Transesophageal Echocardiography for the Occasional Cardiac Anesthesiologist

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Full-time cardiac anesthesia practice is uncommon. Because of this fact and because cardiac surgery is performed in thousands of hospitals, many anesthesiologists are called on occasionally to provide cardiac anesthesia. At the same time, transesophageal echocardiography (TEE) has become a routine tool in many cardiac centers, resulting in a growing demand for the occasional cardiac anesthesiologist to perform TEE. This review course will describe a practical approach for the occasional cardiac anesthesiologist to provide TEE, and it will review the most common and best-established applications of TEE in cardiac surgical patients.

Basic Practice Requirements and Examination

For the occasional cardiac anesthesiologist, a minimum goal is to provide the basic level of TEE as defined by the 1996 guidelines for perioperative TEE, which state that anesthesiologists with basic training in perioperative TEE "should be able to use TEE for indications that lie within the customary practice of anesthesiology" and "must be able to recognize their limitations in this setting and request assistance, in a timely manner, from a physician with advanced training." Specifically, these guidelines require the basic practitioner to use TEE to diagnose the following conditions: markedly abnormal ventricular filling or function, extensive myocardial ischemia or infarction, large air embolism, severe valvular dysfunction, large cardiac masses or thrombi, large pericardial effusions, and major lesions of the great vessels. To make these diagnoses, 8 of the 20 cross-sections delineated in the comprehensive examination will suffice (Figure 1) (1,2): This examination can be completed in 2–3 min.

Even this basic examination requires some time to master. If you have no experience in TEE, you should work with another physician who has advanced training in TEE until you have performed at least 50 TEE examinations and are prepared to function at the basic practitioner level (3). As you use TEE in your cardiac practice, be sure to record your examinations and interpretations. Archive these data either in a collaborative fashion with your hospital's echocardiography laboratory, or, when this is not possible, archive them independently. They are important medical records and must be available for comparison with other cardiac studies and subsequent echocardiograms. A standardized interpretation form is available from the website of the Society of Cardiovascular Anesthesiologists (http://www.scahq.org/) along with billing codes. The National Board of Echocardiography offers an examination in perioperative echocardiography. If you plan to use TEE in the years to come, I recommend you take this examination to demonstrate your competence in TEE. For more information on the test and study syllabus visit their website (http://www.echoboards.org/pte/examination.html).

Inevitably, your surgical colleagues will ask your opinion on more advanced applications such as the mechanism of mitral regurgitation or the adequacy of a mitral repair. Until you have mastered the advanced application(s) requested, resist the urge to offer a less than expert interpretation. Instead, do your very best to anticipate such requests and organize appropriate back-up from an advanced TEE practitioner. To help you anticipate these requests, I have provided in the next section an overview of the most common and best-established perioperative TEE applications.

TEE Applications in Cardiac Surgery

Aortic Diseases

TEE has a proven role in the perioperative assessment of aortic injury and aortic dissection, when prompt and accurate diagnosis is vital to patient survival. In one study of 160 consecutive victims of blunt chest trauma, TEE was diagnostically superior to and faster than aortography for detection of aortic injury (4). Unlike aortography, TEE reliably distinguishes between subadventitial disruptions that require emergent surgery and intimal tears that do not (5). Other studies indicate that identification of aortic injury with TEE can be quite challenging and not always more reliable than aortography (6). If local expertise with

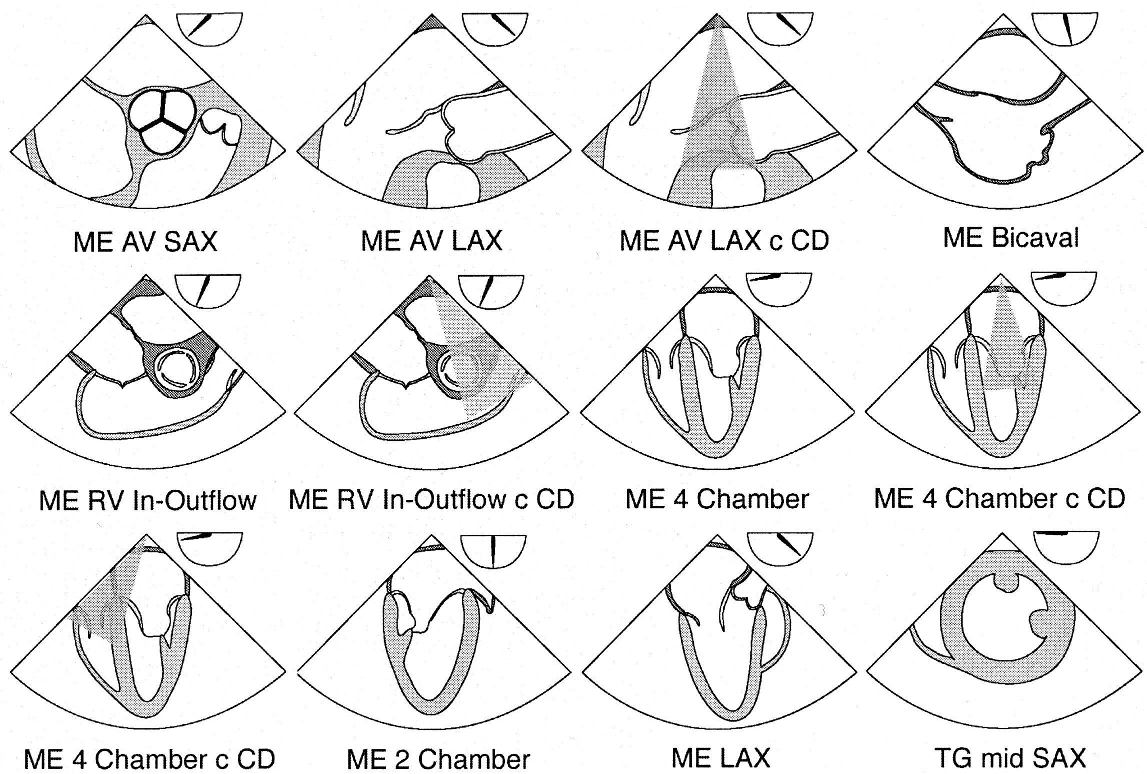

Figure 1. The eight basic cross sections are depicted. Four cross sections are shown with color Doppler (CD) sectors superimposed over the four different cardiac valves. Other abbreviations are ME = midesophageal; TG = transgastric; AV = aortic valve; SAX = short axis; LAX = long axis; RV = right ventricle; In-Outflow = inflow and outflow; mid SAX = midventricular short axis. This figure was adapted from and reproduced in part with permission from Shanewise et al. (1).

TEE is available and the patient is in need of urgent surgery, TEE may be the best alternative. For the detection of aortic dissection, TEE has proven superior to aortography and computed tomography (7). It is associated with a shorter time to diagnosis, less morbidity (renal dysfunction and neurologic events), and shorter hospital stays than aortography (8). Although marginally less specific than magnetic resonance imaging (MRI) for some dissections (those originating in the aortic arch where TEE imaging is partially obstructed by the trachea), TEE requires less time and expense than MRI or any other comparably reliable alternative (9). Moreover, TEE can delineate the mechanisms and severity of associated aortic regurgitation, thereby identifying patients in whom valve repair is likely to be successful (10). Similarly, TEE detected aortic atheromas have important implications. In 130 patients older than 65 yr undergoing coronary artery bypass grafting, TEE detection of protruding atheroma of the ascending aorta proved to be the most important independent predictor of stroke (11). When these atheromas are detected by TEE, alteration of the aortic cannulation technique (12), raising the blood pressure during cardiopulmonary bypass (13), or performing coronary surgery without bypass (14) may reduce the incidence of stroke. In addition, postoperative warfarin therapy may be indicated to reduce the long-term risk of stroke (15). Although TEE is not as sensitive as epiaortic scanning for detection of atheromas of the aortic arch, it is a good screening tool: if TEE reveals no significant atheromas in the ascending or descending aorta, none are likely to be present in the arch (16). When intraoperative TEE reveals severe atheromatous disease of the aorta, off-pump coronary surgery results in lower risk of death and stroke than on-pump surgery (17).

Unsuspected Cardiovascular Disease

TEE can reveal unsuspected cardiovascular disease and the need for major changes in management. For example, in 5 of 182 patients scheduled for coronary artery surgery, intraoperative TEE detected unsuspected mitral regurgitation so severe that unscheduled mitral valve repair was performed (18). Conversely, in 22 of 51 patients scheduled for combined coronary artery and mitral valve surgery, it revealed so little mitral valve dysfunction that the mitral repair was omitted. In a different study of 170 consecutive patients referred for mitral valve repair, intraoperative

TEE correctly identified the flail or prolapsing segment(s) 90%–97% of the time (19). In another prospective study of 5016 patients, prebypass information from TEE led to modification of the surgical procedure in 11.6% of the patients undergoing valve procedures and 27% of patients undergoing coronary surgery (20). Numerous case reports document that TEE can detect other problems necessitating changes in perioperative management, including intracardiac shunts and masses, great vessel obstruction, pulmonary embolism, and other conditions.

Global Ventricular Function

Left ventricular (LV) fractional area change (FAC) is measured using the simple formula (EDA − ESA)/EDA where EDA is the cross-sectional area at end-diastole and ESA at end-systole. Marked changes in FAC are apparent by simply viewing the real-time images. Thus, severe LV depression is easy to detect with TEE. Although FAC correlates reasonably well with other approximations of ventricular function, significant limitations apply. First, TEE often underestimates the LV long axis (it foreshortens the left ventricle). Second, the mid-ventricular short-axis view may be a poor guide to overall ventricular ejection, if other areas of the ventricle have markedly different function. And third, FAC, like other traditional echocardiographic indices of systolic function, is load dependent: changes in preload and afterload markedly alter FAC without changing the intrinsic function of the ventricle. Measurement of right ventricular (RV) function is more difficult than LV function because of the right ventricle's complex shape and response to changes in loading. However, severe RV dysfunction is not difficult to recognize. The hallmarks are severe hypokinesis or akinesis of the RV free wall, enlargement of the right ventricle to exceed the size of the left ventricle, a change in shape of the right ventricle from crescent to round, and a flattening or bulging of the intraventricular septum to the left.

LV Preload

TEE reveals changes in LV preload more reliably than filling pressures. In 30 patients scheduled for cardiac surgery, Cheung et al. (21) removed 15% of each patient's blood volume in 6 equal aliquots before bypass. TEE demonstrated a significant decrease in EDA after removal of the first aliquot (approximately 200 mL) and a linear decrease with subsequent aliquots. The pulmonary artery occlusion and central venous pressures also declined but correlated poorly with EDA. In most adults, an EDA of <12 cm^2 indicates hypovolemia, but values between 12–15 cm^2 may not because of variations in patient size and diastolic compliance. However, when a volume challenge increases EDA, then stroke volume also increases (22). Although quantitative TEE measurements of ventricular preload are well validated, as noted above, they are tedious and impractical to perform intraoperatively. Instead, clinicians assess LV filling and function subjectively using the "trained eye." This approach is a valid method to guide fluid administration, and in patients with concentric hypertrophy, it may identify the need for higher than normal filling pressures to achieve optimal LV filling and function (23).

LV Filling Pressure

TEE provides practical ways to estimate LV filling pressure. When TEE Doppler interrogation of pulmonary venous flow reveals that the majority of left atrial filling occurs during ventricular systole, then left atrial pressure is usually <15 mm Hg (24). Although acute changes in ventricular function may affect this sign, alternative TEE methods are available (25,26). Accordingly, TEE cannot estimate left atrial pressure precisely, but can reliably identify clinically significant elevations in most patients.

Cardiac Output

Real-time TEE images of LV filling and ejection permit qualitative, immediate detection of extreme changes in cardiac output. However, TEE can quantify cardiac output more precisely by measuring both the velocity and cross-sectional area of blood flow at appropriate locations in the heart or great vessels. The product of these measurements is stroke volume. Appropriately performed TEE estimates of cardiac output should fall within 0.3–0.8 L/min of thermodilution estimates except in patients with severe tricuspid regurgitation when thermodilution may underestimate output (27,28).

Myocardial Ischemia

Within seconds after the onset of myocardial ischemia, affected segments of the heart cease contracting normally. In 50 patients undergoing cardiovascular surgery, new intraoperative segmental wall motion abnormalities (SWMA) diagnostic of myocardial ischemia occurred in 24 patients and ischemic ST segment changes in only 6 (29). Three patients who sustained intraoperative myocardial infarctions (MI) developed SWMA in the corresponding area of myocardium that persisted until the end of surgery, but only one of these three had ischemic ST segment changes intraoperatively. Subsequent studies in comparable patients confirmed these advantages of TEE over ECG monitoring (30). Moreover, when multiple TEE cross-sections are monitored (not just the one cross-section, as was done in the above studies), the detection rate of SWMA more than doubles (31). Limitations of TEE in the detection of ischemia should be recognized. When an area of myocardium is clearly in view, segmental contraction can be difficult to evaluate if the heart rotates or translates markedly during systole, or if discoordinated contraction occurs as a result of bundle-branch block or ventricular pacing. Consequently, a valid system for SWMA assessment must evaluate both regional endocardial motion and myocardial thickening. A marked worsening of segmental wall motion and wall thickening (in the absence of similar global changes) is required to make the diagnosis of ischemia; less pronounced changes are not consistently interpreted, even by experts. Not all SWMA are indicative of myocardial ischemia. Myocarditis, myocardial infarction, and myocardial stunning cause SWMA. In coronary surgery, differentiating infarction, stunning, and ischemia is vitally important. When TEE reveals LV wall thickness of $<$0.6 cm, old infarction in that thinned area is almost certain (32). If inotopic stimulation improves segmental motion of a SWMA, then stunning, not ischemia, is likely (33). One other cause of SWMA is severe hypovolemia in patients with preexisting SWMA (34). However, with the exception of myocardial stunning and severe hypovolemia as noted above, a sudden, severe decrease of segmental contraction is almost certainly attributable to myocardial ischemia.

Valvular Surgery

TEE has profoundly affected valvular heart surgery by providing the surgical team with a definitive evaluation of their intervention in the operating room, where any needed revisions can be accomplished immediately. In a study of 154 patients undergoing valve surgery, intraoperative TEE documented unsatisfactory repairs in 10 patients (6%) requiring immediate further surgery (35). Although six of these 10 patients had abnormal V waves or elevated pulmonary capillary wedge pressures, hemodynamic values were normal in the other four patients and only TEE indicated defective repair. At the conclusion of surgery, TEE revealed adequate valvular function in 123 of 154 patients (80%): 18 of whom (15%) suffered a major postoperative complication, six dying (5%). In contrast, TEE revealed moderate valve dysfunction in seven patients (5%): six of whom suffered major complications (86%), three dying (50%). Subsequent studies have confirmed that intraoperative TEE assessment of mitral valve function is predictive of postoperative mitral function and outcome (36). Even with the maturation of valve repair techniques, a significant number of repairs should be revised (20,37). During valve replacement surgery, TEE reliably detects periprosthetic leaks (surprisingly common). Although moderate or severe periprosthetic leaks should almost always undergo immediate repair, almost half of the small leaks resolve with the administration of protamine (38). Although immediate prosthetic valve malfunction is rare, it can occur and go undetected if TEE is not used (39).

Coronary Artery Bypass Surgery

TEE can have a major impact during coronary artery surgery. In one study of 50 patients, TEE identified two patients in whom new SWMA provided the only immediate sign of unsuspected graft occlusion and prompted graft thrombectomies (40). In another study of 82 high-risk patients, Savage et al. used staged blindings of the cardiac surgeons and anesthesiologists at critical points during surgery. After these clinicians documented their planned management at each stage, the TEE results were revealed and led to at least one significant change in anesthetic management in 51% of patients and surgical management in 33% of patients including additional unplanned or revised grafts (15%) and unplanned valve procedures (20%) (41). These high-risk patients had postoperative infarction and mortality rates below predicted rates.

Congenital Heart Surgery

Pediatric TEE probes are used in infants as small as 3 kg. Stevenson et al. (42) reported that intraoperative TEE reliably detected residual cardiac defects in 17 (7%) of 230 consecutive patients undergoing congenital heart surgery. These patients were reoperated immediately for revision of the residual defects. However, a subsequent publication from the same center found that the number of residual defects missed by intraoperative TEE increased from 2% to 13% when TEE was performed by the attending anesthesiologist rather than a separate echocardiographer (43). This study generated considerable controversy. Although it does not resolve the issue of whether a separate echocardiographer is required to adequately perform TEE in patients undergoing congenital heart repairs, it does amply demonstrate that patients can suffer severe consequences when intraoperative TEE is not expertly performed, interpreted, and acted on. In this study, the deaths of seven patients may have been related to the delayed recognition of residual defects.

Acute Hypotension

During acute hypotension, qualitative estimates of LV filling and ejection serve as the practical guide for administration of fluids, inotropes, and vasopressors. For example, severe hypovolemia is easily recognized as a marked decrease in LV EDA and a marked increase in LV ejection. LV failure is recognized as just the opposite. In 60 consecutive patients with severe, persistent hypotension after cardiac surgery, TEE confirmed the presumed etiology of the hypotension in only 30 of these patients (44). In two patients, TEE prompted emergency surgery and in five others it prevented unnecessary reoperations. In another study, unstable cardiac surgical patients in the operating room ($n = 57$) or intensive care unit ($n = 83$) underwent emergent TEE (45). Based on the TEE findings alone, 22 of these patients had urgent surgical interventions. The average time to diagnosis was 11 min. Even in the desperate setting of prolonged CPR, TEE has value; it reveals the need for significant management changes in 31% of resuscitations (46).

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