Real-Time Three-Dimensional Transesophageal Echocardiography in Transcutaneous, Catheter-Based Procedures for Repair of Structural Heart Diseases

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Current Cardiovascular Imaging Reports 2009, **2**:xx–xx
Current Medicine Group LLC ISSN 1941-9066

We review the use of real-time three-dimensional transesophageal echocardiography (RT3D-TEE) in guiding percutaneous catheter-based procedures to repair structural heart defects. The utility of this novel imaging technique in percutaneous mitral valve repair and valvuloplasty, aortic valve insertion, device closure of atrial and ventricular septal defects, obliteration of the left atrial appendage, and pulmonary vein ablation is described. The main advantages of RT3D-TEE lie in its ability to visualize the entire length of intracardiac devices, including their tips, and to demonstrate their relationship to cardiac structures, to provide en face views of cardiac structures (such as the interatrial septum and the mitral valve) that are unobtainable in real time by any other imaging technique, and to allow for continuous monitoring during the procedure. It is likely that RT3D-TEE will become the standard of care for guidance of percutaneous, catheter-based procedures.

Introduction

Transcutaneous, catheter-based repair of congenital or acquired cardiovascular defects has been challenging the invasive cardiology community for the past half century. Although the most obvious advances were achieved in percutaneous coronary intervention and angioplasty of other arteries, there have been many recent attempts to repair structural heart defects.

In the beginning, this attempt was led by pediatric cardiologists, who used interatrial balloon septostomy as the initial treatment in newborns with transposition of the great vessels [1]. Later, improvements in catheters, devices, and technical skills resulted in a plethora of transcatheter procedures that could successfully replace open-heart surgery and provide similar or even better results without the pain and risk of thoracotomy and cardiopulmonary bypass.

These procedures also decreased the length and the costs of hospitalization. Some of them (eg, mitral balloon valvuloplasty for mitral stenosis or closure of secundum atrial septal defect [ASD]) have already become the standard of care. Others (eg, transcutaneous aortic valve replacement for aortic stenosis or transcatheter mitral annuloplasty and mitral clipping for mitral regurgitation) are still considered experimental. However, the state of the art is moving rapidly, fueled by clinical needs, imagination, ingenuity, courage, and by industrial and economic drives.

Imaging has always been an essential part of any transcatheter procedure. Historically, cardiac catheterizations under fluoroscopy and contrast angiography were considered the gold standard in the diagnosis of structural heart defects and in the catheter guidance to the site of lesion. Although this radiologic technology is still in routine use, it suffers from poor depth resolution and inability to differentiate between various soft tissues. It frequently requires the use of toxic radio opaque contrast and exposes the patient to ionizing radiation.

Several modalities of echocardiographic images have been added to the imaging armamentarium of transcatheter procedures. Two-dimensional (2D) modalities include transthoracic echocardiography (TTE), intracardiac echocardiography (ICE), and transesophageal echocardiography (TEE). Although TTE is totally noninvasive,

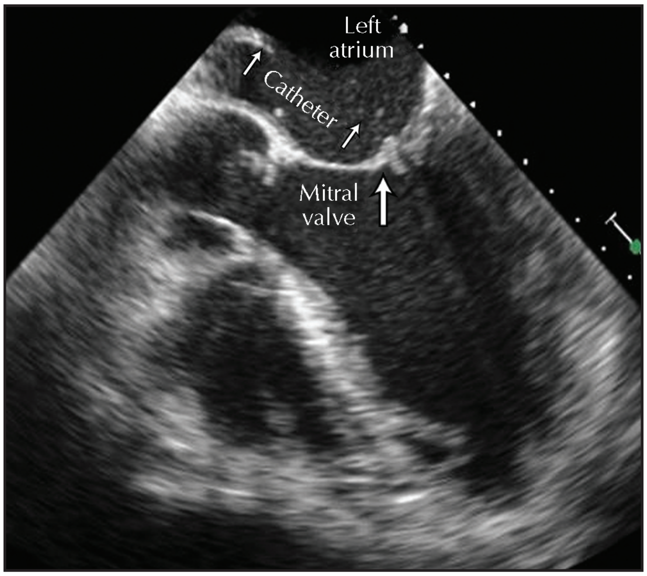

Figure 1. Two-dimensional (2D) transesophageal echocardiogram (TEE) obtained during mitral valve clipping. Although in reality the guiding catheter enters the left atrium across the interatrial septum and traverses the mitral valve, on this 2D-TEE, the most distal portion of the catheter and its tip are barely visible.

the image quality is frequently suboptimal, especially during catheterization procedures that do not allow a change in patient position for image optimization.

ICE is invasive. The 2D transducer is mounted on an 8- to 10-F catheter, which is advanced intravenously to the right heart to provide images of selected cardiac structures. The procedure is well tolerated by patients and does not require additional sedation. Although the image quality is good, ICE catheters are monoplane transducers that provide only a limited number of imaging planes. Furthermore, the transducers are disposable and are quite expensive (over $2000).

2D-TEE has been used extensively during transcatheter procedures. The imaging planes are unlimited, and the image quality is good. However, the esophageal intubation and the presence of the transducer in the esophagus are frequently unpleasant, and require extra sedation or even general anesthesia. Although all the 2D modalities have improved our ability to visualize the details of cardiac anatomy and to evaluate intracardiac blood flow by Doppler techniques, they suffer from a limitation that interferes with imaging during transcatheter procedures. This limitation is related to the tomographic nature of the 2D images. Intracardiac catheters move in a three-dimensional (3D) environment, and frequently their course takes them away from the imaging plane. Therefore, the course of the catheters and particularly their tips may not be accurately assessed (Fig. 1). In addition, 2D echocardiography frequently does not show an en face view of a structure, the way it is seen by anatomists or surgeons.

Real-time 3D (RT3D) echocardiography is a recently developed technique and is being increasingly used in echocardiography and cardiac catheterization laboratories [2••]. Over the past several years, improvements in transducer technologies have led to the development of a full-matrix array transducer that acquires pyramidal-shaped datasets. These datasets can be processed online and offline to allow accurate evaluation of cardiac structures, volumes, and mass. More recently, a transesophageal transducer with RT3D capabilities has been developed; it is capable of acquiring high-quality RT3D-TEE images.

The full-matrix array transducers are capable of three different types of data acquisition:

1. *Narrow-angle acquisition*, which generates real-time images at frame rates of 10 to 26 Hz. This acquisition mode is suitable for visualization of structures that are in the far zone of the ultrasound beam (eg, vegetations on right atrial pacemaker wires). Images are displayed in real time and can be rotated in all directions to allow visualization of the cardiac structures from many angles. However, this mode does not allow color Doppler imaging.
2. *3D zoom mode*, in which a truncated pyramidal dataset is generated. The dimensions of this sector can be manually adjusted to display the region of interest. The image can then be rotated in all three axes, allowing visualization of the imaged structure from all angles and views. In this mode, the frame rate usually is low (< 10 Hz), thus lowering temporal resolution. This mode is suitable for structures that are in the near zone of the ultrasound beam and can be imaged at a near-perpendicular angle to the ultrasound beam. Examples include the mitral valve, the interatrial septum, and the orifice of the left atrial appendage (LAA). This mode does not support color Doppler imaging.
3. *Wide -angle acquisition full-volume mode*, in which a larger dataset is acquired in a pyramidal block, allowing larger volumes of cardiac structures to be displayed. This mode requires electrocardiographic gating, and data acquisition is performed over four to seven cardiac cycles. Of note, in this mode, lateral resolution deteriorates when compared with the narrow-angle acquisition mode. However, the temporal resolution is higher compared with the narrow-angle mode (up to 30–40 Hz). The full-volume dataset is amenable to further processing (online or offline) with cropping along any plane, thus allowing for visualization of all structures captured in the pyramidal dataset. This mode is suitable for structures that are in either the far zone or the near zone of the ultrasound beam. It is also capable of color Doppler imaging; a full-volume acquisition over seven cardiac cycles is required. The temporal resolution in color Doppler mode is up to 25 Hz.

These three different imaging modes make detailed anatomic evaluation as well as accurate volumetric assessment of cardiac structures and chambers possible. Use of RT3D-TEE allows for acquisition of high-resolution 3D

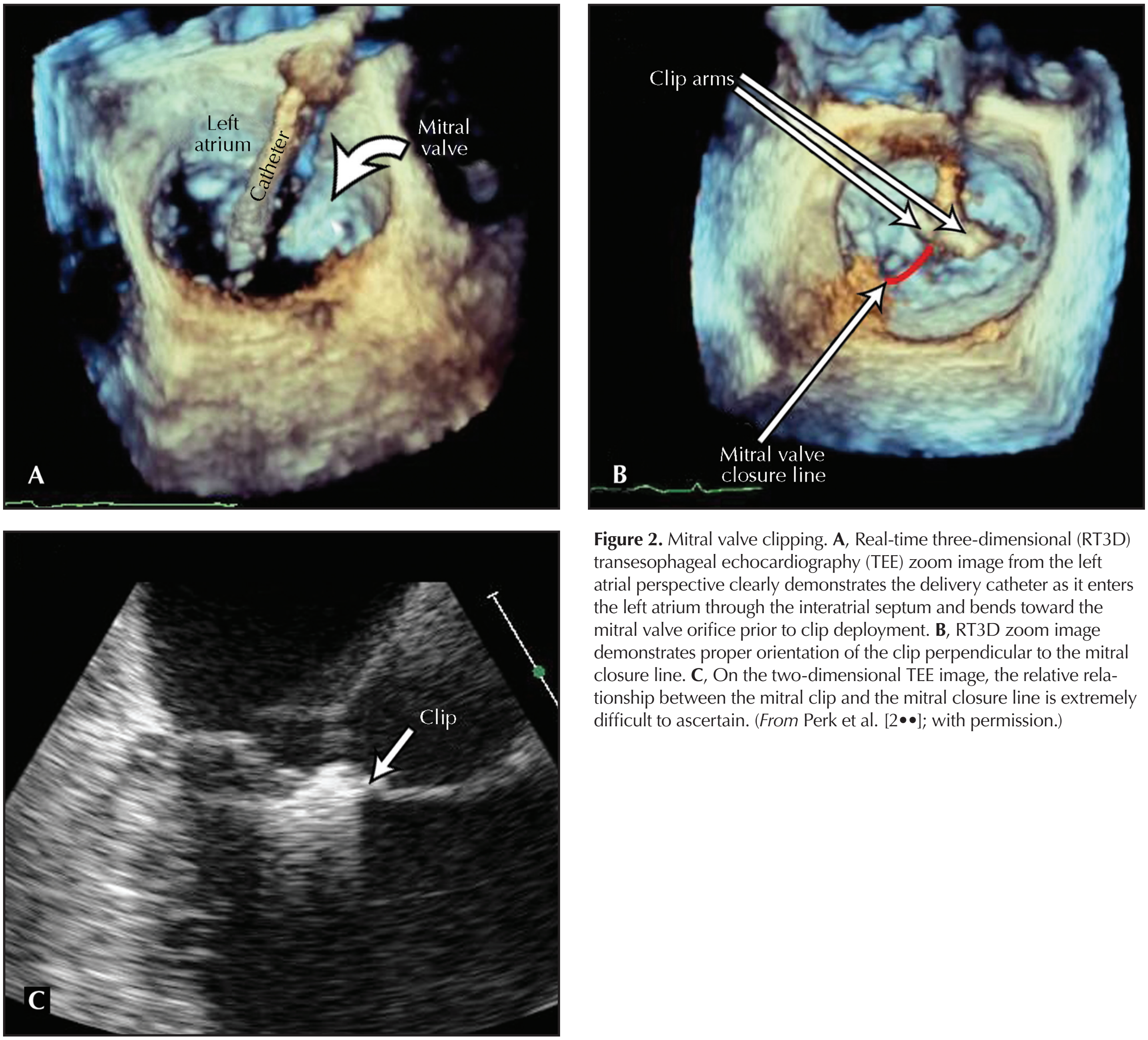

Figure 2. Mitral valve clipping. **A**, Real-time three-dimensional (RT3D) transesophageal echocardiography (TEE) zoom image from the left atrial perspective clearly demonstrates the delivery catheter as it enters the left atrium through the interatrial septum and bends toward the mitral valve orifice prior to clip deployment. **B**, RT3D zoom image demonstrates proper orientation of the clip perpendicular to the mitral closure line. **C**, On the two-dimensional TEE image, the relative relationship between the mitral clip and the mitral closure line is extremely difficult to ascertain. (*From* Perk et al. [2••]; with permission.)

images of intracardiac structures. It also permits visualization of structures en face and from other angles that cannot be obtained by 2D echocardiographic modalities. More importantly, real-time images of the entire intracardiac course of the catheters can be monitored throughout transcatheter procedures. The accurate anatomic relations between the catheter and the device it carries and the target cardiac structure can be assessed continuously. The interventionalist can use 3D images to guide a transcatheter procedure and evaluate its results [3].

This review describes the use of RT3D-TEE in selected transcatheter procedures.

Valvular Heart Disease

Mitral valve clipping

Mitral valve clipping (MVC) is an experimental catheter-based approach for the treatment of mitral regurgitation. It entails placement of a "clip" at the tips of the mitral valve leaflets and creation of an edge-to-edge repair, resulting in a double-orifice mitral valve [4]. MVC offers a treatment alternative to patients who are considered high risk for standard surgical repair [5].

The procedure is performed via a central venous approach and a transseptal puncture. Where the trans-septal puncture is performed is very important because proper location of transseptal puncture increases the likelihood of successful clip deployment at the mitral valve leaflet tips.

The clip is deployed through the guiding catheter (Fig. 2A) and positioned in such a way that the clip arms are perpendicular to the mitral valve closure line (Fig. 2B). The mitral leaflets are then grasped, and the severity of mitral regurgitation is assessed prior to final deployment of the clip. RT3D-TEE provides a detailed anatomy of the mitral valve, including individual scallops of both valve leaflets [6•]. 3D zoom mode is particularly valuable because it provides an en face view of the mitral valve from the left atrial perspective

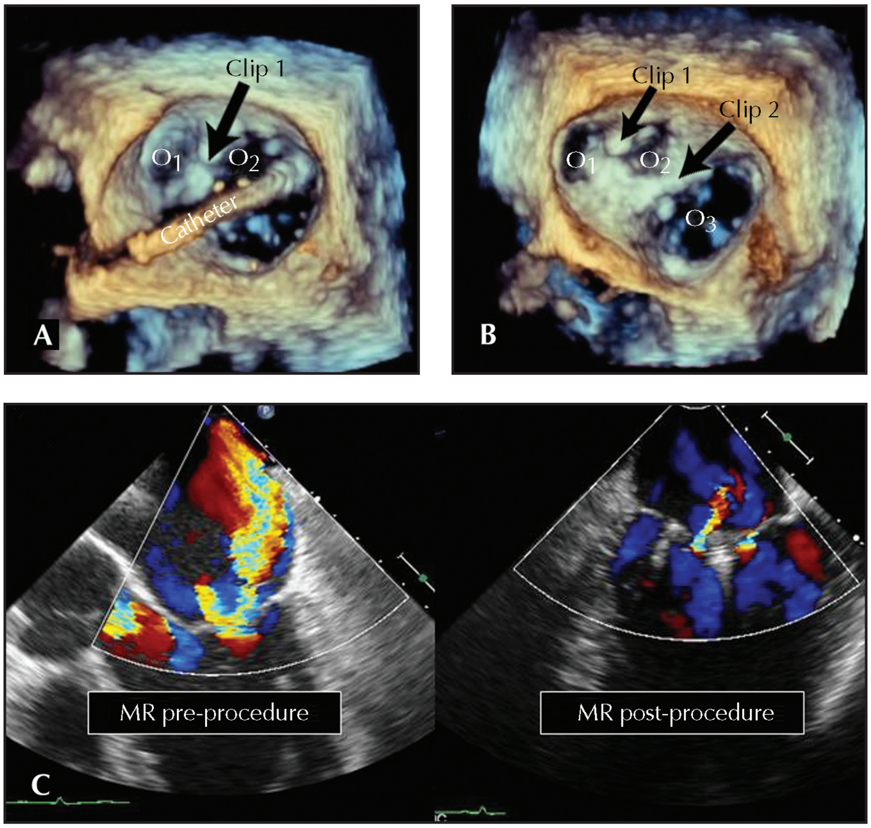

Figure 3. Mitral valve clipping using two clips. **A**, Real-time three-dimensional (RT3D) zoom image from the left atrial perspective demonstrates that clip 1 has already been deployed. The mitral inlet now consists of two orifices: O_1 and O_2. A delivery catheter carrying clip 2 is seen over the orifice O_2. **B**, RT3D zoom image obtained after the deployment of the second clip. Now the mitral valve has three orifices: O_1, O_2, and O_3. **C**, Two-dimensional color Doppler transesophageal echocardiography image demonstrates mitral regurgitation (MR) before clipping (*left*) and after placement of the second clip (*right*). (*From* Perk et al. [2••]; with permission.)

(the so-called "surgical view"). Such a view cannot be obtained by any other imaging technique.

When compared with 2D imaging, RT3D-TEE provides better visualization of all the catheters, guides, and device assemblies, as well as the clip itself. Because in RT3D imaging the entire length of the guiding catheters and devices is continuously monitored, their optimal positioning is enhanced. The position of the catheters and devices relative to pertinent cardiac structures (such as the LAA and mitral valve annulus) can be shown in a single frame, which permits precise guidance to the interventionalist in proper placement of the clip. It is much easier to ascertain that the clip is placed perpendicular to the closure line of the mitral valve by RT3D than by 2D imaging techniques (Fig. 2B and Fig. 2C). On 2D-TEE, clip orientation relative to mitral valve closure line usually requires transgastric views, which on occasion are difficult to obtain.

Occasionally, placement of a second clip may be required if echocardiography reveals significant residual mitral regurgitation. RT3D imaging provides simultaneous visualization of the already deployed clip and facilitates accurate placement of the second clip (Fig. 3).

Mitral balloon valvuloplasty for mitral stenosis

Percutaneous mitral balloon valvuloplasty (PMBV) is considered the technique of choice for the treatment of selected patients with mitral stenosis [7]. 2D-TTE and TEE have been used prior to and during the procedure to accurately assess the severity of the stenosis [8]. It was also used to assess the mitral valve score and the feasibility of valvuloplasty (high scores are associated with lower success rates) [9]. TEE has also been used to evaluate the possibility of left atrial clots, which are considered a contraindication for PMBV [10].

3D-TTE is now considered the noninvasive modality of choice for the assessment of mitral stenosis severity (Fig. 4A). In patients with mitral stenosis, the shape of the left ventricular inflow resembles a funnel, which has its narrowest orifice area at its left ventricular end. Using 3D echocardiography, one can select the narrowest orifice and accurately measure its area.

PMBV is performed via a central venous approach and a transseptal puncture. A balloon is introduced through a guiding catheter into the mitral valve orifice and then inflated in an attempt to create a controlled commissural tear.

2D-TEE is often used to help guide this procedure [11]. This imaging technique is used to guide the transseptal puncture and the positioning of the balloon between the mitral valve leaflet tips prior to balloon inflation. This modality is useful to assess the presence of complications and severity of mitral regurgitation post-inflation that can be created by mitral valve tear. Doppler echocardiography can provide information about the transvalvular gradient and grade mitral regurgitation (if any).

Guiding of the transseptal puncture can be optimized by using RT3D-TEE [12]. Visualization of the transseptal puncture needle tip provides better selection of the puncture site. After the puncture, the entire length of the left atrial portion of the guiding catheter can be visualized. This allows clear delineation of the spatial orientation of

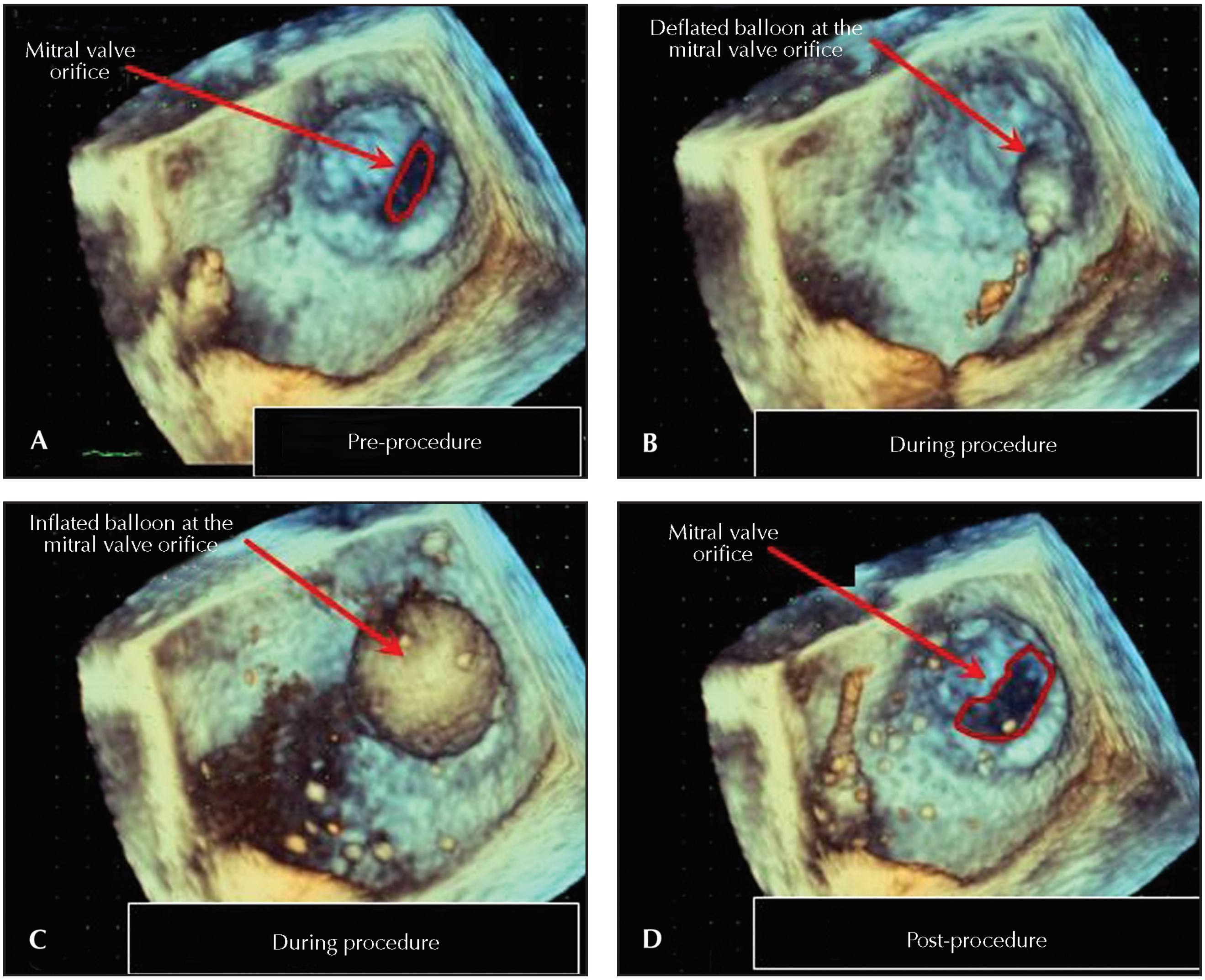

Figure 4. Percutaneous mitral balloon valvuloplasty (PMBV). All images represent real-time three-dimensional (RT3D) zoom view ("surgical view") from the left atrial perspective. **A**, RT3D zoom view demonstrates the shape of the stenosed mitral orifice prior to PMBV. **B**, Deflated valvuloplasty balloon is seen being positioned inside the stenosed mitral orifice. **C**, Inflated valvuloplasty balloon (*arrow*) stretches the mitral orifice. **D**, After PMBV, the orifice of the mitral valve has increased in size.

the catheter and the balloon in the left atrium, and their relation to the mitral valve orifice.

Localization of the balloon in the mitral valve orifice can be achieved using the 3D zoom mode (Fig. 4B). The narrow portion of the balloon is placed through the tips of the mitral valve leaflets. The location is then confirmed by examining the balloon position from several angles by rotating the image, thus obviating the need for changing the imaging angles or adjusting the probe position. Immediately following balloon inflation (Fig. 4C), the mitral valve is inspected to determine if commissural splitting has been achieved, and to assess the increment in the mitral orifice area (Fig. 4D). RT3D imaging can also provide information about potential complications (eg, leaflet tear that, unlike commissural splitting, is perpendicular to the long axis of the mitral orifice). Post-PMBV, mitral regurgitation is a known potential complication. Its mechanism, site, and severity can be assessed by full-volume 3D-TEE.

Percutaneous closure of prosthetic valve dehiscence

Prosthetic valve dehiscence is a common complication of valve replacement surgery. It is estimated that 30% of all prosthetic valve regurgitations are associated with dehiscence. Prosthetic valve dehiscence results in paravalvular regurgitation, which may be severe and can result in heart failure symptoms and hemolysis. The latter can complicate even a very small paravalvular leak.

Until recently, this complication has been treated by repeat open heart surgery to repair the leak, and not infrequently, re-replacement of the prosthetic valve. These reoperations carry a significant risk and suffering to the patient.

A novel percutaneous approach has been attempted to correct these complications [13]. It involves implantation of an occlusion device in the dehisced portion of the mitral or aortic prosthetic valve [14]. In mitral valve dehiscence, the catheter approach to the dehiscence site in most cases is antegrade, using transseptal puncture. Occasionally, the

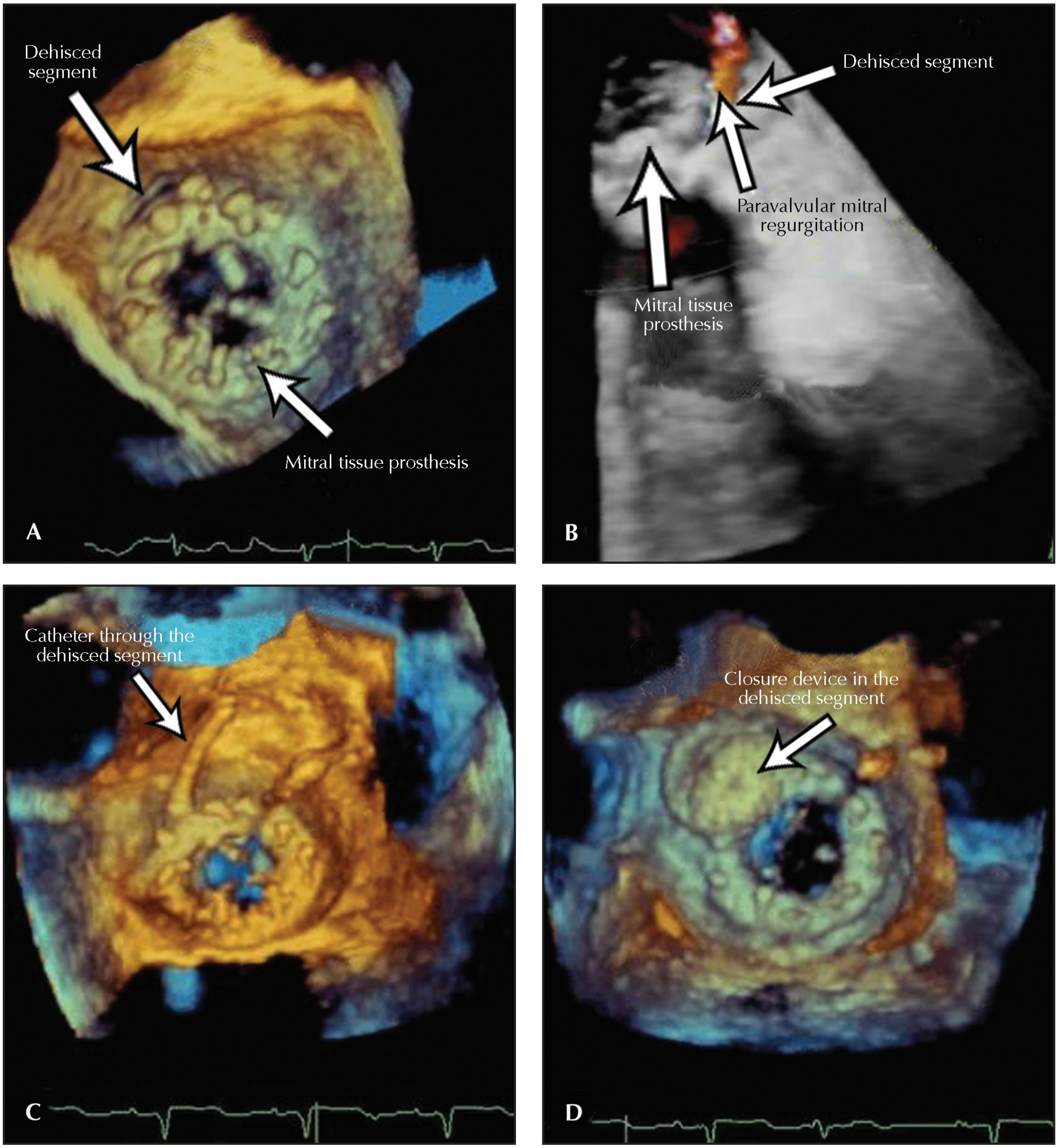

Figure 5. Percutaneous closure of prosthetic valve dehiscence. **A**, Real-time three-dimensional (RT3D) transesophageal echocardiography zoom view from the left atrial perspective demonstrates the precise location and shape of the dehisced segment. **B**, Full-volume color RT3D image shows paravalvular mitral regurgitation due to prosthetic valve dehiscence. **C**, RT3D zoom imaging from the left atrial perspective is used to guide the catheter to the dehisced segment. **D**, RT3D zoom image demonstrates the atrial side of the closure device plugging the dehisced segment.

retrograde approach is preferred, and the dehiscence site is reached via the left ventricle using arterial puncture or even direct percutaneous left ventricular apical puncture.

2D echocardiography can demonstrate paravalvular regurgitation, but usually cannot demonstrate its exact location, size, and shape. This information is essential for the closure procedure. Using the 3D zoom mode, a "surgical" view of the mitral prosthesis can be obtained (Fig. 5A), with clear definition of the location, shape, size, and extent of the dehisced portion [15•]. Full-volume 3D imaging with color Doppler flow imaging (Fig. 5B) enables accurate assessment of valvular regurgitation (paravalvular, transvalvular, or both). This allows identification of patients with suitable anatomy for percutaneous closure

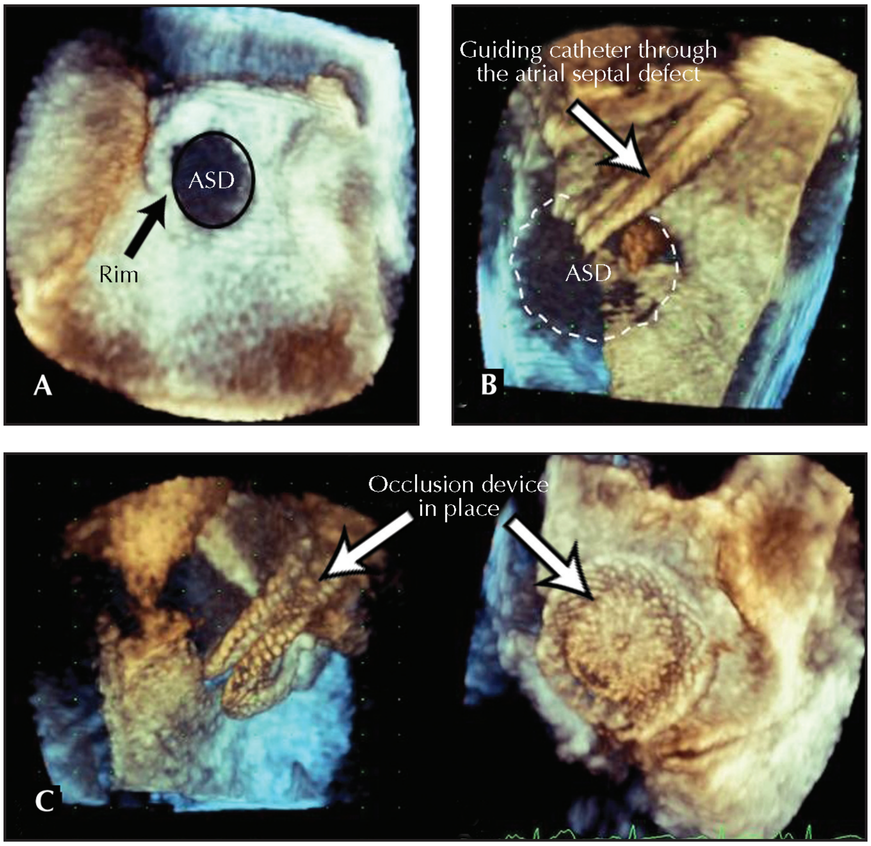

Figure 6. Percutaneous closure of atrial septal defect (ASD). **A**, Full-volume three-dimensional (3D) image with an en face view of a secundum ASD from the left atrial perspective. **B**, Real-time (RT) 3D zoom image is used to guide the catheter used in percutaneous ASD closure. **C**, RT3D zoom image shows that ASD closure device is in place. In the *left panel*, there is a side view of the ASD closure device; the right atrium is to the left of the ASD device. In the *right panel*, the ASD closure device is seen en face from the left atrial perspective.

procedure. Use of RT3D imaging during the closure procedure allows verification of catheter placement through the dehisced segment, avoiding the mitral valve orifice (Fig. 5C). It also enables real-time assessment of the success of the occlusion procedure (Fig. 5D). Occasionally, more than one closure device is required.

Catheter-based aortic valve implantation

In patients with severe aortic stenosis who are not candidates for surgical valve replacement, percutaneous, catheter-based aortic valve implantation (PAVI) is a promising alternative [16]. PAVI is in its infancy, and the issues pertaining to its safety and long-term durability are yet to be determined. PAVI is performed either transfemorally or transapically.

As with other percutaneous procedures, RT3D-TEE is used in both patient selection and intraprocedural guidance. Before the procedure, RT3D imaging allows for precise assessment of the aortic annulus size and the aortic valve morphology. Intraprocedurally, one can use RT3D imaging to continually monitor placement of catheters and devices used in PAVI. Following PAVI, RT3D-TEE is used to evaluate the outcomes of the procedure. It is important to confirm that the orifice of the left main coronary artery remains patent after the aortic valve is deployed.

Cardiac Septal Defects

ASD and patent foramen ovale closure

In suitable patients, percutaneous closure of secundum ASD and patent foramen ovale (PFO) is replacing open-heart surgery as the preferred repair method. Both short- and long-term success rates of percutaneous ASD [17] and PFO [18] closures in such patients are excellent.

Appropriate patient selection for percutaneous device closure is of utmost importance for the procedure's success [19]. RT3D-TEE allows for accurate measurement of the size of the septal defect and the size of the tissue rim that surrounds the defect, as well as for evaluation of the spatial relation between the defect and the aortic valve. These three parameters are crucial in determining if the patient is a candidate for percutaneous ASD or PFO closure, and for choosing the size of the closure device in suitable candidates.

Using the RT3D zoom mode, either the secundum atrial defect or the region of the fossa ovalis can be visualized en face revealing the defect's true size and morphology (Fig. 6A). RT3D-TEE images often demonstrate that the secundum defect is not perfectly round. It may also show fenestrations, tissue strips, and partial membranes within the defect [20]. 2D imaging may underestimate the defect's size because the apparent diameters measured on 2D images are often geometric chords rather than true diameters. In contrast, RT3D-TEE imaging, with its ability to measure true diameters of the ASD, helps avoid inappropriate patient selection for percutaneous ASD or PFO closure.

After the septal defect is sized and deemed amenable to percutaneous repair, a collapsed closure device is deployed via the guiding catheter (Fig. 6B). RT3D-TEE allows for continuous visualization of the tip of the guiding catheter, as well as of the closure device as it is being delivered.

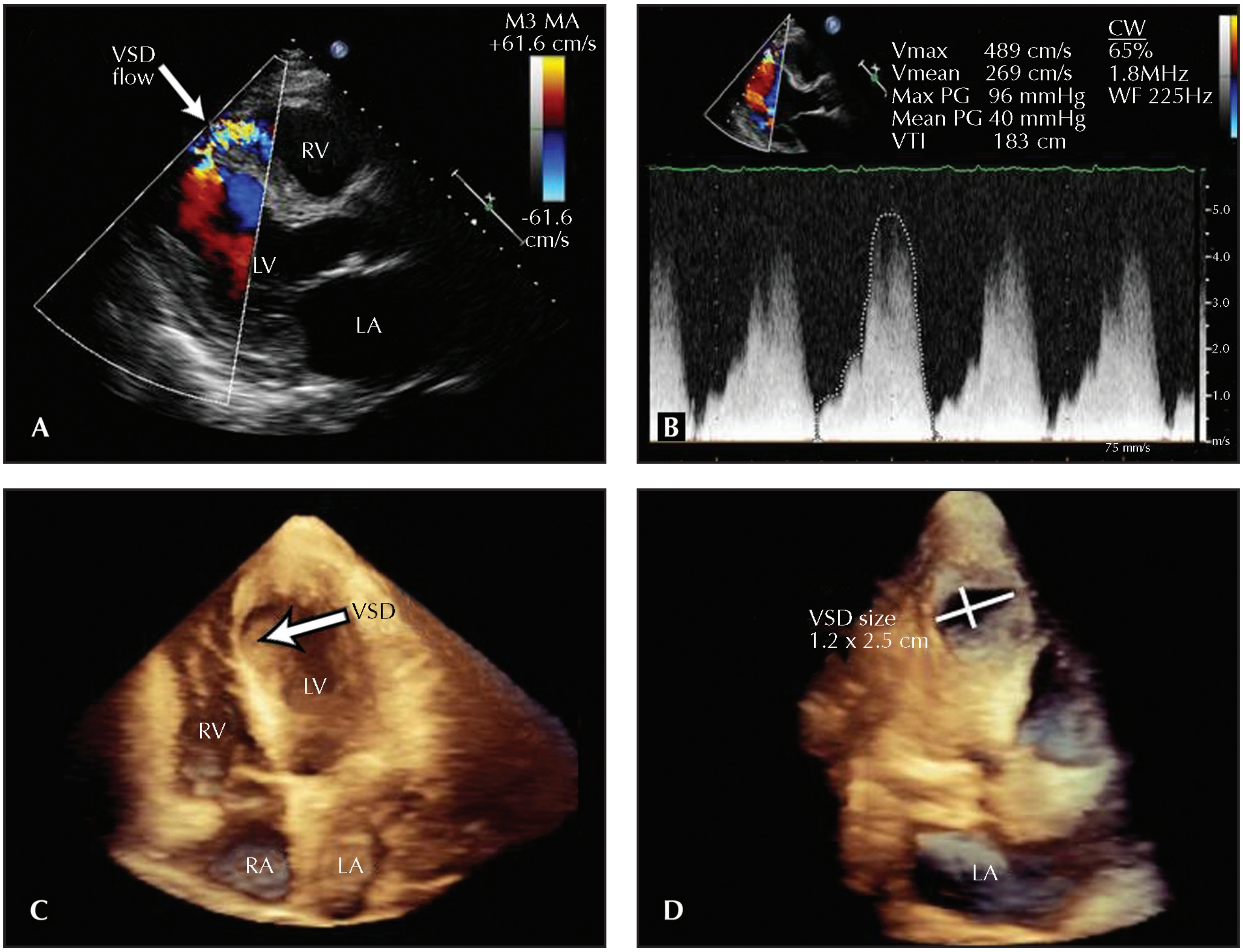

Figure 7. Ventricular septal defect (VSD). **A**, Color Doppler two-dimensional transthoracic echocardiogram in the parasternal long-axis view demonstrates a postinfarction VSD in the apical portion of the interatrial septum. **B**, Continuous-wave Doppler tracing demonstrates a high-velocity flow across the VSD in systole and a lower-velocity flow in diastole. The flow is from the left ventricle into the right ventricle (left-to-right shunt). **C**, Transthoracic three-dimensional (3D) image in the apical four-chamber view shows the location of the postinfarction VSD. **D**, Reconstructed full-volume transthoracic 3D image demonstrates an en face view of the VSD from the left ventricular perspective. LA—left atrium; LV—left ventricle; RA—right atrium; RV—right ventricle. (*From* Halpern et al. [21]; with permission.)

Once the closure device has been expanded and deployed, RT3D imaging is used to ascertain its proper positioning (Fig. 6C). Both the left atrial and the right atrial plate of the device are easily visualized. In addition, RT3D-TEE helps determine if sufficient tissue rim is caught in between the two plates of the device. In case of device malpositioning, RT3D-TEE can be used to guide repositioning of the device. After the device is fully deployed, RT3D-TEE color Doppler imaging is used to verify that no residual blood flow across the device is present.

Percutaneous closure of ventricular septal defect

Traditionally, closure of congenital or acquired ventricular septal defect (VSD) was performed surgically. This operation requires cardiopulmonary bypass and carries a significant risk to the patient. The risk is particularly high in patients with post–myocardial infarction VSD. These patients are frequently hemodynamically unstable. In addition, such a VSD is surrounded by ischemic, friable tissue, which does not permit effective suturing.

Recently, percutaneous, catheter-based closure of VSD has become a nonsurgical option in selected patients [21]. After arterial puncture, a catheter is delivered retrogradely through the aortic valve and into the left ventricle close to the VSD. A separate catheter is advanced to the right ventricle using a central venous approach. This venous catheter is used to snare the arterial catheter. A closure device is then advanced to close the defect [22].

2D echocardiography is frequently used to diagnose the site of the defect (Fig. 7A) and to assess its hemodynamics (Fig. 7B). However, this modality is unable to provide en face view of the defect and therefore cannot demonstrate its exact shape and size.

RT3D echocardiography allows accurate visualization of the defect location, size, and shape (Fig. 7C and Fig. 7D). The information thus obtained is important for a decision about the feasibility of device closure, and aids in

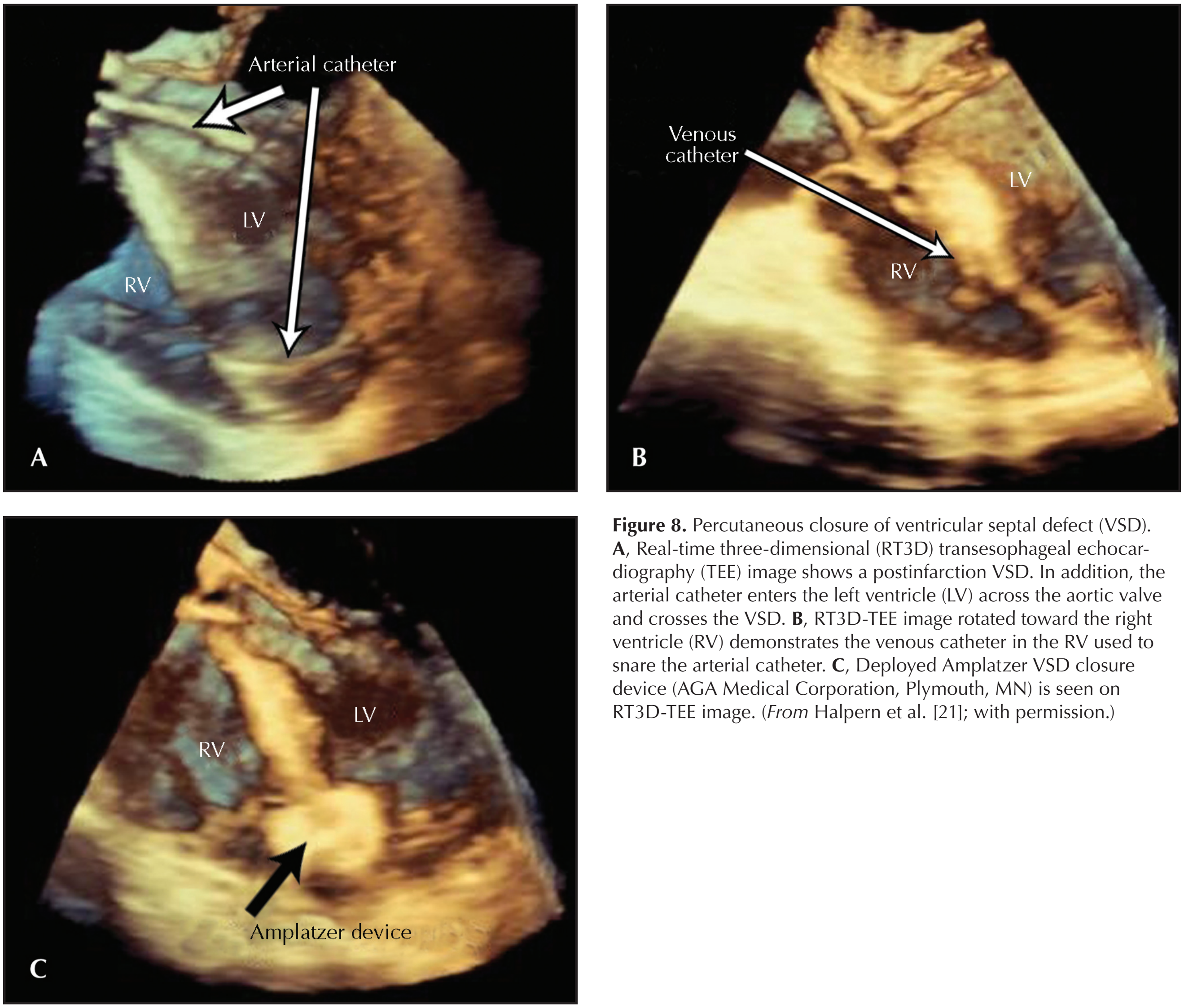

Figure 8. Percutaneous closure of ventricular septal defect (VSD). **A**, Real-time three-dimensional (RT3D) transesophageal echocardiography (TEE) image shows a postinfarction VSD. In addition, the arterial catheter enters the left ventricle (LV) across the aortic valve and crosses the VSD. **B**, RT3D-TEE image rotated toward the right ventricle (RV) demonstrates the venous catheter in the RV used to snare the arterial catheter. **C**, Deployed Amplatzer VSD closure device (AGA Medical Corporation, Plymouth, MN) is seen on RT3D-TEE image. (*From* Halpern et al. [21]; with permission.)

selecting the proper size of the closure device. RT3D-TEE is capable of imaging the entire length of the intracardiac portion of the arterial (Fig. 8A) and venous (Fig. 8B) catheters, and is therefore used to direct the catheters into the defect. It can also guide the accurate positioning and alignment of the closure device and provide immediate assessment of procedural results (Fig. 8C).

LAA Obliteration

The LAA is the most common site of thrombus formation in patients with nonvalvular atrial fibrillation. In addition, LAA clots are commonly seen in patients with mitral stenosis. Anticoagulation is the standard of care for the treatment and prevention of LAA thrombi. In patients who cannot receive anticoagulation, LAA occlusion may be considered as an alternative approach in reducing the embolic risk in such patients. LAA obliteration can be achieved either surgically (by oversewing the mouth of the LAA, for instance) [23] or percutaneously using a closure device [24]. Despite several studies, percutaneous LAA closure continues to be an experimental procedure.

Percutaneous LAA closure is performed via a central venous approach. After transseptal puncture, an introducer is advanced across the interatrial septum and its tip is placed inside the left atrium. In the next step, a pigtail catheter is passed through the introducer and advanced into the LAA. Using the pigtail catheter as a guide, the introducer is then carefully advanced into the LAA. The pigtail catheter is then removed, and a collapsed LAA closure device assembly is passed through the introducer. When the assembly reaches the LAA, the closure device is expanded in order to obliterate the LAA orifice.

As in PMBV, RT3D-TEE in used for both patient selection and procedure guidance. RT3D imaging can be used to accurately visualize the LAA prior to the procedure (Fig. 9A), to demonstrate the intracardiac trajectory of the catheters and introducers, to direct the transseptal puncture, and to guide the placement of the closure device (Fig. 9B).

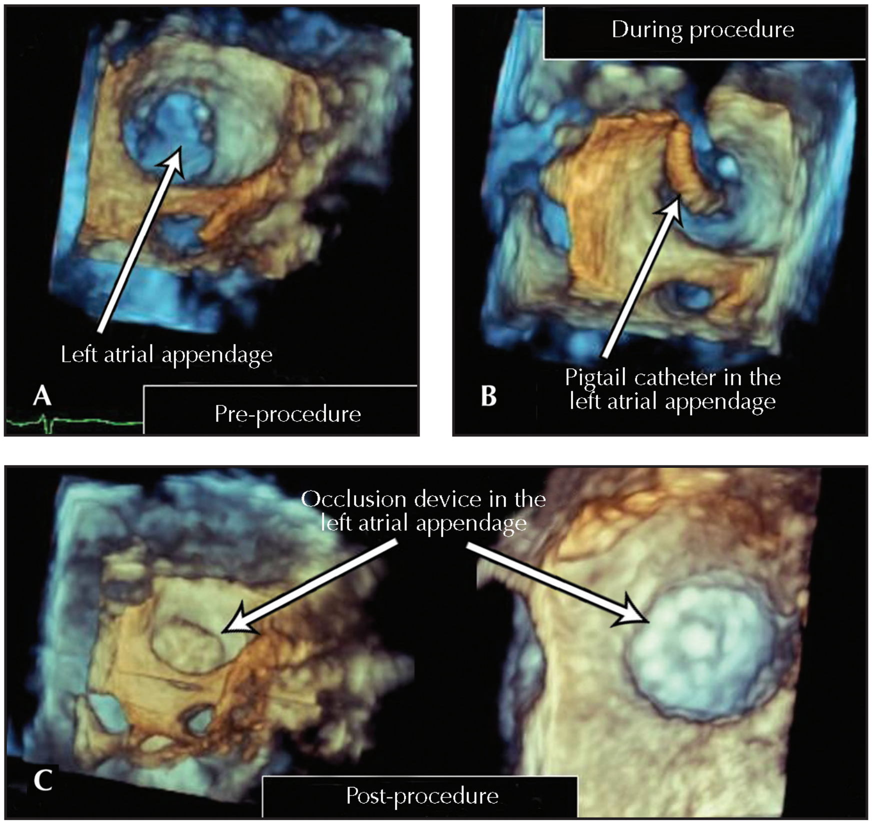

Figure 9. Percutaneous left atrial appendage obliteration. **A**, Real-time three-dimensional (RT3D) transesophageal echocardiography (TEE) en face zoom image of the orifice of the left atrial appendage from the left atrial perspective. **B**, RT3D-TEE image demonstrates proper placement of the pigtail catheter in the left atrial appendage. **C**, 3D-TEE image of a deployed left atrial appendage occluder device; full-volume 3D acquisition is shown on the *left*, and 3D zoom view on the *right*.

The success of device deployment can be assessed in RT3D zoom mode with en face imaging of the closure device at the orifice of the LAA (Fig. 9C). The device is properly placed when its long axis is parallel to the long axis of the LAA. Improper (off-angle) positions of the device are much easier to demonstrate by RT3D than by 2D techniques. RT3D-TEE color Doppler imaging is crucial for ascertaining that no residual communication between the LAA and the left atrium persists after closure device placement. Incomplete obliteration of the LAA orifice has been shown to actually increase the embolic risk. In case of improper device placement, RT3D-TEE is also used to guide recapture and redeployment of the device.

Pulmonary Vein Ablation

In selected patients with either paroxysmal or chronic atrial fibrillation, percutaneous pulmonary vein ablation may offer symptomatic relief and may even obviate the need for long-term anticoagulation [25].

The procedure is performed under fluoroscopic guidance and with the aid of a 3D electrical map of the left atrium superimposed on previously acquired CT or MRI. Neither CT nor MRI images are truly live at the time of pulmonary vein ablation. In addition, both techniques have shortcomings: CT exposes the patient to radiation and potentially toxic iodinated contrast agents; and MRI is time consuming, expensive, and contraindicated in claustrophobic patients and patients with pacemakers or defibrillators.

In some electrophysiology laboratories, ICE is used for additional guidance. However, as noted earlier, ICE is both invasive and expensive. RT3D-TEE is emerging as an alternative to ICE. Utilizing the RT3D zoom mode, one can obtain en face images of the ridge between the LAA and the left-sided pulmonary veins, an area that is important in pulmonary vein ablation procedures [26], and to guide the placement of the radiofrequency catheter in that region.

Other Procedures

RT3D imaging may be useful in monitoring myocardial biopsies and alcohol septal ablation for hypertrophic cardiomyopathy (HCM). During myocardial biopsy, RT3D-TEE may help define the anatomy and guide the deployment of the bioptome tip to the desired region of the heart. This in turn may increase the safety of the procedure and increase the yield for the tissue diagnosis of cardiac rejection, cardiomyopathy, or cardiac tumors.

In HCM, RT3D images may provide the exact location of the septal-leaflet contact, which often is not central but rather displaced medially or laterally within the left ventricular outflow tract. However, RT3D imaging is limited in HCM by the fact that the outcome of alcohol septal ablation may not be evident at the time of the procedure.

Conclusions

RT3D imaging has several advantages over other imaging techniques in guiding percutaneous catheter-based procedures to repair structural heart defects. The primary advantage of RT3D imaging lies in its ability to visualize the entire length of intracardiac devices, including the tips of various catheters, introducers, balloons, and other devices, as well as their relationship to cardiac structures. Another advantage of RT3D imaging is its ability to provide the en face views of cardiac structures of interest to the interventionalist, including the interatrial septum and the mitral valve. Currently, no other real-time imaging technique is capable of such views. Furthermore, 3D rendering of cardiac structures appears more intuitive and more easily understood than multiplane 2D tomographic imaging.

Despite a few limitations (eg, reduced temporal resolution, occasional drop-outs masquerading as cardiac defects), RT3D imaging provides remarkable new insights into cardiac anatomy and pathophysiology.

In summary, we believe that RT3D-TEE will become the technique of choice and the standard of care for guidance of percutaneous, catheter-based procedures. RT3D imaging will likely lead to safer percutaneous procedures because its use may lead to shorter procedure time, and decreased radiation and contrast exposure.

Disclosure

Dr. Kronzon has received grant support from GE Healthcare and has served on the speakers' bureau for Philips. No other potential conflicts of interest relevant to this article were reported.

References and Recommended Reading

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- • Of importance
- •• Of major importance

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