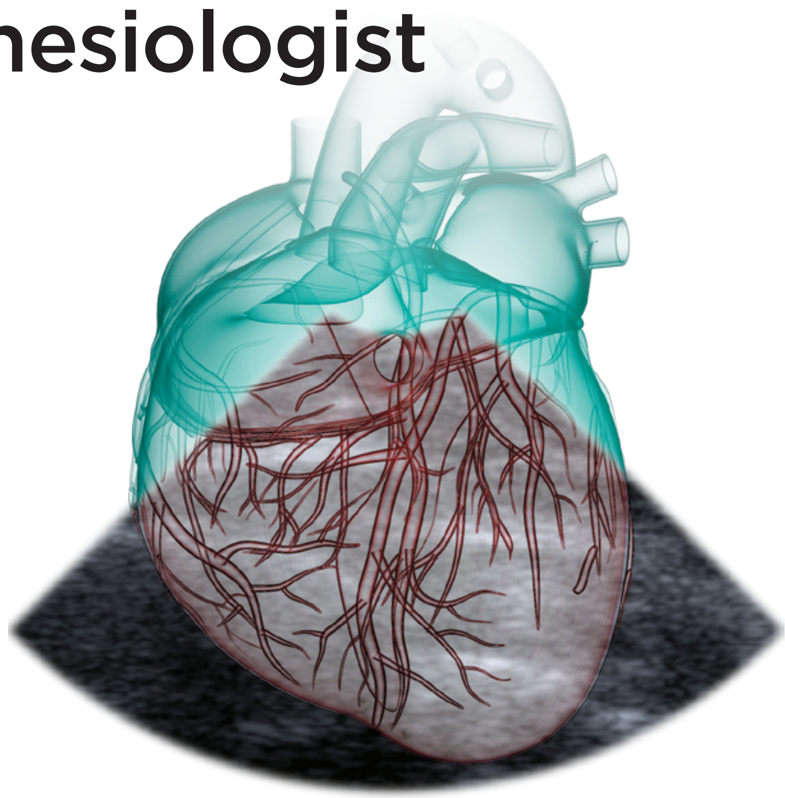
ANESTHESIOLOGY NEWS

Echocardiography
For the Anesthesiologist



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Transesophageal echocardiography (TEE) plays an important role in patient management during the perioperative period. It is routinely used during cardiac surgery but also has great value for the unstable patient undergoing noncardiac surgery. This article presents the anesthesiologist with a practical review of the basic TEE examination, ultrasound physics and fundamental principles, indications for TEE, the TEE certification process, perioperative use of transthoracic echocardiography (TTE), and the increasing use of 3-dimensional (3-D) echocardiography.

Basic Examination

Transesophageal echocardiography provides an excellent diagnostic and monitoring tool for anesthesiologists in the operating room. The TEE examination can be broken down into complete/comprehensive and abbreviated forms; the user may select either depending on the urgency of the situation and other clinical responsibilities.

As with any invasive procedure, the potential risks and benefits of TEE should be discussed with the patient and preoperative informed consent obtained. A study by researchers at Brigham and Women's Hospital, in Boston, retrospectively reviewed more than 7,000 TEE examinations and found rates of procedure-related morbidity and mortality of 0.2% and 0%, respectively. Although rare, the most common TEE-related injuries were odynophagia, dental trauma, malpositioning of the endotracheal tube, upper gastrointestinal hemorrhage, and esophageal perforation. Few contraindications exist to insertion of the TEE probe; these include dysphagia, odynophagia, significant reflux, hematemesis, history of gastric and/or esophageal pathology (a hiatal hernia is not a contraindication but may complicate imaging), and significant resistance during insertion or advancement of the probe (Table 1). By

Table 1. Contraindications To Intraoperative TEE

Dysphagia
Odynophagia
Hematemesis
History of gastric and/or esophageal pathology
Significant reflux
Significant resistance during insertion or advancement of the probe

TEE, transesophageal echocardiography

carefully selecting candidates using these guidelines, as well as minimizing probe manipulation, clinicians can make intraoperative TEE relatively safe and beneficial for assessing cardiovascular function and anatomy.[1]

In 1999, the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists (SCA) developed recommendations on what should be included in a comprehensive TEE examination. Shanewise and colleagues applied these recommendations to the 20 standard imaging views that allow for a complete examination of the ventricular, valvular, and major vascular functions and anatomy.[2] Miller and colleagues subsequently condensed the comprehensive examination into 12 necessary views that would enable basic TEE practitioners to quickly examine and interpret cardiovascular function and anatomy.[3]

The following section describes how to complete the basic TEE examination. The order can vary according to practitioner preference. In any case, the sequence should minimize probe movement.

Image acquisition depends on controllable and uncontrollable factors. Uncontrollable factors, such as the patient's anatomy, "acoustic windows," and shadows from an implanted cardiac device, will affect the quality of the ultrasound images. However, an experienced and skilled user can manipulate both the properties and the position of the probe to obtain adequate images.

The probe is controlled by advancing and withdrawing the instrument to view more distal and proximal structures and by rotating it counterclockwise and clockwise to image left- and right-sided structures. In combination with using the large control dial to anteflex or retroflex the probe tip, using the smaller dial to flex the probe tip right to left, and using the scan angulation control from 0 to 180 degrees, the practitioner can obtain and optimize the required TEE images in order to acquire accurate data for analysis.[4]

The basic examination begins with insertion of the TEE probe. After securing the patient's airway and evacuating the stomach, the clinician should carefully insert a bite guard with lubricating jelly into the patient's mouth. The probe is then passed (with the control lock in the off position) into the upper esophagus using a sustained jaw lift, constant gentle pressure, and a slight twisting motion. Beyond the cricopharyngeus muscle, a distinct loss of resistance will be noted. Particular care must be taken at this point because numerous possibilities exist for trauma and morbidity to both the patient and the probe.[1]

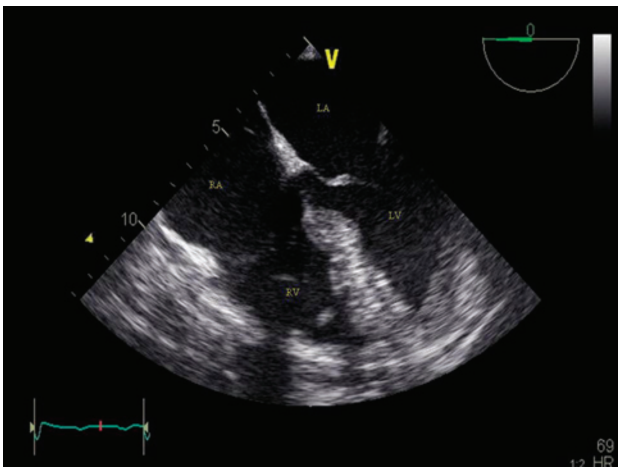

Figure 1. Mid-esophageal 4-chamber view.

The entire heart is visualized in a single view. This view provides an excellent "overview" of ventricular and valvular function.

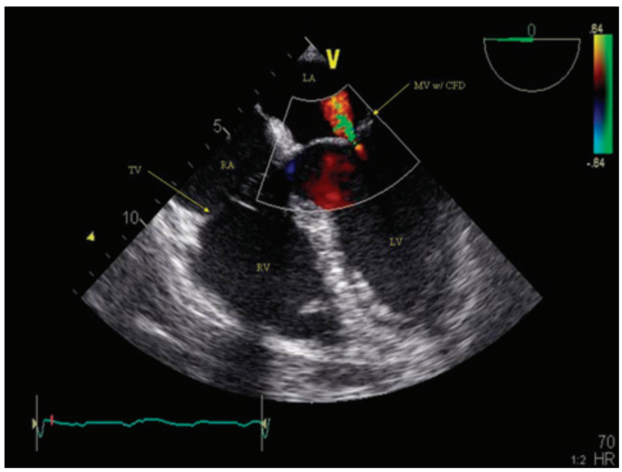

Figure 2. Mid-esophageal 4-chamber view with colorflow Doppler over the mitral valve.

This image allows assessment of atrioventricular valve function and flow patterns.

For meanings of abbreviations, see key on page 8.

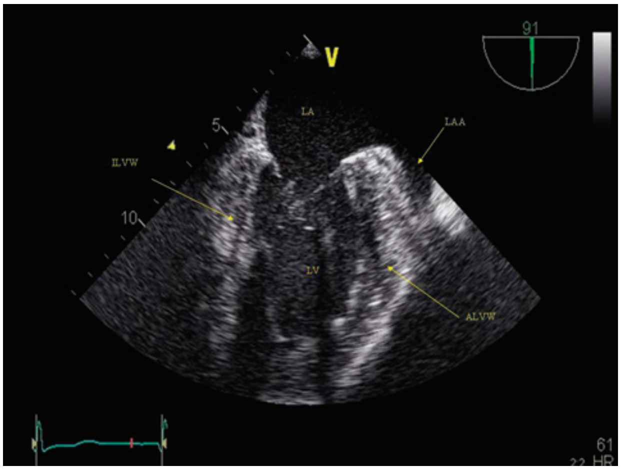

Figure 3. Mid-esophageal 2-chamber view.

This image allows assessment of the anterior and inferior walls of the left ventricle and assessment of the left atrial appendage.

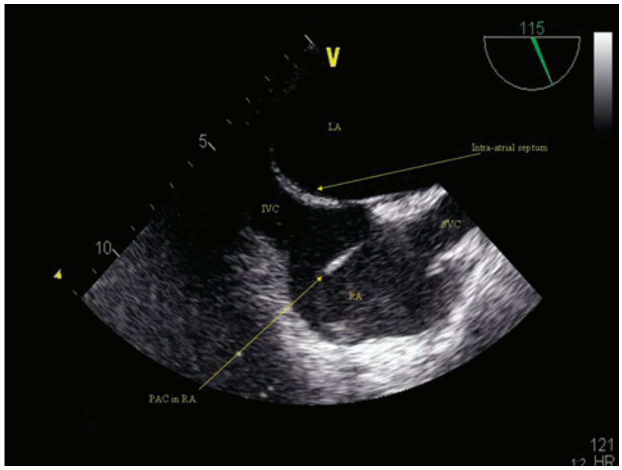

Figure 4. Mid-esophageal bicaval view.

This image allows evaluation of right-sided cardiac structures, including evaluation of the atrial septum for patent foramen ovales.

When positioned in the esophagus, the probe should be gently advanced until a recognizable structure is reached—usually the mid-esophageal 4-chamber (ME-4C) view (Figure 1). This view is obtained by advancing the probe at 0 degrees of scan angulation and slight retroflexion of the tip. All 4 cardiac chambers, the tricuspid valve (TV), and the mitral valve (MV), should be visible with the left-sided structures on the right of the TEE screen and right-sided structures on the left of the screen (as with a chest x-ray). These structures should be evaluated regarding size, shape, structure, and function.[4] This view is easy to obtain and commonly is used as a landmark if the practitioner loses orientation during the examination.

The next images that are relatively easy to obtain are the ME-4C view with colorflow Doppler (CFD) of the MV and the TV (Figure 2). To adjust the viewing box over the MV or TV in the ME-4C view, depress the CFD button on the echocardiography machine and use the track ball. These views will allow the practitioner to assess directional flow and any turbulence through the MV and the TV. They are useful in the assessment of any significant pathology in valvular flow, including tricuspid or mitral regurgitation or stenosis.

The mid-esophageal 2-chamber (ME-2C) view is obtained by advancing the scan angulation to 90 degrees to reveal a long-axis view of the left side of the heart. The anterior wall of the left ventricle (LV) will appear on the right of the screen and the LV inferior wall on the left of the screen. This view may provide the best imaging of the LV apex, LV anterior, and inferior wall function, and the left atrial appendage[4] (Figure 3).

The mid-esophageal bicaval (ME-BC) view is obtained by rotating the scan angulation from 100 to 120 degrees and turning the probe clockwise (Figure 4). The image will reveal the right atrium (RA) with the superior vena cava on the right of the screen and the inferior vena cava on the left of the screen. This view is helpful for identifying RA pathology, masses, thrombi, and atrial septal defects, especially patent foramen ovales when using CFD.[4]

From the ME-BC view, the mid-esophageal aortic valve short-axis (ME-AoSx) view is obtained by reducing the probe scan angulation to 30 to 50 degrees and slightly withdrawing the probe (Figure 5). The left, right, and non-coronary cusps emerge in clockwise order. The anatomy of the aortic valve (AV) can be assessed to identify bicuspid or unicuspid structures.[4]

The next view to be obtained is the mid-esophageal aortic valve long axis (ME-AoLx). This is visualized by simply increasing the scan angulation to 120 degrees while keeping the AV in the center of the screen (Figure 6). This view allows evaluation of the AV, the sinus of Valsalva, the sinotubular junction, and the ascending aorta.[4] By pressing the CFD button on the echocardiography machine and positioning the Doppler window over the AV, the practitioner can evaluate the flow and turbulence across the valve in order to evaluate if regurgitation or stenosis is occurring (Figure 7).

The mid-esophageal RV inflow–outflow (ME-RV IO) view is achieved by reducing the scan angulation to 40 to 60 degrees from the ME-AoLx view and slightly adjusting to include the AV, RV, and RV outflow tract (Figure 8). As a result, the RV, TV, and pulmonic valve (PV) appear in the same frame. With the use of CFD, the practitioner can better evaluate flows in the TV and PV and detect any significant regurgitation or stenosis (Figure 9).

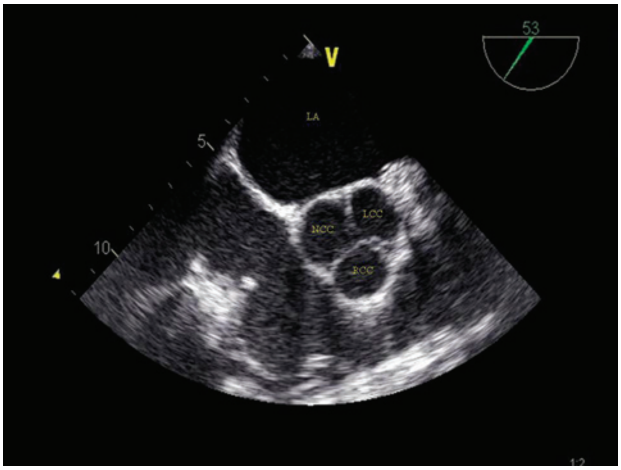

Figure 5. Mid-esophageal aortic valve short-axis view.

This image allows evaluation of the aortic valve leaflet structure and function.

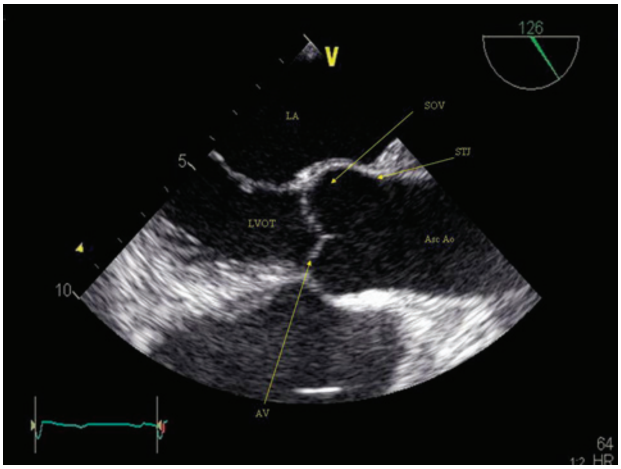

Figure 6. Mid-esophageal aortic valve long-axis view.

This image allows evaluation of the left ventricular outflow tract, and the aortic root.

The last 2 views of the basic examination require the probe to be in neutral position and at a 0-degree scan angle. The practitioner gently advances the probe into the stomach and anteflexes the tip to see the LV with both papillary muscles to obtain the transgastric mid short-axis (TG-MSx) view. The configuration of the screen changes as the posterior medial papillary muscle appears at the top of the screen and the anterior lateral papillary muscle appears near the bottom (Figure 10). In this view, clinicians can evaluate LV wall motion and all 3 coronary artery territories.[6] To obtain the transgastric 2-chamber (TG-2C) view (Figure 11) from this point, adjust the scan angle from 80 to 90 degrees. This view

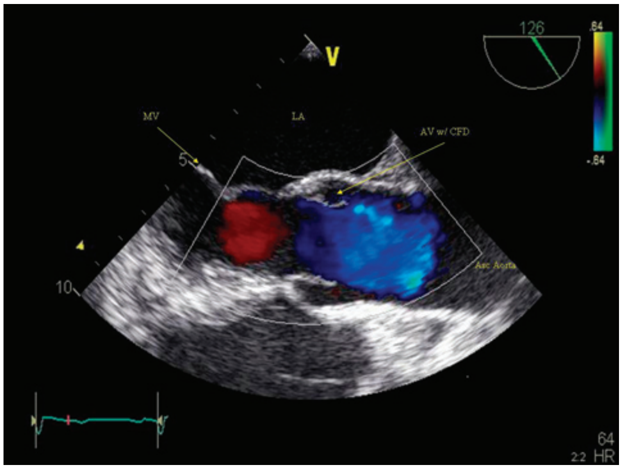

Figure 7. Mid-espohageal aortic valve long-axis with colorflow Doppler.

This image allows evaluation of the aortic valvular function and flow velocities, including interrogation for aortic stenosis or insufficiency.

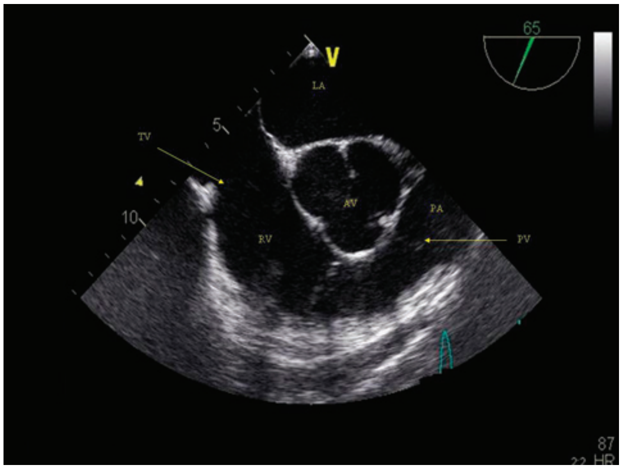

Figure 8. Mid-esophageal right ventricular inflow–outflow view.

This image allows for evaluation of the right ventricle, tricuspid, and pulmonic valve function.

allows a more complete evaluation of the LV anterior and inferior walls as well as the MV subvalvular apparatus.

On completion of the examination, the probe is returned to the neutral position and gently removed from the patient.

Ultrasound and Echocardiography

Resolution, Impedance, and Attenuation

The images generated by 2-D echocardiography result from the transmission of ultrasound waves from a probe through tissues in their path. Because ultrasound

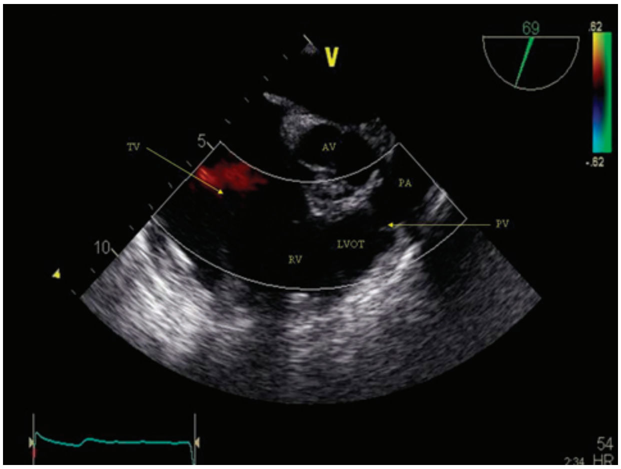

Figure 9. Mid-esophageal right ventricular inflow–outflow with colorflow Doppler.

This image allows for assessment of blood flow across the tricuspid and pulmonic vales.

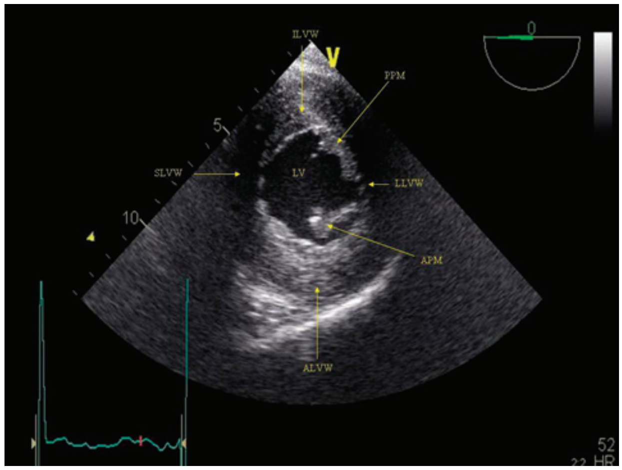

Figure 10. Transgastric mid-short axis view.

This view allows assessment of overall left ventricular function, specifically evaluation of coronary artery perfusion distribution. This view also allows for assessment of overall left ventricular filling or volume status.

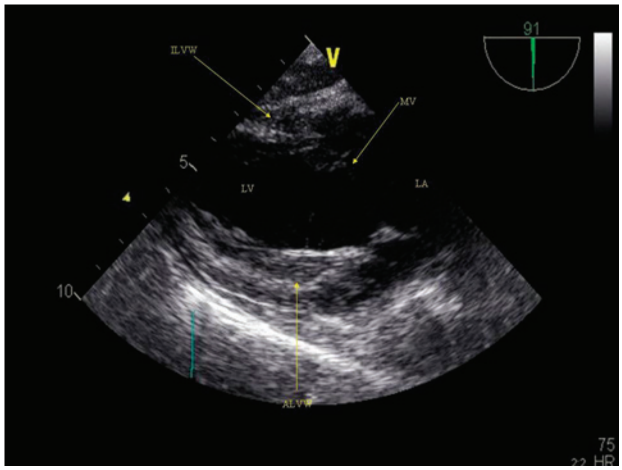

Figure 11. Transgastric 2-chamber view.

This image allows for a complete assessment of the anterior and inferior left ventricular walls, and the mitral valve subvalvular apparatus.

travels at a constant speed in biological tissues (1,540 m per second), the time required for the sound waves to be reflected back determines the exact location of a structure. Echocardiography uses sound waves with frequencies of 2 to 10 mHz, which are higher than the audible range for humans. The shorter the wavelength and the higher the frequency, the better the ultrasound can differentiate 2 distinct objects lying within the plane of the beam. This phenomenon is called *axial resolution*.[5]

Each type of tissue has a different capacity for sound transmission, or *acoustic impedance*. Bone, fluid, and other relatively dense tissues have high acoustic impedance and are excellent transmitters of ultrasound. Air and lung tissue are less dense and thus do not transmit ultrasound well. When an ultrasound wave encounters an interface of 2 tissues with similar acoustic impedance, it continues in its path. When an ultrasound wave encounters tissues with different acoustic impedances, part of that energy is reflected. Large differences in acoustic impedance, such as between tissue and bone, cause a high percentage of energy to be reflected back to the transducer, resulting in echo-dense or bright signals on the screen. Smaller differences in acoustic impedance, such as when tissue interacts with blood, cause less reflection and more transmission.[4,5] An echolucent, or dark, picture is the result.

As ultrasound travels away from the transducer, the signal changes and loses energy. This loss of intensity is referred to as *attenuation*. Returning signals can be amplified by increasing the gain. Lower ultrasound frequencies have less attenuation compared with higher frequencies. Therefore, for structures that are far from the ultrasound probe, it is helpful to use a lower frequency. However, lower frequencies have poorer resolution, so the ultrasonographer must always balance resolution with attenuation. Keeping the structure of interest close to the ultrasound probe will allow use of higher frequencies.[5]

Echocardiography Modes

Basic 2-D imaging is based on brightness mode (B-mode). The brightness of the displayed image is proportional to the strength of the returning signal. Motion

Table 2. ASA/SCA Indications For TEE

Cardiac Surgery
Case-by-case basis in small children
Coronary artery bypass graft surgeries
Open heart (valvular) and thoracic aortic surgical procedures in adults without contraindications
Transcatheter intracardiac procedures (particularly in patients under general anesthesia and intracardiac ultrasound is not used) including:
Septal defect closure
Atrial appendage obliteration
Catheter-based valve replacement/repair
Noncardiac Surgery
Atrial septal defect
Hypovolemia
Lung transplantation
Major abdominal or thoracic trauma
Myocardial ischemia
Patients at risk for severe hemodynamic, pulmonary, or neurologic compromise
Pericardial tamponade
Persistent, unexplained hypoxemia or hypotension
Thromboembolic events
Unexplained, life-threatening circulatory instability that persists despite corrective therapy

ASA, American Society of Anesthesiologists; **SCA,** Society of Cardiovascular Anesthesiologists; **TEE,** transesophageal echocardiography

mode (M-mode) offers a 1-dimensional slice through the heart that is displayed over time and is optimal for timing of cardiac events. M-mode presents the best display of cardiac motion but is limited in its ability to show a detailed picture of cardiac anatomy. B-mode–based echocardiography is able to show shape and lateral motion of structures, whereas M-mode displays only axial motion.[5]

Doppler ultrasonography is an important adjunct for use with 2-D echocardiography to assess speed and direction of blood flow. The Doppler principle states that the velocity and direction an object is traveling affect the change in frequency that the object produces. For example, a red blood cell traveling toward the transducer creates a positive Doppler shift, whereas the same cell traveling away creates a negative Doppler shift. Pulsed-wave and continuous wave Doppler are 2 types of Doppler ultrasonography that permit the echocardiographer to make quantitative measurements of blood flow and to grade the severity of disease.

Pulsed-wave Doppler uses a single crystal to emit and receive sound waves. It is limited by a maximum frequency and blood velocity that can be measured, and is therefore used to gauge slower-moving objects (transmitral blood velocity).[5] Continuous wave Doppler uses 2 crystals, one to continuously transmit sound and the other to continuously receive it. Because this mode has one crystal that is constantly receiving ultrasound signals, it can measure the velocity of blood as it traverses a stenotic aortic valve.[5]

CFD can simultaneously image structures and blood flow. Many sample volumes are recorded and displayed on top of the 2-D echocardiographic image. Traditionally, red indicates blood flow toward the probe and blue indicates flow away from the probe. CFD is susceptible to aliasing artifacts but is an excellent tool for assessing valve function, aortic dissection, and congenital cardiac anomalies.[5]

Achieving the best echocardiography image occurs when one understands the principles of ultrasound and the techniques available, and focuses on the structure under investigation.

Indications for TEE

Transesophageal echocardiography is an important diagnostic and monitoring tool, yet it is not without risks. In May 2010, the American Society of Anesthesiologists and the SCA published practice guidelines for the perioperative use of TEE[6] (Table 2).

TEE for Cardiac Surgery

The recommendations state that TEE should be used for all open heart (valvular) and thoracic aortic surgical procedures in adult patients without contraindications. TEE should be considered in coronary artery bypass graft surgeries to confirm and refine the preoperative diagnosis, to detect new or unsuspected pathology, to adjust anesthetic and surgical plans based on these findings, and to assess the results of the surgical intervention. TEE should be considered on a case-by-case basis in small children undergoing cardiac surgery.[6]

Transesophageal echocardiography may be used during transcatheter intracardiac procedures, particularly if the patient is under general anesthesia and intracardiac ultrasound is not used. Specifically, TEE should be used for septal defect closure, atrial appendage obliteration, and catheter-based valve replacement and repair.

TEE for Noncardiac Surgery

The recommendations for use of TEE in noncardiac surgery include cases when the nature of the procedure or the patient's known or suspected cardiovascular pathology may result in severe hemodynamic, pulmonary, or neurologic compromise. Such cases include but are not limited to lung transplantation; major abdominal or thoracic trauma; pathology such as persistent unexplained hypoxemia or hypotension; and suspected abnormalities such as atrial septal defect, myocardial ischemia, hypovolemia, pericardial tamponade, and thromboembolic events. In addition, TEE should be used when equipment and expertise are available and a patient experiences unexplained life-threatening circulatory instability that persists despite corrective therapy.[6]

TEE for Critical Care

When diagnostic information that is expected to change the management of critical care patients cannot be obtained by TTE or other diagnostic modalities in a timely manner, TEE should be considered. Diagnosis of valvular abnormalities, aortic dissection, intracardiac mass, tamponade, ventricular failure, and hypovolemia with TEE has been reported in this patient population.[6]

Certification

The Basic Perioperative Transesophageal Echocardiography (Basic PTE) certification is offered through the National Board of Echocardiography (NBE). The NBE requires practitioners to pass the Basic PTE examination, but to sit for the test, one must meet several prerequisites. The applicant must have both a current medical license and board certification in anesthesiology. The applicant also must have specific training or experience in perioperative TEE—including the study of 150 TEE examinations and at least 50 basic examinations performed by the applicant. (The applicant also may qualify if he or she has performed 150 basic intraoperative TEE examinations within 4 years, with no less than 25 examinations per year, and have at least 40 hours of American Medical Association Category 1 CME credits for perioperative TEE). Applicants who are advanced TEE-certified may sit for the basic examination.[7] (For more information about obtaining certification, visit http://www.echoboards.org/sites/default/files/BasicPTEeXAM.pdf.)

Transthoracic Echocardiography

Transthoracic echocardiography is another useful tool for assessment of cardiac function in the perioperative period. Unlike TEE, TTE is noninvasive but offers limited images in patients with a large body habitus, positive pressure ventilation, obstructive lung disease, and occlusive surgical dressings. Nevertheless, TTE offers rapid, bedside evaluation of hemodynamics, which is particularly valuable in the unstable patient in the intensive care unit (ICU) or in the recovery room. The modality also may be considered if a patient has contraindications to TEE.

A focused TTE examination that evaluates a specific clinical concern can be performed in approximately 10 minutes.[8,9] New technologies such as portable handheld echocardiography devices, harmonic imaging, digital image acquisition, and contrast echocardiography have increased the availability and quality of TTE imaging.[10]

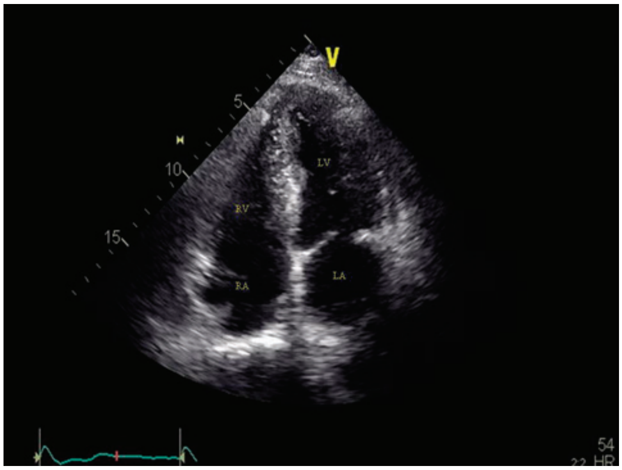

Figure 12. Transthoracic echocardiographic image of all 4 cardiac chambers.

Note that this image is inverted, compared to an image of the heart obtained by transesophageal echocardiography.

Indications

The most common indication for bedside TTE in the ICU is assessment of LV function (Figure 12). Examination of the LV in the parasternal long axis view allows measurement of the valve's dimensions and subsequent calculations of ejection fraction and fractional shortening. A new ischemic event can be diagnosed by observing the valve for abnormalities in the motion of the regional wall. Right-sided cardiac dysfunction, pericardial effusions or tamponade, valvular dysfunction, endocarditis, and intracardiac shunts are other causes of hemodynamic instability that TTE can help to diagnose. This noninvasive tool will continue to be useful in guiding perioperative patient management and is becoming increasingly available to the anesthesiologist.

3-D Echocardiography

Since the early 1980s, TEE has evolved significantly as an imaging modality and subspecialty. It provides less invasive monitoring of the cardiovascular system, as well as quick and reliable assessment of dynamic intraoperative physiologic conditions. In the hands of a skilled anesthesiologist, intraoperative TEE is invaluable. As TEE has matured, new modalities have arisen, including intravascular echocardiography and 3-D echocardiography.

An example of the use of this new technology is 3-D TEE evaluation of the mitral valve. This emerging

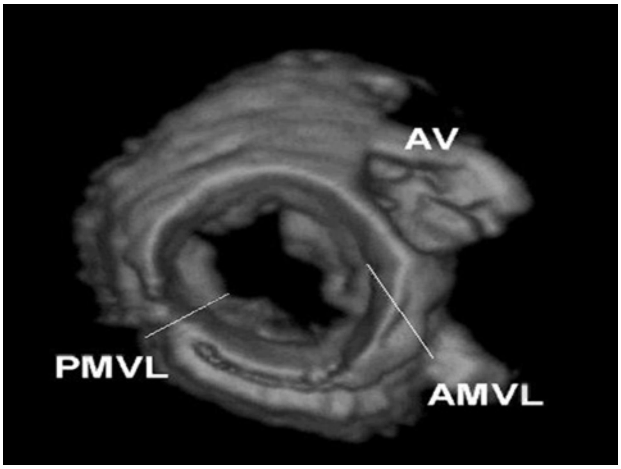

Figure 13. A 3-dimensional TEE image of the mitral valve.

modality has been shown to be superior to 2-D echocardiography in identifying and localizing the valvular pathology.[4,11,12] It also allows better communication of the surgical anatomy and pathology with the surgeon by providing an *en face* view of the valve, and enables superior intraoperative planning (Figure 13).

Conclusion

Transesophageal and transthoracic echocardiography are excellent diagnostic and monitoring tools that are becoming increasingly prevalent in the care of patients during the perioperative period. As long as a few contraindications are kept in mind and a gentle approach is taken, TEE is a very safe and efficient tool for diagnosing causes of hemodynamic instability. Knowledge of the basic TEE examination and principles of Doppler and ultrasound allow the general anesthesiologist to correctly use this technology. Newer equipment, such as high-quality handheld ultrasound and 3-D echocardiography will be commonplace in the near future. Developing proficiency with these resources will allow the anesthesiologist to optimally care for the unstable patient before, during, and after surgery.

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Key

ALVW, anterior left ventricular wall
AMVL, anterior mitral valve leaflet
APM, anterior lateral papillary muscle
Asc Ao, ascending aorta
AV, aortic valve
AV w/CFD, valve with colorflow Doppler
ILVW, inferior left ventricular wall
IVC, inferior vena cava
LA, left atrium
LAA, left atrial appendage
LLVW, lateral left ventricular wall
LCC, left coronary cusp
LV, left ventricle
LVOT, left ventricular outflow tract
MV w/CFD, mitral valve with colorflow Doppler
MV, mitral valve
NCC, noncoronary cusp
PA, pulmonary artery
PAC, pulmonary artery catheter
PMVL, posterior mitral valve leaflet
PPM, posterior medial papillary muscle
PV, pulmonary valve
RA, right atrium
RCC, right coronary cusp
RV, right ventricle
SLVW, septal left ventricular wall
SOV, sinus of valsalva
STJ, sinotubular junction
SVC, superior vena cava
TEE, transesophageal echocardiography
TV, tricuspid valve
VOT, left ventricular outflow tract