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Perioperative transesophageal echocardiography for non-cardiac surgery

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Abstract

Purpose—The use of transesophageal echocardiography (TEE) has evolved to include patients undergoing high-risk non-cardiac procedures and patients with significant cardiac disease undergoing non-cardiac surgery. Implementation of basic TEE education in training programs has increased across a broad spectrum of procedures in the perioperative arena. This paper describes the use of perioperative TEE in non-cardiac surgery and provides an overview of the basic TEE examination.

Principal findings—Perioperative TEE is used to monitor hemodynamic parameters in non-cardiac procedures where there is a high risk of hemodynamic instability. Its use extends to include moderate-risk procedures for patients with significant cardiac diseases such as low ejection fraction, hypertrophic cardiomyopathy, severe valve lesions, or congenital heart disease. Vascular procedures involving the aorta, blunt trauma, and liver transplantation are all examples of procedures that may benefit from TEE. Transesophageal echocardiography examination allows assessment of volume status, ventricular function, diagnosis of gross valvular pathology and pericardial tamponade, as well as close monitoring of cardiac output, response to therapy, and the impact of ongoing surgical manipulation. In patients with unexplained and unexpected hemodynamic instability, ‘‘rescue TEE’’ can be used to help identify the underlying cause.

Conclusions—Perioperative TEE is emerging as a preferred tool to manage hemodynamics in high-risk procedures and in high-risk patients undergoing non-cardiac surgery. A rescue TEE examination protocol is a helpful approach for early identification of the etiology of hemodynamic instability.

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Abstract

L' utilisation de l'échocardiographie transœsophagienne (ETO) a évolué et est aujourd'hui utilisee aupres de patients subissant des interventions non cardiaques á risque élevé ainsi que de patients souffrant de cardiopathie grave subissant une chirurgie non cardiaque. Dans les programmes d'éducation, la mise en œuvre d'une formation de base en ETO a augmenté et permet son utilisation dans plusieurs types d'interventions réalisees en période perioperatoire. Cet article décrit l'utilisation d'ETO perioperatoire en chirurgie non cardiaque et propose un apercu de l'examen d'ETO de base.

L'ETO périopératoire est utilisée pour monitorer les paramétres hémodynamiques lors d'interventions non cardiaques lorsque le risque d'instabilité hémodynamique est eleve. Son utilisation s'étend pour inclure les interventions á risque modéré pour les patients souffrant d'importantes cardiopathies telles qu'une faible fraction d'éjection, une cardiomyopathie hypertrophique, des lesions valvulaires graves, ou encore une cardiopathie congenitale. Les interventions vasculaires au niveau de I'aorte, les traumatismes contondants et les greffes hépatiques sont quelques exemples d'interventions dans lesquelles l'ETO pourrait être utile. L'examen d'ETO permet non seulement d'évaluer la volémie et la fonction ventriculaire, de poser un diagnostic préliminaire de pathologie valvulaire et de tamponnade péricardique, mais aussi d'executer un monitorage precis du debit cardiaque, de la réponse au traitement, et de l'impact des manipulations chirurgicales en cours. Chez les patients manifestant une instabilité: hemodynamique inexpliquee et inattendue, une « ETO de sauvetage » peut etre utilisee pour aider le medecin a en trouver la cause sous-jacente.

L'ETO périopératoire émerge en tant qu'outil de choix pour prendre en charge l'hémodynamie en cas d'interventions á risque élevé ainsi que les patients présentant des risques élevés et subissant une chirurgie non cardiaque. Un protocole d'examen d'ETO ciblé de sauvetage peut être utile pour identifier rapidement l'étiologie d'une instability; hemodynamique.

A 53-yr-old male presents to the operating room for urgent exploratory laparotomy after experiencing 24 hr of nausea, vomiting, and severe abdominal pain. Abdominal radiographs show free air under the diaphragm with a suspected bowel perforation. His medical history reveals daily intravenous cocaine use. After induction with propofol, cisatracurium, and fentanyl, his blood pressure is 60/40 mmHg, and his heart rhythm demonstrates sinus tachycardia with a rate of 130 beats-min^{-1}. Despite several boluses of phenylephrine and epinephrine and intravenous fluid resuscitation, there is no change in his hemodynamic status. Urgent intraoperative transesophageal echocardiography (TEE) examination reveals severe concentric left ventricular hypertrophy with left ventricular cavity obliteration, severe mitral regurgitation, and systolic anterior motion of the anterior mitral valve leaflet consistent with left ventricular outflow tract obstruction. After two litres of fluid, cessation of inotrope therapy, and a phenylephrine infusion, the patient's heart rate normalizes to 82 beats-min^{-1}and his blood pressure increases to 130/76 mmHg (video as Electronic Supplementary Material).

Perioperative TEE has been used in non-cardiac surgery for over two decades.[1,2] Its use has expanded to assist in resuscitation by diagnosing life-threatening perioperative conditions such as myocardial ischemia, pulmonary embolism, cardiac tamponade, and hypovolemia.[3,4]

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As our case vignette shows, the use of TEE is a relatively noninvasive diagnostic approach that can be used in real time to guide perioperative management in a variety of non-cardiac surgical procedures.[5–9]

In this paper, we aim to review the indications for the use of TEE in non-cardiac surgery, TEE exam views, technical aspects of image acquisition, clinical applications, and the use of rescue TEE in non-cardiac surgery.

Perioperative TEE examination

Equipment orientation

As with any ultrasound technology, TEE imaging is based on the piezoelectric effect principle. Knowledge of the echo machine is crucial for obtaining high-quality images. Anesthesiologists should be familiar with ultrasound knobology, probe selection, and the various echocardiography modalities (e.g., two-dimensional [2D], colour flow Doppler, spectral Doppler, and M-Mode) in order to provide accurate hemodynamic assessments. The wave depth should be adjusted for specific views of interest. Higher or lower depth settings result in low-quality images and misdiagnosis. Optimization of 2D gain should be set at the beginning of the exam by ensuring that blood or cardiac chambers are black. Use of colour Doppler imaging requires the smallest possible adjustment of the colour sector to view the relevant structures at higher frame rates, while setting the colour scale to a Nyquist limit of 50–60 cm-sec^{-1} for detecting valvular pathologies. A lower colour scale of 20–30 cm-sec^{-1} should be used for lower-flow areas such the interatrial septum. Utilization of Doppler should also be adjusted for both the scale and baseline. Once the TEE exam is completed and the machine is not in use, the equipment should be put in freeze mode or powered down to sleep mode until reuse.

Insertion of the TEE probe

After reviewing the patient's history for TEE indications/contraindications and obtaining consent, insertion of the probe under general anesthesia is facilitated using a jaw lift and gently directing a well-lubricated probe towards the posterior pharynx and the esophagus.[10] A bite block should be used to prevent damage to the probe or dentition, and force should not be used on encountering resistance. Slight flexing or turning the patient's head to the left, redirecting the probe, or inserting the probe under direct vision using video or conventional laryngoscopy can aid in probe insertion.

Manipulation of the TEE probe

Echocardiographers should be familiar with terminology related to TEE probe manipulation (Fig. 1A), including advancement, withdrawal, turning, and angle rotation. Axial rotation of the transducer is controlled through an electronic switch at the handle with ranges from 0–180°. Anteflexion and retroflexion (i.e., movement in the plane of the probe shaft) are achieved by moving the larger of the two control knobs on the probe handle. The smaller knob moves the probe tip up to 30° to the right or left.

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Suggested views

A comprehensive perioperative TEE exam for patients undergoing cardiac surgery previously consisted of 20 standard views, but it has now been extended to 28 views.[10–12] The American Society of Anesthesiologists/American Society of Echocardiography (ASA/ASE) consensus statement for a basic perioperative TEE examination limits the exam to 11 views.[13] In our opinion, however, 16 views are required to provide a thorough examination for both basic anatomy and hemodynamic assessment (Fig. 2). A "rescue'' or focused TEE exam performed in a hemodynamically unstable patient may be limited initially to a fewer number of views to allow for a more rapid assessment (Table 1). Once the patient is stabilized, a full TEE exam may follow. Echocardiographers should be familiar with acquiring TEE views and understanding their relevant echocardiographic nomenclature.[10]

Acquisition of the views

Transesophageal echocardiography views are obtained through esophageal and gastric windows (Fig. 1B). A TEE exam may begin with mid-esophageal (ME) views followed by transgastric (TG) views. The exact sequence of acquiring views, while often left to the discretion of the individual, should be repeated in the same order regardless of the clinical scenario. This approach will facilitate consistency and efficiency through experience. Table 2 suggests steps for acquiring the 16 proposed views and imaging the relevant structures in the suggested sequence. We acknowledge that certain views might be difficult to obtain in some patients because of variabilities in patient position, anatomy, pathology, and comorbidities, while in others, additional probe maneuvers may be required to optimize the view.

Indications for perioperative TEE in non-cardiac surgery

Knowledge of the potential indications for the use of TEE in non-cardiac surgery is helpful in understanding where elective use of TEE may provide for rapid assessment of anticipated hemodynamic changes and where its benefits are likely to outweigh the various perioperative risks (Table 3). Nevertheless, the final decision for a TEE examination is guided by the patient's medical status, the nature of the surgical procedure, and the specific circumstances as judged by the treating physician.[10,14]

In contrast, rescue TEE is indicated in patients with unexpected or unexplained hemodynamic instability regardless of the surgical procedure or the patient's medical condition. A rescue TEE may be performed intraoperatively, postoperatively in recovery, or in other critical care areas.[12–14] Awareness of the intraoperative and postoperative indications for a rescue TEE can guide patient management in real time and minimize adverse outcomes of high-risk surgeries[4] (Table 3).

While TEE is considered the preferred imaging modality for hemodynamic assessment intraoperatively, transthoracic echocardiography (TTE) is the modality of choice for cardiovascular evaluation in awake patients prior to induction of anesthesia or during postanesthesia recovery. It is important to understand that TEE provides high-resolution images of the posterior cardiac structures, whereas TTE offers generally very good

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visualization of the anterior cardiac structures, the left ventricular (LV) apex, and most of the aortic arch. Both modalities complement each other in the perioperative period.[15]

Contraindications to TEE

In trained hands, the TEE examination is generally a safe and minimally invasive procedure. The overall rate of TEE-related morbidity ranges from 0.2–1.2%.[16] Contraindications to TEE insertion are well described in the literature[14] (Table 4). Before TEE probe placement, clinical assessment is warranted to rule out contraindications, unless assessment is not feasible such as in emergencies or unconscious patients. When TEE is anticipated, the risks and benefits should be explained to the patient preoperatively and consent should be obtained.

Clinical applications for TEE

Perioperative TEE is generally reserved for surgical patients with high-risk medical conditions and patients undergoing high-risk surgical procedures. The proposed TEE exam provides anesthesiologists with an adequate representation of the following structures and functions:

- Ventricular structure and function
- Hemodynamic parameters of volume status, cardiac output, and other related conditions
- Valvular structure and function
- Intracardiac masses
- Cardiac shunts
- Pericardial and cardiac tamponade
- Aortic atheroma and acute aortic syndromes (e.g., dissection)

Assessment of ventricular structure and function

Echocardiography can be used as a real-time monitor of both the left ventricle and the right ventricle. The morphology of both ventricles needs to be assessed in terms of shape, size, wall thickness, and function (including regional wall motion and diastology).[17,18]

Left ventricular systolic function—Hemodynamic instability due to LV systolic dysfunction occurs in a significant proportion of patients undergoing non-cardiac surgery.[2,19,20] A quick visual exam can rapidly ascertain LV function by qualitatively estimating the LV ejection fraction.[21] This is best achieved in the TG mid-papillary short-axis (SAX) view.[22,23] Quantitative surrogates of ejection fraction may be obtained through traditional approaches, such as using the 2D Simpson’s biplane method (echocardiographic gold standard)[24] and fractional area change. These quantitative approaches should be employed along with a dynamic qualitative estimation of the ejection fraction, as loading conditions commonly change in the perioperative period and may lead to erroneous assessments. Importantly, ejection fraction should be interpreted with caution in patients with specific

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cardiac pathologies, for example, in patients with mitral regurgitation or ventricular septal defect.

When LV dysfunction is diagnosed, initiation of inotropes may be required. The left ventricle can then be closely monitored with the inotropic requirement titrated to a desired response. An increase in blood pressure alone should be interpreted with caution, because an increase in afterload following vasopressor therapy can significantly reduce LV contractility and unmask LV dysfunction.[25]

Assessment of regional wall motion abnormalities (RWMAs)

As part of the evaluation of LV systolic function, the left ventricle is examined for RWMAs. The left ventricle is visualized in 17 segments: six anatomical segments at the base of the heart, six corresponding segments at the mid-papillary level, four segments at the apical level, and an apical cap. This approach allows accurate examination of the LV walls and documentation of any abnormal wall motion at baseline.[26] It also allows identification of ischemia within specific coronary artery territories. The right coronary artery provides perfusion to the right ventricle, inferior wall, and posterior one-third of the basal septum of the left ventricle. The left anterior descending artery perfuses the anterior and anteroseptal segments and the apical cap, and the left circumflex artery perfuses the lateral wall segments.

Echocardiography is a sensitive monitor for detection of perioperative myocardial ischemia.[27,28] Analysis of LV segmental function is gleaned from ventricular wall motion and thickening during systole. The TG mid-papillary SAX view of the left ventricle is frequently employed to detect RWMAs, but basal and apical TG views must also be examined before RWMAs can be excluded. Once a new RWMA is detected and appropriate therapy instituted, continued monitoring for response is indicated.

Persistent and treatment-resistant RWMAs may indicate acute coronary syndrome, including myocardial infarction. New-onset mitral regurgitation or deterioration in preexisting regurgitation could also be early echocardiographic features of myocardial ischemia.[29,30] Regional wall motion is commonly classified as 1) normal or hyperkinetic, 2) hypokinetic (reduced thickening), 3) akinetic (absence of thickening), and 4) dyskinetic (systolic thinning or aneurysmal changes).[18]

Left ventricular diastolic function

When surgical patients become hemodynamically unstable without changes in preload or contractility, diastolic dysfunction should be considered a differential etiology.[31] Patients with LV diastolic dysfunction undergoing non-cardiac surgery sustain a higher risk of major adverse cardiac events.[32] Left ventricular diastolic function should be assessed in high-risk patients and in patients with shortness of breath despite normal systolic function. Anesthesiologists with advanced echocardiographic skills may be consulted to determine the severity of the diastolic dysfunction based on mitral inflow, pulmonary venous flow, and tissue Doppler parameters.[33] Change in diastolic function and development of acute diastolic dysfunction with hemodynamic instability have been reported in patients undergoing aortic

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surgery. Early recognition and treatment of acute diastolic dysfunction may be crucial in mitigating adverse outcomes of surgery.[34]

Right ventricular function

Acute and chronic RV dysfunction can lead to significant hemodynamic instability.[35,36] Chronic RV dysfunction often includes RV hypertrophy or dilation and an enlarged right atrium (RA).[37] Specific echocardiographic signs of RV failure include hypokinesis/akinesis of the ventricular free wall, abnormal septal shape and motion, loss of the triangular/crescentic RV morphology, and reduced tricuspid annular plane systolic excursion (TAPSE). A qualitative assessment of the motion of the free wall and the septum is often adequate.[38]

Acute RV failure may raise the suspicion of pulmonary embolism (PE). The proximal pulmonary artery can be visualized for the presence of a thromboembolus (Fig. 3). The development of acute pulmonary hypertension (from both PE and other pathologies) from a sudden increase in the pulmonary vascular resistance may lead to RV failure. The systolic pulmonary arterial pressure or RV systolic pressure can be estimated through Doppler measurement of the tricuspid regurgitation and the right atrial pressure.[39] The latter can be estimated from inferior vena cava (IVC) size and change in diameter associated with respiration.[38,40] The IVC can be imaged in the transgastric view at the level of the mitral valve (MV) by turning the probe clockwise (to the right) to find the liver. Slight probe withdrawal and transducer angle rotation (30–50°) may be required to optimize the view. M-mode imaging is recommended to measure the IVC size and changes in diameter. In spontaneously breathing patients, IVC diameter is measured and collapsibility (due to a decrease in intrathoracic pressure during inspiration) is assessed. In patients whose lungs are mechanically ventilated, however, distensibility (in response to the increase in intrathoracic pressure during ventilation) rather than collapsibility is assessed.[41,42] Patients with an IVC diameter > 2.0 cm with no or minimal respiratory variations (< 50% collapsibility or distensibility) are deemed to have elevated right atrial pressure (>15 mmHg).[38]

For the best Doppler angle, alignment with the tricuspid regurgitant jet is obtained with the modified bicaval view. Right ventricular systolic pressure ≥ 35 mmHg is indicative of pulmonary hypertension, especially when it is associated with signs of RV failure. Further, when treatment is administered to reduce RV afterload, echocardiography is considered an ideal tool to monitor its dose titration and effectiveness.[43,44]

Assessment of preload

Administration of either inadequate or excessive intravenous fluids is associated with morbidity in surgical patients.[45–47] There is emerging evidence of the benefits of goal-directed fluid therapy or a zero-balance approach during major surgeries.[48–51]

Many invasive and noninvasive monitors are used to guide intravenous fluid administration in high-risk patients and procedures. Amongst these, echocardiography appears to be an ideal tool for goal-directed fluid therapy.[52,53] It can rapidly estimate the LV volume by examining changes in the LV size.[13,33] The LV TG SAX mid-papillary view is the most commonly used view to estimate LV volume.[53,54]

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Reduction in the LV cavity (changes in end systole and diastole LV dimension) from baseline or obliteration of the LV cavity during systole may indicate hypovolemia.[53,55] Alternatively, the LV TG long-axis (LAX) one centimetre below the mitral annulus is also a reliable view to monitor and assess volume status by LV dimension.[33] Further, accounting for respiratory variations, IVC diameter measured in the TG view is another indicator of the volume status in both spontaneously breathing (collapsibility) patients and patients whose lungs are mechanically ventilated (distensibility).[41,42,56,57] Other indicators of volume overload include distension of the IVC, distension of the right ventricle, flattening of the septum (D-shaped left ventricle), increase in tricuspid regurgitation, and response to passive leg raise.

Assessment of cardiac output and hemodynamic monitoring

Monitoring the changes in cardiac output remains a key component of hemodynamic management in critically ill patients.[58] Echocardiography is becoming the monitor of choice to measure (and monitor) changes in cardiac output, particularly with the decline in the use of the pulmonary artery catheter.[59,60] The goal of hemodynamic management in patients with significant cardiac disease is to maintain optimal tissue perfusion during the perioperative period.

Technically, stroke volume and cardiac output can be estimated at any cardiac valve by measuring the velocity time integral at the valve multiplied by the valvular cross-sectional area. It can also be estimated through the difference in 2D volume between the end-diastolic and the end-systolic ventricular volume. Most ultrasound systems are equipped with software packages to enable automatic calculation of the cardiac output from the stroke volume and heart rate.[13]

One of the more popular approaches for measuring left-sided cardiac output is estimating the combined 2D LV outflow tract diameter from the ME LAX view and the velocity time integral of the LV outflow tract from the deep TG view (Fig. 4).[61,62] To achieve continuous monitoring of cardiac output, the TEE probe can be left at the deep TG view for frequent measurement of the velocity time integral. The right-sided cardiac output can similarly be estimated by measuring the velocity time integral of the pulmonic valve from the ME ascending aorta SAX view and the 2D RV outflow diameter from the RV inflow-outflow view.[63,64] Measurement of cardiac output in patients with arrhythmias, such as atrial fibrillation, may require multiple measurements of the LV outflow tract velocity time integral.

In rescue TEE, a rapid assessment of LV systolic function and volume status can be achieved by “eyeballing” the left ventricle at the transgastric short-axis view, as this allows simultaneous visualization of three coronary territories and correlates well with global function.[53]

Other related conditions

Ventricular outflow tract obstruction—Left ventricular or RV outflow tract obstruction can also cause hemodynamic instability in perioperative atients.[65,66] Systolic

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anterior motion of the anterior mitral leaflet is the most frequent cause of LV outflow tract obstruction in patients with hypertrophic cardiomyopathy (Fig. 5).[67] Echocardiography is the only tool available for anesthesiologists to diagnose and assess the severity of the LV outflow tract obstruction, optimize the preload, and assess response to therapy.[68–71] Right ventricular outflow obstruction is rare but has been described with hemodynamic instability during lung transplant surgery and post-cardiac surgery in the intensive care unit.[36,72]

Takotsubo cardiomyopathy—Takotsubo cardiomyopathy (broken heart syndrome) is a more common pathology than initially thought and may lead to significant hemodynamic instability.[73] It may be triggered by surgical stress response and excessive sympathetic stimulation during the perioperative period. Echocardiography features include apical ballooning of the left ventricle with a normal to hyperdynamic base.[74]

Valvular lesions—Preoperative echocardiography is helpful in excluding suspected valvular pathology as well as in managing patients with significant valvular lesions undergoing non-cardiac surgical procedures. Details identifying and assessing the severity of valvular lesions have previously been reported.[75,76] Transesophageal echocardiography is used for hemodynamic monitoring in these patients to ensure adequate cardiac output and to assess for changes in the regurgitant volume or in the volume passing through a stenotic lesion. Perioperative management should aim to minimize volume changes through the regurgitant/stenotic lesion and maximize cardiac output. Acute hemodynamic instability may occur in patients with significant valvular lesions.[77–80] In these situations, by monitoring end-diastolic filling and ventricular contractility, TEE-guided management of the surgical patient ensures adequate cardiac output.[81]

Intracardiac masses—Valvular vegetation in septic patients may represent a challenge for perioperative hemodynamic management. Typically, vegetation is seen on the low-pressure and upstream side of the leaflets and on the coaptation lines. Intracardiac masses (primary or secondary), depending on their size and location, could adversely impact hemodynamics in the perioperative period. Often seen in the left atrium, an intracardiac myxoma is considered the most common primary cardiac tumour.[82] Nevertheless, metastatic cardiac tumours are seen more frequently than primary tumours.[83] Intracardiac thrombi are also a major finding and can be a surrogate finding on unstable patients after acute anterior wall myocardial infarction or in situations of low cardiac output. Intracardiac thrombi are commonly found on pacemakers, indwelling catheters, and cannulas.

Hypoxia—Hypoxia is a repeatedly encountered problem during the perioperative period. Unexplained hypoxia that cannot be attributed to a respiratory cause should be investigated for cardiac sources – e.g., cardiac shunts.

Intracardiac and intrapulmonary shunting

In the perioperative setting, right-to-left shunting may result in hemodynamic instability, refractory hypoxemia, or both. Colour flow Doppler and agitated saline contrast can aid in the diagnosis of a shunt. Right-to-left shunting through an atrial septal defect or a patent foramen ovale are the two most common causes of unexplained hypoxemia.[84–86] The

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presence of a patent foramen ovale or other intracardiac shunting may increase the risk of paradoxical embolization or hypoxemia, particularly in orthopedic, neurosurgical, trauma, and laparoscopic procedures.[87–89] The risk of hypoxemia is higher in the presence of increased right-sided pressures, as would occur with pulmonary hypertension, RV dysfunction, pulmonary embolism, and lung resection surgery.[90] In the presence of normal blood pressure, steps to reduce right-sided pressure should be initiated. Occasionally, right-to-left shunting may also occur in the presence of pulmonary arteriovenous fistulas. The agitated saline contrast study may demonstrate a delay in the bubbles reaching the left atrium.[91]

Pulmonary emboli, air and fat emboli monitoring

Pulmonary embolism may lead to significant hemodynamic instability and hypoxia. When compared with other perioperative monitors, echocardiography is a specific and reliable monitor for diagnosing intraoperative pulmonary emboli.[92,93] Intraoperative TEE may allow direct visualization of the embolus in the pulmonary artery or in its most proximal divisions. Nevertheless, findings are commonly those of acute RV overload, particularly with more distal emboli that cannot be visualized – e.g., RV enlargement and RV dysfunction with preservation of the apical contractility (McConnell's sign).[94] Secondary signs of high RV afterload, such as flattening of the interventricular septum during systole and significant tricuspid regurgitation, may also be observed in some patients. The usefulness of intraoperative TEE to detect thromboembolic air and fat embolism has been shown across a number of surgical procedures.[95–98]

Pleural effusion

Significant pleural effusion can lead to intraoperative hypoxia. Echocardiographic appearance of the pleural effusion may differ by etiology and chronicity. A loculated hemothorax or hematoma may give similar echogenic appearance of lung consolidation. In the TEE image, a left pleural effusion appears as a dark echo-free space posterior to the descending thoracic aorta (Fig. 6). A right pleural effusion can be seen by rotating the probe to the right from the ME four-chamber view and advancing it until the liver is seen.[99] Compared with a chest *x-ray*, echocardiography detects volumes of 20 mL vs 200 mL.[100] It is not uncommon to visualize pleural effusion, B-lines, and atelectasis in a patient suffering from hypoxia.[101]

Pericardial effusion and cardiac tamponade

A pericardial effusion is easily visualized as an echo-free space in the pericardial sac (Fig. 7). The diagnostic value of echocardiography in cardiac tamponade is well established.[102,103] Transesophageal echocardiography may show compression of the heart chambers and impaired ventricular filling. The amount of fluid in the pericardium does not always correlate with tamponade, especially with chronic accumulation of pericardial fluid. Early recognition of this life-threatening condition, especially in trauma patients, allows for prompt intervention before impending cardiovascular collapse.[104] Echocardiographic features include pericardial effusion, right atrial collapse with a pericardial effusion, or RV collapse and hemodynamic instability.[105,106] Nevertheless, cardiac tamponade is a clinical

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rather than an echocardiographic diagnosis. Significant pericardial effusion alone may also result in inadequate ventilation and perioperative hemodynamic instability.

Aortic pathology

Examination of the aorta for atherosclerosis, atheroma, aneurysm, and dissection is an important component of the TEE exam. The sensitivity of TEE for pathologies in the ascending and descending thoracic aorta approaches 100%.[107–109] Due to the air-filled trachea (and left mainstem bronchus) impeding ultrasound transmission, the distal ascending aorta may not be visible on TEE, which leaves the potential for false negatives on routine scanning. Using the ME and TG views, the examination should systematically proceed from the ascending aorta distally until the proximal end of the abdominal aorta.

The ascending aorta is examined at the ME LAX view and the ME SAX view. The descending aorta is examined in SAX and LAX views. When atherosclerosis or atheroma is detected, its location and severity need to be reported. For reporting, we recommend the use of the five-point severity scale: Grade I = normal aorta; Grade II = intima thickness > 2 mm; Grade III = atheroma thickness (i.e., lumen protrusion) < 5 mm; Grade IV= atheroma thickness > 5mm; and Grade V= mobile atheroma irrespective of the magnitude of thickness.[107,110] The shape and size of the aortic segments should also be examined for the presence of any aneurysm. Detection of an intimal flap that divides the aorta into false and true lumens indicates aortic dissection.[109] Colour flow Doppler can be used to identify fenestrated communication points (i.e., entry and exit sites) between the two lumens. Transesophageal echocardiography can also detect aortic insufficiency (AI) and involvement of the coronary artery ostia associated with aortic dissection. Clinical presentation of significant blunt trauma to the chest associated with back pain is suggestive of aortic dissection and should prompt the initiation of a TEE exam in hemodynamically unstable patients. Careful inspection of the aorta in multiple planes allows the echocardiographer to evaluate hematomas, intimal disruptions, transections, dissections, or artifacts. Colour flow Doppler is also helpful in identifying flow in false lumens and points of entry.[107]

Further, TEE is a valuable tool to guide endovascular repair of aneurysmal disease. Imaging of the thoracic aorta during stent deployment can identify atheroma at the landing zone, confirm the guidewire in the true lumen, and reveal the presence of endoleaks.[111,112]

Rescue TEE

When performing a rescue TEE, the physician should first evaluate ventricular contractility, adequacy of ventricular diastolic volume, and presence of pericardial effusion to direct further examination (Table 5 and Fig. 8). When no immediate etiology of hemodynamic instability is identified, a more elaborate 16-view exam proposed above should be considered. Additional views for extracardiac pathologies and other conditions mentioned above should be considered. When all else fails, consultations with a more experienced colleague should be sought while aggressive hemodynamic management continues.

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Conclusions and future steps

Perioperative TEE in non-cardiac surgery provides a unique means for detailed real-time cardiovascular assessment with a wide variety of clinical applications. Transesophageal echocardiography may be considered the hemodynamic monitor of choice in high-risk surgical procedures and in high-risk patients undergoing non-cardiac surgery. It should be readily available in the perioperative area to provide evaluation of unexplained hemodynamic instability and cardiac emergencies.

As shown in the various clinical applications, echo-guided hemodynamic monitoring is a relatively novel approach to provide goal-directed therapy in perioperative patients. The use of echocardiography to optimize high-risk patients undergoing non-cardiac surgery is being studied and is anticipated to expand.[113] The concept of monitoring patients' cardiac output in a relatively noninvasive way compared with pulmonary artery catheters has led to changes in the role that TEE plays in the overall perioperative care of non-cardiac surgical patients.

Future studies evaluating the effectiveness of TEE are anticipated. As the use of TEE continues to expand outside the cardiac suite, appropriateness criteria will need to be continually defined. As technology has outpaced education with the invention of smaller and less expensive ultrasound devices, we anticipate that formal echocardiography training programs for anesthesiologists will adapt to the changes and become part of their postgraduate curricula. Additionally, there is no argument that the use of TEE in urgent or emergent situations (rescue TEE) and in non-cardiac surgery has its place; however, defining best practice guidance and developing high-quality training programs and optimal credentialing standards are key challenges that lie ahead.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Disclosures

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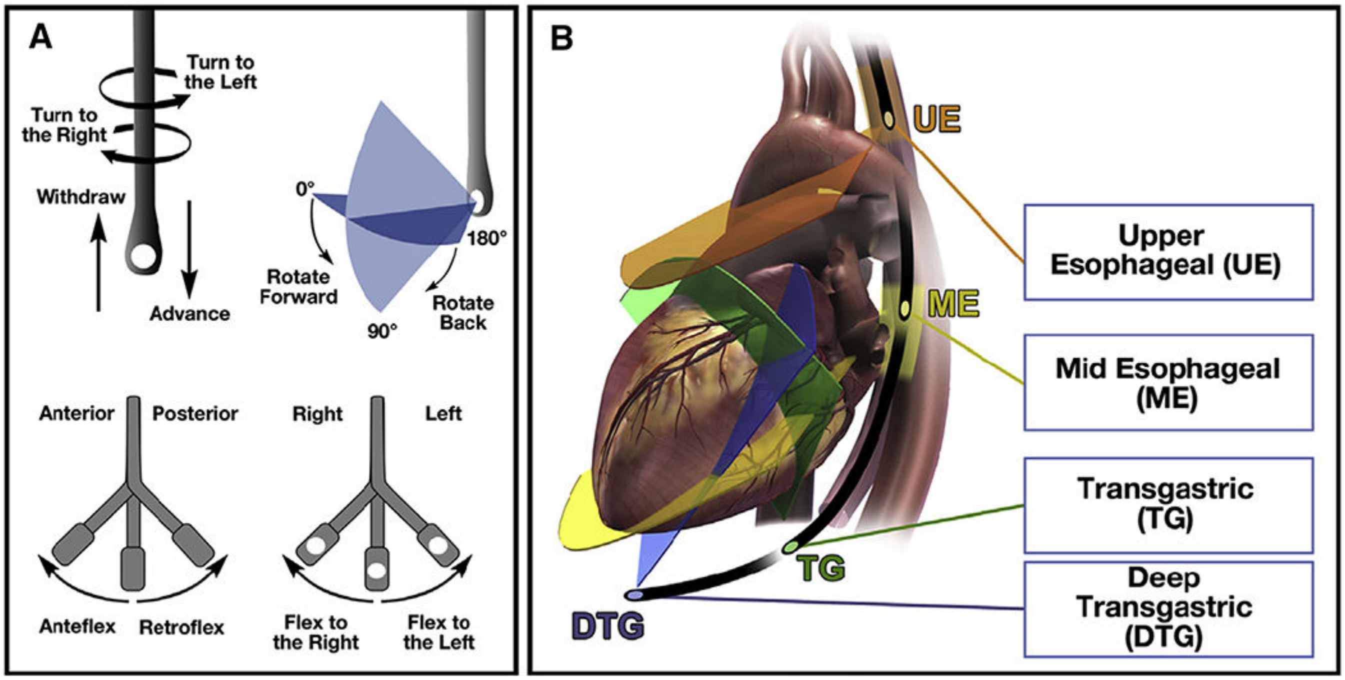

Fig. 1.

Transesophageal echocardiographic (TEE) probe manipulation and terminology used during image acquisition. (A) Terminology used for the manipulation of the TEE probe. (B) Four standard TEE positions within the esophagus and stomach and the associated imaging planes. Reproduced with permission from the Journal of the American Society of Echocardiography[10]

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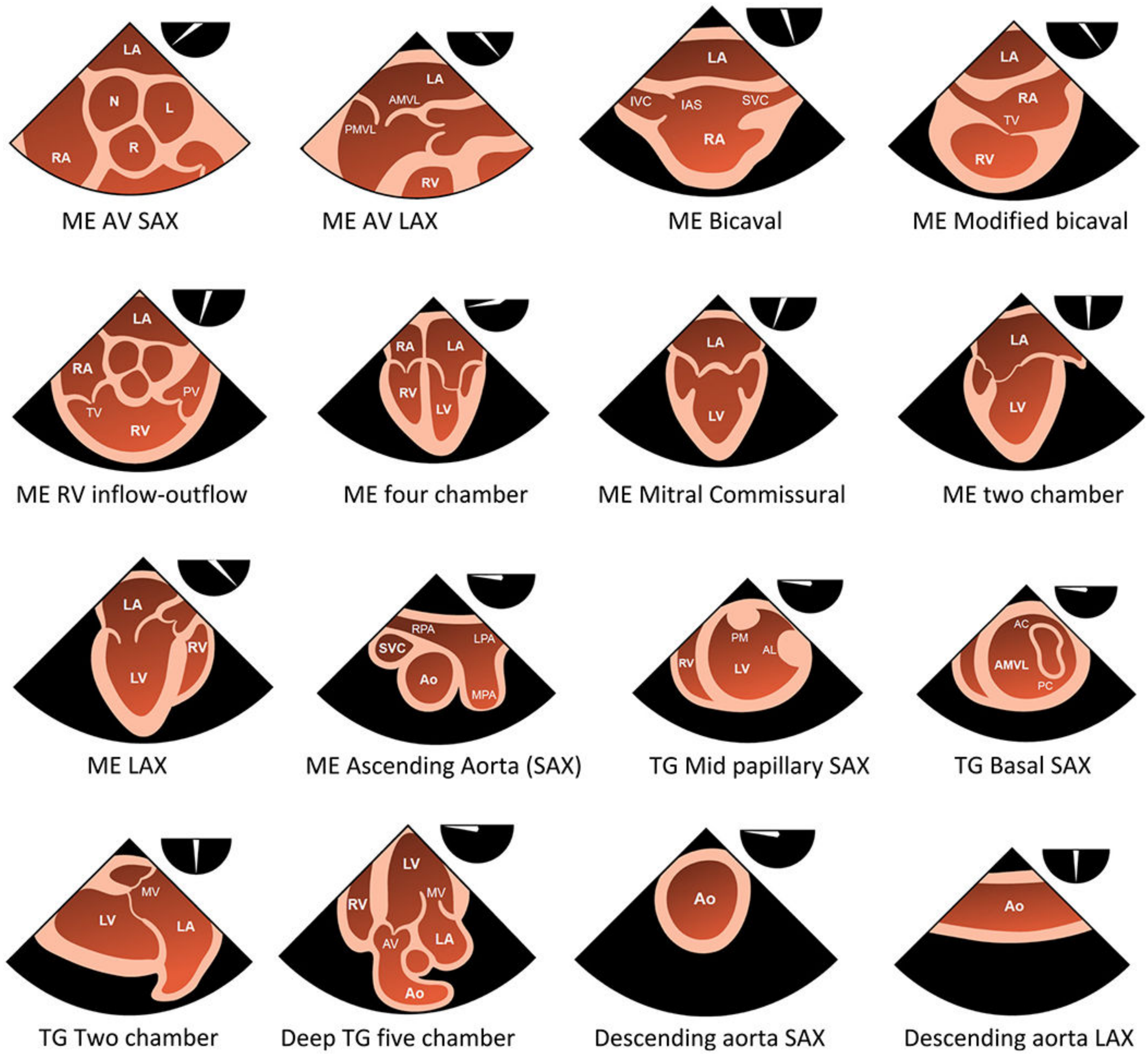

Fig. 2.

Cross-sectional images of the suggested 16 views (approximate angle is indicated top right) of the transesophageal echocardiography. AMVL = anterior mitral valve leaflet; Ao = Aorta; AV = aortic valve; IAS = intra-atrial septum; IVC = inferior vena cava; L = left coronary cusp; LA = left atrium; LAX = long axis; LPA = left pulmonary artery; LV = left ventricle; ME = mid-esophageal; MPA = main pulmonary artery; MV = mitral valve; N = non-coronary cusp; PM & AL = posteromedial and anterolateral papillary muscles; PMVL = posterior mitral valve leaflet; R = right coronary cusp; RA = right atrium; RPA = right pulmonary artery; RV = right ventricle; SAX = short axis; SVC = superior vena cava; TG = transgastric; TV = tricuspid valve

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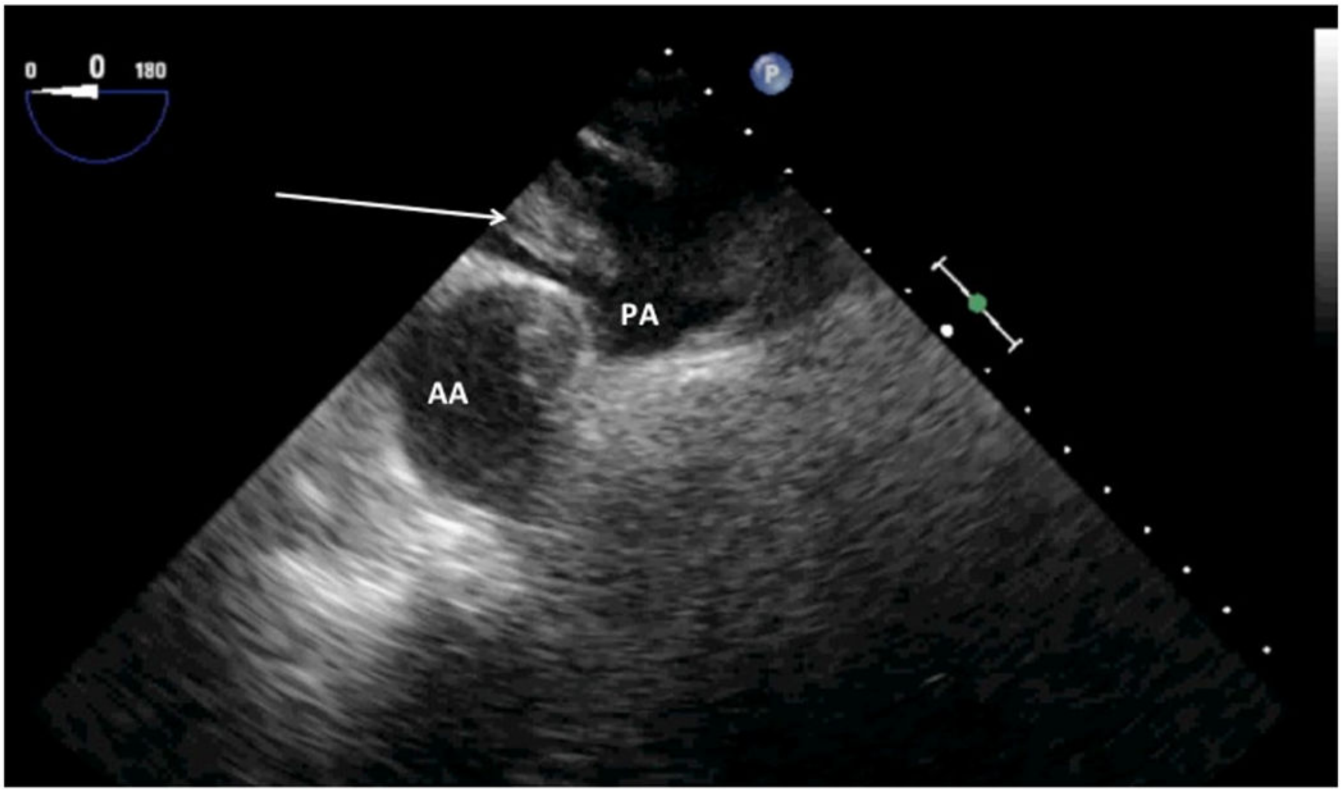

Fig. 3.

Mid-esophageal ascending aorta transesophageal echocardiographic view shows pulmonary embolism in the right pulmonary artery (arrow). AA = ascending aorta; PA = pulmonary artery

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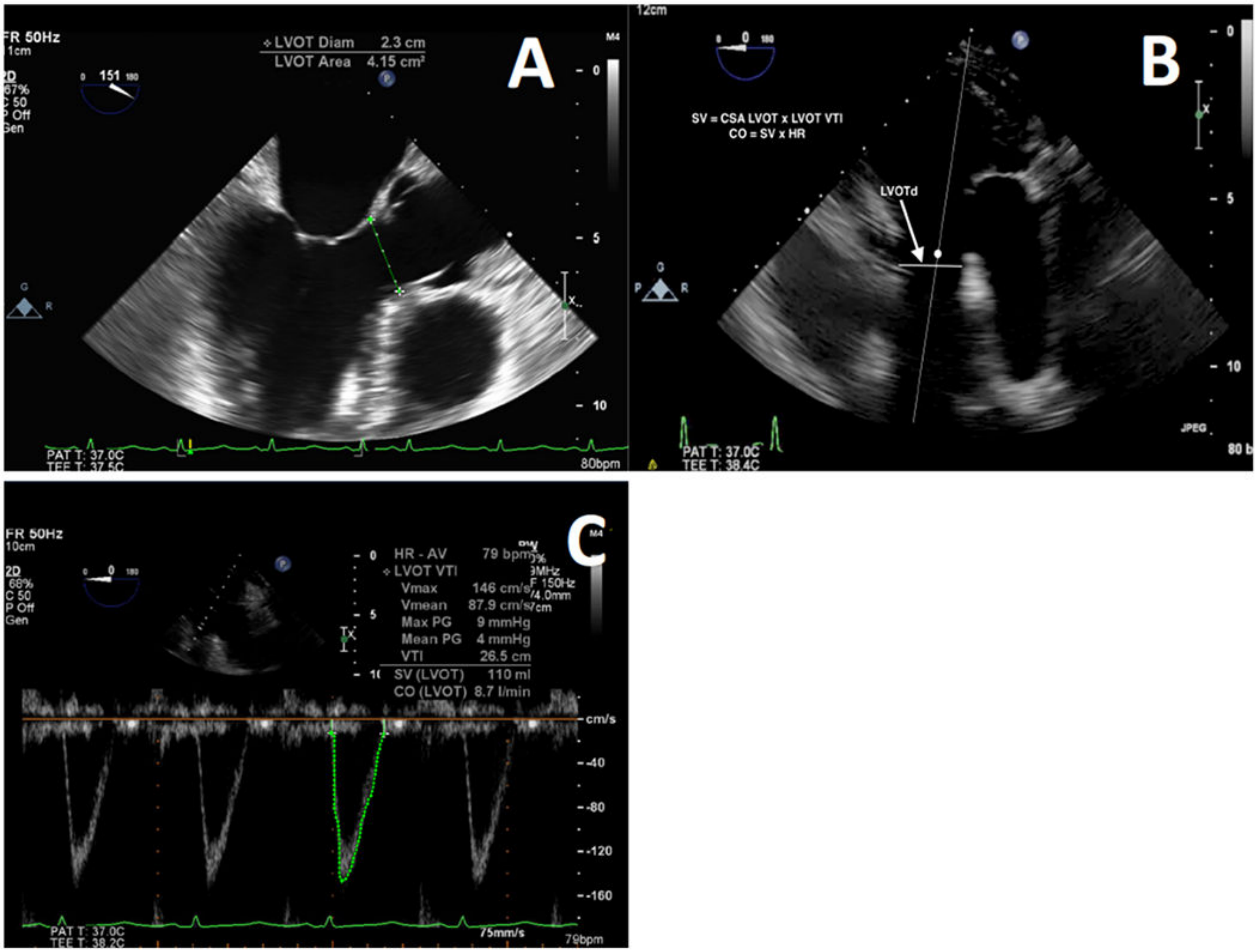

Fig. 4.

Transesophageal echocardiography (TEE) estimation of left-sided cardiac output utilizing pulsed wave (PW) Doppler of the left ventricular outflow tract (LVOT) and LVOT diameter (LVOTd). Left ventricular outflow tract diameter is best measured at the mid-esophageal long-axis view just adjacent to the aortic annulus during systole (A). The deep transgastric (TG) view is then obtained, and the PW cursor is positioned in the LVOT close to the aortic valve (AV) leaflets (B). The velocity time integral (VTI) is traced and the stroke volume (SV) is obtained (C). Heart rate (HR) is shown and cardiac output (CO) is calculated

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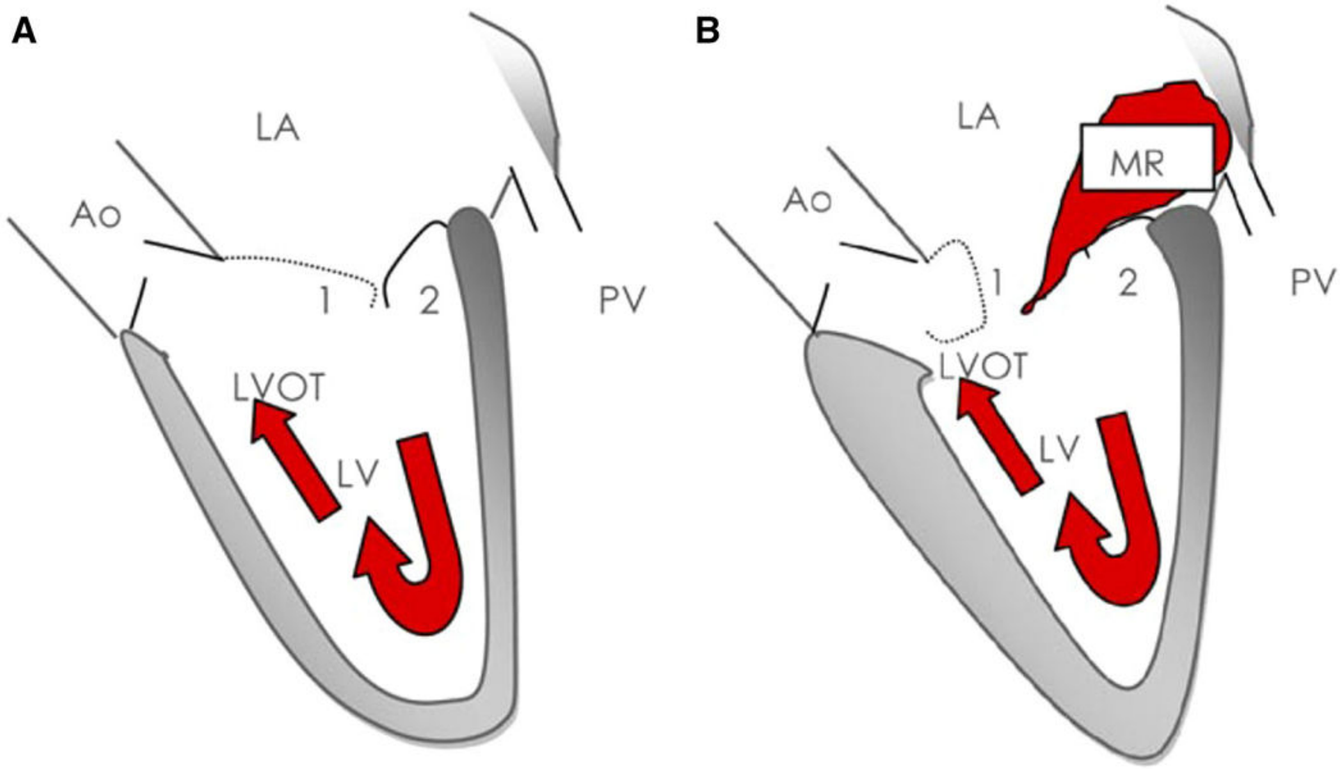

Fig. 5.

A mid-esophageal five-chamber animation showing the left ventricular outflow tract (LVOT) in a normal heart (A) compared with a patient with dynamic LVOT obstruction (B). The obstruction is caused by systolic anterior motion of the anterior leaflet of the mitral valve. Ao = aorta; LA = left atrium; LV = left ventricle; MR = mitral regurgitation; 1 = anterior leaflet; 2 = posterior leaflet

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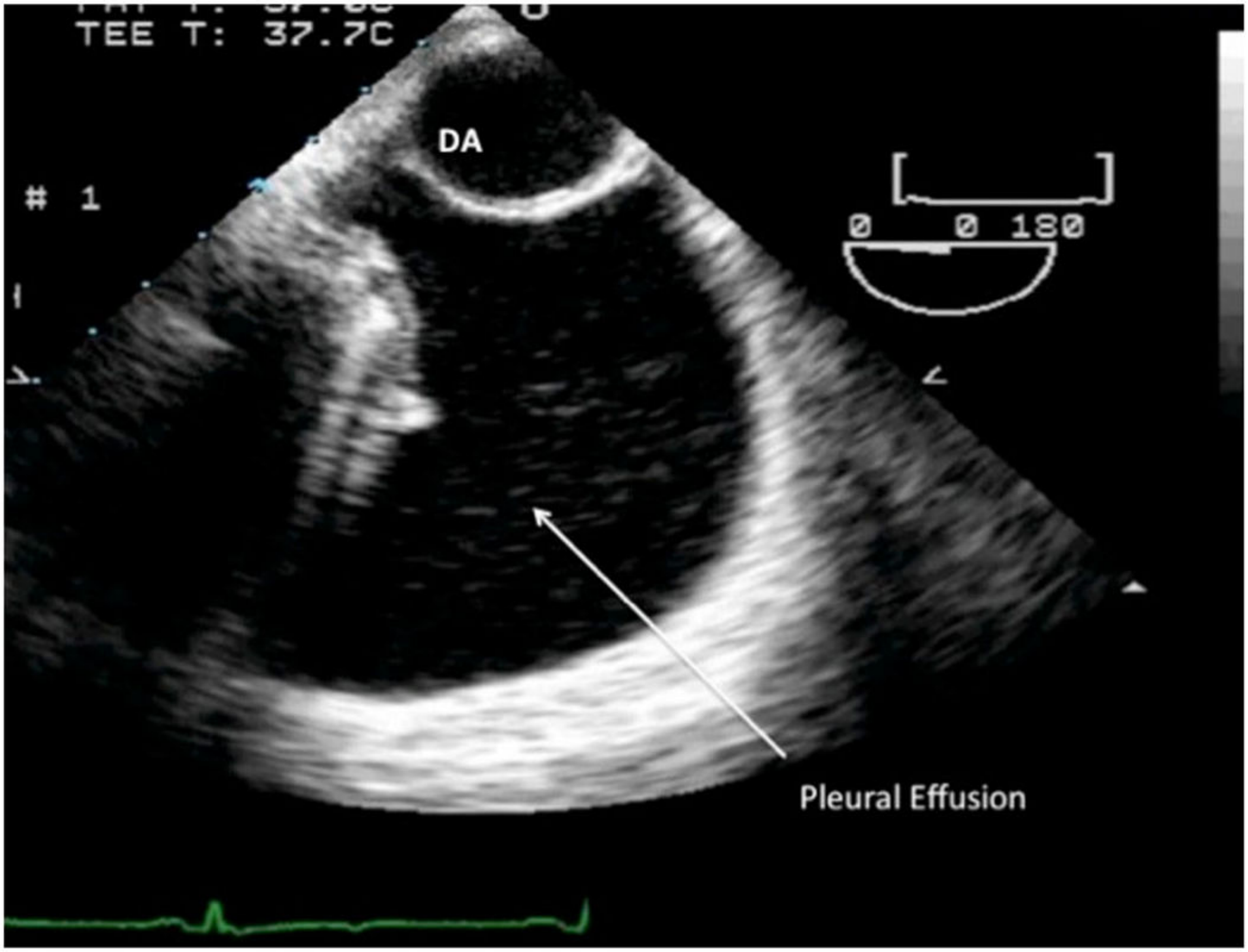

Fig. 6.
Transesophageal echocardiographic view showing left pleural effusion. Notice the location of the effusion in relation to the descending aorta

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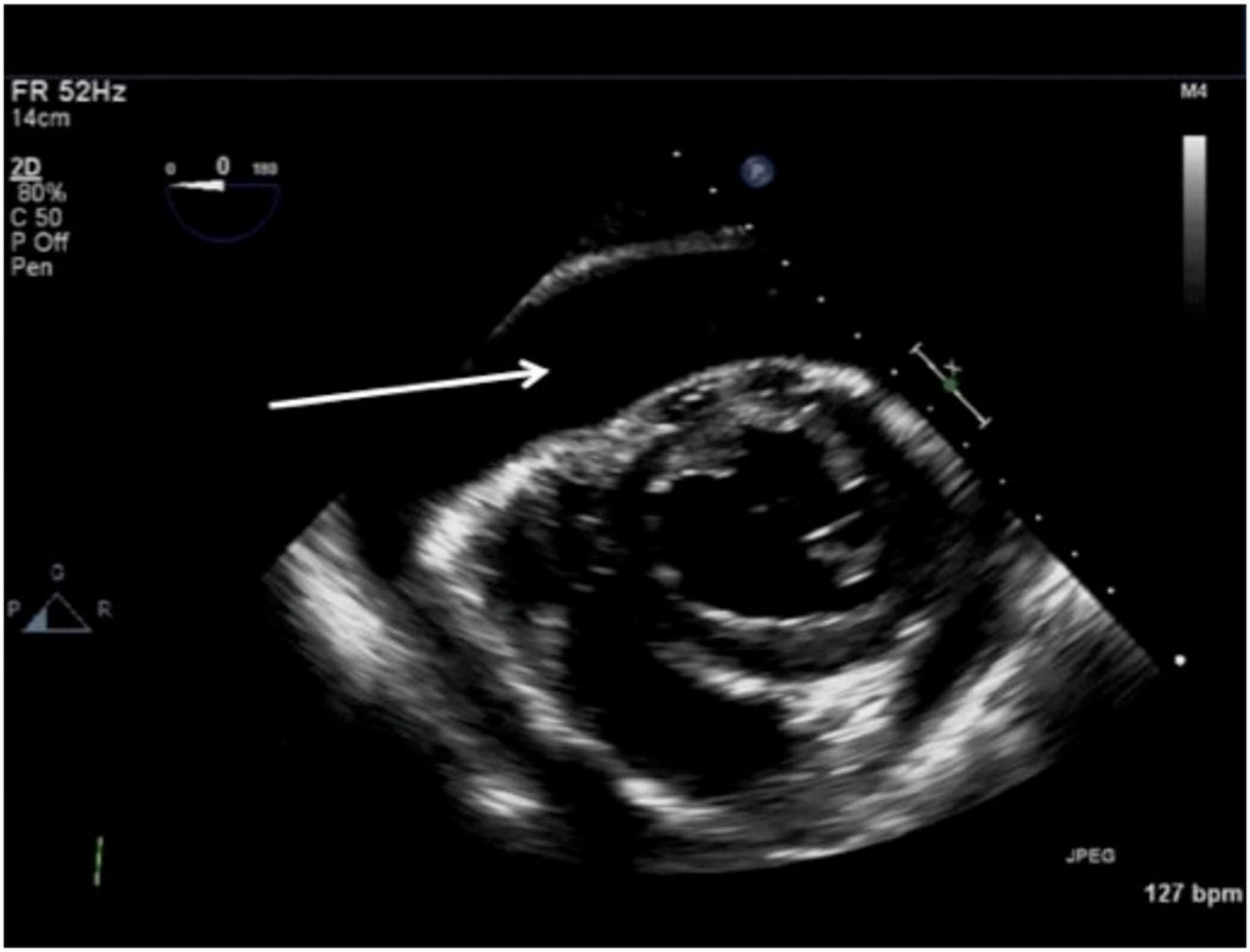

Fig. 7.
Transgastric mid-papillary view in a patient with pericardial effusion (arrow)

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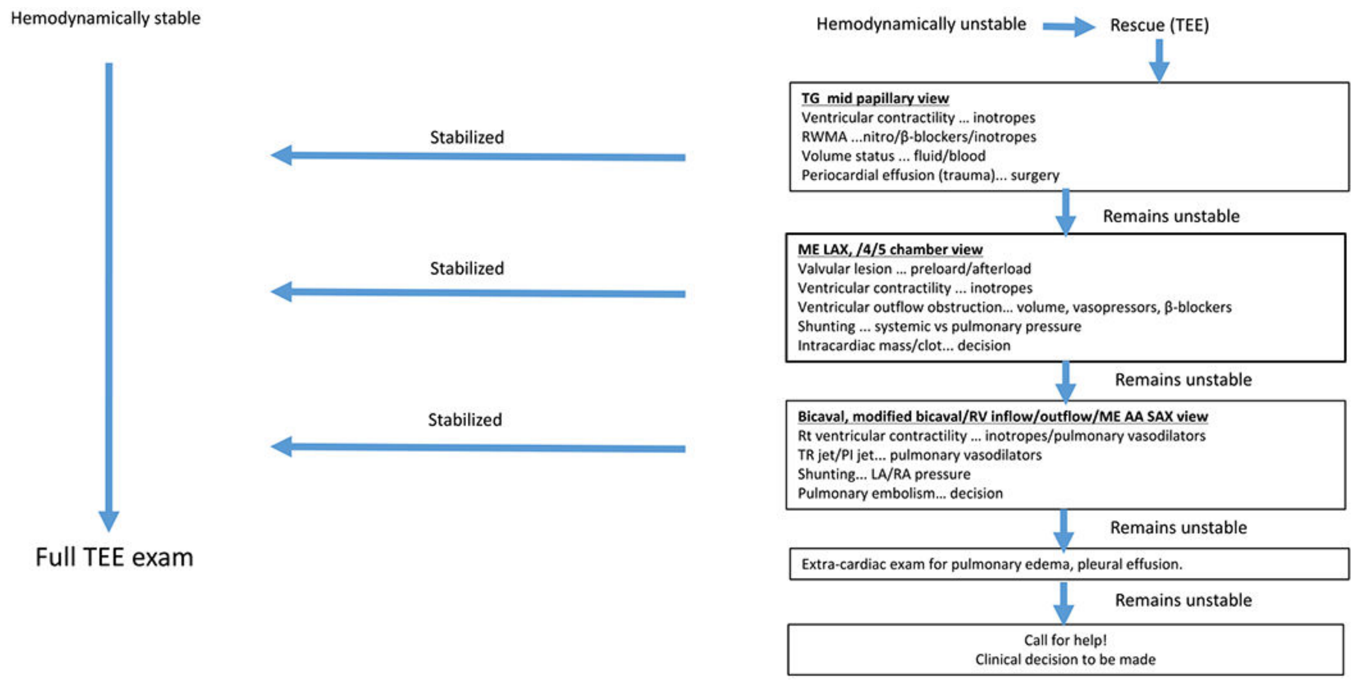

Fig. 8.

Recommended approach and views for rescue transesophageal echocardiography (TEE) exam.[4,33] LA = left atrium; LAX = long axis; ME = mid-esophageal; PI = pulmonary insufficiency; RA = right atrium; Rt = right; RV = right ventricle; RWMA = regional wall motion abnormality; TG = transgastric; TR = tricuspid regurgitation; 4/5 = four & five chamber

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Table 1

Recommended TEE exam sequence in patients undergoing non-cardiac surgery and limited views for rescue TEE

View	TEE	Rescue TEE
Mid-esophageal aortic valve short-axis	√	
Mid-esophageal aortic valve long-axis	√	
Mid-esophageal bicaval	√	√
Modified bicaval	√	√
Mid-esophageal right ventricular inflow-outflow	√	√
Mid-esophageal bicaval	√	√
Modified bicaval	√	√
Mid-esophageal four-chamber	√	√
Mid-esophageal mitral commissural	√	
Mid-esophageal two-chamber	√	
Mid-esophageal long-axis	√	√
Mid-esophageal ascending aorta	√	√
Transgastric mid-papillary short-axis	√	√
Transgastric basal short-axis	√	
Transgastric two-chamber long-axis	√	
Deep transgastric five-chamber	√	
Descending aorta short-axis	√	
Descending aorta long-axis	√	
Additional views (as required)	√	√

TEE = transesophageal echocardiography

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Table 2

Suggested transesophageal echocardiography views and acquisition

TEE Windows and Views	Acquisition and Probe Manipulation (Home Base: ME 4C View)	Structures imaged
ME AV SAX	From the ME 4C with slight probe withdrawal and rotating the angle (40–60°). Slight anteflexion may be required to optimize the view. The wave depth may be reduced to 10–12cm	AV (trileaflet, right coronary cusp being anterior, left cusp posterior, and non-coronary cusp near intra-atrial septum), RA, LA, IAS
ME AV LAX	From ME AV SAX view, further angle rotation (120–140°) with focus on AV, LV outflow tract and proximal aorta. Slight withdrawal with right turn may be required and wave depth of 10 cm	LA, LV (basal part), MV, LV outflow tract, AV (right coronary cusp adjacent to the RV, non-coronary or left cusp is posterior), sinuses of Valsalva, sinotubular junction, and proximal ascending aorta. LVOT diameter is often measured in this view
ME bicaval	From ME AV LAX view, right turn of the probe to position the atria in the centre, and angle rotation (80–110_) is required to obtain the bicaval view. Wave depth may need to be reduced focus is on the IAS (shunt, motion)	LA, RA, IAS, SVC and IVC (Eustachian valve seen in some patients adjacent to the IVC/RA junction). Slight turning of the probe to the right may bring the RUPV in view
ME modified bicaval	Right turn from standard bicaval and angle rotation adjustment be required to bring the TV in view for Doppler alignment	LA, RA, IAS, TV, and IVC. Slight turning of the probe to the right may bring the RUPV into view. Depends on the angle rotation, right atrial appendage and SVC may be visualized
ME RV inflow-outflow	From ME modified bicaval view, slight left turn and angle adjustment (50–70°) is required. The wave depth is adjusted to 14–16 cm to include all the intended structures imaged	RA, TV (anterior leaflet adjacent to AV, posterior leaflet adjacent to annulus/free wall), RV (inferior free wall), RVOT, PV, and proximal PA. The AV, IAS and LA are also visualized
ME 4C	From the ME RV inflow-outflow view, the ME 4C comes in view with an angle adjustment to 0° and a slight left turn. The wave depth is set between 12 −16 cm. Slight retroflexion, angle rotation (0–20°), or slight withdrawal/advancement may be required for view optimization	LA, LV (septal/inferoseptal/ and lateral / anterolateral walls), MV (anterior leaflet adjacent to the septum, posterior leaflet adjacent to the lateral wall), RA, RV (free wall), and TV (septal leaflet and posterior leaflet adjacent to the free wall). Note: A slight withdrawal of the probe brings LVOT and AV into view (five-chamber), while slight advancement of the probe may bring the RV outflow and coronary sinus (CS) into view
ME mitral commissural	From ME 4C view, angle rotation to 60°. Left or right turning may be required to examine the annulus	LA, LV (anterolateral and inferolateral walls), MV (posterior leaflet in both sides of the annulus, anterior leaflet in the middle), papillary muscles (posteromedial and anterolateral), and their chordae
ME two-chamber	From ME mitral commissural view, at the same depth, angle rotation to 90°. Slight left turn may be required to optimize the view	LA, LV (inferior and anterior walls), MV, CS (SAX), and Coumadin ridge separating LAA, and LUPV
ME AV LAX	From ME two-chamber view, further angle rotation to 110–140°. Slight right turn and withdrawal may be required to optimize the view	LA, LV (inferolateral and anteroseptal), MV, LV outflow tract, AV, and proximal ascending aorta
ME ascending aorta (SAX)	From ME AV LAX view, probe withdrawal and angle adjustment (0–30°). Turning the probe to the left allows examination of the PA bifurcation, while right turn allows right PA to come in view. Lower depth may be required to examine the structures	Pulmonary artery (main) and PV (seen in some patients), right pulmonary artery, ascending aorta (SAX), and SVC (SAX)
TG mid-Papillary SAX	From ME 4C, advance the probe into the stomach (40–45cm), and anteflex at the level of papillary muscles. Wave depth is adjusted to 12 cm at angle rotation 0°	LV (inferior, inferoseptal, anteroseptal, anterior, anterolateral, inferolateral) mid walls, Papillary muscles (posteromedial and anterolateral), RV (mid) with slight turning of the probe
TG basal SAX	Advance into stomach and increase anteflex from TG mid-papillary SAX	LV (inferior, inferoseptal, anteroseptal, anterior, anterolateral, inferolateral) basal walls, MV (anterior leaflet near the septum and posterior leaflet adjacent to lateral wall), RV, TV SAX
TG two-chamber	From TG mid-papillary SAX, the angle is rotated 90°. Slight turning and lessening anteflexion may be required	LV (anterior and inferior walls), MV, papillary muscles, chordae, LA, LAA

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TEE Windows and Views	Acquisition and Probe Manipulation (Home Base: ME 4C View)	Structures imaged
Deep TG five-chamber	From TG SAX view, the probe is advanced ~2 cm, anteflex and slight turning of the probe may be required to optimize the view	LV, LV outflow tract (best for Doppler alignment), AV, proximal ascending, MV
Descending aorta SAX	From ME 4C, the probe is turned to the left to position the descending Ao in the centre. The wave depth is adjusted to 4–6 cm. The probe could then be advanced to examine the entire thoracic descending aorta (depth 25–45 cm)	SAX of the descending thoracic aorta (until the level of the diaphragm). Celiac artery may be visible as well
Descending aorta LAX	From descending aorta SAX, multiplane angle is rotated to 90° to obtain LAX	LAX of the descending thoracic aorta (until the level of the diaphragm)

NOTE: Zoom option or lower depth may be used for a closer view

AMVL= anterior mitral valve leaflet; Ao = aorta; AV = aortic valve; CS = coronary sinus; IAS = intra-atrial septum; IVC= inferior vena cava; L = left coronary cusp; LA = left atrium; LAA = left atrial appendage; LAX = long axis; LPA= left pulmonary artery; LUPV = left upper pulmonary vein; LV = left ventricle; LVOT = left ventricular outflow tract; ME = mid-esophageal; MPA= main pulmonary artery; MV = mitral valve; N = non-coronary cusp; PA = pulmonary artery; PM & AL= posteromedial and anterolateral papillary muscles; PMVL = posterior mitral valve leaflet; R = right coronary cusp; RA= right atrium; RPA= right pulmonary artery; RUPV = right upper pulmonary vein; RV= right ventricle; SAX = short axis; SVC= superior vena cava; TG = transgastric; TV= tricuspid valve; 4C = four chamber

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Table 3

Indications for perioperative transesophageal echocardiography (elective & rescue) exam

Preoperative identification

1. High-risk patients – known or suspected cardiovascular pathology that might result in hemodynamic compromise (cardiac lesions) Common examples:
    - Presence of significant valvular lesions or significant coronary artery disease
    - Presence of significant systolic dysfunction (ejection fraction is 30% or less)
    - Presence of significant diastolic dysfunction (moderate to severe)
    - Presence of decompensated heart failure
    - Presence of hypertrophic cardiomyopathy
    - Presence of significant shunting
    - Patients with congenital heart disease and significant residual pathology
2. Patient suspected to have intraoperative hemodynamic instability and major fluid shifts (surgical procedures) Common examples:
    - Major vascular procedures
    - Major abdominal procedures
    - Organ transplant
    - Neurosurgical procedures in the sitting position or at risk of air embolism
    - Intra-abdominal tumours with IVC extension
    - Major thoracic surgical procedures
    - Mediastinal surgery with cardiac or major vessel involvement
    - Other surgical procedures as judged by the anesthesiologist
3. Special procedures (diagnostic imaging)
    - Endovascular thoracic aneurysm repairs
    - Ventriculoatrial shunt neurosurgical procedure (to determine the position of the catheter at SVC)
4. Patient has known or suspected cardiovascular pathology that might result in pulmonary compromise Common examples:
    - Severe pulmonary hypertension
    - Significant shunting
    - Hypoxemia
    - Significant right-sided cardiac pathology
5. Surgical patients with major abdominal or thoracic trauma
6. Patients with hemodynamic instability presenting for emergent non-cardiac surgery
7. Patients with emergent thoracic aortic dissection presenting for non-cardiac surgery

Intraoperative Indications

8. Unexplained persistent hypotension (not responding to traditional therapy)
9. Persistent unexplained hypoxemia
10. Low cardiac output or heart failure
11. Intraoperative cardiac arrest

Postoperative Indications

12. Hemodynamic instability
13. Myocardial ischemia
14. Substantial or escalating vasopressor or inotrope requirements

15	Patient requiring major resuscitation

IVC = inferior vena cava; SVC = superior vena cava

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Table 4

Contraindications for perioperative transesophageal echocardiography

Medical conditions
- Lack of patient consent
- Esophageal stricture or history of dysphagia
- Post-esophageal or gastric surgery
- Esophageal or gastric tumour
- Active/recent upper gastrointestinal bleeding
- Tracheoesophageal fistula
- Other esophageal/gastric diseases (e.g., Mallory-Weiss tear, scleroderma)
Trauma-related
- Active upper gastrointestinal bleeding
- Patient with unprotected airway
- Basal skull fracture
- Esophageal or mouth trauma

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Table 5

Questions that need to be answered when performing a rescue transesophageal echocardiography

1. Are the LV and RV contracting adequately?
2. Are there RWMAs?
3. What is the patient's volume status? (Is the heart ''full'' or ''empty''?)
4. Is there a significant valvular lesion?
5. Is there a ventricular outflow tract obstruction?
6. Is there a significant pericardial effusion?
7. Is there an intracardiac mass or clot?

LV = left ventricle; RV = right ventricle; RWMAs = regional wall motion abnormalities