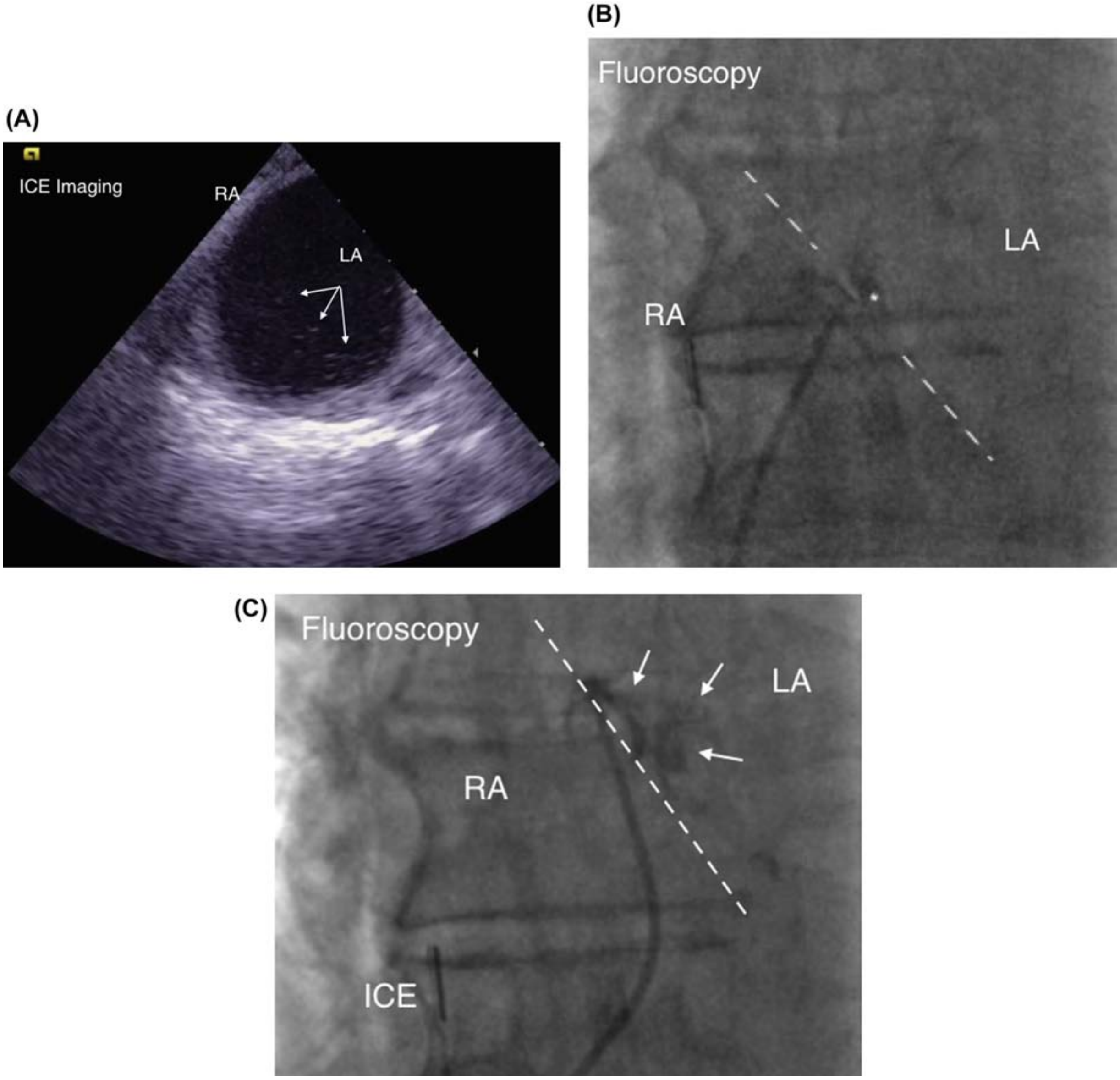

FIGURE 15.11 (A) An intracardiac echocardiography (ICE) image of a patient with a negative agitated saline bubble study on transesophageal echocardiography who has a positive study with ICE and a femoral injection of agitated saline. The bubbles that have crossed from the right atrium (RA) into the left atrium (LA) are marked with arrows. (B) Injection of contrast toward the septum (location highlighted by dashed white lines), revealing the origin of the PFO (indicated by the white star). (C) An injection of contrast into the PFO via the multipurpose 1 catheter which is sitting in the PFO, showing contrast spilling freely through the small PFO into the left atrium (LA). Short arrows show contrast flowing freely into the LA; dotted line shows the septum. (D) An Amplatzer Sizing Balloon inflated across the septum allowing for both fluoroscopic (left) and echocardiographic (right) measurements to choose the right PFO device. Double arrow lines show where measurements are taken at the waist. (E) From a different patient, an Amplatzer Sizing Balloon inflated through a PFO showing a large, noncompliant PFO. *ICE*, intracardiac echocardiography; *RA*, right atrium; *LA*, left atrium.

without saline bubbles around the upper septum, whereas the agitated saline contrast entering from the SVC with a brachial injection is directed to the inferior aspect of the right atrium and away from the foramen ovale. During the PFO closure procedure, agitated saline contrast is preferentially given through the femoral sheath and, therefore, may be more likely to reveal transseptal shunting.

In Case #2, with the MRI confirmed stroke and abnormal TCD findings, the patient was brought for possible PFO closure even though the TEE result was negative. After sheaths were placed and the ICE catheter was advanced, an agitated saline contrast medium injection through the femoral sheath was performed showing bubbles, indicated by arrows, crossing the septum early (Fig. 15.11A). However, there was difficulty engaging the PFO with the J-tipped

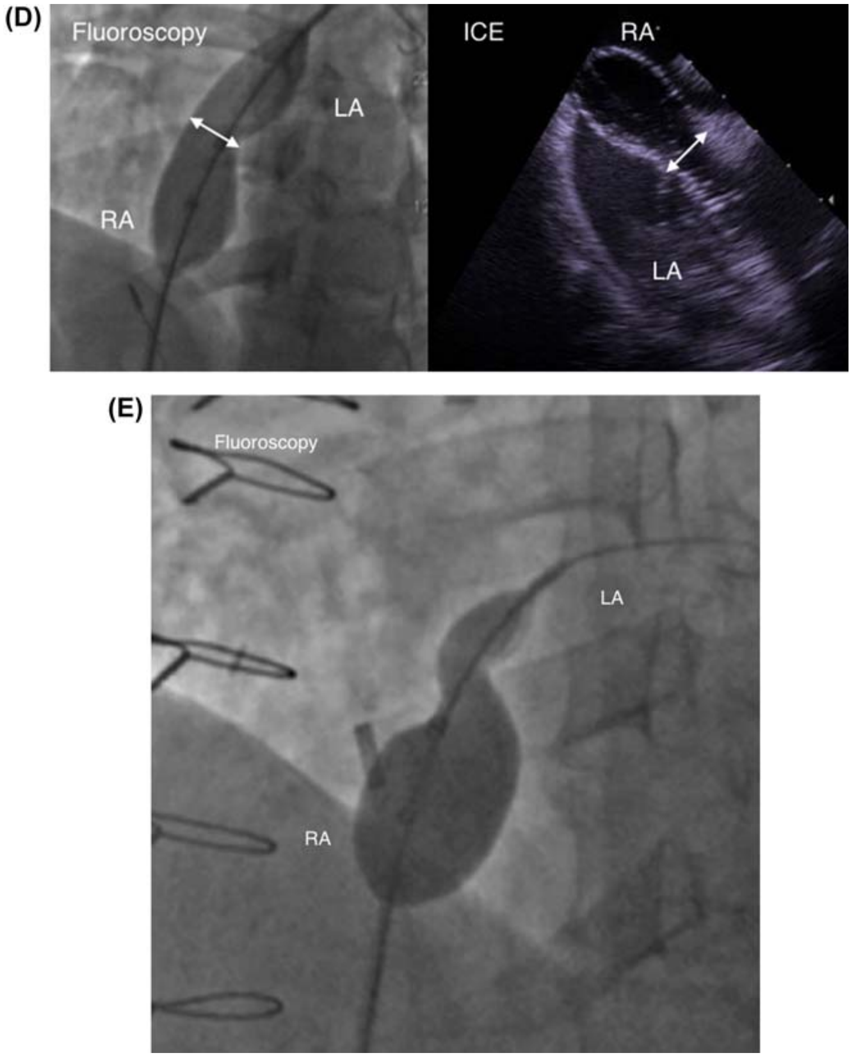

FIGURE 15.11 cont'd.

wire and crossing the septum. In this case, we used contrast medium injections to locate the PFO and to understand the anatomy of the septum. When there is difficulty to even engage the PFO, a nonselective injection can be performed in the right atrium toward the septum. With the MP 1 catheter aimed toward the septum and after aspirating the catheter to remove entrained air, a hand injection of contrast medium is performed under fluoroscopy. In this case, contrast revealed the origin of the PFO, marked by an asterisk, slightly below the tip of the catheter (Fig. 15.11B). The catheter was withdrawn slightly, rotated counterclockwise, and then advanced into the PFO and another hand injection of contrast was performed. This "PFOgram" helped delineate the shape and size of the PFO and confirm patency as contrast was seen entering the left atrium (Fig. 15.11C). If the catheter slips entirely into the left atrium, then an injection can be performed slowly while withdrawing the catheter to delineate the PFO. This injection revealed a small PFO that was patent, which helps explain the difficulty crossing the septum. As noted previously, at this point using a straight tipped wire, or continuing with gentle forward pressure with the catheter alone, should allow the operator to enter the left atrium and continue with the procedure.

Although a contrast medium injection helps to define the PFO size, more precise measurements can be obtained using a sizing balloon. Once the extra-stiff 0.035″ guidewire has been placed into the left upper pulmonary vein, a balloon, such as a 24 mm Amplatzer Sizing Balloon II (Abbott, St. Paul, MN, USA), can be inserted over the wire straddling the PFO. Slow manual inflation with a 50:50 contrast/saline mixture allows for visualization of the PFO geometry and size. Care should be exercised to ensure it does not shift suddenly into either atrium. Once inflated at low pressure and a "waist" has developed, measurements can be made using fluoroscopy or with the concurrent ICE images (Fig. 15.11D).

In Case #1, balloon sizing confirmed a small, noncompliant PFO (Fig. 15.10C). In addition to the width of the PFO, the compliance and length can be important to ensure the device is large enough to seal the defect without risk of dislodgment. Fig. 15.11E, from a different patient, shows a large, noncompliant PFO requiring a larger device to close it.

In Case #3, a 56-year-old woman with migraines suffered a cryptogenic stroke, and subsequent evaluation revealed a PFO. At the time of attempted PFO device closure, the baseline agitated saline study from the femoral vein demonstrated a large right-to-left shunt. Despite the presence of a large shunt, the J-wire did not pass through the PFO, so the MP catheter was placed against the septum, and a hand injection of contrast was performed revealing a narrow but long, tunnel-like PFO (Fig. 15.12A).

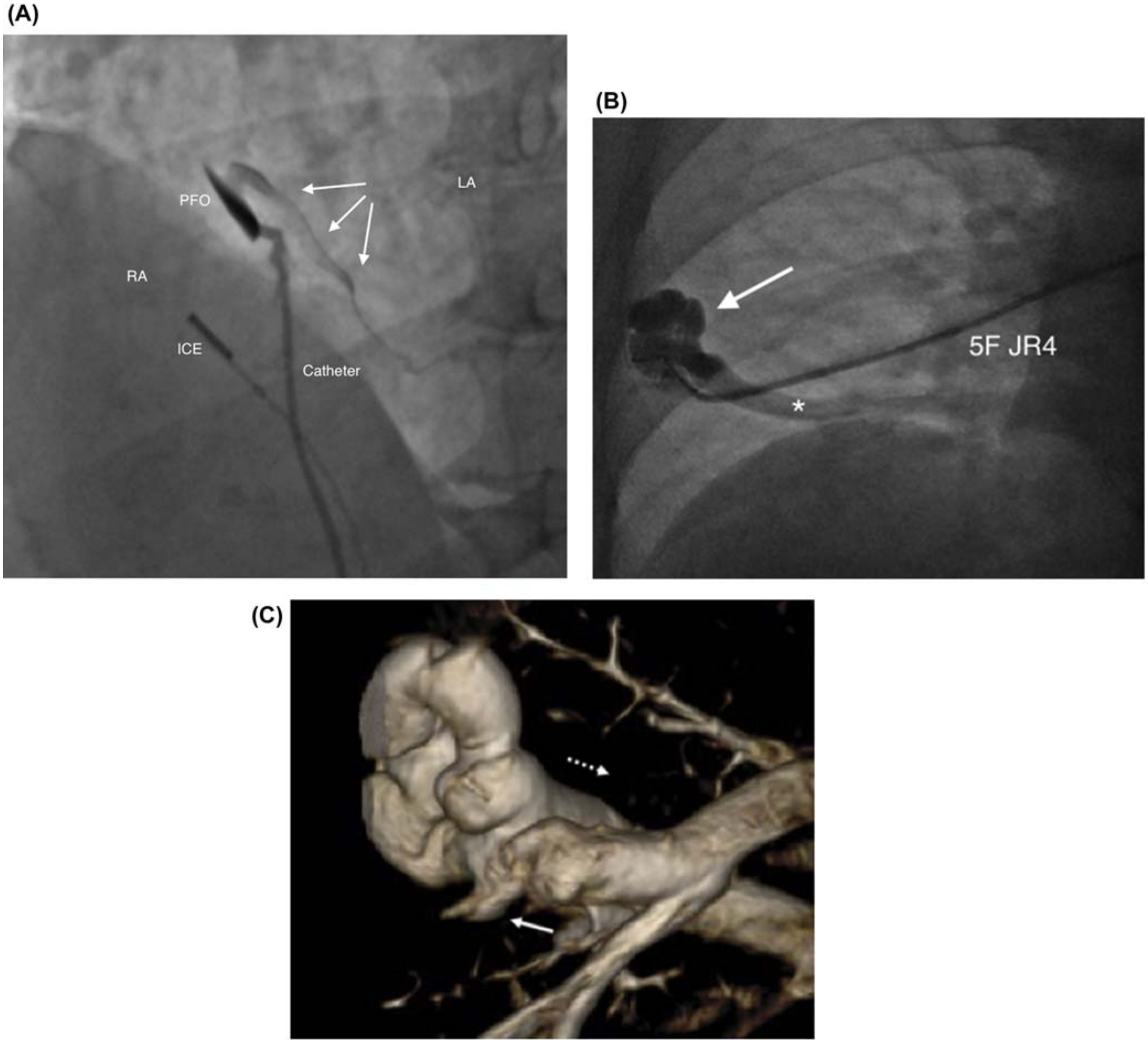

FIGURE 15.12 (A) Contrast medium injection through a PFO showing its opening is narrow, which must be accounted for when choosing the device size. Arrows show contrast flowing freely into the left atrium (LA) from the right atrium (RA). *ICE*, intracardiac echocardiography. (B) Fluoroscopic image for a 5F JR4 catheter selective into a subsegmental pulmonary artery, opacifying the arteriovenous malformation (denoted with an arrow) and contrast returning via a pulmonary vein (with an asterisk). (C) A subsequent 3D reconstruction from a computed tomography scan of the arteriovenous malformation in (B). Solid arrow depicts flow into the arteriovenous malformation and the dotted arrow shows flow away through a pulmonary vein.

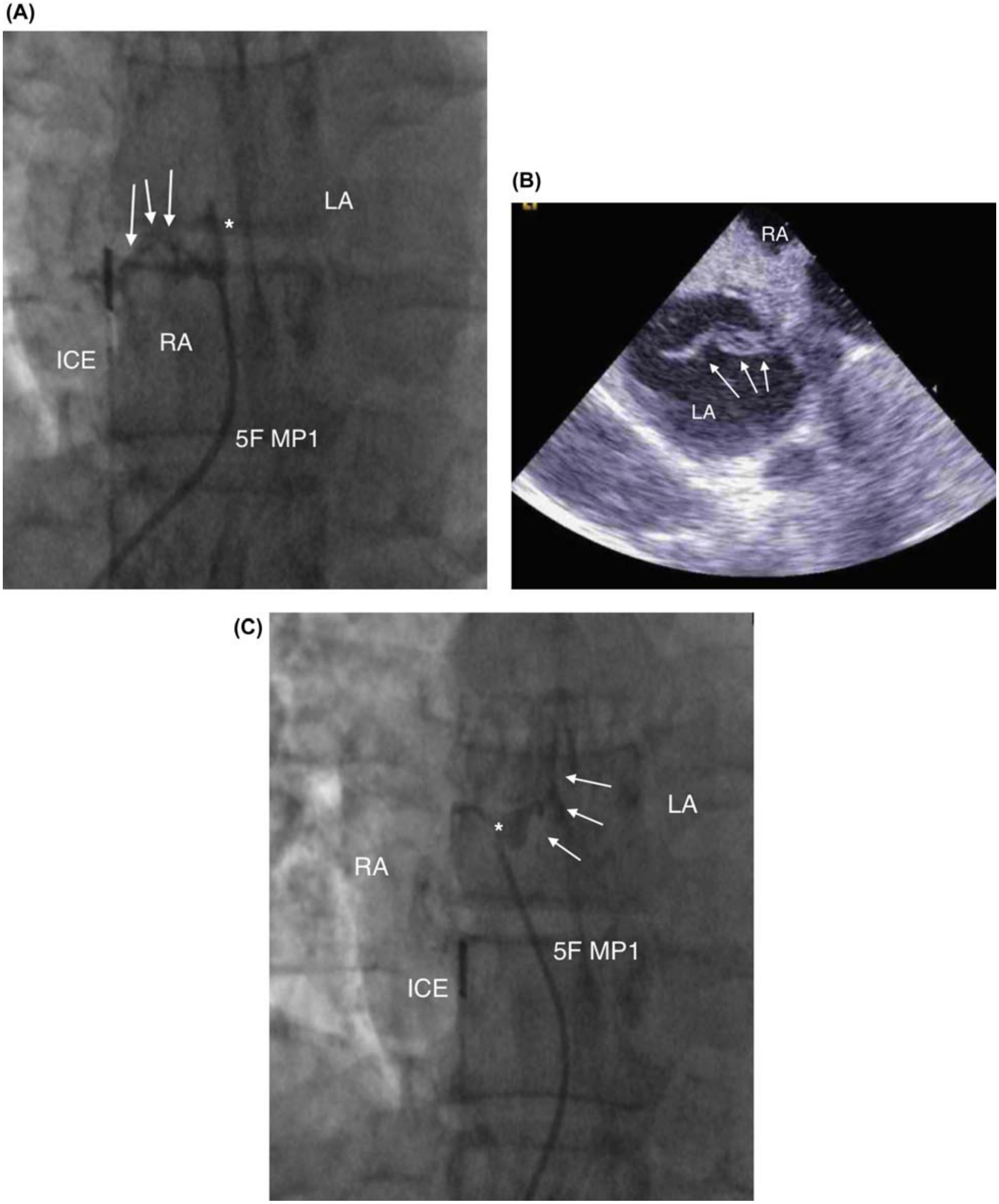

FIGURE 15.13 (A) Fluoroscopy of an intracardiac echocardiography (ICE) imaging catheter on the left side of the image with a 5F MP1 catheter engaged into the foramen ovale (asterisk), filling it with contrast medium and the contrast medium is seen spilling back (arrows) into the right atrium (RA) without any entering the left atrium (LA), suggesting a sealed foramen ovale pouch. (B) An intracardiac echocardiography image of the interatrial septum during agitated saline contrast medium injection under Valsalva release, showing a stream of bubbles (arrows) crossing from the right atrium (RA) to the left atrium (LA), confirming the presence of a PFO despite a negative radiographic contrast medium injection as seen in (A). (C) Once the 5F MP1 catheter was slightly withdrawn, rotated counterclockwise and readvanced into the PFO (asterisk), angiographic contrast medium flowed fully into the left atrium (LA) indicated by arrows. *ICE*, intracardiac echocardiography; *RA*, right atrium.

After closing the PFO with a 25 mm Gore Cardioform Septal Occluder, a repeat agitated saline contrast medium injection was performed to confirm closure. Surprisingly, there was a significant persistent right-to-left shunt. Repeated agitated saline contrast medium injections, with adjustment of the ICE catheter to interrogate the pulmonary veins, revealed agitated saline bubbles in the right inferior pulmonary vein, suggesting a transpulmonary shunt in addition to the PFO that was just closed. An angiogram performed into the right main pulmonary artery revealed an area in the periphery that appeared to be an arteriovenous malformation (AVM). A 5F Judkins Right (JR) 4 catheter was positioned just before the area and selective angiography was performed showing a large AVM (Fig. 15.12B), which was subsequently reconstructed in 3 dimensions by computed tomography (Fig. 15.12C). The patient later underwent occlusion of this AVM to ensure all routes for paradoxical emboli were sealed. In this case, the PFO was probably an "innocent bystander" since the flow through the pulmonary AVM was much greater; but that was only discovered after the PFO was closed because there was such a large residual shunt [29]. During the case, it is helpful to meticulously reassess all imaging data both preoperatively and intraoperatively when there are difficulties in closing the PFO.

In Case #4, a 66-year-old man suffered a stroke and the subsequent workup revealed no obvious cause of stroke, but there was a small PFO with early shunting of agitated saline contrast at rest on TEE. The patient was brought for PFO closure, but the J-tipped wire would not cross the septum, despite appearing to slide under the septum secundum. As noted previously, we used the technique of engaging the septum with the 5F MP 1 catheter and performing contrast medium injections, and we could delineate what appeared to be a sealed foramen ovale (Fig. 15.13A). However, based on the MRI-proven stroke as well as agitated saline contrast seen crossing the septum on the TEE, we performed an agitated saline contrast medium injection from the femoral sheath. As shown in the ICE image in Fig. 15.13B, there was a string of dense bubbles crossing the septum after release of the Valsalva maneuver. Given this finding, we concluded that either there was another opening in the septum or perhaps a pulmonary AVM was the cause of the right-to-left shunt. The catheter was withdrawn slightly and with counterclockwise rotation, the catheter was readvanced to perform a contrast medium injection which now showed free-flowing contrast into the left atrium (Fig. 15.13C). At this point, a straight wire was used to cross the PFO and bring the MP1 catheter into the left atrium, and the remainder of the procedure was completed without difficulty. We concluded that the initial catheter position was in a blind pouch of the partially closed PFO, but was not directed toward the actual opening into the left atrium.

Although the PFO closure procedure is usually straightforward, anatomic variations, inconsistent imaging, and small, tunnel-like PFOs can make it more challenging. It is important to review all preoperative cardiac imaging and complement it with intraoperative imaging, including a full ICE interrogation of the interatrial septum and agitated saline contrast study at the beginning of the procedure. If there is difficulty crossing the septum, a series of attempts using ICE-guidance, including a soft straight tipped wire or the catheter alone, can often overcome the obstacle of a small PFO. If not, hand injections of angiographic contrast medium can provide critical additional information about the location and geometry of the PFO, to allow adjustments and permit crossing into the left atrium. Finally, using a sizing balloon can confirm the PFO size and provide guidance in choosing the appropriate occluder size.

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