The earliest application of intracardiac imaging was primarily used to improve on angiography by correctly defining vascular (pertaining to coronary arteries) and intracardiac anatomy. This was followed by its use for ablation procedures in electrophysiology. The primary goal in an electrophysiology procedure was to aid in transseptal puncture and localization of the catheters inside the heart. Because the images outlined the atrial septum and adjacent structures well, the idea to use it to close atrial-level communication was born.

Initially, intracardiac echocardiography (ICE) was used sporadically for closure of intra-atrial communications; its use, however, increased gradually but steadily, and currently it has become a preferred method for closing atrial septal defects (ASDs) and the patent foramen ovale (PFO). The image provided by the probe is of high quality, and hence, the ICE application has been extended to aid in closing ventricular septal defects (VSDs), primarily the perimembranous defects such as balloon mitral commissurotomy, percutaneous pulmonary valve placement, and closure of the left atrial appendage. The use of ICE has also been described during placement of a stent in coarctation of the aorta. In this article, we will describe the use of ICE for the lesions described previously, as well as the future direction of ICE.

**ICE Catheters**

**AcuNav**

The AcuNav catheter (Biosense Webster, Inc., Diamond Bar, CA) is available in two sizes with 8- and 10.5-F shafts. It works with Sequoia, Cypress, or Aspen imaging systems, all of which are manufactured by Siemens Medical Solutions USA, Inc. (Malvern, PA). The frequency of the transducer varies from 5.5 to 10 MHz.

**ClearICE**

The ClearICE device (St. Jude Medical, Inc., St. Paul, MN) is in the early stages of testing in humans and is a steerable catheter (± 140°) with bidirectional steering and curvature. It works with the Vivid i system (GE Healthcare Technologies, Wauwatosa, WI). However, it is unclear whether this catheter will become available in the open market.
The ViewFlex Plus (St. Jude Medical, Inc.) was developed in association with Philips Medical Systems (Bothell, WA) and is a steerable catheter via two-way articulation and runs on the ViewMate ultrasound system (EPMedSystems, Inc., Berlin, NJ). It has a frequency of 4.5 to 8.5 MHz, with an imaging depth of 12 cm. The ViewFlex PLUS appears to be somewhat similar to the AcuNav catheter in that the catheter can be rotated axially and steered in anterior and posterior directions; however, it cannot be steered leftward or rightward.

**CLOSURE OF ATRIAL-LEVEL COMMUNICATIONS**

The use of ICE is most common in interventional treatment of ASD and PFO. The probe is advanced through the femoral vein into the right atrium. Due to catheter rigidity, we recommend using fluoroscopy while advancing the catheter from the femoral vein to the right atrium. This is also important because the catheter tip may get stuck inside the branches of the venous system, increasing the chances of potential injury as the catheter is being advanced. For patients who weigh 77 lbs or less, we use bilateral femoral venous access. For patients who weigh more than 77 lbs, the ipsilateral vein can be used for the ICE probe and device delivery sheath. Two separate punctures are recommended.

Once the catheter is in the right atrium, a first look at the heart is performed. A typical starting location is the home view (Figure 2A). The home view shows the tricuspid valve, the right ventricle, the right ventricle inflow and outflow tracts (RVOT), the aortic valve and the anterior part of the atrial septum, the pulmonary valve, and the proximal part of the pulmonary artery. Tricuspid regurgitation and pulmonary insufficiency can
be evaluated in this view by performing color Doppler echocardiography. The catheter is rotated clockwise to view the left atrium, left atrial appendage, mitral valve, pulmonary veins, and finally, the proximal descending aorta. Once this scan is complete, the catheter is rotated counterclockwise until the atrial septum is in view again. At this time, the catheter can be locked, and the posterior tilt is performed. With a very mild posterior tilt, the atrial view (also called septal view) is achieved (Figure 2B). The atrial view delineates the left atrium, part of atrial septum, and the right atrium and is an important view because the superior rim can be evaluated with the catheter in this position. Further posterior tilt, cephalad advancement, and right tilt will provide the interventionalist with a bicalval view (Figure 2C). In order to see the inferior vena cava (IVC) rim, the catheter may have to be pulled out, whereas to further interrogate the superior vena cava (SVC) rim, it may have to be advanced in. The aortic short-axis view can be obtained by using the right/left knob on the catheter (Figure 2D). In addition, the entire catheter may have to be rotated clockwise for better visualization of the aortic short-axis view. The short-axis view is crucial in evaluating the aortic and posterior rims. The short-axis view is crucial in evaluating the aortic and posterior rims. A device that is stable in bicalval and aortic short-axis views assures the interventionalist that the four atrial septal edges (aortic, posterior, SVC, and IVC) are sandwiched by the device discs. The relationship of the device to the tricuspid valve and to the atrioventricular valve rim can be evaluated in the home view. Evaluation of the mitral valve after device placement can sometimes be cumbersome. But it can, nevertheless, be evaluated by unlocking the catheter and turning it in a clockwise rotation (Figures 3 through 5). The device should only be released after ensuring that the discs are not impinging on the atrioventricular valves and the device is properly seated. For a detailed review of the atrial septal rims nomenclature, the reader is referred to one of our previous publications.4

All devices tend to conform to the atrial septum after release, with changes in the angle and position of the device. Therefore, after releasing the device, we strongly recommend evaluating device stability before completing

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**Figure 3.** Atrial view with the catheter and wire in the left upper pulmonary vein. The fluoroscopic image (A); delivery catheter across the defect (B); and the device inside the sheath (C).

**Figure 4.** Balloon sizing of the defect. Fluoroscopic measurement of the stop-flow diameter (A). Sizing balloon across the defect (B). Slow and gentle balloon inflation to achieve stop-flow diameter (C, D). Stop-flow diameter of the ASD achieved (E).
Figure 5. Steps involved in Amplatzer septal occluder (AGA Medical Corporation, Plymouth, MN) deployment. The top frames are fluoroscopic images, and the bottom frames are the corresponding ICE images: deployment of the left disc in the left atrium (A); deployment of the device in atrial view (B); and deployed device in short-axis aortic view (C).

Figure 6. Interrogation of the device after release. The key points to remember are to evaluate at least four atrial septal rims and confirm that they are sandwiched between the two discs of the Amplatzer device. Caval view demonstrating SVC and IVC rims (A) and aortic short-axis view demonstrating the aortic and posterior rim (B).
the procedure (Figure 6). For deployment and postdeployment assessment of the Helex septal occluder device, please see Figure 7.

**CLOSURE OF VENTRICAL SEPTAL DEFECTS**

Use of ICE for muscular VSD has not been described, and at the current time, transesophageal echocardiography (TEE) is the ideal imaging technique to monitor VSD closure. ICE can also aid closure of perimembranous VSD in addition to TEE. ICE catheter manipulation can be much different—and perhaps a little more complicated—when closing perimembranous VSDs. If the patient has a concomitant PFO or ASD, the catheter can be advanced through the PFO into the left atrium. In fact, in our first case the catheter was advanced through an existing PFO into the left atrium. The images obtained with the catheter in the left atrium are similar to TEE images. However, if the ICE probe is in the right atrium, the home view will delineate the membranous portion of the ventricular septum; the defect can be easily seen and measured. A short-axis view is then obtained to measure the defect in orthogonal view. An appropriately sized device can be placed under ICE monitoring. It should be noted that there is currently no approved device available to close perimembranous VSD in the United States.

**BALLOON MITRAL VALVULOPLASTY**

Under ICE guidance, a transseptal puncture is performed while visualizing the atrial septum. The septum is best visualized with catheters in the neutral position with slight posterior and rightward rotations. The mitral valve can be assessed by clockwise rotation of the ICE catheter until the mitral valve is visualized. Alternatively, the ICE probe can be advanced into the right ventricle to assess the mitral valve. Balloon valvuloplasty and gradient assessment can be performed with the help of the ICE catheter. It is important to become comfortable in manipulating the ICE catheter before advancing the catheter into the ventricle. The interventionist must learn to be an echocardiographer and should be skilled in manipulation and interpretation of the images. The presence of an expert echocardiographer in the laboratory can be very helpful for interventionists who are considering starting the ICE program (Figure 8).

**BALLOON PULMONARY VALVULOPLASTY**

ICE use may be helpful in performing balloon pulmonary valvuloplasty in obese patients when conven-
tional images are not adequate to measure the pulmonary valve annulus. The home view yields excellent images of the tricuspid valve, RVOT, and pulmonary valve. In addition, the catheter can be advanced into the right ventricle to best visualize the RVOT. Measurement of the pulmonary valve annulus has been very accurate in our experience. Evaluation of the pre-valvuloplasty and post-valvuloplasty gradient is helpful

Figure 8. Images obtained during balloon mitral valvuloplasty (A through H). Views obtained from the right atrium without color (A) and with color (B) using Doppler of the mitral valve demonstrating restricted movement of the valve. Mitral valve inflow gradient of 12 mm Hg (C). Transseptal puncture and passage of the Inoue (Toray Industries, Inc., Tokyo, Japan) balloon dilator into the left atrium (D through F). Wire advanced into the left atrium (G). Tip of the Inoue catheter near the mitral valve (arrow) (H). Balloon across the mitral valve with progressive dilation across the mitral valve annulus (arrows) (I through P). This is followed by reassessment of the mitral valve, gradient, and regurgitation. The gradient has improved (N) and absence of significant regurgitation is shown (O). The final frame shows the residual atrial communication after removal of the sheath from the atrial septum (P).
Figure 9. Use of ICE while placing the Edwards Sapien transcatheter heart valve (Edwards Lifesciences, Irvine, CA) in the pulmonary position. The ICE interrogation is similar to the evaluation that is performed during pulmonary stenosis. Views form the RVOT without color (A) and with color (B) Doppler showing a previously implanted stent in RVOT homograft. Note the presence of severe regurgitation. Balloon dilation of previously placed stent (C, D). Placement of the Edwards Sapien valve (E, F). Color flow evaluation showing unrestricted flow (G) across the valve and no pulmonary insufficiency (H).

Figure 10. ICE evaluation for occlusion of the left atrial appendage. Measurement of the ostium of the left atrial appendage (A). Catheter inside the left atrial appendage (B). Cineangiography after placement of the catheter in the left atrial appendage (C). Device placement in the left atrial appendage (D). Position of the Amplatzer device in the left atrial appendage as seen by fluoroscopy (E). Color flow evaluation by ICE of the device (F). The left pulmonary vein (red flow) can be seen clearly.
in deciding whether further valvuloplasty is required during the same setting.

**PERCUTANEOUS PULMONARY VALVE PLACEMENT**

ICE has been utilized by us and others to aid in the placement of the percutaneous pulmonary valve. ICE is not mandatory in this procedure, but it can act as an accessory guide to the interventionist during the entire procedure; the preprocedure stenosis and regurgitation can be measured accurately. Paravalvar leaks and the competency of the valve can be evaluated easily after placement of the valve (Figure 9).

ICE USE AS A TEE PROBE

In small infants, TEE probe insertion is contraindicated due to various reasons (size of the esophagus, surgery for tracheoesophageal fistula, etc.). The ICE probe can be advanced into the esophagus for monitoring ASD closure and also for diagnostic purposes. The drawback of ICE in small infants is that the angle of the anterior-posterior tilt is wide, and hence the maneuverability of the probe is very limited; the image essentially becomes single-plane.

ICE DURING CLOSURE OF THE LEFT ATRIAL APPENDAGE

We know that ICE is valuable during transseptal puncture of the atrial septum; however, ICE may also be valuable to assist in placement of devices in the left atrial appendage. We believe that ICE is very helpful in assessing the size and shape of the left atrial appendage. During placement of the device, ICE can accurately assess the position of the device in the appendage and its relationship to the mitral valve, and it can acutely warn us of complications such as tamponade. With the recent introduction of the Amplatzer cardiac plug (AGA Medical Corporation) (not yet approved in the US) for occlusion of the left atrial appendage, we believe that ICE will play an important role in this intervention. Figure 10 clearly demonstrates that ICE is a valuable tool during the procedure. We used the Amplatzer septal occluder device to occlude the appendage. This is an off-label use of the device, and the procedure was performed at our own discretion without approval of the manufacturer. For ideal images of the left atrial appendage, the catheter can be advanced through either an already existing atrial communication or after performing transseptal puncture. Alternatively, images can also be obtained from the right atrium by placing the ICE catheter close to the atrial septum.

ICE USE IN THE COARCTATION OF THE AORTA

Some physicians have stated that ICE can be helpful in providing images of the coarctation lesion during stenting coarctation of the aorta (Carlos Ruiz, oral communication, June 2007). The ICE probe can be placed in the innominate vein or in the left pulmonary artery. At this time, however, we do not have experience using ICE for coarctation interventions.

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