REVIEW

Transesophageal Echocardiography in Critical Care

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Abstract

Purpose of Review In this article we describe the utility, indications, contraindications, limitations, and clinical situations in which transesophageal echocardiography (TEE) examination can be instrumental in managing patients in the intensive care unit (ICU).

Recent Findings TEE is a safe and semi-invasive diagnostic modality that can be used to differentiate pathologies, determine hemodynamic status, guide management, and determine response to therapy. Its presence has expanded beyond the operating rooms into the critical care world. Despite limited randomized trials, evidence indicates its significant benefits and potential for early diagnosis to reduce morbidity and mortality.

Summary Patients in the ICU present with multifactorial form of shock, hypoxemia needing monitoring and mechanical circulatory support. TEE is a low-risk diagnostic and monitoring tool which is invaluable in the ICU. Its advantages include superior visualization of cardiac structures and accurate assessment of abnormalities. Judicious utilization of TEE holds the potential to significantly influence clinical decision-making in a favorable manner.

Keywords Transesophageal echocardiography · Management of shock hemodynamics · Hypoxia evaluation · Mechanical circulatory support · Shock in ICU

Introduction

Patients admitted to critical care units invariably present with a diverse array of systemic pathologies, necessitating intricate and judicious management strategies. These critically ill patients need a variety of monitoring and diagnostic modalities. Within this context, echocardiography has emerged as an indispensable modality, assuming a vital role in clinical practice [1, 2••] diagnosis and management of structural heart disease, differentiating etiology of shock and hypoxemia, assisting with placement of mechanical support devices and guiding the management of critically ill patients [3]

TEE offers superior diagnostic capability when transthoracic echocardiographic (TTE) images may be inadequate. Examples include patients with wounds or surgical dressings over the chest and abdomen, patients who are placed in the prone position on mechanical ventilation, or those who are obese. TEE also carries a diagnostic advantage during advanced cardiac life support as it can guide resuscitation during ongoing chest compressions and for continued assessment and to place mechanical circulatory support (MCS) devices if indicated. A survey of the literature underscores the transformative potential of TEE, manifesting in novel diagnoses in 27% to 98% of cases and precipitating substantive alterations in treatment paradigms in up to 80% of instances. [3–5].

Indications

In a critical care setting, TEE is an invaluable diagnostic tool in a myriad of scenarios. These include instances of unexplained hemodynamic instability, hypoxemia, cardiorespiratory arrest, post-cardiac surgery complications, tamponade (Fig. 1), suspected pulmonary emboli, the suspected thoracic aortic dissection, trauma cases involving the cardiovascular system and shock, endocarditis, and identification of cardiac or aortic

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sources of embolism [2••, 5, 6]. TEE plays a crucial role in assessing volume status and in titrating fluids, vasopressors, and inotropes. It is also used to guide the placement and confirm the positioning of central venous lines, pulmonary artery catheters, and MCS devices. TEE serves to guide the insertion of extracorporeal membrane oxygenation (ECMO) cannulas, monitor hemodynamics on ECMO, guide management decisions, and facilitate weaning from MCS devices [6]. Additionally, TEE is instrumental in differentiating the causes of hypoxemia, such as identifying cardiac etiologies, intracardiac or intrapulmonary shunts, congestion, and the presence of pleural effusion. It also plays a crucial role in ruling out the cardiac source of embolism in patients with stroke or transient ischemic attack, and in confirming the absence of a left atrial appendage (LAA) clot before cardioversion [3, 5–7].

Contraindications

While complications associated with TEE are infrequent, instances of mechanical and esophageal injuries have been documented. Thorough evaluation and exclusion of esophageal and gastric pathologies are imperative before performing a TEE. Absolute contraindications encompass a spectrum of conditions, including esophageal perforation, strictures, tumors, tears, diverticuli, active upper gastrointestinal (GI) bleeding, previous esophageal surgeries, and recent upper GI surgery or intervention [3, 6, 8].

Relative contraindications include unstable atlantoaxial joint disease, severe symptomatic cervical arthritis, symptomatic hiatal hernia, recent upper GI bleeding, peptic ulcer disease, large abdominal aortic aneurysm, Barrett's esophagus, and coagulopathies [3, 6, 8].

Safety

The semi-invasive nature of TEE mandates consideration of potential complications stemming from the blind insertion and manipulation of the ultrasound probe. These complications may encompass oropharyngeal issues such as lip bruising, dental injury, or laryngeal perforation [3, 5, 9]. Esophageal implications may involve odynophagia, dysphagia, and the risk of Mallory-Weiss tears, while gastric trauma is also a conceivable adverse outcome [10, 11]. Furthermore, more severe complications such as splenic laceration, compression of mediastinal structures, airway compromise, thermal injury, burns, and even tongue necrosis may occur. While it is imperative to recognize these potential complications associated with TEE probe placement and manipulation, it is crucial to underscore their rarity [6].
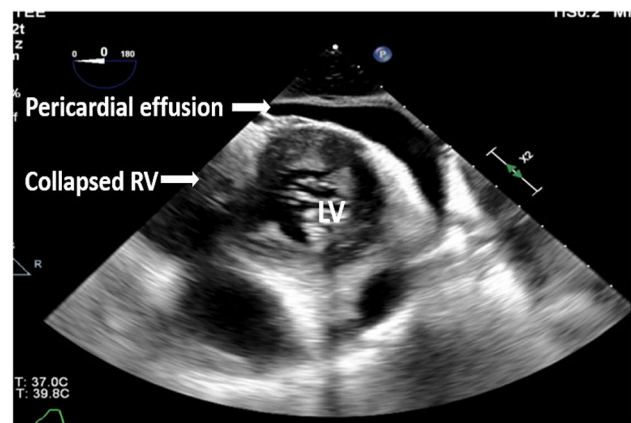
Fig. 1 Transgastric short-axis (TG-SAX) view showing pericardial effusion causing tamponade causing near RV collapse and a small underfilled LV

Limitations to Use

TEE-derived information should be integrated with the clinical examination, invasive hemodynamic monitoring, biomarkers of hypoperfusion, and so on. Limitations include misconceptions of easy mastery of technique, technical errors such as image exclusion, and interpretive omissions and misinterpretation. In addition to being semi-invasive, TEE is less repeatable when compared to TTE, requires training and competence, involves a high fixed cost of equipment, and provides intermittent data [3, 6, 12•, 13].

TEE for Hemodynamic Assessment and Evaluation

The integration of TEE examination with invasive measurements of systemic arterial and venous pressures and biomarkers of tissue perfusion can facilitate functional hemodynamic monitoring [14–16]. This integrated approach proves instrumental in providing a comprehensive assessment of the circulatory system, optimizing tissue perfusion and assessing heart–lung interactions. The amalgamation of TEE data with invasive measurements allows for the differentiation of shock etiologies, identification of multiple shock states, and valuable insights such as fluid responsiveness, fluid tolerance, myocardial dysfunction, risk or presence of congestion, dynamic left ventricular obstruction, and other acute conditions that contribute to life-threatening hemodynamic instability, such as pulmonary embolism and aortic dissection (Refer to Figs. 2 and 3).

Fig. 2 Left: Ascending aorta SAX view with Stanford Type A dissection Right: ME aortic valve LAX view with Stanford type A dissection of ascending aorta
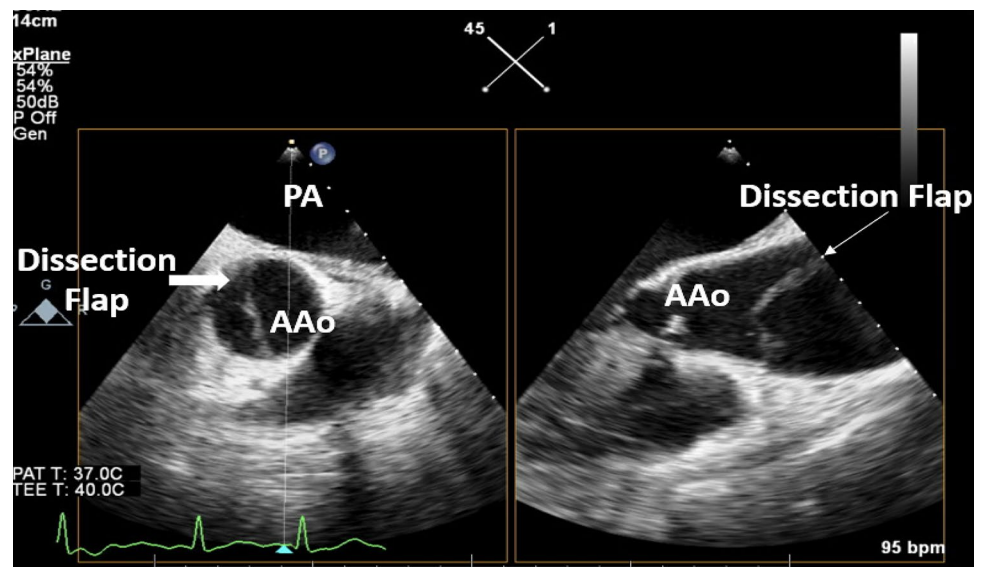
Fig. 3 **Left**: Ascending aorta SAX view with an occlusive pulmonary embolus in the right PA. **Right**: ME 4-chamber (ME-4C) view with dilated RV indicating acute RV failure from pulmonary embolism
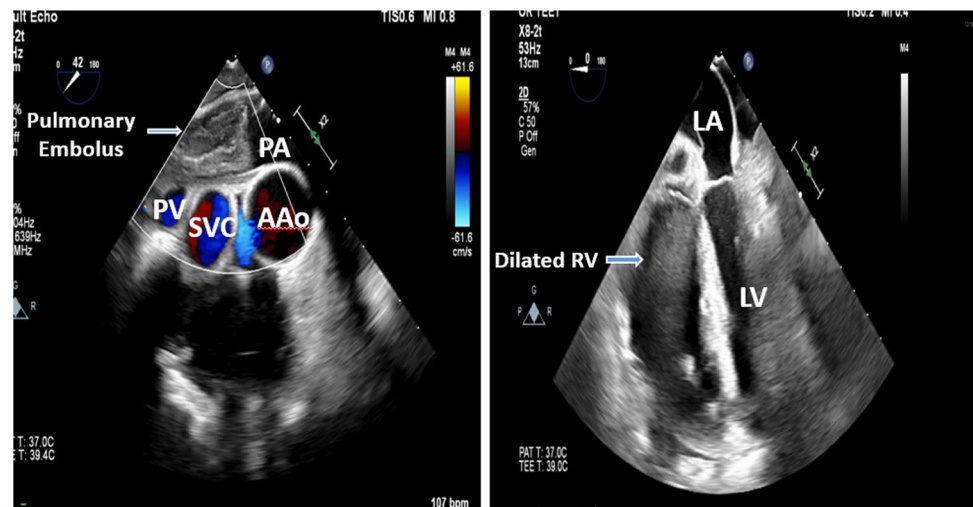
Preload Assessment

TEE is invaluable in assessing preload in critically ill patients, offering both qualitative and quantitative insights. A hyperdynamic left ventricle (LV) may indicate low filling pressures, while specific observations like kissing papillary muscles or LV end-systolic cavity obliteration may suggest hypovolemia progressing to shock. Care must be taken to avoid foreshortened views and assess the position of the inter-ventricular septum (IVS) and right ventricular (RV) function. Additionally, respiratory variations in velocity time integral (VTI) at the left ventricular outflow tract (LVOT) can help evaluate stroke volume and fluid responsiveness [7, 18, 19].

TEE facilitates the assessment of volume responsiveness by examining LV chamber size and function before and after fluid bolus administration [20]. It allows evaluation of both static predictors like estimated filling pressures and dynamic predictors like variations in the LVOT velocity time integral (LVOT-VTI). Additional indicators, such as changes in left ventricular end-diastolic area (LVEDA) in the trans-gastric mid-papillary short-axis (SAX) view with fluid bolus or passive leg raise, enhance the evaluation. This comprehensive approach, combined with invasive monitoring and perfusion biomarkers, guides clinicians in effective management and indicates resuscitation adequacy.

Measurement of LVOT-VTI

The LVOT-VTI can be acquired using the trans-gastric long-axis (LAX) or deep trans-gastric five-chamber view, providing insights into LVOT flow dynamics and quantifying the blood volume ejected through the LVOT with each heartbeat. This parameter aids in measuring cardiac output and differentiating causes of hypotension, particularly in

identifying hypovolemia, assessing fluid responsiveness, and detecting dynamic LVOT obstruction with a dagger-shaped profile [18, 19].

In mechanically ventilated patients, measurements are typically taken at end-expiration or during apnea. LVOT diameter measured in mid-systole using the mid-esophageal aortic valve LAX view, preferably with a zoomed image for accuracy. VTI assessment with Doppler should be made at the same site where LVOT diameter is measured.

Normal LVOT cross-sectional area ranges from 3 to 5 cm^2, with stroke volume between 60 and 75 mL. The normal LVOT-VTI falls within 15 to 20 cm. Assumptions include treating the LVOT as circular when it is oval, and limitations involve potential underestimation with an off-axis Doppler and overestimation when the Doppler is closer to the aortic valve (AV). Multiple VTI measurements should be averaged to accommodate fluctuations in stroke volume (SV) due to conditions such as atrial fibrillation, hypovolemia, or tamponade.

TEE Views for Assessment of Hemodynamics and Shock

A systematically performed TEE assessment stands as an indispensable tool for the comprehensive evaluation of hemodynamic states [21]. Shock is one of the most common causes for ICU admission. Basic knowledge of TEE views is essential when making a clinical inference [5] (Refer to Table 1).

TEE as Pulmonary Artery Catheter

Pulmonary artery catheterization (PAC) can provide useful information about systemic hemodynamics and heart–lung interactions. However, in patients who do not have a PAC, TEE can be used to estimate chamber pressures using Doppler principles. RA pressure or central venous pressure (RAP/CVP) can be estimated using size and distensibility of the IVC. Right ventricular systolic pressure (RVSP) can be estimated based on Doppler assessment of tricuspid valve regurgitation (TR) jet which then should correlate with PA systolic pressure (PASP) if there is no RVOT obstruction or pulmonic valve stenosis [24]. PA systolic pressures and Doppler assessment of pulmonic valve insufficiency jet can be used to assess PA systolic and diastolic pressures as seen in Table 2.

Additionally, TEE can be used to estimate left atrial pressure (LAP) and LV end-diastolic pressures (LVEDP) if there are MR or aortic regurgitation (AR) jets present respectively [7].

TEE facilitates the measurement of cardiac output (CO) and stroke volume (SV). These measurements can be obtained at various locations, including the AV, LVOT, and RVOT. However, the LVOT is commonly chosen for such assessments using the following formulas.

Cardiac Output (CO):

$$CO = Heart\ Rate(HR) \times Stroke\ Volume(SV)$$

Stroke Volume (SV):

$$SV = LVOT - VTI \times Cross$$
$$- Sectional\ Area\ of\ LVOT(LVOT - CSA)$$

Rescue TEE for Hemodynamic Instability [25]

In the ICU, a systematic TEE examination can play a pivotal role in establishing a rapid and accurate diagnosis. As a dynamic, real-time monitoring tool, echocardiography serves as a linchpin at the patient's bedside, affording insights into the dynamic fluctuations of cardiorespiratory status and valuable hemodynamic assessment of patients presenting with shock states and hemodynamic instability [5, 26] (Refer to Fig. 4). It is imperative to correlate echocardiographic findings with the clinical context to ensure a precise diagnosis [2••]. Several conditions contribute to hemodynamic instability, broadly categorized as follows:

Obstructive Shock:

- Cardiac Tamponade: TEE examination will reveal the presence of pericardial effusion and tamponade physiology (Refer to Fig. 1). TEE can be used to guide bedside pericardiocentesis.
- Pulmonary Embolism: Signs include acute RV strain, septal deviation towards the left, and evidence of RV overload (Refer to Fig. 3). Other causes include patient-ventilator dyssynchrony, auto-positive end-expiratory pressure (auto-PEEP) and tension pneumothorax.

Distributive Shock:

- Arises from vasodilation and low systemic vascular resistance (SVR), and is seen in conditions such as sepsis, anaphylaxis, inflammatory responses, vasoplegia post-cardiopulmonary bypass, and liver failure. May present in isolation or in combination with other shock pathologies.
- Echocardiography will show collapsible IVC, SVC, LV hypercontractile with preserved or higher ejection fraction. LVOT-VTI will have respiratory variations.

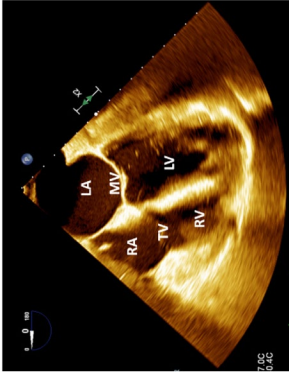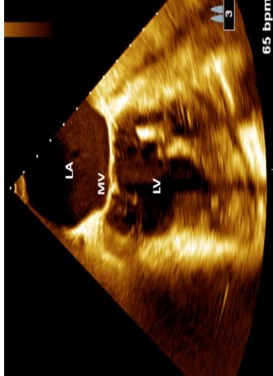**Table 1** TEE Views for Assessment of Shock

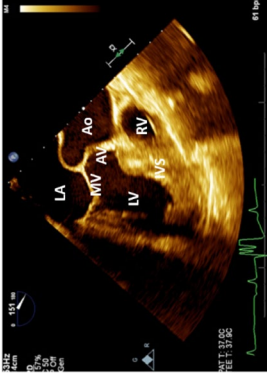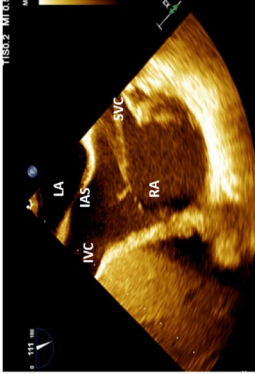| TEE View name	How to Obtain the view [22]	Image	Information obtained from this view	Clinical Examples
Midesophageal (ME) 4-chamber	• Transducer angle: 0–10° • Level: midesophagus • Maneuver: Avoid fore-shortening		• LV size and function, LV hypertrophy • LV contractility and perfusion (anterolateral and infero-septal wall), presence of regional wall motion abnormality (RWMA) • Volume status • RV to LV cavity size ratio (RV dysfunction / ventricular interdependence) • RV free wall contractility • Pericardial effusion / tamponade physiology • Assessment of left atrial (LA), right atrial (RA) size • Color Doppler for gross valvular abnormality – mitral and tricuspid valves • Diastolic function assessment • Tissue Doppler imaging	Cardiogenic shock may present with RWMA. LV ejection fraction can be assessed qualitatively and quantitatively from this view. RV dysfunction will present with dilated RV, shift of septum towards the left, and decrease in tricuspid annular plane systolic excursion (TAPSE). If septum is towards the left only during systole, there may be RV pressure overload. If septum bows towards left side during both systole and diastole, there may be RV pressure and volume overload Hypovolemia will present with a decrease in both LV end-diastolic volume measurement and decrease in LV end-systolic volume measurement Tamponade will present with fluid in pericardial cavity and RV collapse during systole and RA collapse in diastole
Mid esophageal(ME) 2-chamber	• Transducer angle: 80–100° • Level: midesophagus		• RWMA • LV hypertrophy • Color, pulse wave and tissue Doppler • Assessment of LAA • Mitral valve (MV) pathology	Left anterior descending artery ischemia may present with RWMA in the anterior wall Right coronary artery ischemia may present with RWMA in the inferior wall LAA can be the site of a clot in patients with atrial arrhythmia and a potential source of stroke

Table 1 (continued)

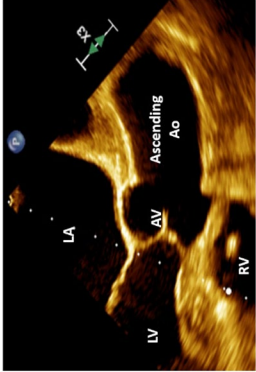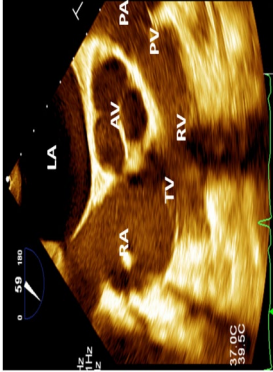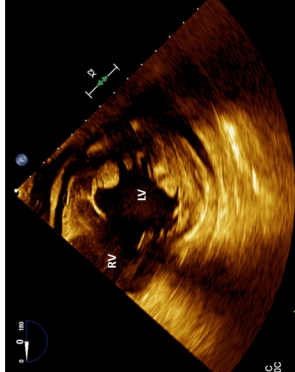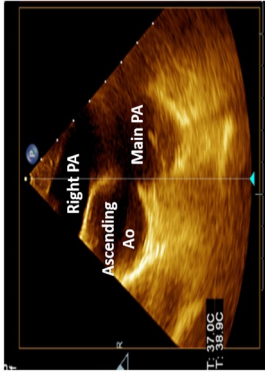| TEE View name	How to Obtain the view [22]	Image	Information obtained from this view	Clinical Examples
Mid esophageal long-axis (LAX)	• Transducer angle: 120–140° • Level: mid esophageal		• LV size, function • RWMA anteroseptal and inferolateral walls • Gross valvular abnormality – MV and aortic valve (AV), two-dimensional, color flow assessment • Systolic anterior motion (SAM) – hypertrophic obstructive cardiomyopathy (HOCM) with left ventricular outflow tract (LVOT) obstruction • Aortic root assessment, ascending aortic pathology • LVOT measurement for calculating cardiac output (CO)/ aortic valve area (AVA) • Position of mechanical circulator support (e.g., percutaneous temporary left ventricular assist device) • Ascending aorta (Ao) assessment	MV can be evaluated for acute mitral regurgitation (MR) as can happen with Infective endocarditis or acute chordal rupture AV can be evaluated for presence of aortic stenosis or insufficiency. Acute aortic inefficiency may be from infective endocarditis or aortic dissection LVOT obstruction can lead to acute hemodynamic instability, which may present with turbulence in the LVOT and posteriorly directed jet of mitral regurgitation
Midesophageal bicaval and modified bicaval	• Transducer angle: 90–110° • Level: mid esophageal		• RA pathology • Superior vena cava (SVC) and inferior vena cava (IVC) assessment • Intra-atrial septum assessment. Presence of atrial septal defect (ASD) or patent foramen ovale (PFO) • Fluid responsiveness – diameter changes in SVC / IVC • Thrombus, tumor or mass in RA, paradoxical thrombus. Tumors or clots from IVC • Guiding placement and confirming position of central venous catheters, ECMO cannula • Assessment of tricuspid valve and calculating RV systolic pressure using Doppler (modified bicaval view)	In hypotensive patients, assessment of SVC and IVC size and collapsibility can guide to type of shock In patients with hypoxia, this view can help diagnose presence of atrial septal defects with a color and saline contrast study Patients with suspected pulmonary hypertension RV systolic pressure can be estimated using tricuspid regurgitation jet from modified bicaval view

Table 1 (continued)

TEE View name	How to Obtain the view [22]	Image	Information obtained from this view	Clinical Examples
Midesophageal aortic valve Long axis view (LAX)	• Transducer angle:120–140° • Level: ME • Maneuver: from ME LAX withdraws + anteflex		• Assessment of AV pathology – stenosis, regurgitation, infective endocarditis, tumor, Lambl excrescences • Assessment of ascending aortic aneurysm or dissection • Prosthetic AV evaluation • Presence of subaortic or supra-aortic membrane or stenosis • LVOT and aortic annulus measurements	Type A aortic dissections can be diagnosed from this view Paravalvular leak in prosthetic aortic. Valve can be diagnosed in this view
Midesophageal aortic valve Short axis (SAX) view ME RV inflow-outflow view	• Transducer angle: 25–45° • Level: ME • Maneuver: anteflex from ME 5-chamber view		• AV pathology – bicuspid AV, endocarditis, presence of stenosis / regurgitation • Tricuspid valve and pulmonary valve pathology, right ventricular outflow tract (RVOT) pathology • Presence of ventricular septal defects (VSD)	Aortic stenosis can be assessed by looking at opening of aortic valve in systole. Tricuspid regurgitation can be evaluted qualitatively and quantitatively.
Transgastric LV SAX mid-papillary	• Transducer angle: 0–20° • Level: transgastric • Maneuver: advance + anteflex		• Cardiac function, LV hypertrophy, volume status • RWMA – • Fractional area change (FAC) calculation to assess LV systolic function • Interventricular septum position – RV-LV interdependence to detect RV pressure and/or volume overload • To detect presence of pericardial effusion	All coronary arteries territories can be assessed in this view. In patients with suspected myocardial infarction (MI) it provides valuable information on the possible culprit artery

Table 1 (continued)

TEE View name	How to Obtain the view [22]	Image	Information obtained from this view	Clinical Examples
Deep transgastric 5-chamber view	• Transducer angle: 0–20° • Level: transgastric • Maneuver: advance, ante flex, left flex		• AV pathology assessment – stenosis, regurgitation • Calculate LVOT-VTI for calculating cardiac output and AV area, calculation of shunt fraction across septal defects (Qp:Qs) • Confirm position of temporary percutaneous left ventricular assist device	
Inferior vena cava (IVC)—Hepatic vein (HV) view	• Transducer angle: 50–70° • Level: transgastric • Maneuver: right flex and advance		• IVC collapsibility, distension and size to assess volume responsive or detect presence of venous congestion [23] • IVC compression • Doppler profile of IVC and hepatic veins to asses tricuspid valve function	IVC size and respiratory variations can help differentiate shock physiology. IVC tumor, thrombus, mass can be seen.
Descending aortic SAX and LAX	• Transducer angle: 0–10° and X plane for perpendicular axis • Level: transgastric to ME		• Detect presence of aortic aneurysm, dissection • Detect and quantify aortic atherosclerosis • Guide placement of Intra-aortic balloon pump (IABP) position and percutaneous LVAD, VA ECMO cannula • Detect presence of pleural effusion	

Table 1 (continued)

TEE View name	How to Obtain the view [22]	Image	Information obtained from this view	Clinical Examples
Ascending aortic short axis view	• Transducer angle: 0–30° • Level: upper esophageal • Maneuver: anteflex		• Aortic pathology – aortic dissection and dilation • Pulmonary artery (PA) pathology – pulmonary embolism, dilated PA in pulmonary hypertension, PA acceleration time measurement • Calculation of PA mean and diastolic pressures using Doppler-based hemodynamic calculation • Confirm position of PA catheter, guide placement and confirm position of percutaneous right ventricular assist device (RVAD)	

Hypovolemic Shock:

- Relative or absolute hypovolemia or bleeding, presenting with a small and collapsible IVC, decreased LVEDA, reduced LVOT-VTI, and low cardiac output.
- Both Hypovolemia and Low Afterload: TEE enables qualitative and quantitative assessment of preload, aiding in the differentiation between hypovolemia and low afterload. Both conditions may appear hyperdynamic with decreased end-systolic diameter. Differentiation is achieved through LVEDA measurement—normal with low SVR and reduced with hypovolemia. LVOT-VTI/cardiac output measurements help assess if cardiac output is decreased or high [18, 19].

Cardiogenic shock:

- Cardiogenic shock is defined as the heart's inability to maintain adequate tissue perfusion to meet metabolic demands [27, 28]. It is common in critically ill patients and is associated with high mortality rates. Rapid recognition, determination of underlying causes, and assessment of hemodynamic status are vital for effective management. Echocardiography serves as a cornerstone in the evaluation and management of cardiogenic shock due to its ability to provide real-time, non-invasive assessment of cardiac structure and function.
- Cardiogenic shock can arise from various conditions such as myocardial ischemia, infarction, mechanical complications of infarction like acute mitral insufficiency, ventricular septal rupture, valvular heart diseases like aortic stenosis, mitral stenosis, mitral regurgitation, decompensated heart failure (either systolic or diastolic), arrhythmias, dynamic LVOT obstruction, pulmonary embolism, or biventricular dysfunction. Diagnosis of cardiogenic shock on TEE involves qualitative and quantitative assessment with multiple TEE views. Cardiogenic shock will typically present with reduced ejection fraction, reduced cardiac output calculated from LVOT-VTI, likely dilated IVC, presence of ischemia presenting with RWMA, and gross valvular abnormalities or infective endocarditis which can be evaluated by TEE. Cardiogenic shock may be due to isolated left or right ventricular failure or biventricular failure.

Left Ventricular Dysfunction

Differential diagnoses include acute coronary syndrome, sepsis-induced cardiomyopathy, stress cardiomyopathy (Takotsubo), myocarditis, toxin-induced cardiomyopathy, etc. Ischemia will present with RWMA in respective

Table 2 Measurement of Atrial and Ventricular Pressures using TEE

Parameter	How to obtain	Equation
Central venous pressure or RA pressure	Measurement of IVC size and collapsibility index (IVC-ci) CVP is inversely related to IVC-ci. TEE views - IVC-hepatic vein view	$IVC\text{-}ci = (IVC \text{ max diameter} - IVC \text{ min diameter}) / IVC \text{ max diameter} * 100$
RVSP or PASP	From continuous wave Doppler at tricuspid valve getting maximum TR velocity (Vtr) and adding CVP or RA pressure (CVP/RAP). TEE Views – modified bicaval and sometimes RV inflow-outflow	$RVSP \text{ or } PASP = 4\,(Vtr)^2 + RAP$
Pulmonary artery mean pressure (PAMP)	Doppler velocity at pulmonic valve early peak of velocity (V early PI) and adding Right atrial pressure (RAP). TEE view - Upper esophageal Ascending aortic short axis	$PAMP = 4\,(V\,earlyPI)^2 + RAP$
Pulmonary artery diastolic pressure (PADP)	Doppler velocity tracing from pulmonic valve (V late PI) peak of late velocity and adding right atrial pressure (RAP). TEE views- Upper esophageal Ascending aortic short axis.	$PADP = 4\,(V\,latePI)^2 + RAP$
Left atrial pressure (LAP)	Doppler velocity tracing of mitral valve (Vmr) and systolic blood pressure from arterial line or blood pressure cuff (SBP). TEE view- Mid esophageal 4 chamber, Mid-esophageal long axis views.	$LAP = SBP - 4\,(Vmr)^2$
Left ventricular end diastolic pressure (LVEDP)	Doppler velocity tracing at AV if aortic insufficiency (Vai) jet is present. TEE view - Deep transgastric five chamber view.	$LVEDP = DBP - 4\,(Vai\,end)^2$

coronary artery distribution (Refer to Fig. 5). RWMA is assessed through various TEE views, such as ME 4-chamber, 2-chamber, LAX, and transgastric midpapillary SAX. The global LV function can be measured by Simpson's or 3D ejection fraction assessment. Consideration of the impact of inotropic support on measurements is essential. Nonischemic conditions that may mimic RWMA include bundle branch blocks, external pacing, and stress-induced cardiomyopathy. TEE can evaluate mechanical complications following myocardial infarction, such as chordal or papillary muscle rupture. The posteromedial papillary muscle is more prone to rupture due to a single blood supply. Other complications, such as post-myocardial infarction, ventricular septal rupture, and LV free wall rupture, can be diagnosed by TEE. TEE can evaluate for the presence of valvular heart disease and grade severity like mitral stenosis and regurgitation, aortic stenosis, and regurgitation. It can also quantify the LV dysfunction associated with valvular heart disease. TEE can evaluate diastolic dysfunction and guide fluid management in patients with LV dysfunction.

Right Ventricular Dysfunction

Causes could be secondary to LV dysfunction, acute pulmonary embolism, RV infarction, severe tricuspid regurgitation

[29], cor pulmonale secondary to lung disease, etc. TEE can evaluate RV size, function, and presence of RWMA and assess inter-ventricular septum position. Acute pressure/volume overload, RV ischemia, pulmonary embolism, worsening pulmonary hypertension, post-cardiopulmonary bypass complications, or chronic cor pulmonale. TEE views to evaluate RV function include mid-esophageal 4 chamber, trans-gastric SAX, and RV inflow-outflow view.

In patients with hemodynamic instability due to arrhythmias where the patient requires cardioversion, careful surveillance for thrombus in the LAA, LV apex, shunts, and right heart helps prevent thromboembolic phenomena [30].

Mechanical Circulatory Support

In-hospital cardiac arrests are emergencies requiring immediate differential diagnosis. TEE can play a critical role in managing patients during this time. It offers real-time imaging, allowing clinicians to assess cardiac function, identify potential causes of arrest, decrease duration of pulse check, and guide resuscitative efforts. TEE facilitates visualization of cardiac structures, assessment of ventricular wall motion, evaluation of valvular function, and detection of reversible causes such as cardiac tamponade or massive pulmonary embolism [13, 31]. Moreover, TEE optimizes

chest compressions by providing immediate feedback on the effectiveness of cardiopulmonary resuscitation (CPR) and the return of spontaneous circulation (ROSC). This real-time imaging modality enhances diagnostic accuracy, aiding timely decision-making in the intense setting of cardiac arrest, ultimately contributing to improved patient outcomes. In peri-arrest situations, TEE also informs the need for MCS, guides the selection of the appropriate type of support, assists in their placement, prevents complications, evaluates therapy response post-placement and can also provide hemodynamic information needed during weaning of MCS [26, 31, 32].

- LV and RV function
- Valve function, particularly aortic regurgitation
- Devices in the heart or prosthesis
- Thrombus
- Aorta dissection or calcification
- Presence of ASD, PFO, VSD

Table 3 contains details on the types of temporary MCS devices and assessment using TEE.

Intra-Aortic Balloon Pump

The intra-aortic balloon pump (IABP) functions as a short term MCS device for cardiogenic shock, MI, ventricular dysfunction, high-risk PCI, unstable angina, and challenges post-cardiopulmonary bypass (Refer to Fig. 6). TEE enables the practitioner to evaluate the necessity for IABP, identify contraindications to placement, confirm proper position, and assess complications and hemodynamic response by examining LV and RV function (Refer to Table 3) [13, 31, 32]. Subsequent TEE monitoring gauges the therapeutic response, identifies complications and helps with weaning. An IABP is typically inserted via the femoral artery and infrequently via the axillary artery. It resides in the descending aorta which is seen in the SAX view of the aorta. To visualize its tip, the probe is pulled back and the position of the tip is marked on the probe. Further withdrawing the probe and turning it counterclockwise brings the left subclavian artery into view near the aortic arch. The distance between the tip and the left subclavian artery is measured and should ideally be 2–3 cm.

Temporary Left Ventricular Assist Device

A temporary left ventricular assist device (LVAD) is usually placed in the LV via the aorta for ventricular unloading (Refer to Fig. 7). Its use has significantly increased over the last several years. Typical indications include cardiogenic shock, high risk PCI, bridge to transplant and as an LV vent. Placement is usually from the femoral artery or axillary artery. For placement, the guidewire and catheter are first

seen in the descending aorta (transfemoral approach). For its final positioning in the LV an ME LAX view is obtained. This view helps visualize the mitral valve, LV, LVOT, aortic valve and ascending aorta. The teardrop-shaped inlet should ideally be 3.5-4 cm from the aortic valve [13, 31, 32], outlet about 3 cm above the aortic valve (Refer to Table 3) The temporary LVAD should be free in the LV and not against the mitral valve apparatus; it is important to check for mitral regurgitation in the same view. The position of the septum should be midline and is evaluated in the ME four-chamber and LAX views. The P level and weaning can be determined based on the LV and RV function and septum position.

RV Assist Device Placement and Management

A temporary RV assist device is a double lumen cannula inserted via the right internal jugular vein into the right side with its tip residing in the pulmonary artery (Refer to Fig. 8) for RV failure or in refractory hypoxia. The device drains venous blood from the right atrium to an ECMO for oxygenation and is pumped back into the pulmonary artery [33]. The inflow cannula entering from the SVC can be seen in the mid-esophageal bicaval view (right side of the screen). Obtaining the RV inflow-outflow view helps to visualize the cannula traversing the right atrium, tricuspid valve, RV and pulmonic valve into its final position in the pulmonary artery. The tip of the outflow cannula is best seen by obtaining the ascending aorta short-axis view in the upper esophagus at 0° [13]. The tricuspid valve and interventricular septum position should be assessed, and the cannula should be repositioned or the pump speed adjusted based on echocardiographic findings.

Veno-Arterial Extracorporeal Membrane Oxygenation (VA ECMO)

VA ECMO provides temporary biventricular support for oxygenation and circulation, utilizing either central or peripheral cannulation strategies. Indications include refractory cardiogenic shock, high-risk PCI/cardiac procedures, refractory arrhythmias and as a bridge to transplant or LVAD [13, 31, 34]. Central cannulation involves venous cannula placement in the RA or SVC and IVC, visible in the bicaval view [35] as seen in Fig. 9. The central arterial cannula in the aortic arch or ascending aorta can be seen in the ascending aorta SAX view. Peripheral cannulation includes the venous cannula in the RA visualized in the bicaval view, and the peripheral arterial cannula in the descending aorta (femoral) or aortic arch (axillary). Continuous flow monitoring is crucial, with a comprehensive assessment post-placement for potential complications like dissection, hypoperfusion. In the case of LV distension,
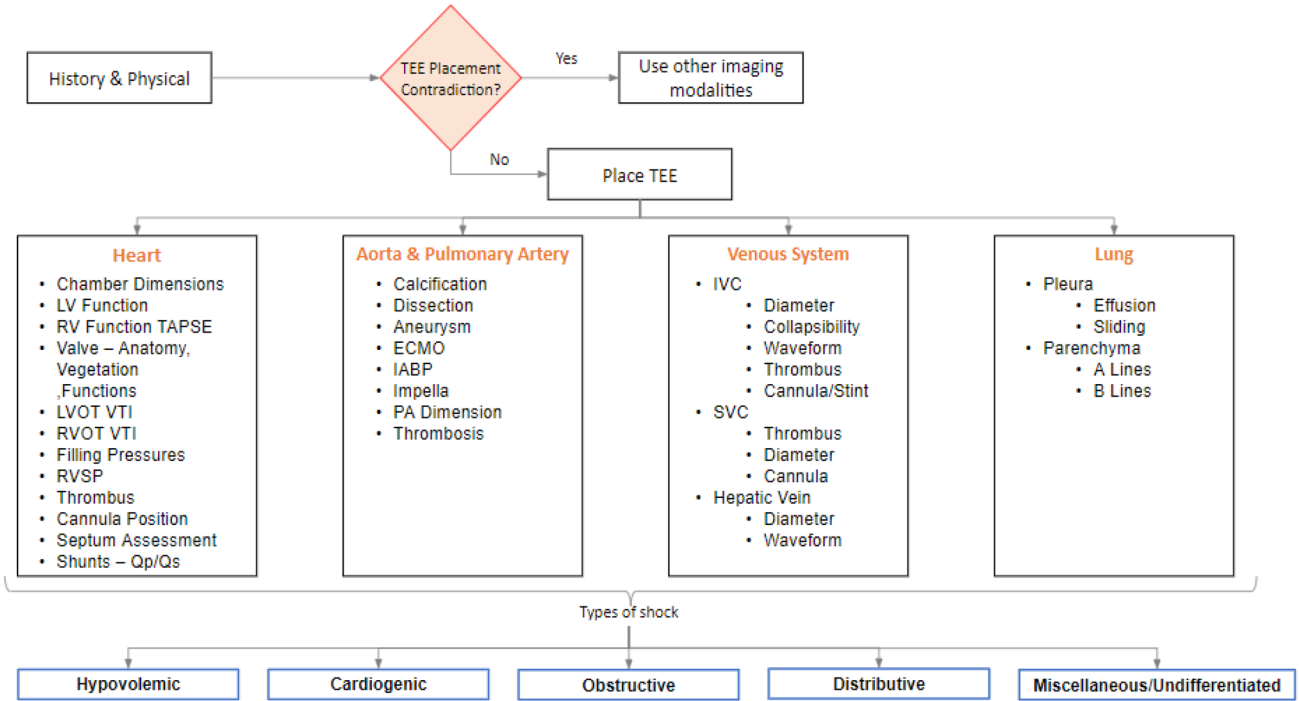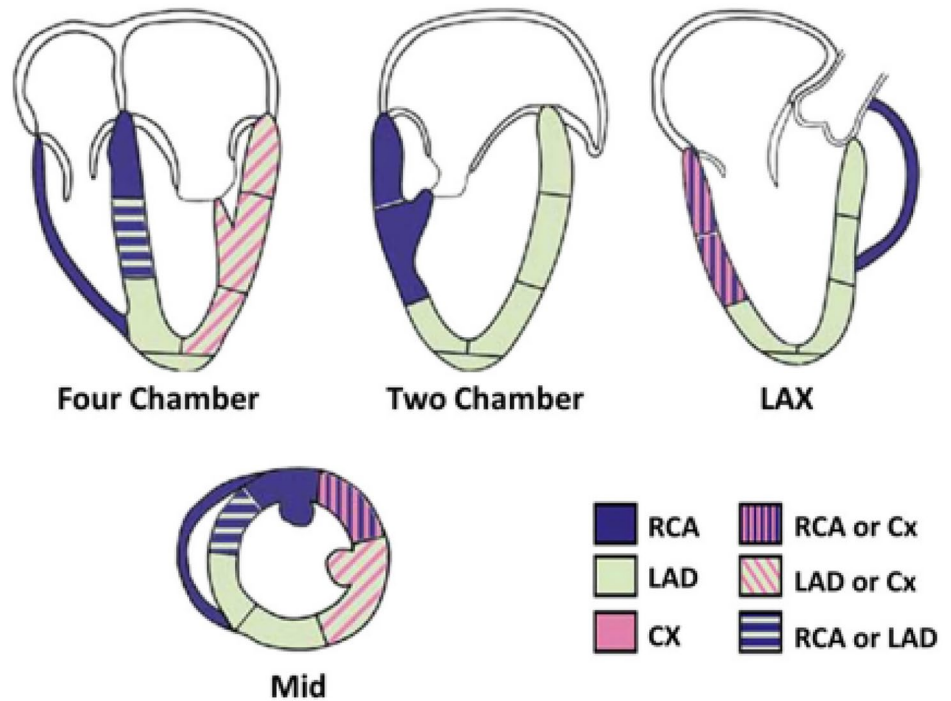
Hemodynamic Instability/Hypoxia/Rescue TEE

Fig. 4 Comprehensive TEE Review in Critical Care

Fig. 5 Image demonstrating areas of myocardial perfusion from different coronary arteries. Areas with mixed color are supplied by more than one coronary artery [17]

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Four Chamber   Two Chamber   LAX

Mid

RCA   RCA or Cx
LAD   LAD or Cx
CX   RCA or LAD

Table 3 Mechanical Circulatory Support

MCS	Imaging Goals	Imaging views	Complications	Contraindications on TEE
IABP	**Femoral cannulation** – guidewire and balloon visualization in descending aorta **Axillary** – visualize guidewire in the arch and balloon in descending aorta **Positioning** – 2-3 cm below the left subclavian artery (LSCA)	Descending aorta SAX and LAX views Aortic arch SAX and LAX views Rotate counterclockwise at the end of aortic arch to visualize LSCA	High position occludes LSCA, low position can occlude renal / mesenteric arteries Aortic injury or dissection Disruption of aortic atheroma IABP rupture	Aortic insufficiency Aortic dissection Severe grade >3 aortic calcifications
LV Assist Device	**Femoral cannulation** – guidewire and catheter visualization in descending aorta and advanced into the LV via ascending aorta **Axillary** – guidewire and catheter are visualized in the arch and advanced into LV via ascending aorta **Positioning** – LV tear drop inlet 3.5-4 cm from aortic valve and outlet, 3 cm from aortic valve LV size and function assessed pre- and post-deployment	Descending aorta SAX and LAX views Aortic arch SAX and LAX views ME LAX view Ascending aorta SAX and LAX views ME 4-chamber view Transgastric SAX view	Aortic injury or dissection Disruption of aortic atheroma Injury to AV Injury to MV apparatus LV perforation and tamponade	Thrombus in LA or LV Aortic regurgitation Aortic dissection Severe aortic stenosis Severe grade >3 aortic calcifications
RV Assist Device	**Peripheral cannulation** – wire and cannula in the right atrium, RV and main pulmonary artery **Positioning** – cannula entering from SVC and/or IVC Distal tip in the main PA trunk RV size and function assessed pre- and post-deployment	ME 4-chamber view RV inflow-outflow view Ascending aorta SAX and LAX views for the distal tip ME bicaval view Transgastric IVC - hepatic vein view	Tamponade RV rupture PA injury SVC-IVC injury Thrombus formation	Thrombus in the RA, RV or PA Tricuspid valve stenosis SVC thrombosis or stenosis
VA ECMO	**Peripheral cannulation** – femoral vein and artery: cannula in the IVC/RA and descending aorta respectively Internal jugular vein and axillary artery: cannula in the SVC/RA and aortic arch **Central cannulation** – venous cannula in the right atrium or IVC and SVC; arterial cannula in the aortic arch **Positioning** – RV and LV function and dimensions Cannula position based on site of insertion Aortic valve should be opening and low threshold for LV vent placement	Descending aorta SAX and LAX views Aortic arch SAX and LAX views ME LAX view Ascending aorta SAX and LAX views ME 4-chamber view Transgastric SAX view ME – RV inflow-outflow view ME – bicaval view	Cannula malposition LV distension and Pulmonary edema Cardiac tamponade Thrombus formation	Aortic dissection Thrombus in the RA Aortic regurgitation

Table 3 (continued)

| MCS	Imaging Goals	Imaging views	Complications	Contraindications on TEE
VV ECMO	**Peripheral cannulation** Femoral vein – drainage cannula from femoral vein to IVC return cannula from femoral vein to IVC For internal jugular (IJ) vein – SVC and RA Dual lumen cannula typically from right IJ vein into RA and IVC During cannulation, passage of guidewire in IVC and SVC can be confirmed **Positioning** – central ECMO- cannula in the RA and PA Check for PFO, cannula in the SVC/IVC Septum position	ME 4-chamber view RV inflow-outflow view ME bicaval view Transgastric IVC – hepatic vein view	Cannula malposition Ensure cannula tips are not too close to avoid recirculation Rule out tamponade Rule out thrombus formation	RV or LV dysfunction Proximal pulmonary artery thrombus
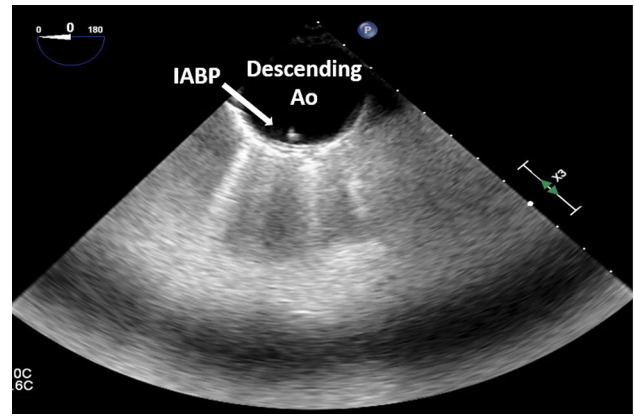
Fig. 6 IABP seen in the descending aorta SAX at A0. Here in the descending aorta IABP tip, aortic dissections, plaque and malpositioning can be identified
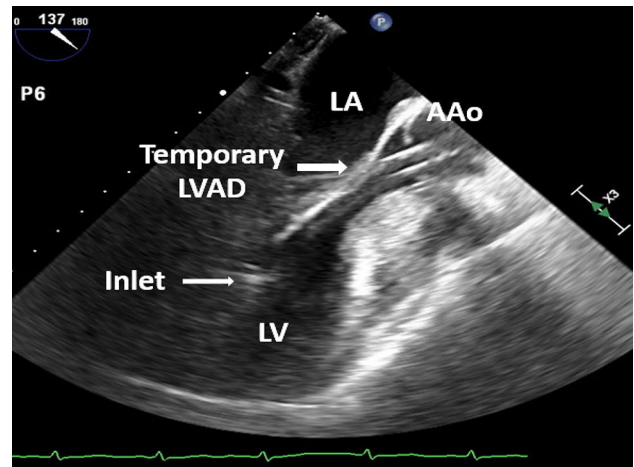

Fig. 7 Temporary LVAD seen in the ME-LAX view with inflow in the LV and outflow in the ascending aorta. LVAD position, Flow and mitral valve function can be assessed in this view

consider LV venting or decompression with IABP or temporary LVAD. Successful weaning predictors include LVEF > 20%, lateral mitral S' velocity > 6cm/sec, aortic VTI > 10 cm, and increased lateral e' and tricuspid annular S' velocity [31, 36, 37].

ECMO-Cardiopulmonary Resuscitation (ECPR)

VA ECMO can be used as an adjunct to CPR during cardiac arrest to improve perfusion to organs and improve survival rates. ECPR is initiated emergently if ROSC is not achieved in younger, witnessed, reversible cardiac arrests within 10 min [38, 39]. TEE can be a key player in successful placement and initiation of bedside VA ECMO during these emergent situations. Unique advantages of TEE include visualization of guidewires in the aorta (for arterial cannula) and
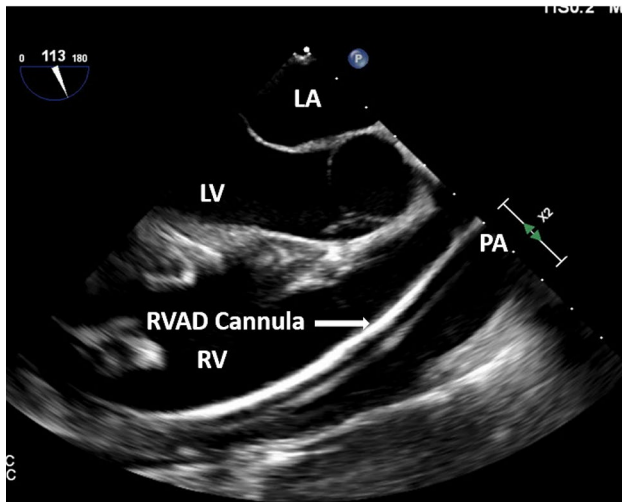
Fig. 8 RV assist device in the LAX view rotated to the patient's right. The device can be seen traversing the RV and entering the pulmonary artery above
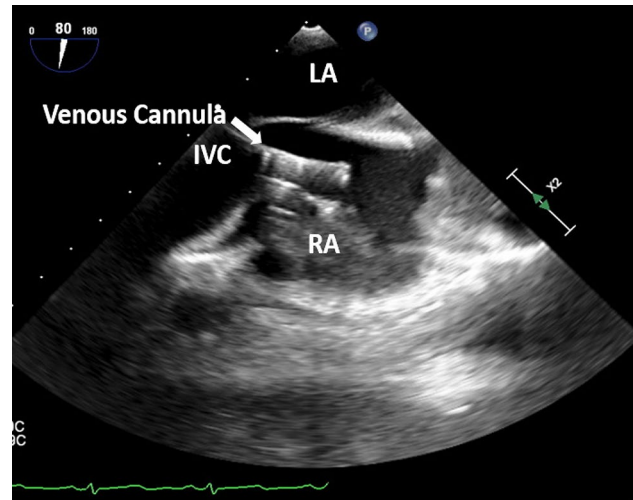

Fig. 9 Venous cannula seen in the RA entering from IVC in the ME bicaval view

right atrium (for venous cannula), no interference with chest compressions and lack of radiation exposure.

Veno-Venous Extracorporeal Membrane Oxygenation (VV ECMO)

VV ECMO is used for patients whose oxygenation and ventilation are compromised despite appropriate mechanical ventilation and medical therapy. Extracorporeal Life Support Organization (ELSO) guidelines help provide direction on indications, maintenance and weaning of VV ECMO [34, 35] Venous blood can be drained from the SVC, IVC, RA or femoral vein. In single-site and two-site insertions, oxygenated blood is returned to the RA with its direction towards the tricuspid valve. This can be visualized on the TEE in the ME four-chamber view, RV inflow-outflow view, and modified bicaval view [13, 31, 35].

Hypoxemia Evaluation

While TEE has found its widest application in evaluating cardiac structures and for hemodynamic monitoring, it can also provide high quality images of other important structures, including the lungs, aorta and venous system. Figure 10 provides a comprehensive evaluation of TEE for hypoxemia which offers a unique opportunity to assess and alter our management with supportive findings.

Lung Ultrasound with TEE

Transesophageal lung ultrasound (TELU) is a novel technique increasingly being used to evaluate the pulmonary system. Though not validated, some of its findings can be inferred from transthoracic lung ultrasound (TTLU). The left lung is effectively visualized via the aorta, while visualization of the right lung poses difficulty due to proximity of the right side of the esophagus to vertebral bodies. Lack of an acoustic window from the scapula makes posterosuperior segments accessible only to TEE [2••, 39, 55].

Indications include hemodynamic instability, hypoxemia and routine evaluation if a TEE is already in place. Performing TELU during every TEE examination in the ICU will help advance our understanding in this evolving field.

Method

For lung parenchymal assessment, the left subclavian artery, left superior pulmonary vein and IVC-RA junction are identified at 0° which corresponds to apical, mid and basal levels respectively [40]. Please refer to Table 4 for additional details.

The omniplane is rotated to 90° and the probe is turned to each side to carefully examine anterior, lateral and basal segments at each level. Presence of A lines, B lines, air bronchograms and hepatization are important findings for our critically ill patients in the ICU which may alter our management [40, 41]. A-lines are reverberation artifacts of hyperechoic
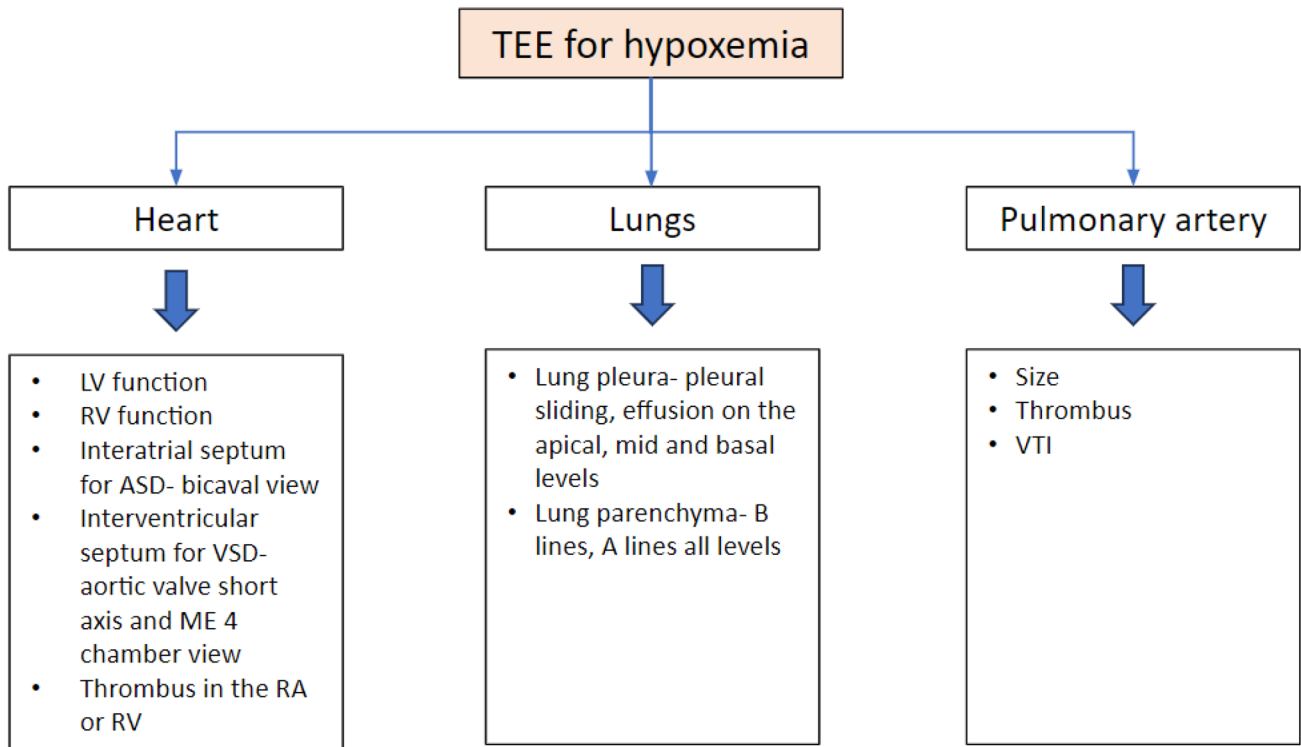
Fig. 10 Comprehensive TEE for hypoxemia

horizontal lines equidistant from the pleura at regular intervals [21, 42]. Their presence is diminished by B lines and enhanced by pneumothorax. B lines or comet tails are vertical reverberation artifacts arising from the pleural line. The presence of three or more indicates pulmonary edema or interstitial disease [42, 43]. Lung consolidation appears as liver-like areas of increased density called hepatization. Air bronchograms are hyperechoic foci in these consolidated areas [21, 39, 42]. Dynamic vs static air bronchograms help distinguish consolidation from atelectasis.

Pleura should also be assessed at all three levels. The near field of visceral pleura may be difficult to assess because of the phased array probe and the far field may be obscured due to artifacts. This makes non-tension pneumothorax difficult to diagnose on TELU. Lung sliding can be appreciated. In cardiac surgery, intraoperative TEE is commonly employed to detect the presence of pleural effusion with a 97% sensitivity and 100% specificity [40, 43]. Pleural effusions can

be unilateral or bilateral and are qualitatively classified into simple and complex, depending on their echogenicity [36]. Please refer to Figs. 11 and 12.

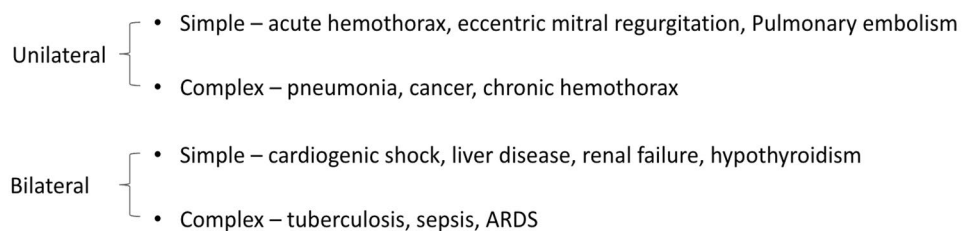Capper's method for quantification of pleural effusion.

Pleural fluid volume = Maximal cross-sectional area (CSA) x axial length (AL).

This correlated well with actual volume of pleural effusion [40, 44]. CSA is measured by tracing the maximal surface area and AL is determined from the craniocaudal length by manually advancing the probe.

Veins

Standard views on TEE are used to analyze the SVC, IVC, hepatic vein, coronary sinus and pulmonary veins. Thrombosis, stenosis, and fluid overload can be diagnosed. Thrombosis is of particular concern, especially among our critically ill ICU patients as discussed earlier, leading to a risk

Fig. 11 Classification of Pleural Effusion

Unilateral
- Simple – acute hemothorax, eccentric mitral regurgitation, Pulmonary embolism
- Complex – pneumonia, cancer, chronic hemothorax

Bilateral
- Simple – cardiogenic shock, liver disease, renal failure, hypothyroidism
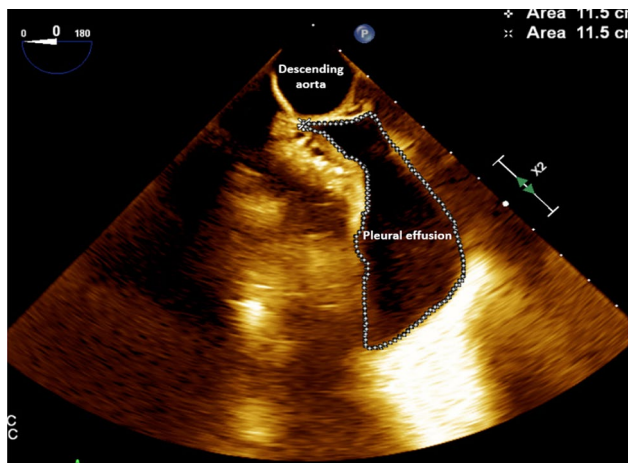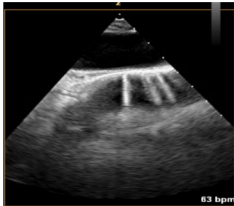- Complex – tuberculosis, sepsis, ARDS

Fig. 12 Left Pleural Effusion in the descending aortic SAX view

of pulmonary embolism. All the veins must be evaluated with and without color, and pulsed wave Doppler signals should be obtained whenever alignment is possible. Flow should be antegrade and S and D waves above the baseline are considered normal (As seen in Fig. 13). SVC and IVC are best seen in the bicaval view, and the hepatic vein is best seen by advancing the probe into the stomach from the bicaval view and decreasing the omniplane. Obtaining these views in conjunction with the RV inflow-outflow view and ascending aorta SAX view can be extremely helpful for pulmonary artery catheter placement, especially in patients with mechanical circulatory devices where pressure tracings may not be discernible.

The venous excess ultrasound score or VExUS was developed as a prognostic tool for acute kidney injury, but is being increasingly used to guide fluid management [45]. IVC, hepatic vein, portal vein and renal vein need to be assessed for determining the score. IVC is assessed in the SAX view and a diameter of > 2 cm and collapsibility of < 50% is considered abnormal (Refer to Fig. 14). After obtaining the hepatic vein view, the probe is advanced and the thick, echo-dense portal vein can be seen in the liver parenchyma. At times the left renal vein may be visualized by rotating the probe to the left in the stomach at a multiplane angle of 90° [20].

There are several limitations to the above method. Mechanical ventilation, IVC stents, cannulas in the IVC, tricuspid regurgitation, and increased intra-abdominal and intrathoracic pressures make IVC collapsibility inaccurate. Intrarenal vein flow is difficult to visualize, and portal vein flow measurements may be questionable due to challenges with alignment. Relying mainly on IVC diameter and hepatic vein flow will simplify VExUS grading and provide a good picture of volume status [46, 47] (Refer to Fig. 15)

Heart

Cardiac causes of hypoxemia are most commonly due to shunts or thromboembolic phenomenon. The TEE calculation of Qp:Qs, or the ratio of pulmonary to systemic blood flow helps diagnose and quantify intracardiac or extracardiac shunts. By comparing the flow through the pulmonary circulation (Qp) to the flow through the systemic circulation (Qs), clinicians can determine if there is a shunt, its direction

Table 4 Hypoxemia Evaluation and Lung
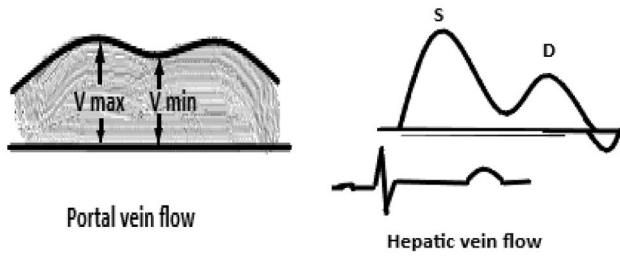
Level	Method	Image
Apical	- Find left subclavian artery at 0° - Rotate right and left at 90° Omni plane	
Mid	- Find left superior pulmonary vein at 0° - Rotate right and left at 90° Omni plane	
Basal	- Find IVC–RA Junction at 0° - Rotate right and left at 90° Omni plane	

Fig. 13 Left: Normal portal vein flow Right: Normal hepatic vein flow

Fig. 14 Doppler flow classification of Hepatic, Portal, and Renal Vein

a crucial step. The presence of right-sided valvular vegetations [49, 50] are a supportive finding for chronic pulmonary thromboembolism.

Recent Developments

TEE as an imaging modality has greatly advanced since its advent in 1976 [51]. Three-dimensional imaging has been around for more than a decade but faster image processing, improved frame rates, and automated analysis have

IVC > 2cm or <50% collapsibility

Hepatic Vein

Normal S>D
Mild S<D
Severe S wave reversal

Portal Vein

Normal <30% Pulsatility Index
Mild 30-40% Pulsatility Index
Severe >50% Pulsatility Index

Renal Vein

Normal continuous monophasic flow
Mild biphasic flow that is discontinuous
Severe discontinuous monophasic diastolic flow

(left-to-right or right-to-left), and the degree of shunting. Imaging of the interatrial septum, interventricular septum, pulmonary veins and coronary sinus can reveal shunts and congenital causes of hypoxia.

It is crucial to look for the presence of pulmonary embolism in the ascending aorta SAX view in hypoxic and hemodynamically unstable patients. It increases morbidity and mortality significantly [2••, 48]. Careful imaging of IVC, SVC, RA and RV for thrombus if PE is suspected is

decreased imaging time and greatly improved accuracy [52]. Smaller probes with 2D, 3D, 4D, color and Doppler capabilities are being launched. Efforts are being made to integrate artificial intelligence to automate functions, improve valve assessments, volume quantification and optimize structural heart evaluations [52, 53•, 54]. Automated volume measurements, speckle and strain tracking are some unique and exciting offerings that are anticipated to further enhance TEE's role in critical care [7, 53, 54].
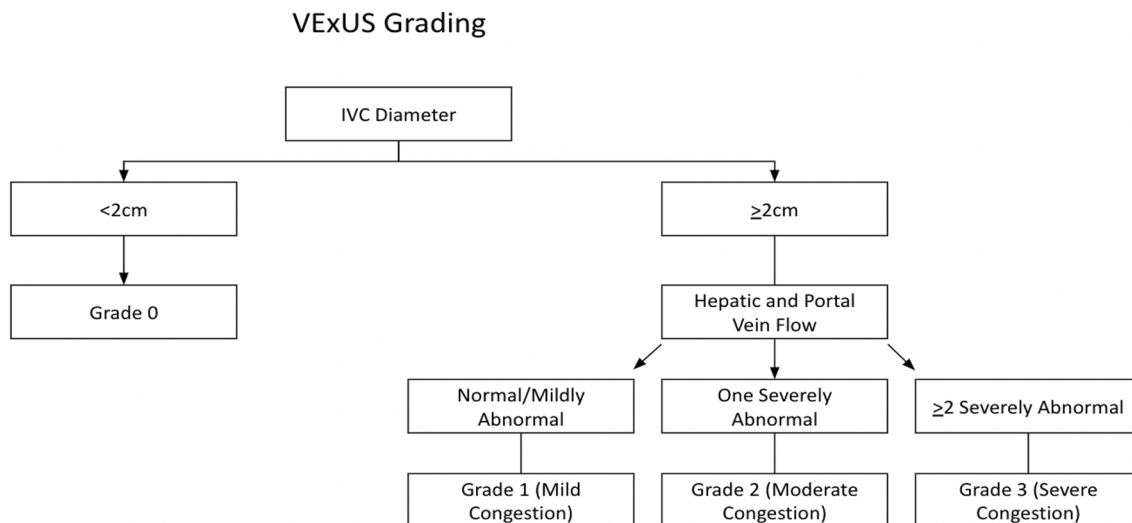
VExUS Grading

Fig. 15 VExUS Grading using Hepatic and Portal vein flow

Conclusion

TEE is a versatile diagnostic tool offering a comprehensive assessment of cardiac function in critically ill patients. While less common than TTE in the ICU, TEE is particularly valuable in scenarios such as mechanical ventilation, prone positioning, and when there are challenges with TTE windows due to body habitus or surgical dressings. Ongoing education and competence assessment for providers is crucial for optimal utilization and to prevent complications.

Author Contributions Dr. Bora and Dr. Pulijal contributed to reviewing literature available for the article and drafting it in detail. We also acquired images using transesophageal echocardiography for the manuscript and prepared tables.

Compliance with Ethical Standards

Conflicts of Interest Dr. Vaibhav Bora declares that he has no conflicts of interest. Dr. Sri Varsha Pulijal declares that she has no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors. All tables and figures are original.

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- Of importance
- • Of major importance

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