Review Article

Simulation for transthoracic echocardiography of aortic valve

Navin C. Nanda, K. K. Kapur[1], Poonam Malhotra Kapoor[2]

Distinguished Professor of Medicine and Cardiovascular Disease and Director, Heart Station/Echocardiography Laboratories, University of Alabama at Birmingham, Alabama, USA, [1]Department of Cardiology, Apollo Indraprastha Hospital, [2]Department of Cardiac Anaesthesia, CTC, AIIMS, New Delhi, India

ABSTRACT

Simulation allows interactive transthoracic echocardiography (TTE) learning using a virtual three-dimensional model of the heart and may aid in the acquisition of the cognitive and technical skills needed to perform TTE. The ability to link probe manipulation, cardiac anatomy, and echocardiographic images using a simulator has been shown to be an effective model for training anesthesiology residents in transesophageal echocardiography. A proposed alternative to real-time reality patient-based learning is simulation-based training that allows anesthesiologists to learn complex concepts and procedures, especially for specific structures such as aortic valve.

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INTRODUCTION

Aortic valve is a trileaflet valve which is thickened at its tips (Arantius) and allows a complete seal, while closing to avoid any back flow into the LV cavity, by overlapping neighboring leaflets by 2-3 mm. Sinuses of Valsalva are outpouching's behind the aortic cusps when the valve is open. The sinuses support the aortic leaflets superiorly. The sinuses provide a reservoir for diastolic blood flow to the coronary vessels RCA arises from the right anterior sinus while the LCA arises from the left posterior sinus [Figure 1]. The right posterior sinus does not give rise to coronary artery and is called non-coronary sinus. The fibrous annulus supports the aortic cusp and is continuous with the mitral annulus as well as the mitral aortic inter Valvular ridge. Hemodynamic affections of aortic valve include aortic stenosis (AS), aortic regurgitation (AR) or both.

TRANSTHORACIC ECHOCARDIOGRAPHY AND SIMULATION

Transthoracic echocardiography (TTE) is a noninvasive and readily available diagnostic technique that is observing an increased perioperative use by anaesthesiologists. A focused, goal-directed examination can be performed in <10 min that has been shown to alter patient management and may improve outcomes. A prospective, observational study demonstrated that a focused TTE performed by anesthesiologists resulted in alterations in the management for 84% of the patients, and the results correlated with cardiologists' formal results in 90% of the cases. Moreover, three-dimensional (3D) models allow visualization of valves from an atrial or ventricular perspective, thus offering better insight into the complex pathophysiological mechanisms responsible for the disease process.[1] In the hands of a trained anesthesiologist, clinical information may be obtained quickly when sufficient time is lacking to obtain a formal TTE examination.

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Address for correspondence: Dr. K. K. Kapur,
Senior Consultant, Department of Cardiology,
Apollo Indraprastha Hospital, New Delhi, India.
E-mail: heartclinicnoida@gmail.com

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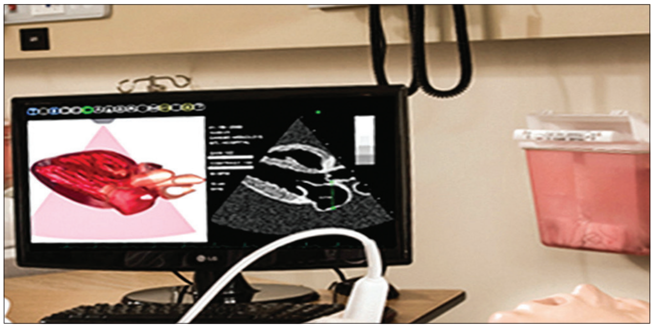

Figure 1: Real-time echo simulation with augmented reality. (photo courtesy by CAE-DSS Imagetech)

Simulation allows interactive TTE learning using a virtual 3D model of the heart and may aid in the acquisition of the cognitive and technical skills needed to perform TTE [Figure 1]. The ability to link probe manipulation, cardiac anatomy, and echocardiographic images using a simulator has been shown to be an effective model for training anesthesiology residents in transesophageal echocardiography. A proposed alternative to real-time reality patient-based learning is simulation-based training that allows anesthesiologists to learn complex concepts and procedures.

This module allows real-time simulated TTE imaging of the virtual heart using a mannequin. The life size mannequin torso has soft skin with accurate, palpable anatomical landmarks to aid in the positioning of the handheld ultrasound probe. The screen display allows the user to identify the position of the probe on the virtual chest as well as to see the orientation of the ultrasound plane. The anatomy display includes a representation of the chest wall, ribs, sternum, and spine as well as great vessels, lungs, pericardium, diaphragm, and liver.

As the learner scans the mannequin, the high-resolution monitor displays a realistic simulated ultrasound image beside a real-time 3D graphic representation of the anatomy, including the surrounding structures and organs [Figure 2]. The 3D anatomy feature can be toggled on or off, or it can be customized to adapt to the learner's level of knowledge and ultrasound imaging skill. This augmented reality feature improves understanding of how the heart works and speeds the path to proficiency in obtaining ultrasound images. As a learner progresses, the instructor may turn off the 360° anatomical image and transform the echo simulator into an ultrasound imaging system that more closely resembles what a resident would find in a clinical setting.

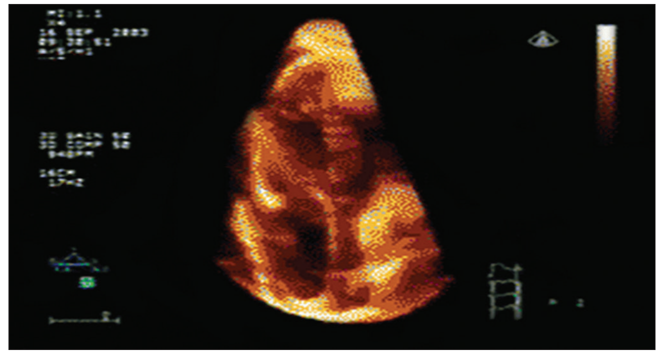

Figure 2: Three-dimensional echocardiography (three-dimensional)

PATHOLOGY OF SIMULATOR FOR AORTIC VALVE

Heart works pathology has modules for both TTE and transesophageal echocardiogram (TEE) imaging have been created to facilitate the echocardiographic evaluation of patients with structural and hemodynamic disturbances.

This module includes:

- Mechanical aortic valve
- Aortic stenosis (AS) and mitral stenosis Doppler.

MECHANICAL AORTIC VALVE

This model demonstrates bileaflet mechanical aortic valve prosthesis. The Doppler profile permits detailed evaluation of prosthetic function while the characteristics of the left ventricle and aorta reflect the underlying native pathology, i.e. ventricular hypertrophy and poststenotic dilation of the ascending aorta [Figure 3].

BRIEF ANATOMY OF THE AORTIC VALVE

Aortic valve is a trileaflet valve which is thickened at its tips (Arantius) and allows a complete seal, while closing to avoid any back flow into the left ventricular (LV) cavity, by overlapping the neighboring leaflets by 2–3 mm.

Sinuses of Valsalva are outpouchings behind the aortic cusps when the valve is open. The sinuses support the aortic leaflets superiorly. The sinuses provide a reservoir for diastolic blood flow to the coronary vessels. The right coronary artery arises from the right anterior sinus while the left coronary artery arises from the left posterior sinus [Figure 4]. The right posterior sinus does not give rise to coronary artery and it is called noncoronary sinus.[2]

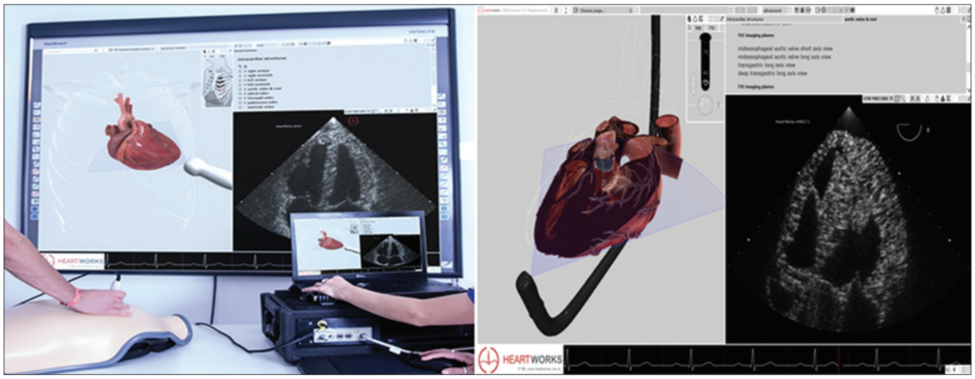

Figure 3: Transesophageal echocardiogram image of mechanical aortic valve. (photo courtesy by CAE-DSS Imagetech)

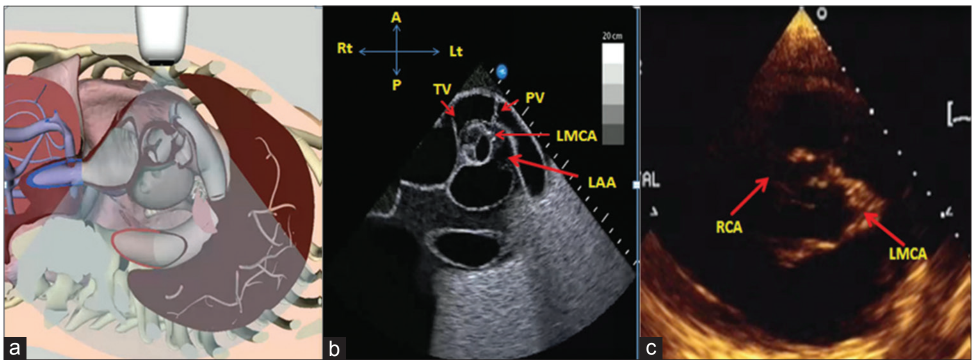

Figure 4: (a-c) Aortic valve on mannequin in PSSAX, it is being trileaflet, and the left main coronary artery is originating from the left posterior sinus. The right coronary artery is shown in similar echocardiographic view being arising from the right anterior sinus. (photo courtesy by CAE-DSS Imagetech)

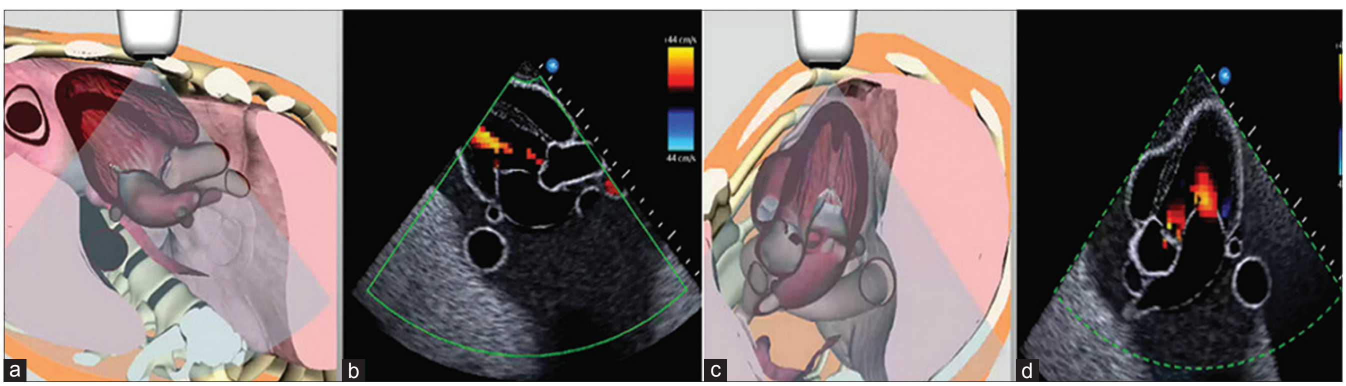

Figure 5: AR on simulator in different views of aortic valve. (a and b) PSPLAX view and (c and d) apical simulated view. (photo courtesy by CAE-DSS Imagetech)

The fibrous annulus supports the aortic cups and it is continuous with the mitral annulus as well as the mitral aortic intervalvular ridge.

Hemodynamic affections of aortic valve include AS, aortic regurgitation (AR), or both.

Bicuspid valve

Bicuspid aortic valve is one of the most common cardiac abnormalities occurring in 1% of the population.[3] It can result in AS, AR, or combined AS and AR. Usually, the AS is initially mild and progressively increases over several years [Figure 5].

The bicuspid aortic valve is also prone to infective endocarditis (IE). A classical bicuspid valve has two aortic sinuses. However, several variations of the bicuspid aortic valve occur including an incomplete cusp called raphe. This variant usually has three aortic sinuses. The commissiornal plane dividing the cusps could be horizontal, oblique, or vertical. An “acquired” bicuspid valve sometimes results from inflammatory (rheumatic) or calcific fusion of two adjacent cusps, thus giving an appearance similar to congenital bicuspid valve.

AORTIC STENOSIS

Severe AS has an extremely adverse prognosis for symptomatic patients not eligible for the standard surgical aortic valve replacement. Transcatheter aortic valve replacement (TAVR) has been emerged as a new minimally invasive treatment for such high-risk patients.[4] In the case of the Edwards Sapien® valve, the procedure consists of the delivery of a balloon-expandable stented tissue valve to the site of the native pathological valve via transfemoral or transapical catheterization. We hypothesize that the presence of large deposits of calcium *in situ* is a significant cause of intra- and post-procedural complications. Hence, the simulation of the deployment in the patient-specific aortic root (AR) models encompassing the patient's pathophysiological features may represent a valuable procedural planning tool and lead to improved design of TAVR device [Figure 6].

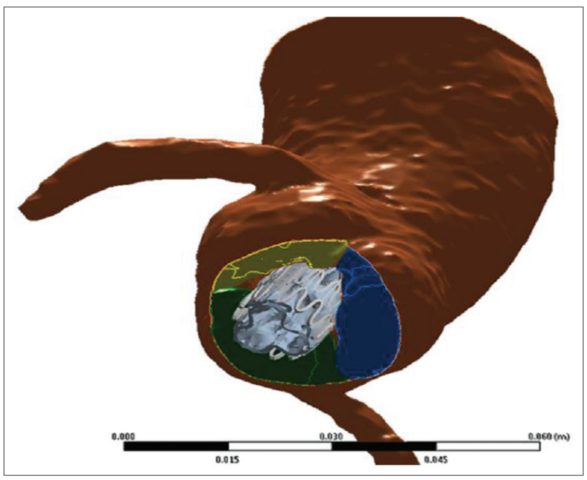

Figure 6: Finite element model of a patient-specific aortic root and SAPIEN® valve in midway position before deployment

INDICATION OF TRANSTHORACIC ECHOCARDIOGRAPHY IN AORTIC STENOSIS

Class 1

- To confirm the presence and severity of AS
- Assessment of the LV size and function
- Re-evaluation in mild/moderate AS on symptom change
- Re-evaluation for the LV size/function in asymptomatic severe AS.

ETIOLOGY OF AORTIC STENOSIS

The etiology of aortic valve stenosis may be congenital (unicuspid, bicuspid, or trileaflet aortic valve with unequal cusps), rheumatic aortic valve stenosis, or sclero degenerative AS [Figure 7]. However, other pathologies causing LV outflow tract obstruction may mimic AS that include sub-aortic membrane, hypertrophic cardiomyopathy, and supravalvular stenosis. The AS jet is usually eccentric, and therefore, multiple imaging planes are required for parallel Doppler interrogation. Usually, apical 5C, right parasternal, and high left parasternal imaging planes are utilized for optimal alignment of the Doppler beam to the direction of AS jet [Figure 8].

CRITERIA FOR AORTIC STENOSIS

In asymptomatic patients with severe AS, a closely monitored treadmill stress echo can be performed to objectively evaluate exercise capacity and to observe for any improvement in the calculated aortic valve area.

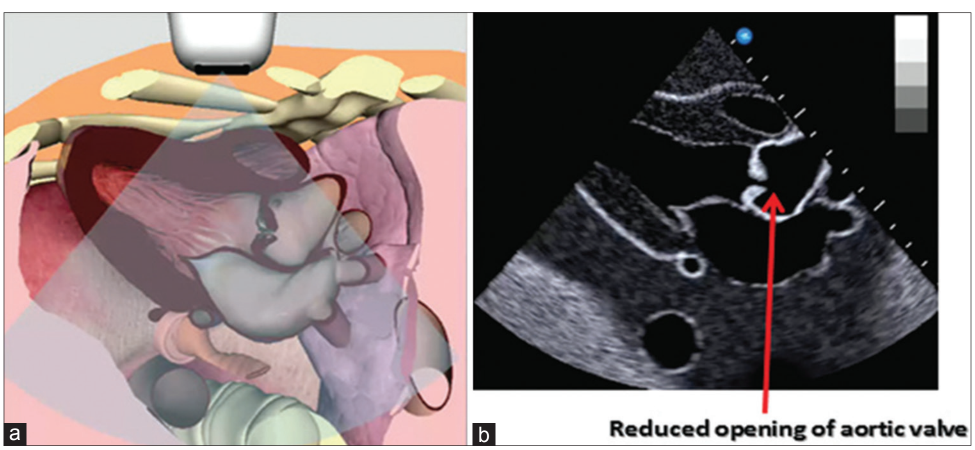

Figure 7: (a and b) Simulated PLAX view of aortic stenosis, depicting the reduced opening of the aortic valve. (photo courtesy by CAE-DSS Imagetech)

In patients with significant LV dysfunction and AS, a markedly low AVA is sometimes observed together with low transvalvular gradient. This "low gradient" AS can be appropriately categorized into critical versus noncritical using dobutamine infusion to increase cardiac output in an attempt to increase the aortic valve opening [Table 1].

AORTIC REGURGITATION

Aortic regurgitation may be the cause of diseases affecting the aorta such as dilatation and aortic dissection or may be due to pathologies of the leaflets such as congenital bicuspid valves, calcifications, myxomatous, rheumatic or IE. AR causes volume overload in LV that leads to its progressive dilatation and could lead to systolic dysfunction [Figure 9a and b].

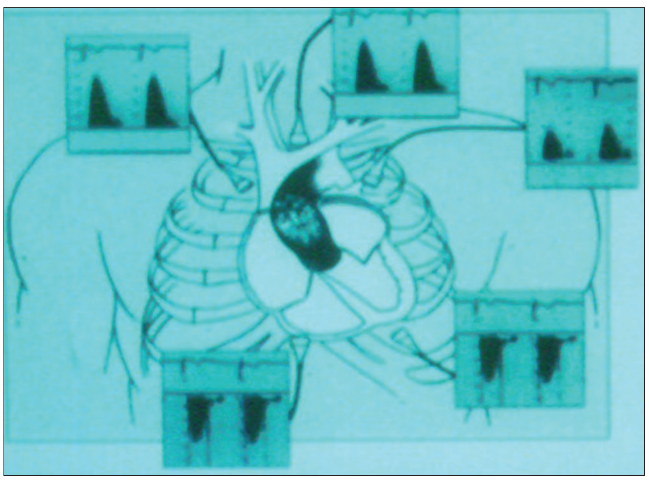

Figure 8: Proper alignments to aortic stenosis jet for better Doppler study

Indication of transthoracic echocardiography in aortic regurgitation

- To confirm the presence and severity of AR
- Assessment of left ventricular size and function
- Re-evaluation in mild/moderate AR on symptom change.

Assessment of regurgitation and severity of aortic dilatation in patients with enlarged AO root [Table 2].

Aortic valve implantation

Mentice aortic valve implantation is designed for interventional cardiologists and cardiac/cardiothoracic surgeons who wish to start training on transcatheter aortic valve implantation/TAVR (TAVI/TAVR). The module allows for safe and cost-effective training for individual instruction or as part of a hospital quality improvement or change-of-process program [Figure 10].

Table 1: Quantification of aortic stenosis

Aortic valve area (cm^2)	
	>1.5 mild
	1-1.5 moderate
	0.75-1 moderately severe
	<0.75 severe
Peak gradient (mmHg*)	
	20-40 mild
	40-60 moderate
	>60 severe
Mean gradient (mmHg*)	
	<20 mild
	20-40 moderate
	>40 severe

*At average heart rates of 70-100/min and average cardiac output

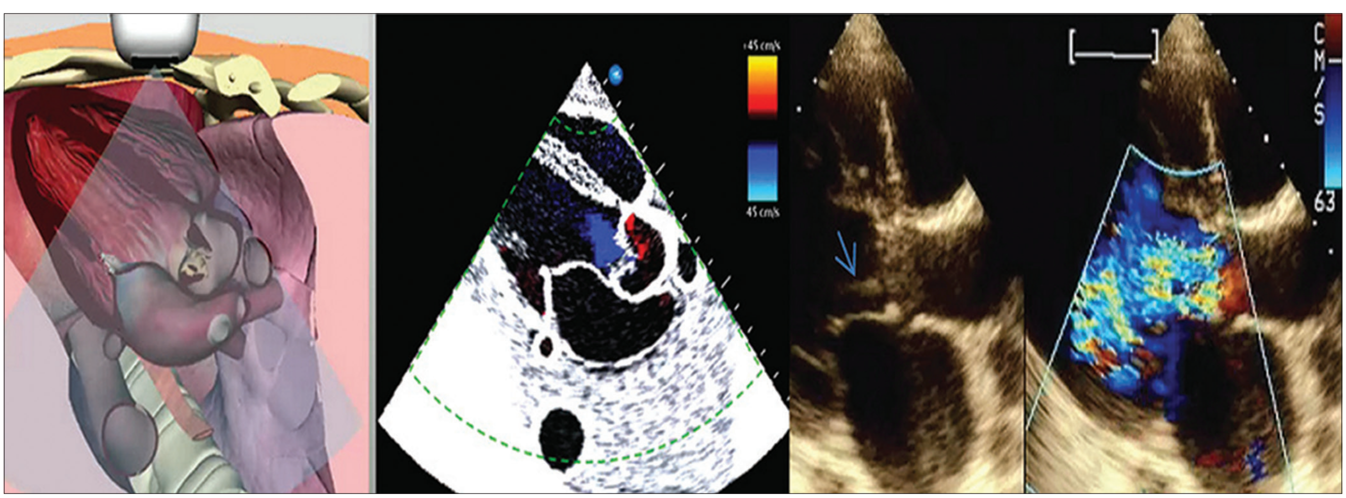

Figure 9: Echocardiographic picture showing Aortic regurgitation jet on the simulator. (photo courtesy by CAE-DSS Imagetech)

This module assumes familiarity with preoperative computed tomography imaging, echocardiography and extensive experience with endovascular intervention, and cardiac catheterization. Both balloon- and self-expandable valve types are supported, which facilitates a discussion on pros and cons, as well as to understand the differences in deployment technique. The stepwise approach, where each step of the procedure is carried out in a safe, simulated environment, prepares the trainee to meet unexpected events in the operating room. Together with a VIST®-C extension, the module can be run with bifemoral access to further enhance training realism.

An ideal platform for the following reasons is required:
- Teaching patient selection and preoperative planning
- Training of TAVI/TAVR in a stepwise approach
- Managing and minimizing radiation dose exposure
- Training of required technical and manipulation skills

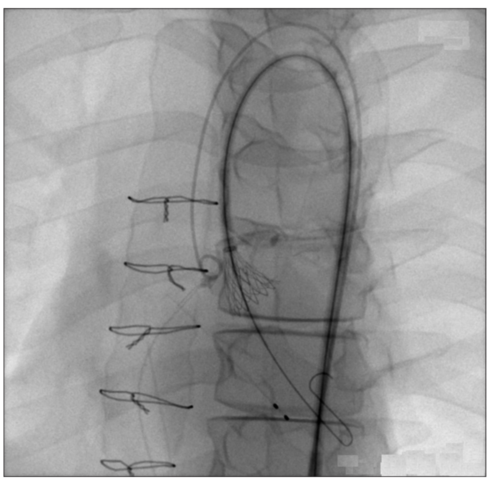

Figure 10: The module allows for safe and cost-effective training

- Review, validation, and amendment of the procedure plan.

Aortic valve implantation is designed for understanding and learning the critical steps involved in the complex high-risk procedure of TAVI/TAVR.

Infective endocarditis-aortic valve

IE involving the AV occurs either on a pre-existing rheumatic or bicuspid aortic valve disease. However, a normal valve IE is also fairly common. The

Table 2: Aortic regurgitation severity

Jet width proportional to the left ventricular outflow tract width (%)	
	<25 mild
	25-66 moderate
	>66 severe
Vena contracta (mm)	
	<2 mild
	3-6 moderate
	>7 severe
Proximal flow convergence - regurgitant orifice (cm2)	
	<0.1 mild
	0.1-0.3 moderate
	>0.3 severe
Regurgitant fraction (%)	
	<30 mild
	30-50 moderate
	>50 severe
Regurgitant volume (ml)	
	<30 mild
	30-60 moderate
	>60 severe
Pressure half-time (m)	
	>350 mild
	250-350 moderate
	<250 severe

A pan-diastolic back flow in descending aorta using suprasternal view indicates more than moderate regurgitation

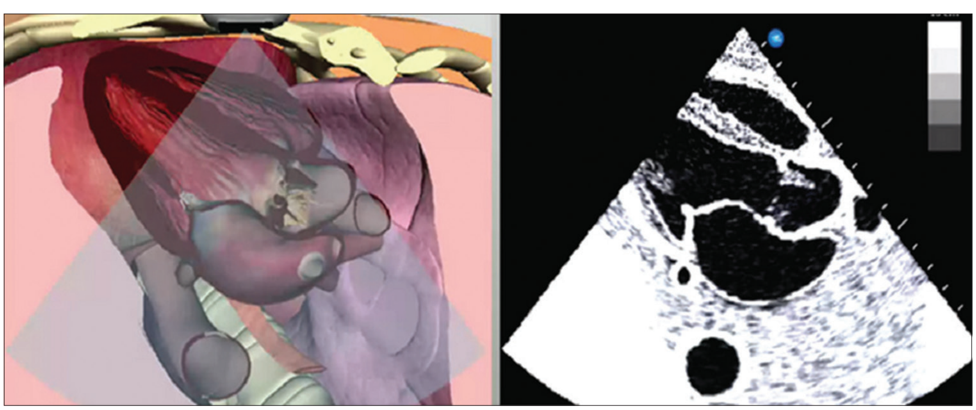

Figure 11: Aortic valve vegetation (shaggy, fluffy echo densities). (photo courtesy by CAE-DSS Imagetech)

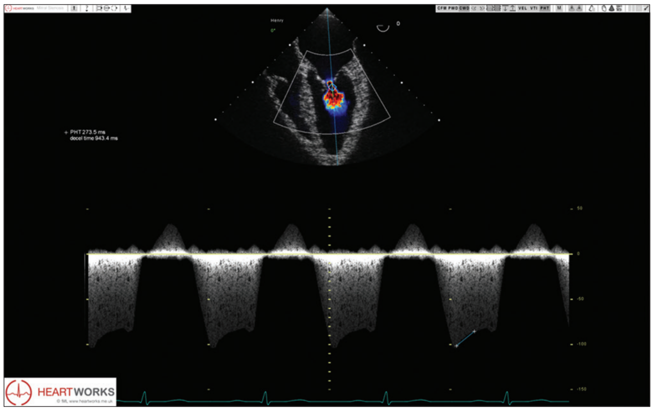

Figure 12: Transesophageal echocardiogram image of mitral stenosis with Doppler

echocardiographic hallmark of IE is a mobile-oscillating nodular, linear, or shaggy echo density on involving either one or more aortic valve cusps. Varying grades of AR are usually seen in such patients. Sub-acute or chronic complications include ring or annular abscess, pseudo aneurysm of the ascending aorta, aorta to the left atrium/right ventricle fistula, and flail aortic leaflets [Figure 11]. TTE has sensitivity and specificity of 65–70% in detecting vegetation.[5,6] If a strong clinical suspicion for IE exists in a patient with a negative TTE study, TEE should be suggested, which has a much higher predictive accuracy (more than 90%).

Aortic stenosis and mitral stenosis Doppler

Flow velocity has been added to the existing AS and mitral stenosis models (pathology module 2). Spectral and color flow Doppler demonstrates characteristic appearances with stenotic flow [Figure 12].[9,10]

CONCLUSION

Accurate patient-specific AR models including the vessel wall thickness and calcification deposits represent a useful tool to guide TAVR and to help in preventing the migration of the valve during the deployment procedure. In addition, optimizing the positioning of the valve during deployment, as well as alternative approaches to TAVR valves tailored to patient's specific pathology, for example, polymeric valves, may offer better procedural outcome. Future research should focus on collaborative efforts to validate previously identified predictors and to explore the role of others, and well-designed large-scale studies that include different devices should focus on long-term clinical outcomes. Given the clinical and economic impact of such interventions,[7,8] clinicians should appropriately risk stratify patients. Well-established predictors can be useful tools to guide clinical decision-making before and after TAVR (appropriate device selection and decision for permanent pacing, respectively), and subsequently improve the clinical outcomes.

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Conflicts of interest

There are no conflicts of interest.

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