REVIEW ARTICLE

Transcatheter Aortic Valve Replacement—Part 3: The Central Role of Perioperative Transesophageal Echocardiography

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TRANSCATHETER AORTIC VALVE REPLACEMENT (TAVR) has emerged as an attractive management option in high-risk patients with severe aortic stenosis (AS), typically the elderly patient with multiple comorbidities.[1,2] Since its introduction 10 years ago, significant advances have resulted in widespread dissemination with ongoing improvements in hardware design, procedural success, and clinical outcomes.[3-8] A pivotal randomized controlled trial (N = 358: 21 participating centers) has shown that TAVR significantly improved survival as compared with optimal medical management in patients with AS deemed too high risk for surgical aortic valve replacement (AVR) (hazard ratio = 0.55; 95% confidence interval, 0.40-0.74; $p < 0.001$).[9] A companion randomized trial (N = 699: 25 participating centers) that compared TAVR with surgical AVR in high-risk patients showed that TAVR was clinically equivalent to conventional AVR.[10] Consequently, the worldwide TAVR experience should continue to expand because it already represents a viable management option in high-risk patients with AS.

The anesthetic management of TAVR already has been reviewed in 2 dedicated articles in this *Journal*.[1,2] The aim of this third article is to review the central role of perioperative transesophageal echocardiography (TEE) in the conduct of TAVR, in which it remains an important diagnostic and monitoring tool. Specific anesthetic techniques will not be reviewed here, but general anesthesia is preferred when TEE is to be performed. TEE can be used with noninvasive ventilation and sedation although the limitations of this approach need to be recognized and the risks and benefits need to be weighed.[11] This review also focuses on the echocardiographic role during each of the critical periods of the TAVR procedure. The detailed specifications of the currently available valve prostheses, namely Edwards-Sapien (Edwards Lifesciences, Irvine, CA) and CoreValve (Medtronic, Minneapolis, MN), already have been described extensively in the literature.[12-14]

The echocardiographic management of TAVR has three phases, each of which has unique considerations and complications (Table 1). The baseline TEE examination before valve implantation should be comprehensive and follow the guidelines developed by the Society of Cardiovascular Anesthesiologists and the American Society of Echocardiography.[15] Although the focus of this baseline echocardiographic examination will be the aortic valve, important concomitant baseline abnormalities should not be overlooked. The TEE examination during valve implantation typically is punctuated by 3 main events: balloon valvuloplasty of the native aortic valve, positioning of the valve prosthesis, and valve deployment. This intense period of clinical activity may be called the "golden hour." The TEE examination after deployment of the aortic valve is focused on valve position, valve function, ventricular function, and the presence of procedure-related complications. This review also focuses on certain complications that may occur after TAVR in which further TEE guidance is needed for management.

Transesophageal echocardiography during a TAVR procedure should be performed by an experienced and credentialed echocardiographer (anesthesiologist and/or cardiologist) who must be prepared to participate actively in the rapid decision-making process that frequently arises during TAVR. Consequently, it is essential that during the "golden hour," the echocardiographer must be focused on the echocardiographic examination during these key phases of the TAVR procedure to provide reliable data to guide clinical decision making and acute management of TAVR complications.[16] Because TEE often is performed in conjunction with fluoroscopy, it also is important for the echocardiographer to be aware of the potential of the TEE probe to interfere with optimal fluoroscopic images at various stages of the procedure, particularly at the time of valve positioning and deployment. In many cases, there is no interference, and the probe can remain in the midesophageal position; however, the echocardiographer must work with the proceduralists when partial withdrawal of the probe is necessary.

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Table 1. Transesophageal Echocardiographic Checklist During Transcatheter Aortic Valve Implantation

Before implantation	Measure aortic valve annulus
	Assess aortic valve and aortic root
	Assess for subaortic valve lesions, such as masses and septa
	Measure ascending aortic diameter
	Assess aortic atheroma
	Assess baseline biventricular function
	Assess regional wall motion abnormalities
	Assess baseline mitral and tricuspid valve function
Implantation	Assist and confirm guidewire placement
	Assist and confirm balloon valvuloplasty
	Assess aortic valve function after balloon valvuloplasty
	Assist and confirm position of valve prosthesis
	Assess aorta to rule out rupture or dissection
	Assess biventricular function
After implantation	Assess position of valve prosthesis
	Assess prosthesis for valvular and paravalvular AR
	Assess aortic valve area and aortic valve gradients
	Assess aorta for possible dissection
	Examine ventricles for wall motion abnormalities
	Rule out pericardial effusion/rupture

BASELINE TRANSESOPHAGEAL ECHOCARDIOGRAPHIC EVALUATION BEFORE VALVE IMPLANTATION

A comprehensive baseline TEE examination is performed after anesthetic induction.[15] This portion of the TEE examination will assess biventricular function, identify any preexisting ventricular wall motion abnormalities, survey the aorta for severe/mobile plaque, and thoroughly evaluate the valves, particularly the aortic and the mitral valve. The evaluation of global biventricular function allows the clinician to anticipate the patient's ability to tolerate the acute hemodynamic instability during TAVR and may aid in the appropriate selection of pharmacologic hemodynamic support. The aorta should be scanned in its entirety for the presence of mobile or severe atherosclerotic plaque, which may contribute to the risk of coronary occlusion, stroke, aortic dissection, and the difficulty of device insertion (Fig 1). Often, this is correlated to preoperative data from computed tomography (CT) scans that can better assess areas within the aortic arch not seen by TEE. The detection of mobile or severe thoracic aortic atheroma, especially in the aortic arch, is a major risk factor for cerebral embolism and, hence, clinical stroke during transfemoral TAVR.[17] This atheroembolic risk may be minimized but not eliminated by accessing the aortic valve by another route, such as the transapical approach or the transaxillary approach.[18,19]

Transesophageal echocardiographic evaluation of the aortic valve should confirm severe AS by standard criteria (Fig 2), including both Doppler gradients and aortic valve area (planimetry and/or continuity equation). It also should assess for baseline aortic regurgitation (AR) because the degree of AR often worsens in TAVR procedures that include balloon valvuloplasty.[2] The Doppler gradients can be obtained using transgastric long-axis or deep transgastric long-axis views for the best alignment of the ultrasound beam with the turbulent blood flow across the stenotic aortic valve.

The aortic valve area can be calculated by planimetry and/or by continuity equation. It is important to recognize that each technique has limitations. Planimetry of the calcified aortic valve in the midesophageal short-axis view can be challenging because of poor resolution of aortic leaflet edges (Fig 2A). Furthermore, aortic valve planimetry may overestimate the valve area if the tracing of the valve area is not made at the level of the leaflet tips.[12] Choosing the optimal time point for aortic valve planimetry is confounded by the motion of the aortic annulus during each cardiac cycle.[20] More recent data suggest that 3-dimensional (3D) TEE analysis may enhance the accuracy of aortic valve area planimetry despite aortic annular motion.[20]

Although the continuity equation allows a calculated aortic valve area, this method assumes that the left ventricular outflow tract (LVOT) is circular. Newer imaging studies using CT scanning and 3D TEE have seriously challenged the validity of this assumption by providing data that show that the LVOT frequently is eccentrically shaped.[21,22] The eccentricity of the LVOT shape frequently confounds the accuracy of the continuity equation for the aortic valve area because calculating a circular LVOT area based on the measurement of the LVOT diameter underestimates the true LVOT area.[23,24] The substitution of the true LVOT area based on measurement by 3D TEE and/or CT scanning into the continuity equation significantly improves the diagnostic

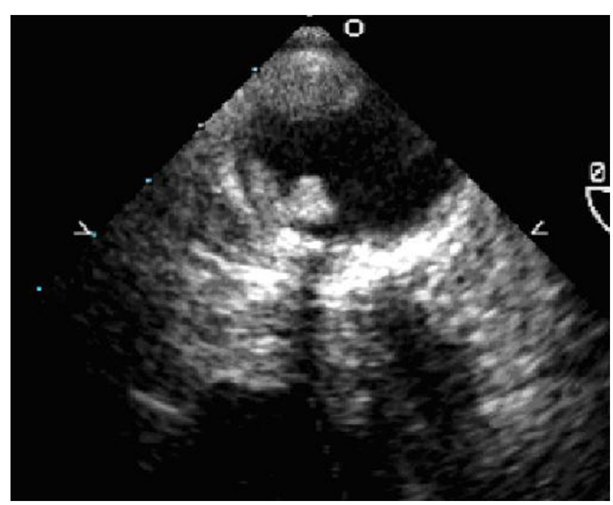

Fig 1. A short-axis view of the descending thoracic aorta (multiplane at 0°). There is severe aortic atheroma that is pedunculated and mobile on real-time imaging. This aortic atheroma pattern is a strong clinical predictor for stroke after transfemoral transcatheter aortic valve implantation. Although it does not eliminate the risk of stroke, a transapical approach may decrease the potential for atheroembolism.