The Changing Paradigm in the Treatment of Structural Heart Disease and the Need for the Interventional Imaging Specialist

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Abstract

Percutaneous interventions in structural heart diseases are emerging rapidly. The variety of novel percutaneous treatment approaches and the increasing complexity of interventional procedures are associated with new challenges and demands on the imaging specialist. Standard catheterisation laboratory imaging modalities such as fluoroscopy and contrast ventriculography provide inadequate visualisation of the soft tissue or three-dimensional delineation of the heart. Consequently, additional advanced imaging technology is needed to diagnose and precisely identify structural heart diseases, to properly select patients for specific interventions and to support fluoroscopy in guiding procedures. As imaging expertise constitutes a key factor in the decision-making process and in the management of patients with structural heart disease, the sub-speciality of interventional imaging will likely develop out of an increased need for high-quality imaging.

Keywords

Structural heart disease, percutaneous procedures, interventional imaging, multimodality imaging, transoesophageal echocardiography, computed tomography, magnetic resonance imaging

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Over the past 30 years, several percutaneous transcatheter technologies and devices for interventions in structural heart diseases (SHDs) have been introduced (see Table 1). There are numerous technologies that are in development or are currently being used to treat patients with SHD that use transcatheter techniques. The variety of percutaneous treatment approaches has led to a revolution and evolution in clinical care. The past few years have seen a greater application of novel, catheter-based treatments for SHDs. Many of these non-surgical catheter-based interventions have been successfully used to treat patients with SHD that use transcatheter techniques. The variety of percutaneous treatment approaches has led to a revolution and evolution in clinical care. The past few years have seen a greater application of novel, catheter-based treatments for SHDs. Many of these non-surgical catheter-based interventions have been successfully used to treat patients with SHD.

Moreover, detailed information is provided regarding the anatomy in relation to neighbouring structures.

New technologies for the treatment of SHD are proliferating; consequently, the number of interventions for SHD is increasing and the procedures are becoming more complex. This has produced a need for greater expertise in the evaluation and imaging of SHD. Due to these changes in the therapeutic armamentarium, interventional imaging appears to be becoming a requisite sub-speciality.

Imaging Modalities for Structural Heart Disease Procedures

Two-dimensional (2D) TOE (or alternatively 2D intracardiac echocardiography) in conjunction with fluoroscopy and cineangiography has been the standard imaging practice in most catheterisation laboratories; however, these imaging modalities are limited in the visualisation of soft tissue, complex 3D structures and their relationships. The introduction of 3D TOE, cardiovascular magnetic resonance (CMR) imaging and MSCT has overcome some of these limitations and, as a result, these additional modalities are being widely adopted in the process of selecting SHD patients, monitoring and guiding procedures, and assessing procedural results. The development and implementation of advanced cardiac imaging constitutes one of the key factors in the success of SHD interventions.

Three-dimensional Transoesophageal Echocardiography

The introduction of 3D TOE has led to a major technological advance in echocardiographic imaging. Realtime 3D TOE imaging provides unique en face views and excellent detail of patients’ 3D anatomy and soft
Table 1: Overview of Congenital and Structural Heart Disease Interventions

Valvular
- Valve repair techniques
- Balloon valvuloplasty
- Paravalvular leak closure
- Transcatheter valve replacement

Congenital
- Atrial septal defect closure
- Ventricular septal defect closure
- Closure of patent ductus arteriosus
- Interventional treatment of coarctation
- Closure of fistulae

Structural
- Patent foramen ovale closure
- Left atrial appendage closure
- Closure of post-myocardial infarction ventricular septal defects
- Interventional techniques to treat heart failure

Figure 1: Multimodality imaging to evaluate a patient for Transcatheter Aortic Valve Replacement (TAVR)

(A) A three-dimensional (3D) reconstruction of a 3D transoesophageal echocardiography data set is used to measure the size of the aortic annulus before a TAVR procedure. (B) Final positioning of the TAVR prosthesis (SAPIEN 3, Edwards Lifesciences Ltd, Newbury, UK) is demonstrated in an x-plane image (left: long axis view; right: short axis view). (C) Example of 3D reconstruction of a computed tomography data set (Medis Medical Imaging BV, Bilthoven, Netherlands). Annular parameters are measured in different views (top left, bottom right and left). The distribution of calcium can be seen (top right, bottom left and right) and the overlay on the fluoroscopic image (top middle) allows for determination of the best fluoroscopic angle for device implantation. The virtually-positioned valve (red arrowhead) shows no interference with the left coronary artery (yellow arrowheads) in this case.

tissue structures. It also allows for the 'live' guidance of interventional procedures. Wires, catheters, sheaths, devices and target structures can be seen in one single view and in relation to each other, thus facilitating the guidance of standard and complex SHD interventions.

While 3D TOE is gaining acceptance, it is still not available in all centres. Two-dimensional TOE has the advantage of providing higher resolution images, which can be helpful in specific situations where precise measurements are needed. Echocardiographic guidance with 2D in conjunction with 3D TOE is crucial and is recommended for many different kinds of mitral intervention, aortic and mitral paravalvular leak closure, transcatheter aortic valve replacement (TAVR) (Figure 1A and B), left atrial appendage (LAA) occlusion (Figure 2), atrial septal defect and patent foramen ovale closure as well as for percutaneous closure of ventricular septal defects.

Multi-slice Computed Tomography and Cardiovascular Magnetic Resonance Imaging

Although TOE is the most widely used imaging modality, MSCT and CMR are helpful imaging techniques for the pre- and post-procedural assessment of anatomy, pathology and function of cardiac structures, device assessment, and for the detection of complications post-procedure.

MSCT provides accurate data for sizing devices for TAVR (Figure 1C) and LAA occlusion (Figure 3A–D). Before a TAVR procedure, the diameters, areas and perimeters of the aortic annulus, sinuses of Valsalva and ascending aorta can be accurately determined. In addition, the location and distance of the coronary ostia from the aortic valve and bypass grafts can reliably be visualised. The amount and distribution of calcification can be identified. MSCT-based analysis of the aortic root and vascular access sites has become routine in the pre-procedural evaluation of patients for TAVR. In post-procedural assessment, MSCT has been beneficial in detecting complications like reduced aortic-valve leaflet motion in patients with bioprosthetic aortic valves. In addition, MSCT is useful for the evaluation of LAA anatomy and measurements regarding device selection, assessment of procedural success and longer-term outcomes. MSCT is also beneficial in other SHD procedures. It has been used to assess the function and anatomy of the mitral valve complex. As new mitral valve devices undergo clinical trials, MSCT will likely play a critical role in determining patient eligibility (see Figure 4 for an example of this), especially in the assessment of patients with mitral annular calcification. Investigators have shown that MSCT can be used to diagnose and differentiate interatrial shunts. In patients with paravalvular leaks, ECG-gated computed tomography angiography has proven useful in characterising the precise anatomy of the paravalvular leaks, thus facilitating appropriate occluder device selection.

Limitations of MSCT include ionising radiation, a lower temporal resolution than TOE, and the inability to use it during interventional procedures. Nonetheless, due to the proven utility of MSCT in the context of SHD interventions, this imaging modality will likely play a role in the development of future sizing algorithms.

There is limited experience with CMR; however, it is an attractive alternative imaging modality in pre- and post-procedural evaluation of SHD, particularly in patients with renal failure and in patients with difficult echocardiographic windows. This non-invasive imaging modality allows for detailed visualisation of cardiac anatomy and functional assessment including quantification of chamber size and volume, left ventricular function (systolic and diastolic), myocardial tissue characterisation and precise wall motion analysis without exposing the patient to ionising radiation.

Similar to cardiovascular MSCT, CMR also provides imaging with excellent spatial resolution and can perform 3D multiplanar reconstruction. Figures 5 and 6 demonstrate the usefulness of CMR imaging in patient selection for the Revivent™ Myocardial Anchoring System (BioVentrix, San Ramon, CA, USA). There are, however,
Integrated Multimodality Imaging

More recently, advances in software and hardware development have enabled the integration of various imaging modalities into a single data set, thus resulting in realtime fusion imaging after the separate acquisition of two image data sets. The side-by-side registration of data rendered by different non-invasive imaging modalities such as echocardiography, advanced computed tomography and magnetic resonance imaging technologies and fluoroscopy may overcome some of the limitations of each of the modalities when used as a sole imaging method. Such a multimodal imaging approach may thereby provide increased diagnostic and procedural accuracy by combining anatomical and functional information (see Figure 1C, Figure 3–E and Figure 4C).42–44

Challenges during Structural Heart Defect Interventions

Currently, interventional transcatheter techniques are being used to treat patients with SHD, including those at high surgical risk. SHD interventions require specifically-designed diagnostic catheters, guiding catheters, guide wires, sheaths and dedicated implantation tools and devices. The visualisation of moving wires, catheters, sheaths and devices within the 3D space of the moving (beating) heart in relation to the target regions constitutes one of the major procedural challenges. In this context, 3D TOE imaging facilitates the manipulation and alignment of devices to the target lesion, thereby increasing the odds of achieving procedural success.

The dynamic and interactive nature of SHD interventions requires a multidisciplinary team with expertise in imaging and intervention. It is crucial that the imaging specialist and the interventionalist communicate with each other at all times during an interventional procedure to ensure optimal and safe deployment of the device. The orientation of echocardiography and fluoroscopy images differs significantly. TOE images are typically obtained through a relatively narrow imaging window through the oesophagus, whereas the rotation of the C-arm allows for the acquisition of multiple views of the same structure. Thus, the same structure is seen from different perspectives by the echocardiographer and the interventionalist, identifying the same structure simultaneously on echocardiographic and fluoroscopic images is complicated, therefore the echocardiographer and the interventionalist must make sure that they are communicating effectively to ensure effective manoeuvring of devices to obtain the best possible results. As each imaging technique provides unique and supplemental information, the combination of multiple imaging techniques is helpful in precisely defining the anatomy and facilitating device deployment. Thus, the accurate description of anatomy, pathology and function and their effective communication between team members are key factors in a successful procedure. The use of realtime multimodality fusion imaging facilitates this process.42–43

Figure 2: Two- and Three-dimensional (2D/3D) Transoesophageal Echocardiography (TOE) Guidance of a Left Atrial Appendage (LAA) Closure Procedure with an Amplatzer™ Cardiac Plug (St. Jude Medical Inc, MN, USA)

Figure 3: Measurements of the Left Atrial Appendage (LAA) Ostium in a Three-dimensional Computed Tomography Reconstruction and Integration of Structures of Interest into a Fluoroscopic Image by Using the 3mensio Structural Heart Software (3mensio Medical Imaging, Bilthoven, Netherlands)
The reconstructed mitral valve annulus is marked with a yellow arrow. A valve model (yellow asterisk) can be positioned and left ventricular outflow track obstruction estimated. This is demonstrated in a short axis plane (A) and in long axis planes (B, D). (C) The overlay of the reconstructed mitral annulus and the valve model on a fluoroscopic image allows the best angiographic angulation for valve implantation to be determined. LVOT = left ventricular outflow tract.

Figure 5: The Revivent™ Myocardial Anchoring System (BioVentrix; San Ramon, CA, USA) Enables Left Ventricular (LV) Volume and Radius Reduction Through Scar Exclusion and structures is required. Furthermore, imaging is important for information on the exact location and anatomy of the target lesions. Due to the complexity of the visual–spatial relationships, imaging specialists are key members of the interventional heart team. As with all cardiovascular procedures, experience is requisite to develop the skills necessary in the clinical setting. Imagers as well as interventionalists performing SHD interventions therefore require specific training on the use of each unique interventional device, as well as knowledge on the specific implantation requirements of these devices. Specific guidelines and recommendations, particularly for TOE monitoring of interventional procedures, have been produced by various cardiac societies. These documents emphasise the value of interventional imaging.

As there are numerous devices available for the treatment of SHD and more in development, substantial growth in the field is expected. Consequently, interventional imaging as a sub-specialty is likely to become even more important than it currently is and is likely to develop into a well defined and recognised sub-specialty.

Conclusion

SHD intervention is a burgeoning field. The sub-speciality of interventional imaging will likely develop out of an increased need for high-quality imaging. Imaging expertise constitutes a key factor in the decision-making process and in the management of patients with SHD in order to offer patients optimal outcomes from transcatheter interventions.


