The exponential growth of transcatheter valve therapies (1) has created exceptional opportunities as well as unprecedented challenges for the cardiovascular imaging community. The new (October 2014) Centers for Medicaid and Medicare Services professional fee schedule and interventional transesophageal echocardiography code for supporting imaging guidance of transcatheter interventions (2) now compensate imaging experts for time spent in the catheterization laboratory. Although this marks an official recognition of this kind of imaging and is likely to augment such procedures, the nature of involvement for specialist imagers in the catheterization laboratory continues to be in a state of flux; it varies widely, often on the basis of available expertise, procedural complexity, and perceived cost versus benefit. On one side, some institutions are exploring minimalistic approaches with little or no added imaging besides fluoroscopy. In contrast, the development of new techniques such as fusion imaging, holographic displays, remote imaging with robotic arms, anatomical modeling with 3-dimensional (3D) printing, and bioengineering techniques promises more clarity in the interventional suite and also makes necessary more technical expertise in image acquisition and interpretation. In this Editor’s Page, we explore the existing challenges and opportunities in the rapidly changing landscape of cardiac imaging for guiding structural interventions.

DO ALL STRUCTURAL INTERVENTIONS NEED IMAGING SPECIALISTS?

To perform complex structural heart interventions, proceduralists must understand anatomy to a degree similar to that expected of cardiac surgeons. However, invasive tools available to them for providing real-time 3D visualization are somewhat limited. In the absence of direct surgical exposure, the team must rely heavily on noninvasive imaging for anatomic intelligence. The expertise needed for intraprocedural multidimensional imaging, lack of resources, familiarity, and direct operability may partly explain why some interventionists would find it more practical to use minimalistic approaches. Although an experienced interventionist may be able to achieve a good outcome even in the absence of imaging guidance, a wealth of evidence from transcatheter aortic valve replacement trial registries as presented by Hahn et al. (3,4) in this issue of JACC suggests that even at the best centers, experienced operators need additional imaging for the early identification of catastrophic structural complications. It would be safe to presume that echocardiography, at least by the transthoracic approach, would remain useful for quality assurance during TAVR. For more complex transcatheter therapies, however, there may be a heavier dependence on imaging guidance using transesophageal echocardiography. For example, structural valve interventions such as transcatheter mitral valve repair often benefit from using 3D and multiplanar transesophageal echocardiographic approaches. Interventionists are expected to be able to interpret the 2-dimensional (2D) and 3D echocardiographic images and use them to visualize the progress of the procedure. Several centers have already started creating special structural heart fellowships, and proposals have been made for Accreditation Council for Graduate Medical Education.
Education-accredited courses for providing combined training in both structural imaging and interventions. For the foreseeable future, there is little doubt that the model of having a skilled interventional imager in the catheterization laboratory will provide the highest imaging quality assurance and optimal outcomes for complex structural intervention. We can clearly get an excellent appreciation of the 3D space with imaging that will only get better with time, and it is logical that procedures can be better optimized when operators can visualize better. However, there remains one uphill task that needs a Gordian knot-like solution. As seen by the debate in this issue, there is still uncertainty about how much imaging is needed; the most pressing issue for imagers and imaging investigators should be not how nice the picture is but proving how much it adds to improving patient outcome.

**CHOICE OF IMAGING FOR PROCEDURAL GUIDANCE**

Historically, x-ray fluoroscopy has been used as the primary imaging modality during catheter-based interventions. Apart from the obvious limitation of radiation cost, fluoroscopy does not provide 3D visualization. Imaging techniques such as multiplanar 2D and 3D echocardiography, computed tomography, and cardiac magnetic resonance imaging provide spatial resolution superior to that of fluoroscopy. Structural cardiac interventions have been performed directly under imaging guidance using any of these techniques, but the interventional approaches and hardware are designed mostly for fluoroscopic approaches and are not easily navigated using other imaging techniques. A previous Editor’s Page in 2011 highlighted the clinical value of multimodality image fusion technology for scaling of the spatial information and circumventing limitations of a single imaging technique (5). The cover of the present issue of *JACC* and in the iPIX by Clegg et al. (6) illustrates case scenarios in which the fusion of ultrasound and fluoroscopy can now be performed for structural heart interventions. Ultrasound-fluoroscopy fusion entails imaging data streamed in real-time from each image source to a personal computer running the fusion and visualization software. The complex steps required for coregistration and for delivering optimal display resolution and interpretation, however, still require the services of an expert imager for effective use of this technology. The potential advantage of hybrid echocardiography-fluoroscopy is the real-time intraprocedural panoramic volumetric 3D view of structural heart disease targets.

This advantage facilitates eye-hand coordination and the ability to manipulate devices in 3D space with more precise control of the catheter and guidewire than with traditional fluoroscopy alone. Ongoing research is actively seeking to reduce the use of, or even replace, fluoroscopy in cardiac interventional procedures, especially in pediatrics.

**NOVEL IMAGING DISPLAYS**

Another technological breakthrough that may accelerate image display even further is the field of medical holography. There are already prototypes of industrial equipment for performing digital holography using interference patterns computed numerically by simulating light propagation toward an object’s geometry, including how light is scattered from an object (7). The interference pattern can be applied on a film, creating a static hologram, or on a “digital film” such as an addressable liquid crystal or digital micromirror device, and the display is then digitally updated to create dynamic holograms. With increased use over time, we predict greater reliance on fusion images and 4-dimensional holographic echocardiographic displays for assisting catheter and guidewire navigation. A recent feasibility study confirmed the ability of holographic displays in analyzing mitral valve pathology using visual inspection of the mitral valve during surgery or transesophageal echocardiography serving as the gold standard (8). The use of holographic technology will have potential application during mini-invasive procedures such as MitraClip placement for effective visualization to improve patient safety and the speed of procedures. Ultimately, only robust, randomized comparisons of different approaches will establish the final clinical utility.

**IMAGE-DRIVEN SIMULATIONS AND MODELING**

Within the past 5 years, simulators designed to train operators in the intricacies of catheter-based interventions (i.e., eye-to-hand coordination, translating the manipulation of objects in 3D space with movements on a 2D screen, etc.) have been developed. In interventional cardiology, simulation-based training has been used in both the investigative phase as well as the post-approval rollout of a variety of structural heart interventions. Moreover, recent studies using computational evaluation techniques combined with patient-specific 3D transesophageal echocardiographic data have demonstrated that computational simulation with patient-specific 3D transesophageal echocardiographic data allows us to
quantitatively determine both biomechanical and physiologic abnormalities in mitral valve function and predict success after mitral valve repair (9). Another imaging-driven technology that will likely have a substantial impact for simulations in catheterization laboratories is the field of 3D bioprinting (10–12). In 3D bioprinting, layer-by-layer precise positioning of biological materials, with spatial control of the placement of functional components, can be used to fabricate 3D structures. The creation of a real physical model of the underlying cardiac lesion will have a significant impact on understanding, planning, and practical preparation for catheter-based structural heart procedures. Besides actual understanding of defects, 3D bioprinting can also be used to create device designs or even creating a design that would best fit a given structural defect for more personalized therapeutic approaches (13). Such device designs could also include living tissue material. For example, imaging-driven bioprinting of tissue-engineered living aortic valve conduits has already been undertaken to create anatomically accurate, living valve scaffolds (11). The future will reveal the potential ways in which such a scaffold could be delivered using transcatheter techniques.

**ONSITE VERSUS REMOTE IMAGING**

Finally, the combination of digital imaging and telementorics is expected to expand the use of ultrasound in catheterization laboratories, allowing an expert to perform an examination from a distance, virtualizing both ultrasound image acquisition and interpretation. The emergence of such an efficient system would be valuable in lieu of the shrinking pool of cardiovascular specialists in the face of an aging population and the growing burden of structural heart diseases. It is likely that evolution of robotic systems would be matched by equal advances in remote controlling interfaces that could allow experts to be mobile and operate remote arms by using touch screens, touch pads, tablets, or wearable devices (14,15). For example, the DaVinci Canvas consists of the integration of a rigid laparoscopic ultrasound probe with the DaVinci robot, video tracking of ultrasound probe motions, endoscope and ultrasound calibration and registration, autonomous robot motions, and the display of registered 2D and 3D ultrasound images (16).

In summary, the field of interventional imaging is evolving rapidly, with a level of complexity that demands increasing technical knowledge and expertise. Just as the development of complex industries throughout the 20th century led to the “division of labor” as a cost-effective economic model, there is little doubt that the field of structural heart interventions will continue to invest in specialist imagers to conduct the steps of a well-orchestrated structural intervention. However, there is also the danger of our enthusiasm galloping ahead of actual needs; we need to think about how we train future imagers, how we overcome modality parochialism, and to what degree any single imager can attain proficiency (e.g., how many modalities, to what depth). Similarly, it is important to ponder where we will find suitable candidates for what is turning out to be an unending duration of training that is regularly burdened by additional requirements, in the face of the looming physician shortage. Finally, and most important, the imaging community should restrain its well-known enthusiasm to “see better and show better” and should rapidly focus on marrying technological marvels with robust outcome data for patient care. Otherwise, interventional imaging will only come full circle.

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