VIEWPOINT
FELLOWS-IN-TRAINING

Imaging in Structural Heart Disease
The Evolution of a New Subspecialty

Nadeen N. Faza, MD,a Özge Özden Tok, MD,b Rebecca T. Hahn, MDc

ABSTRACT

Structural heart disease is a new field in cardiovascular medicine, which has resulted in the creation of a new imaging subspecialty. Structural heart disease imagers have been instrumental in stimulating innovations in both the imaging and interventional spheres. Perhaps most importantly, they play a key role on the clinical heart team, interacting with team members and patients before, during, and long after a structural procedure is performed. (J Am Coll Cardiol Case Rep 2019;1:440–5) © 2019 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Recent years have witnessed an exponential growth in the evolving world of structural heart disease interventions. The term “structural heart disease” in fact is a relatively new term first created in 1999 to encompass all noncoronary cardiovascular disease processes and catheter-based interventions (1). In those early days of the “heart team,” a partnership with imaging colleagues was essential for appropriate patient selection and technical procedure success. Nowadays, advances in the field, fueled by robust clinical trial data, have changed the landscape of structural heart disease interventions. The evolution of cardiac imaging has revolutionized the field by refining the pre-procedural planning phase and guiding increasingly complex transcatheter interventions. Structural heart disease imagers (SHDIs) are irrefutable key players in the heart team (2) and have played a fundamental role in the unparalleled speed and breadth of development of structural heart disease devices (Table 1).

ROLE OF IMAGING IN STRUCTURAL HEART DISEASE INNOVATIONS

Structural heart disease intervention is a disruptive innovation, one that has already displaced traditional open surgical procedures and allowed treatment of a greater number of patients at a lower cost (3–5). The last decade has signaled significant advances in the field of structural heart interventions. From transcatheter aortic and pulmonic valve replacement, left atrial appendage occlusion procedures, percutaneous mitral repair techniques, and, more recently, transcatheter mitral valve replacement and tricuspid interventions, the advances in interventions and imaging are inextricably linked. For example, the commercial availability of 3-dimensional (3D) echocardiography made the edge-to-edge repair procedure more efficient, precise, and adaptable (6,7). The collaboration of ultrasound and device companies, in part driven by initiatives from imaging societies such as the American Society of Echocardiography, continues to fuel advances in imaging that can then help drive device innovation (8–10). The imaging-intensive nature of all these procedures requires imagers to have an understanding of diverse anatomical targets, the capabilities of advanced imaging technologies, and the ability to navigate through the evolving landscape of structural heart interventions.

From the aHouston Methodist DeBakey Heart and Vascular Center, Houston Methodist Hospital, Houston, Texas; bCardiology Department, Memorial Bahçelievler Hospital, Istanbul, Turkey; and the cColumbia University Medical Center/NewYork-Presbyterian Hospital, New York, New York. Dr. Hahn is a speaker for Boston Scientific and Baylis; a speaker and consultant for Abbott Structural, Edwards Lifesciences, Philips Healthcare, and Siemens Healthineers; is a consultant for 3Mensi, Medtronic, and Navigate; and is the Chief Scientific Officer for the Echocardiography Core Laboratory at the Cardiovascular Research Foundation for multiple industry-sponsored trials, for which she receives no direct industry compensation. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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techniques, and the performance of multifaceted procedural interventions. Because of this knowledge base, imagers have become integral to the continued advancement of the field.

**ROLE OF THE SHDI**

As the indications for transcatheter heart disease interventions expand, and as multiple novel devices are being designed and studied under various clinical trials, more emphasis is being placed on the inclusion of competent imagers on the heart team. A well-functioning heart team requires individuals with extensive knowledge and experience in 2-dimensional (2D) and 3D echocardiographic imaging, in addition to multislice computed tomography (MSCT) imaging, cardiac magnetic resonance, and fluoroscopic imaging. SHDIs are the “eyes” of the heart team, able to assess the patient from diagnosis to post-procedural follow-up.

**PRE-PROCEDURAL DIAGNOSIS AND PROCEDURAL PLANNING.** The identification of appropriate patients for intervention requires expertise in the imaging diagnosis of significant structural heart disease. Our understanding of the pathophysiology of valvular disease also continues to progress in part because of the use of advanced imaging techniques. For instance, previously underdiagnosed patients with low-flow, low-gradient severe aortic stenosis and discordant parameters of stenosis severity can now be diagnosed by using stress echocardiography and MSCT calcium scores (11-13). These patients significantly benefit from surgical and transcatheter aortic valve replacement (14,15).

After the diagnosis of significant structural heart disease, the success of a structural intervention heavily relies on pre-procedural imaging and planning, with MSCT imaging playing a major role (16-18). Imaging determines anatomical candidacy for a specific intervention, defines device sizing, and predicts potential procedural complications. The imager must have extensive knowledge of the different conventional and novel surgical and transcatheter techniques and devices. By incorporating device construct with anatomical and hemodynamic data from multiple imaging modalities, the SHDI formulates a patient-specific management plan. Recent advances in 3D printing of patient-specific models from data acquired from MSCT imaging and transesophageal echocardiograms (TEEs) have been more widely applied for accurate determination of device sizes in addition to prediction of potential complications (19,20).

**INTRAPROCEDURAL GUIDANCE.** To be effective members of the structural heart team, SHDIs need to communicate through a unified language with all members of the team. The open communication with the rest of the team requires mutual respect and recognition of each team member’s role. The language developed may be unique to each team but enables accurate and effective communication in a precise and concise manner. In addition to verbal cues, imaging protocols must be developed so that all members of the team are on the “same page” anatomically.

Knowledge of the interventional procedure steps, different catheters, wires, and delivery systems, as well as different fluoroscopic angles, is crucial in successfully guiding an intervention. Both interventionist and imager should understand the nuances of catheter manipulation, the strengths and limitations of imaging with catheters in place, and, most importantly, how working together as a team will result in procedural success. The ability to quickly move between a variety of imaging planes and different imaging modalities (2D and 3D), as well as anticipate the imaging needs of the interventionist, are crucial SHDI skills. Knowledge of the potential complications and actively screening for them throughout an intervention enables their timely detection and management.

Advances in imaging technology may also improve intraprocedural guidance. Fusion imaging is an important tool that may obviate the need to mentally overlay anatomical landmarks acquired by live echocardiographic imaging with fluoroscopic images. Current fusion imaging techniques superimpose pre-acquired MSCT images or live TEE images onto the fluoroscopic image to provide a visual roadmap of the target structure and surrounding anatomical landmarks (8). Integrating multimodality imaging methods in addition to fusion imaging facilitates procedures, and decreases procedure time, radiation dose, and the amount of contrast agent used (21). Intracardiac echocardiography, now available with 2D and 3D modalities, is increasingly used intraprocedurally when TEE imaging is difficult (9,22). More recently, virtual and augmented reality have been used for both pre-procedural planning and intraprocedural guidance (23).

**POST-PROCEDURE FOLLOW-UP.** SHDIs play a role in following up with patients after the intervention. This follow-up is important for identification of early
and late complications, and the need for a re-intervention (24,25). New echocardiographic imaging guidelines have recently been published for the evaluation of valvular regurgitation after percutaneous valve repair or replacement (26). This document provides much needed guidance as the number of patients undergoing transcatheter interventions continues to increase.

**CHALLENGES FOR SHDIs**

Advancing the field of SHDIs is pivotal in further advancing the field of structural interventions. The field faces several challenges, however.

**SAFETY HAZARDS.** A recent study has shown that SHDIs are exposed to radiation doses as high as, if not higher, than those to which interventional primary operators are exposed (27). This stems from the fact that interventional suite design does not typically anticipate the needs of the SHDI. In addition, musculoskeletal injuries have been reported as a result of prolonged use of lead shields (28). Recognizing the health hazards that SHDIs are exposed to and striving to ensure maximal radiation protection and minimal musculoskeletal injuries should be a major focus of catheterization laboratory leadership.

**LACK OF DEDICATED TRAINING.** There are two major issues with training SHDIs. First, very few dedicated structural imaging fellowships exist that focus on procedural planning and guidance. Second, specific training guidelines and certification examinations for this new subspecialty are lacking. The 2019 American College of Cardiology/American Heart Association/American Society of Echocardiography Advanced Training Statement on Echocardiography gives suggested minimum TEE procedure volumes to achieve Level III competency for what is termed “Special Cardiovascular Ultrasound Procedures” (essentially structural heart disease imaging) (29); however, accomplishing this training under the supervision of “certified” faculty would require a formal certification process. As clinical trial data further support the use of transcatheter techniques in larger populations of patients, the need arises to formalize dedicated training programs, develop competency-based training guidelines, and create certification examinations. Targeted and dedicated training for SHDIs should expose trainees to a wide range of pathologies and multimodality imaging techniques, as well as clinical trials and investigational devices, in the context of the multidisciplinary heart team.

**INADEQUATE REIMBURSEMENT MODELS.** The current reimbursement model, which mainly relies on relative value units, does not take into account the expertise needed in guiding interventions, the lengthy nature of the structural interventional procedure and the time spent in the catheterization laboratory/hybrid operating room, or the risks associated with exposure to radiation (28). Societal and administrative recognition and support of the fundamental role of SHDIs for procedural success, and development of appropriate means for revenue sharing, pave the way for establishing a reimbursement model that reflects the expertise and skill set in addition to the time required to master procedural planning and procedural guidance.
CURRENT LANDSCAPE/FUTURE DIRECTIONS

The past year has specifically witnessed a paradigm shift in the structural heart interventions arena. In the mitral space, the MitraClip (Abbott Structural, Minneapolis, Minnesota) device, studied under the COAPT (Cardiovascular Outcomes Assessment of the MitraClip Percutaneous Therapy for Heart Failure Patients with Functional Mitral Regurgitation) trial, has shown decreased re-hospitalizations and mortality in medically optimized patients with functional mitral regurgitation (30). The MITRA-FR (Percutaneous Repair with the MitraClip Device for Severe Functional/Secondary Mitral Regurgitation) trial, however, failed to show the same benefit (31). One of the key differences between the 2 trials lies in the echocardiographic inclusion criteria for mitral regurgitation severity and ventricular size and function (32), as well as differences in long-term technical success (33). With U.S. Food and Drug Administration approval of the expanded indications for edge-to-edge repair, ensuring optimal patient selection will be key to achieving procedural success and favorable patient outcomes, and it will depend on accurate pre-procedural quantitation of both valvular and ventricular function using advanced imaging techniques.

More recently in August 2019, the U.S. Food and Drug Administration approved the use of transcatheter aortic valve replacement (TAVR) in low-risk patients after 2 clinical trials showed at least comparable outcomes of TAVR in this patient population with severe aortic stenosis (3,4). The risk-benefit analysis places more emphasis on pre-procedural imaging prediction of procedural complications as well as the long-term imaging follow-up to determine structural valve dysfunction (34,35).

Advanced imaging techniques will also play a role in the timing of intervention. Because of a higher mortality associated with “watchful waiting” in asymptomatic aortic stenosis (36), newer modalities such as strain imaging (37) may detect early myocardial dysfunction. Cardiac magnetic resonance quantitation of extracellular volume fraction may accurately detect early and reversible myocardial fibrosis (38). 18Fluoride-positron emission tomography/CT uptake detects early and possibly reversible valve calcification in both native and bioprosthetic valves (39,40).

The once-forgotten tricuspid valve is now recognized as a determinant of mortality, and efforts to image the valve (41) will drive further interventional innovation (42). The TriValve Registry, the largest prospective international registry of various transcatheter tricuspid valve interventions, has shown not only device feasibility but also improvement in outcomes associated with reduction in regurgitation (43). New methods for assessing the morphology and function of the tricuspid valve also require advanced imaging modalities and the development of new metrics of disease severity (44).

WOMEN IN STRUCTURAL HEART DISEASE IMAGING

Although approximately one-half of all medical school graduates are women, <20% of cardiologists who see adult patients are women. Douglas et al. (45) recently reported the results of a survey of 4,850 internal medicine trainees from 198 residency programs. Women were more likely than men to have never considered going into cardiology (63% vs. 37%) and less likely to choose cardiology (34% vs. 12%). The top perceptions of cardiology in descending order of significance were adverse job conditions, interference with family life, and a lack of diversity. Women were more likely than men to practice general cardiology (48% women vs. 39% men; p < 0.001) or echocardiography (10% women vs. 3% men; p = 0.001) rather than invasive subspecialties such as interventional cardiology (3% women vs. 23% men; p = 0.001) or electrophysiology (6% women vs. 10% men; p < 0.01) (46).

These observations shed light on an unusual phenomenon of greater sex balance seen in the SHDI field. Because women more often practice echocardiography, many have overcome the barriers of working in the interventional field to become part of the heart team. Similar to women in interventional cardiology, a major challenge remains exposure to radiation, especially during training or early career years, which often coincide with childbearing years. Development and adoption of specific guidelines to address radiation safety concerns and optimize radiation safety measures for SHDIs will ensure that talented and skilled women with a passion for the field are able to overcome this challenge and continue to contribute significantly to the field and its advancement.

CONCLUSIONS

SHDIs, the “eyes” of the heart team, undoubtedly play an instrumental role in planning and guiding structural interventions in addition to detecting complications. With the increasing complexity of structural heart disease being successfully managed percutaneously, more emphasis will be placed on including highly trained and experienced SHDIs on the heart team, to ensure optimal patient selection,
pre-procedural planning, intraprocedural guidance, and patient follow-up. Establishing formal training programs in addition to advocating for administrative and societal recognition and support are key in advancing the field of SHDIs, and in turn structural heart disease interventions.

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