Dynamic Imaging for Structural Heart Disease Interventions

Why three-dimensional image guidance is important in structural cardiac interventions.

BY JOHN D. CARROLL, MD

Imaging for structural heart disease (SHD) interventions can be divided into two major categories. The first category is the use of imaging for the diagnosis and initial planning of the intervention. This is classical diagnostic imaging except that the interventional planning requires assessment of features that are often not described and quantified by the traditional diagnostic interpretation. For example, the length and diameter of a patent ductus arteriosus; the size, shape, and rim tissue of an atrial septal defect (ASD); and the degree of commissural fusion, degree of leaflet and subvalvular deformity, and distribution of calcium in a stenotic mitral valve represent the kinds of quantitative information the interventionist will need to plan the intervention.

A novel extension of preprocedure imaging for planning is the development of rapid prototyping technology (Figure 1). The medical image is transformed by complex image processing into a surface model that has a file structure called *.stl.* This file can then be sent to a variety of commercially available rapid prototyping machines, which then build a physical model of the patient's heart. The materials of the model can range from hard plastic to more compliant materials. These models can be used to plan an intervention and have been shown to be especially useful in complex SHD interventions.[1]

The second major category of imaging for SHD interventions is imaging to guide the intervention itself. *Image guidance* refers to the use of medical images typically acquired in real-time for guidance, navigation, and orientation.[2] There are sequential tasks involved in performing SHD interventions that require image guidance. Often, x-ray imaging is used to navigate delivery systems from a peripheral access point to the heart. X-ray and ultrasound are then used to guide the delivery system to its final location. Imaging is used to deliver or deploy a device. Finally, imaging is used to assess the results.

Figure 1. Physical model of a heart from a patient with mitral stenosis. The patient had a cardiac CTA, which was processed into an .stl file to allow for printing of the model in a rapid prototyping machine. There is a cutaway that allows examination of the left ventricle and mitral valve apparatus (in red). This is a unique use of three-dimensional (3D) images to plan for SHD interventions.

WHY IS 3D IMAGING IMPORTANT IN SHD?

First, the target of the intervention is often not seen by two-dimensional (2D) fluoroscopy because the target is usually a soft tissue structure, such as a heart valve or a septal defect. Second, the target is not a linear tube but often a more complex structure in 3D space. Imaging using 2D fluoroscopy or traditional transesophageal echocardiography (TEE), transthoracic echocardiography (TTE), and intracardiac echocardiography produces either flat projection images or planar cut sections of the 3D target. Although all current SHD interventions can be performed using these 2D modalities, the reconstruction of the 3D target must occur in the brain of the interventionist. This is not only a work

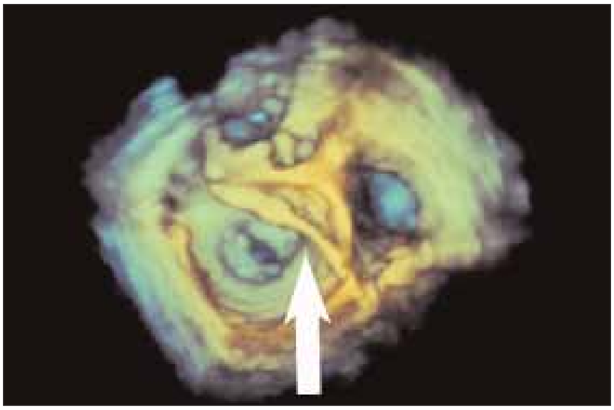

Figure 2. Three-dimensional TEE image of an Inoue balloon catheter (Toray Industries, Inc., New York, NY) above a stenotic mitral valve. The arrow points to the catheter that is directed at the mitral valve orifice, viewed from the back of the left atrium. This real-time 3D TEE guidance allows easier and more directed catheter navigation to cross the valve. The image is pseudocolored to bring out depth, with blue representing more distant areas.

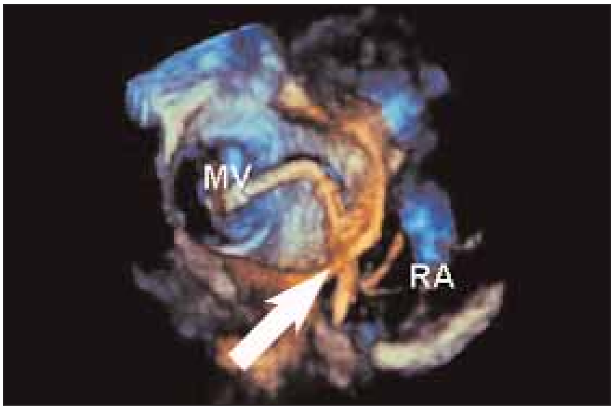

Figure 3. Three-dimensional TEE image of a mitral clip delivery system in a patient with mitral regurgitation. The arrow points to the catheter system crossing the interatrial septum. Notice that the catheter has been deflected above the valve. MV, mitral valve; RA, right atrium.

burden but also excessively relies on the visual skills of the interventionist. More complex procedures, such as percutaneous mitral valve clipping, bring out the limits of human performance and often result in prolonged procedures, in part due to the very challenging tasks of alignment and grasping a moving 3D target using slice images. Thus, imaging using 3D modalities is very important when the intervention is complex and precision of guidance and placement are needed. It is also of critical importance when navigation occurs in a large 3D space, such as a cardiac chamber.

Many of the emerging SHD interventions have a critically important task that is likely to be clearly facilitated if the real-time image were 3D. For example, the position of a percutaneously implanted aortic stent valve requires precision of placement and correct alignment to the aortic annulus. Placement can be poor if a 2D image is used with unappreciated foreshortening such that the operator is "fooled" as to where to implant the stent valve. Closure of a large ASD, typically with a deficient aortic rim, has a critical point when the left atrial disc is deployed, and the correct alignment of the disc to the plane of the defect is important before the central and right atrial discs are deployed.[3]

WHAT ARE THE 3D IMAGING APPROACHES FOR SHD INTERVENTIONS?

There are two types of 3D image-guided approaches. The first uses a 3D CTA- or MRA-derived image that is obtained before the procedure. The image is segmented to show the important anatomical features needed for the intervention. This segmented image is transferred to a workstation in the procedure room that allows image display. The image must then be registered, scaled, and located in 3D space with the x-ray system. Registration involves lining up objects that are present in both images. The vertebral column, cardiac borders, and other internal landmarks have been used. Subsequently, when the x-ray system is rotated, the CTA or MRA image rotates to maintain this alignment of the two images. In this fashion, the operator can use live fluoroscopy with a background 3D image of cardiac structures, including those that are soft tissue. This type of 3D image-guided approach has been used for stenting of aortic coarctation, ventricular septal defect closure, and ASD closure.[4] It currently is limited by the static nature of the CTA or MRA image, but in the near future, moving 3D images should be imported into the workstations and registered with fluoroscopy. Registration is not as easy as it may sound because the heart is moving from cardiac, respiratory, and patient movement. In the future, more sophisticated tracking systems will need to be developed to overcome these significant limitations.

The other major approach in 3D image guidance is the recently released real-time 3D ultrasound imaging. In the fall of 2007, Philips Medical Systems (Bothell, WA) released the Live 3D TEE iE33 Echo System. This 3D ultrasound technology is available in both TTE and TEE modalities. The TEE mode has much clearer images in most adult patients and therefore will be the focus of this discussion. Real-time 3D TEE involves a special TEE probe; the ultrasound machine must immediately process the large amount of data to provide the operator with a real-time image. The probe may heat up during prolonged 3D acquisition and is automatically shut off to prevent patient harm. There are a variety of graphic display modalities.

TABLE 1. ADVANTAGES AND LIMITATIONS OF 3D TEE IMAGING FOR MITRAL VALVE INTERVENTIONS
Advantages
• Enhanced understanding of mitral valve structure
• Facilitation of transseptal puncture
• Improves localization
• Crossing valve
• More rapid alignment of catheter
• Directly visualize crossing device
• Appreciation of being off centerline
• Direct visualization and monitoring
• Assessment of results
• Mitral regurgitation assessment in 3D
Limitations
• The images are not always great: better spatial and temporal resolution needed
• There is a learning curve to optimally use the technology
• More people needed and more complex procedure
• Anesthesia
• Ultrasound team
• Need for deeper sedation or even general anesthesia
• Hemodynamic assessment confounded by variations in sedation and actions of anesthesiologists
• Subvalvular apparatus not well visualized

REAL-TIME 3D TEE DRAMATIC IMPACT ON SHD INTERVENTIONS

This is the first time in the history of interventional cardiology that we have had real-time 3D images to navigate equipment and deploy devices. Although the temporal and spatial resolution are less than 2D ultrasound imaging, the 3D images provide an incredible visual guidance, especially when navigating catheters in a cardiac chamber, aligning delivery systems to a 3D target, and performing device deployment and assessing its impact. Table 1 shows some of the advantages and limitations of real-time 3D TEE imaging for complex SHD interventions.

Real-time 3D imaging is especially appropriate for more complex interventions that are currently being developed and entering clinical trials. Left atrial appendage occlusion to prevent thromboembolic complications from atrial fibrillation is an example of a new intervention that will be facilitated by 3D imaging. Some other interventions, such as patent foramen ovale (PFO) closure, are often more straightforward, and the delivery systems and devices are more self-centering. On the other hand, the 3D anatomy of the PFO is only starting to be appreciated, and 3D TEE provides a means to study PFO in an individual patient and perhaps in the future allow the selection of the best device.[5]

MORE PROCEDURES FACILITATED BY 3D IMAGING

There are a variety of examples of how 3D imaging is changing many SHD interventions. Transseptal puncture becomes much easier if the operator is using fluoroscopy with a 3D CTA image from the patient that is faded in the background of the fluoroscopy image. In this overlay image, the operator will see that the needle is actually engaging the fossa ovalis rather than having to rely on the possibly correct location of the catheter tip in an x-ray image and by the subtle tactile sense, the “septal bump or pulsation,” that occurs with engagement of the tip of the catheter against the septum. Examples of using 3D TEE imaging include all types of closures (ie, PFO, ASD, and ventricular septal defect), closure of paravalvular leaks, and the performance of mitral valve interventions to treat mitral stenosis and mitral regurgitation. As seen in Figures 2 and 3, the 3D images show the object of interest, the mitral valve, and the catheters that are being navigated to the valve. Immediately after acquisition, the 3D images can be oriented in any viewing angle and cropped to highlight anatomical features of interest. The images can also be pseudocolored to bring out the depth in the image.

CONCLUSION

Three-dimensional imaging for SHD interventions is starting to enter clinical practice. The technologies need to undergo further improvements, but the impact of 3D imaging is already palpable. ■

John D. Carroll, MD, is Professor of Medicine, University of Colorado Denver, and Director, Interventional Cardiology, University of Colorado Hospital, in Aurora, Colorado. He has disclosed that he receives research grant support, speaking honorarium, and royalties from Philips Healthcare. He is an investigator in structural heart disease clinical trials sponsored by AGA Medical, St. Jude Medical, and Evalve. He receives research grant support from Edwards Lifesciences and Evalve. Dr. Carroll may be reached at (720) 848-6508; john.carroll@uchsc.edu.

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