

CME Aortic Valve Anatomy and Assessment by Transesophageal Echocardiography

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A 68-year-old woman is scheduled to undergo an abdominal aortic aneurysm repair. On her preoperative evaluation, she complains of occasional dyspnea with exertion, and on physical examination, she has a systolic murmur. Intraoperative transesophageal echocardiography (TEE) is planned to monitor the patient and evaluate valvular pathology, with a focus on the aortic valve (AV).

ANATOMY OF THE AORTIC VALVE

Interrogation of the AV with TEE should include a complete assessment of valvular and aortic root anatomy and function. The “aortic root” comprises AV annulus, cusps, sinuses of Valsalva, coronary ostia, and sino-tubular junction (STJ) (Fig. 1). The normal AV composes 3 cusps with similar size and morphology, which are suspended from the sinuses of Valsalva. They are named based on their association to the coronary ostia: the left coronary cusp (LCC), the right coronary cusp (RCC), and the noncoronary cusp (NCC). Each cusp has a valve body, a coaptation surface, and a functional hinge point that attaches to the aortic root in a semilunar fashion. The cusps open fully during systole, forming an equilateral triangle with each cusp parallel to the long axis of the left ventricular (LV) outflow tract (LVOT) and ascending aorta, and close (coapting completely) during diastole.

Abnormal embryonic development resulting in failure of commissural formation can result in a unicuspid (unicommissural or acommisural) or bicuspid valve, whereas an extraneous commissure will result in a quadricuspid valve.¹ A bicuspid AV is the most common congenital heart defect, affecting up to 1% to 2% of the population.²

The nodule of Arantius is a normal anatomical structure located at the center of each AV cusp. It composes fibrous material, enlarges with age, and has no clinical implications. Lambli's excrescences, which are thin mobile filaments, are usually attached to the ventricular surface. Lambli's excrescences are rarely implicated in cerebrovascular events and should not be confused with papillary fibroelastomas, which are the most common primary tumors of the cardiac valves (typically ventricular side of aortic; atrial side of mitral) and may accentuate platelet and fibrin aggregation and become a source of arterial embolism (Video 1, see Supplemental Digital Content 1, <http://links.lww.com/AA/A673>).³

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TEE EVALUATION OF THE AORTIC VALVE

Four basic views serve as the foundation of TEE imaging of the AV (Table 1, Video 2, see Supplemental Digital Content 2, <http://links.lww.com/AA/A675>).⁴ The midesophageal AV short-axis (ME AV SAX) view is the only view in which all 3 cusps are simultaneously visible (Fig. 2A). The NCC is adjacent to the interatrial septum, the RCC is most distal from the probe facing the right ventricular cavity, and the remaining cusp is the LCC. The imaging plane should be

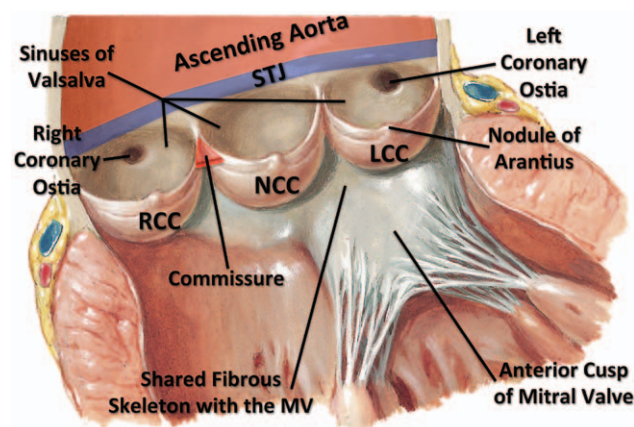

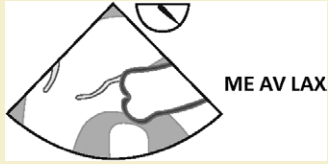




Figure 1. Anatomy of the aortic root along its long axis. The interleaflet triangle between the non- and left coronary cusp is continuous with the anterior leaflet of the mitral valve. The commissures are the coaptation lines that run parallel between the leaflets. LCC = left coronary cusp; NCC = noncoronary cusp; RCC = right coronary cusp; STJ = sino-tubular junction; MV = mitral valve. [Netter medical illustration used with permission of Elsevier. All rights reserved]—Nodule of Arantius (singular form).



Video 1. This is a midesophageal long-axis view demonstrating the echocardiographic appearance between a Lambli's excrescence and papillary fibroelastoma. The Lambli's excrescence is a thin fibrous strand, whereas the papillary fibroelastomas is a larger pedunculated mass that is typically broad based and attached by a stalk. Typically, Lambli's excrescences are found on the ventricular side unlike this example in which it is seen on the aortic side. Please note this is a particularly large example of a papillary fibroelastoma. AV = aortic valve; MV = mitral valve; PA = pulmonary artery; RA = right atrium; RV = right ventricle; TV = tricuspid valve.

View	Multiplane	Structures	Applications	Disadvantages
 ME AV SAX	30°-60°	LCC, LMCA, NCC, RCC	AVA by planimetry en face view of leaflets. CFD to assess AR and supra/infravalvular flow disturbances	CWD/PWD not parallel with blood flow
 ME AV LAX	120°-140°	Asc aorta, LVOT NCC/LCC, RCC	CFD to assess AR measurement of the root. M-Mode infravalvular flow disturbances	CWD/PWD not parallel with blood flow
 TG LAX	90°-120°	LVOT	CWD/PWD to assess gradients/velocities. LV stroke volume CWD for AVA via CE	May be difficult to align CWD/PWD
 Deep TG LAX	0°-20° (anteflexion)	Arch, Asc aorta, LVOT	CWD/PWD to assess gradients/velocities LV stroke volume CWD for AVA via CE	Detailed anatomy difficult to view. May be difficult to obtain view

AR = aortic regurgitation; Asc = ascending; AV = aortic valve; AVA = aortic valve area; CE = continuity equation; CFD = color flow Doppler; CWD = continuous wave Doppler; LAX = long axis; LCC = left coronary cusp; LMCA = left main coronary artery; LV = left ventricle; LVOT = left ventricular outflow tract; ME = mid esophageal; NCC = noncoronary cusp; PWD = pulse wave Doppler; RCC = right coronary cusp; SAX = short axis; TG = transgastric.

withdrawn to image the sinuses of Valsalva and the probe anteflexed slightly to visualize the right and left coronary ostia and the STJ. The probe may also be advanced so that the imaging plane passes through and then under the AV annulus, revealing the LVOT in a SAX view.

Multiplane rotation from the ME AV SAX to 120° to 160° brings into view the ME AV long-axis (LAX) view (Fig. 2B). In this view, the RCC is always in the distal sector field, while the posteriorly displayed cusp (in the proximal sector, adjacent to the base of the anterior mitral leaflet) may be either the LCC or NCC depending on imaging plane orientation. In the ME AV SAX, the sector can be centered in either the NCC or LCC and then rotated by 90° to visualize the respective cusp in the ME AV LAX view. The AV annulus diameter should be measured in the ME AV LAX during midsystole at the hinge points of opposing cusps, inner edge to inner edge, in a plane that is perpendicular to the long axis of the LVOT. The sinus of Valsalva and STJ should be evaluated (and measured in similar fashion) at end-diastole, as measurements are less likely to be affected by aortic compliance and loading conditions (Table 2).^{5,6}

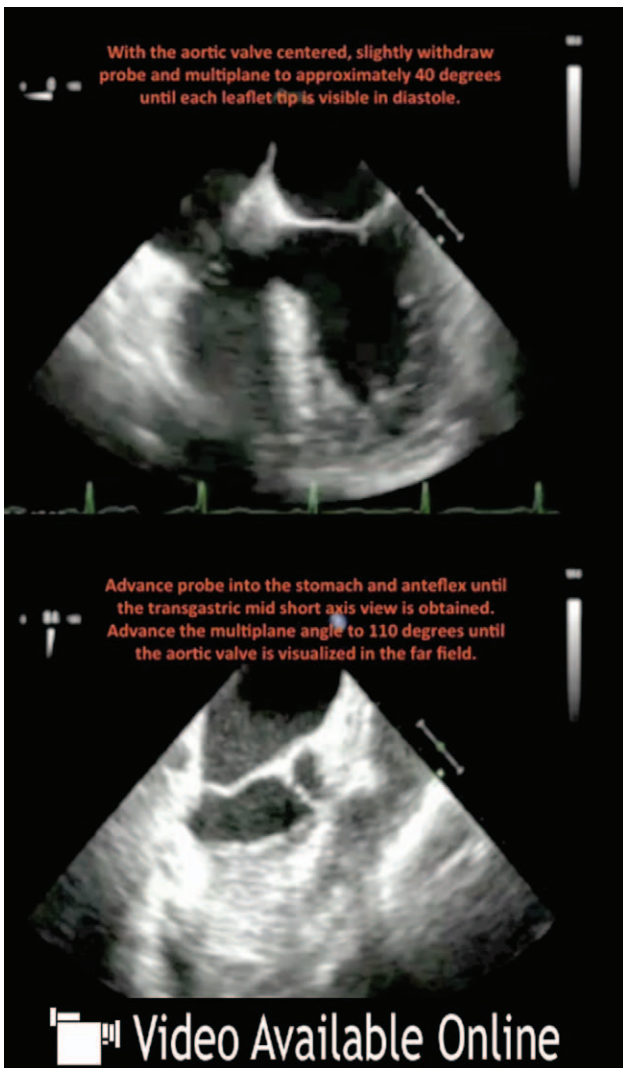
The deep transgastric LAX view (deep TG LAX) is obtained by probe advancement to 50 to 60 cm (at 0°) into the stomach, adjacent to the LV apex (Fig. 3A), followed by probe anteflexion toward the heart base and slow withdrawal. In this view, the LVOT and AV are in the far-field, and systolic blood flow is directed away from the transducer (diastolic flow toward). The cusp positioned adjacent to the mitral valve is the NCC or LCC, and the cusp to the left of the sector (adjacent to the interventricular septum) is the RCC.

The TG LAX view is obtained from the TG mid-SAX view by multiplane angle rotation (120°) until the AV appears in the far-right (distal) sector field (Fig. 4A). Turning the probe slightly to the right helps align the LVOT, AV, and proximal ascending aorta. The cusp toward the left of the far sector is the RCC, and the cusp adjacent to the mitral valve is either the NCC or LCC. Blood flow velocities across the LVOT and AV are assessed in these TG views because of the parallel alignment of the blood flow and Doppler beam.

TWO-DIMENSIONAL IMAGING EVALUATION

The AV should be examined for congenital and acquired abnormalities, and individual cusps should be evaluated for thickening, asymmetry, and coaptation defects. Examination of the anatomic integrity of the body of the cusps should be aided by color flow Doppler (CFD) (at “normal” Nyquist limit of 50–60 cm/s).

Planimetry can be used to measure the valve area (normal 3–4 cm²) in the ME AV SAX view. The minimal orifice of the AV should be traced along the edges of the AV cusps at the point of maximal opening during midsystole. Alternatively, the 3 commissures are considered the apices of an equilateral triangle, and the AV area (AVA) is its surface (AVA = ¼ × (inter-commissural distance)²√3). Although these methods are simple and rapid, they can prove inaccurate since the plane of measurement may be oblique to the actual orifice plane, or valve calcification can obscure the true orifice or make identification of the cusp edge difficult.⁷ Either technique provides a measurement of the anatomic



Video 2. This demonstrates the 4 basic views of the aortic valve via transesophageal echocardiography. The examination begins in the midesophageal 4-chamber view. An off-axis image in the midesophageal short-axis view may give a false appearance of malcoaptation during diastole or a thickened leaflet.

(geometric) AVA, in contrast to the functional (or effective) AVA calculated with Doppler.

DOPPLER EVALUATION

CFD across the AV can be used to evaluate the direction, timing, and location of blood flow. Blood flow across a normal AV is laminar during systole and is absent across the AV or in the LVOT in diastole. A turbulent, mosaic pattern flow during systole indicates acceleration across a narrowed orifice, while diastolic flow is seen across the AV and inside the LVOT with aortic insufficiency. Systolic acceleration proximal to the AV indicates subaortic narrowing, such as in hypertrophic cardiomyopathy, systolic anterior motion of the mitral valve, and/or LVOT obstruction.

Blood flow velocity across the AV can be assessed by continuous wave Doppler (CWD), which typically reveals a laminar pattern with a quick upstroke that peaks in early systole. The CWD cursor should be placed along the area of fastest flow across the AV (may be imaged with CFD) and should be moved side to side to record the maximum velocity. This can be assisted by turning the spectral Doppler volume up to identify the highest pitch velocity. The height of the velocity waveform varies with valve area, amount of flow, and the Doppler angle of incidence. Normal peak Doppler velocities across the left LVOT and AV are <1.5 m/s, and there is minimal acceleration across a normal AV.

The peak pressure gradient is estimated from the peak velocity using the simplified Bernoulli equation:

$$\text{Peak pressure gradient} = 4 \times \text{peak velocity}^2$$

Pressure gradients are flow dependent, and as volume flow rate through the AV increases and decreases, the pressure gradient changes respectively. Conditions that decrease AV flow rate include LV dysfunction, mitral valve pathology, and left-to-right intracardiac shunts. Increased transvalvular flow is associated with hyperdynamic LV function, sepsis, and severe aortic regurgitation. Integration of the velocity signal will produce the velocity time integral (VTI); this requires manual tracing of the digital signal using the on-board measurement package of the individual echocardiographic system (Fig. 3B).

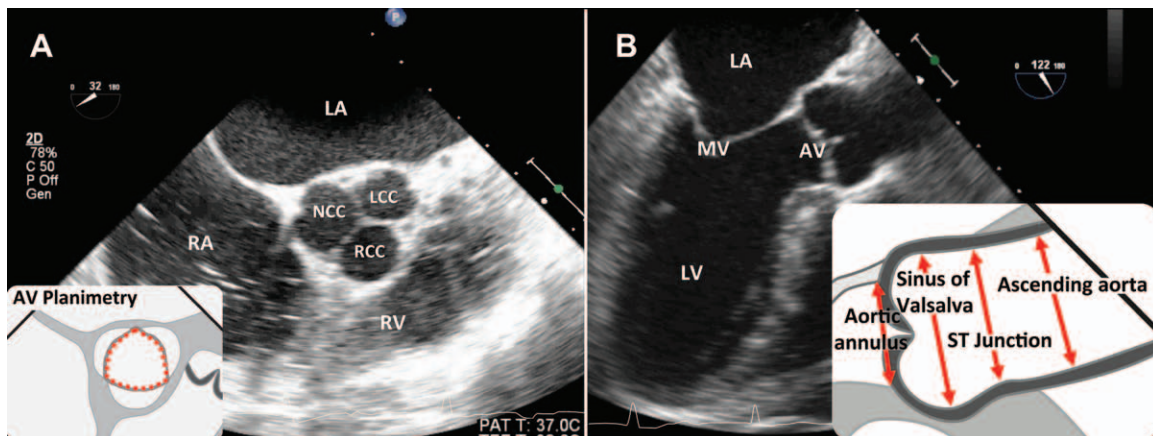


Figure 2. Midesophageal echocardiographic images of the aortic valve (AV) in short axis (A) and long axis (B). The inset figure in A demonstrates planimetry (tracing the 2-dimensional image). The inset figure in B demonstrates aortic root measurements in the long-axis view = with inner-edge to inner-edge technique. AV = aortic valve; LA = left atrium; LCC = left coronary cusp; LV = left ventricle; MV = mitral valve; NCC = noncoronary cusp; RCC = right coronary cusp; RA = right atrium; RV = right ventricle; ST = sino-tubular.

Stroke volume (product of VTI and LVOT area) can be accurately calculated by pulsed wave Doppler (PWD) analysis of the LVOT in the TG LAX or deep TG LAX views. The angle of the Doppler beam should be as parallel to blood flow as possible (aided with CFD) to yield the greatest amplitude spectral waveforms. The PWD sample volume is moved 0.5 to 1 cm away from the AV annulus, until a smooth velocity curve with a “closing artifact” is obtained.⁷ The average of 3 (in normal sinus rhythm) or 5 (in atrial fibrillation) velocity envelopes are used for VTI measurements to be used in the calculation.⁸ Angles of incidence >30° lead to underestimation of the peak velocity and VTI.

Table 2. Indexed Values of the Aortic Root		
	Average diameter (cm/m ²)	Upper normal limit (cm/m ²)
Annulus	1.3 ± 0.1	1.6
Sinuses of valsalva	1.7 ± 0.2	2.1
Sino-tubular junction	1.5 ± 0.2	1.9
Proximal ascending aorta	1.5 ± 0.3	

Errors may also be introduced via inaccurate assessment of LVOT area by diameter measurements. The LVOT area is considered a circle and calculated from an LVOT diameter assessed in the ME AV LAX view, parallel and about 0.5 to 1 cm proximal to the site of measurement of the aortic annulus. However, there is a discrepancy between anatomic (2-dimensional planimetry) and physiologic (2-dimensional CWD VTI continuity calculation) area. The PWD sample for the assessment of LVOT velocity should be placed in the same subvalvular location where the LVOT diameter is measured. This is more important if there is flow acceleration proximal to the AV.

Determination of AVA is then accomplished via the continuity equation: AVA = LVOT stroke volume/VTI of aortic velocity. This AVA measurement is based on velocities and is therefore the “effective” AV orifice. Major limitations of the continuity equation are errors in measuring the LVOT diameter and flow dependency of the VTIs.

M-Mode

The high temporal resolution of M-mode is used to image the motion of the AV cusps. With the M-mode cursor placed

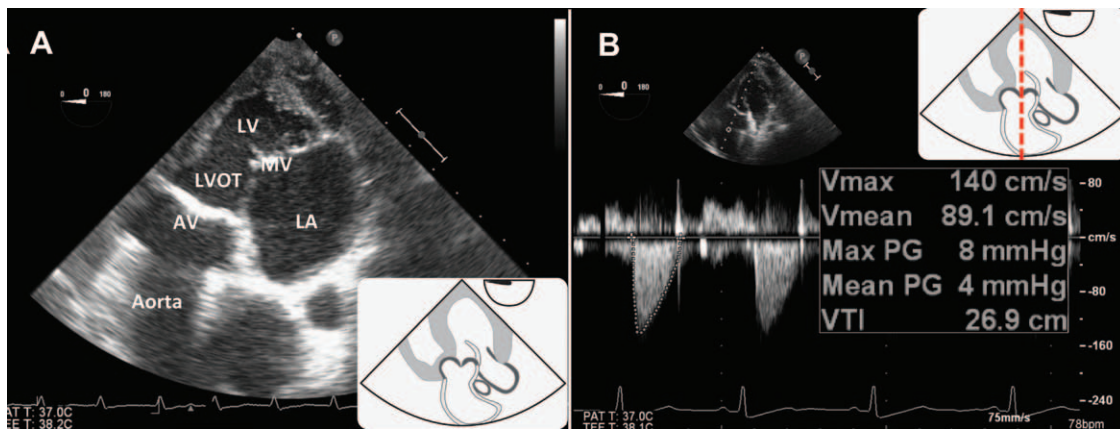


Figure 3. Deep transgastric view of the aortic valve [A] and continuous wave Doppler recording of velocity [B]. The spectral velocity waveform is traced along the outer edge, excluding the fine linear signals to derive the velocity time integral (VTI). From the VTI = the mean AV gradient is calculated. AV = aortic valve; LA = left atrium; LV = left ventricle; LVOT = left ventricular outflow tract; MV = mitral valve; PG = pressure gradient; Vmax = maximum velocity; Vmean = mean velocity.

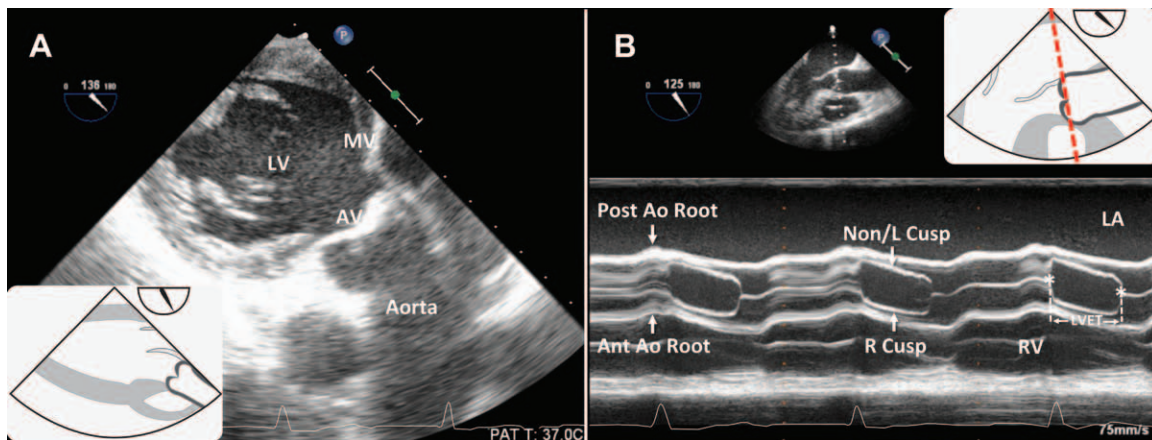


Figure 4. Transgastric long-axis view (A, with the M-mode cursor across the AV in the midesophageal AV long-axis view [B]). Ejection time is measured between the 2 asterisks. Ant Ao = anterior aortic; AV = aortic valve; LA = left atrium; LV = left ventricle; MV = mitral valve; Non/L = non/left; Post Ao = posterior aortic; R = right; RV = right ventricle.

Teaching Points

- A complete examination of the aortic valve (AV) should include assessment of valvular and aortic root anatomy and function, using 4 views: midesophageal AV short-axis, midesophageal AV long-axis (LAX), transgastric, and deep transgastric LAX.
- Measurement of the left ventricular outflow tract and AV annulus should be performed in the midesophageal AV LAX view in midsystole and of the sinuses of Valsalva and sino-tubular junction during end-diastole.
- The normal AV has a smooth, filled-in spectral waveform with a laminar pattern that peaks in early systole. Velocity is flow dependent.
- Determination of AV area is done with planimetry (tracing the 2D image), the equilateral triangle technique, or calculated with the continuity equation. A source of error with the continuity equation is accurate determination of left ventricular outflow tract diameter. With planimetry, the valve orifice is traced in midsystole or calculated as the area of an equilateral triangle.
- Systolic flow acceleration with color flow Doppler indicates a narrowed orifice, and diastolic flow across the AV indicates regurgitation. Attention to location, timing, and direction of flow elucidates pathology.

across the cusps in the ME LAX view, a normal AV is shown with a “box” waveform (Fig. 4B). Premature opening of the AV (before the QRS complex) is seen with increased LV pressure. Premature closure of the AV (before the T wave) may be indicative of dynamic outflow obstruction due to hypertrophic cardiomyopathy or systolic anterior motion of the mitral valve. This may cause the M-mode “box” to “tremble” as it prematurely collapses. An eccentric closure line of the M-mode box is often seen with a bicuspid AV.

LV ejection time (LVET), a flow-independent index of LV systolic function, can be derived from M-mode across the AV in the ME AV LAX view (Fig. 4B) or CWD in the TG views. With M-mode, LVET is the time from opening to closure of the AV cusps. LVET may also be assessed via spectral Doppler (duration of LV ejection). Normal LVET is 362 ± 42 milliseconds and is obtained by determining the mean of 3 consecutive waveforms.⁹ A shortened LVET (LV failure or rapid heart rate) indicates decreased stroke volume, whereas a prolonged LVET (compensated aortic stenosis or slow heart rate) reflects increased stroke volume. ■■

DISCLOSURES

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REFERENCES

1. Snieciński RM, Shanewise JS, Glas KE. Transesophageal echocardiography of a unicuspid aortic valve. *Anesth Analg* 2009;108:788–9
2. Hoffman JJ, Kaplan S. The incidence of congenital heart disease. *J Am Coll Cardiol* 2002;39:1890–900
3. Hort W, Horstkotte D. Fibroelastoma and Lambl’s excrescences: localization, morphology and pathogenesis, differential diagnosis and infection. *J Heart Valve Dis* 2006;15:591–3
4. Shanewise JS, Cheung AT, Aronson S, Stewart WJ, Weiss RL, Mark JB, Savage RM, Sears-Rogan P, Mathew JP, Quiñones MA, Cahalan MK, Savino JS. ASE/SCA guidelines for performing a comprehensive intraoperative multiplane transesophageal echocardiography examination: recommendations of the American Society of Echocardiography Council for Intraoperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transesophageal Echocardiography. *J Am Soc Echocardiogr* 1999;12:884–900
5. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, Picard MH, Roman MJ, Seward J, Shanewise JS, Solomon SD, Spencer KT, Sutton MS, Stewart WJ; Chamber Quantification Writing Group; American Society of Echocardiography’s Guidelines and Standards Committee; European Association of Echocardiography. Recommendations for chamber quantification: a report from the American Society of Echocardiography’s Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. *J Am Soc Echocardiogr* 2005; 18:1440–63
6. Roman MJ, Devereux RB, Kramer-Fox R, O’Loughlin J. Two-dimensional echocardiographic aortic root dimensions in normal children and adults. *Am J Cardiol* 1989;64:507–12
7. Baumgartner H, Hung J, Bermejo J, Chambers JB, Evangelista A, Griffin BP, Iung B, Otto CM, Pellikka PA, Quiñones M; American Society of Echocardiography; European Association of Echocardiography. Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. *J Am Soc Echocardiogr* 2009;22:1–23
8. Perrino AC Jr, Harris SN, Luther MA. Intraoperative determination of cardiac output using multiplane transesophageal echocardiography: a comparison to thermodilution. *Anesthesiology* 1998;89:350–7
9. Swaminathan M, Phillips-Bute BG, Mathew JP. An assessment of two different methods of left ventricular ejection time measurement by transesophageal echocardiography. *Anesth Analg* 2003;97:642–7