Expert Document

Indian Academy of Echocardiography Guidelines for Performance of Transesophageal Echocardiography in Adults

Nitin J. Burkule[1], Manish Bansal[2], Satish C. Govind[3], R. Alagesan[4], Chandrashekhar K. Ponde[5], Satish K. Parashar[6]

[1]Department of Cardiology, Jupiter Hospital, Thane, Maharashtra, India, [2]Department of Cardiology, Medanta - The Medicity, Gurugram, Haryana, India, [3]Department of Cardiology, Narayana Institute of Cardiac Sciences, Bengaluru, Karnataka, India, [4]Institute of Cardiology, Madras Medical College, Chennai, Tamil Nadu, India, [5]Department of Cardiology, Hinduja Hospital, Mumbai, Maharashtra, India, [6]Department of Cardiology, Metro Hospital, New Delhi, India

Reviewed by: Sameer Shrivastava, Department of Cardiology, Fortis Escorts Heart Institute and Research Center, New Delhi, India, K. Raghu, Department of Cardiology, Care Hospital, Hyderabad, Telangana, India, Ravi R. Kasliwal, Department of Cardiology, Medanta- The Medicity, Gurugram, Haryana, India

Abstract

Transesophageal echocardiography (TEE) has unique advantages over conventional transthoracic echocardiography (TTE). Compared with TTE, TEE generally provides excellent quality images, especially of the posteriorly situated cardiac structures, such as atria, pulmonary veins, mitral valve, and left atrial appendage. TEE also offers a useful alternative to TTE in patients in whom transthoracic acoustic windows are suboptimal. Furthermore, TEE is the most suited imaging modality for use in the operating rooms and cardiac catheterization labs for guiding cardiac surgical or interventional procedures. However, specific training and competence are required for performing TEE successfully, smoothly, safely and with minimum patient discomfort. This document describes the basic principles of TEE examination, including patient selection and preparation, periprocedural monitoring, and probe handling and maneuvers. Commonly recommended views and the techniques to obtain these views are described in detail, followed by evaluation of specific cardiac structures. Finally, the role of TEE in certain specific clinical settings, such as during advanced circulatory support, is also discussed.

Keywords: Atrial septal defect, interventional echocardiography, left atrial appendage, patent foramen ovale, perioperative echocardiography, simulation training

Table of Contents

Videos available on: www.jiaecho.org

Access this article online

Quick Response Code:

Website: www.jiaecho.org

DOI: 10.4103/jiae.jiae_39_21

Address for correspondence: Dr. Nitin J. Burkule, Department of Cardiology, Jupiter Hospital, E. Ex. Highway, Thane - 400 606, Maharashtra, India. E-mail: burkule.nitin@gmail.com

Submitted: 14-Jul-2021 **Accepted in Revised Form:** 15-Jul-2021 **Published:** 19-Aug-2021

How to cite this article: Burkule NJ, Bansal M, Govind SC, Alagesan R, Ponde CK, Parashar SK. Indian Academy of Echocardiography Guidelines for performance of transesophageal echocardiography in adults. J Indian Acad Echocardiogr Cardiovasc Imaging 2021;5:89-126.

Abbreviations

2D: Two-dimensional
3D: Three-dimensional
AF: Atrial fibrillation
AML: Anterior mitral leaflet
AS: Aortic stenosis
ASD: Atrial septal defect
ASO: Amplatzer® septal occluder
ATL: Anterior tricuspid leaflet
BP: Blood pressure
CDS: Clip delivery system
COCATS: Core Cardiology Training Statement
CPR: Cardiopulmonary resuscitation
CT: Computed tomography
CW: Continuous-wave
ECG: Electrocardiogram
HEPA: High-efficiency particulate absorbing
IABP: Intra-aortic balloon pump
ICU: Intensive care unit
IV: Intravenous
IVC: Inferior vena cava
LA: Left atrium
LAA: Left atrial appendage
LV: Left ventricle (or left ventricular)
LVOT: Left ventricular outflow tract
ME: Mid-esophageal
MR: Mitral regurgitation
MS: Mitral stenosis
MV: Mitral valve
MVA: Mitral valve area
PFO: Patent foramen ovale
PH: Pulmonary hypertension
PML: Posterior mitral leaflet
POCUS: Point-of-care ultrasound
PTL: Posterior tricuspid leaflet
PW: Pulsed-wave
RA: Right atrium
RF: Radiofrequency
RV: Right ventricle (or right ventricular)
SAX: Short-axis
SGC: Steerable guiding catheter
SVC: Superior vena cava
TAVI: Transcatheter aortic valve implantation
TEE: Transesophageal echocardiography
TEER: Trans-catheter edge-to-edge repair
TR: Tricuspid regurgitation
TTE: Transthoracic echocardiography
TV: Tricuspid valve
VAD: Ventricular assist device

Introduction

Transesophageal echocardiography (TEE) is an important cardiac imaging modality with unique advantages over conventional transthoracic echocardiography (TTE). Given the close proximity of esophagus to the heart with minimum intervening structures, TEE generally provides excellent quality images, especially of the structures situated posteriorly, such as atria, pulmonary veins, mitral valve (MV), and left atrial appendage (LAA). Accordingly, TEE is routinely utilized for better delineation of pathologies related to these structures. Additionally, TEE offers a useful alternative to TTE in patients in whom transthoracic acoustic windows are suboptimal, a scenario commonly encountered in the intensive care units (ICU). Finally, TEE is the most suited imaging modality for use in the operating rooms and cardiac catheterization labs for guiding cardiac surgical or interventional procedures.

Aim of the Document

TEE requires specific skillset for obtaining diagnostic quality images as the probe manipulation and echocardiographic-anatomic orientation are vastly different from TTE. Furthermore, TEE is a semi-invasive test and is associated with patient discomfort as well as a small risk of minor and major complications. For these reasons, dedicated training in TEE is required to gain competency in performing this test successfully, smoothly, safely and with minimum patient discomfort. This document describes the following aspects of performance of TEE-

- Basic principles,
- Patient selection and preparation,
- Periprocedural monitoring,
- Probe handling and maneuvers,
- Commonly recommended views and the techniques to obtain these views,
- Evaluation of certain specific cardiac structures/ pathologies,
- Role of TEE in certain specific clinical settings.

Technical and Cognitive Skills Requirement

Performance of adult TEE examination requires adequate training and competence.[1] Following are the necessary cognitive skills-

- Thorough knowledge and understanding of TTE,
- Understanding appropriate indications and absolute contraindications for TEE and the risks of the procedure,
- Knowledge of the procedure of conscious sedation and cardio-respiratory monitoring during the procedure.
- Thorough knowledge of all TEE views and their echocardiographic-anatomic correlation,
- Knowledge of various disease processes with resultant alterations in cardiac structure and function,
- Thorough understanding of cardiac hemodynamics,
- Competence in distinguishing adequate from inadequate TEE examination,
- Basic knowledge of other cardiac imaging modalities such as computed tomography (CT) and cardiac magnetic resonance imaging, which can complement the TEE examination, and
- Competence in preparing a detailed report of a TEE examination.

In addition to above, following are the mandatory technical skills-

- Competence in performing complete TTE,
- Dexterity to use all the controls of the TEE probe with one hand and simultaneously maneuvering the probe with the other hand, with good hand-eye coordination,
- Ability to use local anesthesia effectively in the oropharynx and judging its adequacy with gag reflex,
- Competence in using safe and effective conscious sedation,
- Ability to pass the TEE transducer safely into esophagus and stomach and adjusting various probe angulations to get best images and Doppler data,
- Ability to recognize the abnormalities in cardiac structure and function in multiple views,
- Ability to recognize various artifacts,
- Proficiency in performing qualitative and quantitative analysis of the acquired data in a manner that can help the clinician, and
- Ability to safely sterilize the TEE probe.

The 2015 Core Cardiology Training Statement (COCATS) 4 Task Force 5 recommends that minimum training for independent performance and interpretation of TEE should include performance of 25 esophageal intubations and 50 supervised complete multiplanar diagnostic studies.[2] This should be further supplemented by continued instruction under the supervision of an experienced operator for an additional 50 studies. The recommended duration of training is six months. The 2019 American College of Cardiology/American Heart Association/American Society of Echocardiography document mentions that more advanced (i.e., Level III) training in TEE requires the performance and interpretation of a minimum of 150 TEEs, which represents an additional 100 studies beyond Level II.[3]

Three-dimensional (3D) TEE requires additional skills and knowledge about 3D basics, image formation, image format, incremental information available and how this can be used in the diagnosis and management of various pathologies, including structural heart interventions.

Probe Hardware

A TEE probe is a modified flexible gastroscope with remotely controlled ultrasound transducer at the distal tip. Although the exact hardware design varies for different vendors, a typical TEE probe consists of the following parts[4] [Figure 1].

a. Distal tip (transducer lens): It has a round face-plate behind which reside the acoustic lens and an array of packed piezoelectric crystals [two-dimensional (2D) TEE- 128

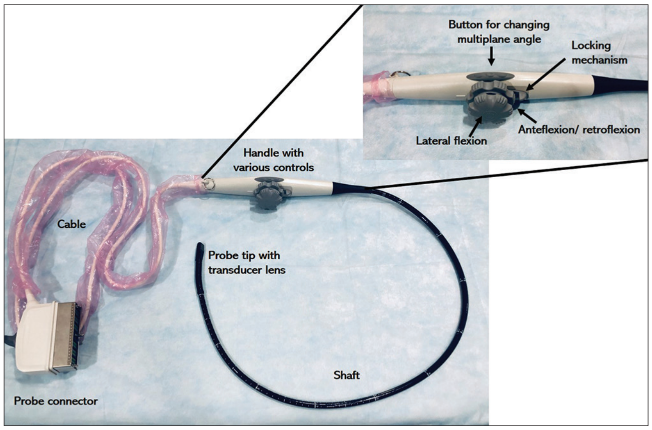

Figure 1: Different parts of a transesophageal echocardiography probe

crystals, 3D TEE- 2500 crystals], resting on the backing material. The piezoelectric crystals when stimulated by electric field emit ultrasonic waves and conversely, upon receiving returning echoes, they generate electrical signals. The frequency of the TEE transducer is between 3.5-7.5MHz for adult probes and 5-10MHz for pediatric probes. The distal tip portion of the probe can be remotely flexed in anteroposterior and side- by-side direction by two control knobs at the handle. Additionally, the phased array of the piezoelectric crystals can be electronically rotated from 0° to 180° to generate multi-angle imaging planes

b. Flexible shaft: It contains the cables carrying electrical impulses and mechanical commands, encased in a synthetic housing providing electrical and water insulation. Any damage to this insulation by bite marks or wear and tear should be inspected periodically. The adult TEE probe has a diameter of 5-6 mm at the shaft and 12 mm at the tip, while the pediatric TEE probe has a diameter of 5-6 mm at the shaft and 10 mm at the tip. These sizes can generally be easily accommodated in the esophagus of adult and pediatric patients, respectively. The probe has markings at 10 cm intervals from the tip, which indicate the depth of insertion. For storage, it is preferable to hang the probe by handle mount in an airy wooden cupboard, just like gastroscopes, rather than winding it up in a suitcase.

c. Handle (controls housing): This is the fusiform and bulky part of the TEE probe with one large wheel to control anteflexion and retroflexion of the tip and one small wheel to control side-by-side flexion. A locking mechanism is available at the inner end of the wheel to fix the position of the tip as desired. It is suggested to always keep the lock in neutral position while inserting, removing, or manipulating the probe in-vivo to avoid internal injury by the flexed probe. The handle also has two closely spaced buttons for 'forward' or 'backward' electronic rotation of the imaging plane from 0° to 180°. Some of the recent probes a have a third button in the middle which can be customized for image acquisition, orthogonal imaging or initiating color Doppler

d. Cable and the connector: They connect the TEE probe to the probe connector socket present on the echocardiography machine.

The absorption and scattering of ultrasound energy by the biological tissues causes thermal bioeffects raising the local temperature at the site of contact between the probe tip and the esophageal wall. The echocardiography machine monitors probe tip temperature and provides a warning when the temperature is elevated beyond safe limits. In such cases, it is advisable to press 'freeze' button to stop imaging for a short period of time to allow the tip to cool down. Ignoring and overriding this waring must be avoided to prevent thermal injury to the esophageal wall. Similarly, in the operating room, when TEE probe is left in-situ during the surgery and is not in use, the imaging should be 'frozen' to avoid esophageal burns. It is even better to switchover to TTE probe during such periods and keep it frozen.

Cleaning, Disinfection, and Maintenance of the Probe

The TEE probe, especially the 3D TEE probe, is a sophisticated, expensive equipment which is flexible, delicate, heat sensitive and reusable that needs extra care in maintenance. The procedure for cleaning, low-level disinfection, high-level disinfection, storage and carriage should be clearly established and followed by medical and paramedical personnel.[5-7] Patients' oral cavity, esophagus and stomach contain pathogens, which should not be transmitted to other patients and personnel. Moreover, injury to the mucous membrane may result in bleeding which may contaminate the probe with blood borne pathogens. The commonly involved pathogens include bacteria like helicobacter pylori, pseudomonas aeruginosa, salmonella group and mycobacterium group; and viruses like hepatitis B, hepatitis C, human immunodeficiency virus, and severe acute respiratory syndrome coronavirus 2.

The exact incidence of transmission of infection during the TEE procedure is not known, but with upper gastrointestinal endoscopy, it is 1 in 1.8 million procedures.[8] The hospital infection control team and biomedical engineers from the equipment company should be consulted in selecting the required substances for cleaning the probe and for high-level disinfection. Various leading vendors also provide probe disinfection recommendations on their websites.[9,10] The aim is to prevent cross infection of patients and medical workers.

Ten steps for cleaning, disinfection and storage of the probe

Following are the recommended steps for cleaning, disinfection and storage of a TEE probe[11]

- Step 1: After the probe is removed from the patient, it should immediately be wiped with lint free gauze. It is then rinsed with running water for 1 minute to remove the body fluids. Do not allow the body fluids to dry which happens when the probe is left unattended after a procedure

- Step 2: The probe is then immersed for 5 minutes in a tray containing a combination of enzymes (e.g., Cidezyme® Xtra from Johnson and Johnson) to completely remove any proteinaceous and lipid materials present. These solutions have cellulase, lipase, protease, amylase, and proprietary enzymes with advanced proteolytic action. Hence, overexposure may degrade the outer covering of the probe shaft. It is preferable that the person doing the sterilization should wear protective clothing in the form of a disposable cap, glove, plastic apron, eye protection and mask
- Step 3: The probe is then rinsed again with clean running water and wiped dry using lint free gauze. This is to remove the water which may dilute the concentration of the disinfectant and to also remove any debris
- Step 4: The connector can be plugged into an electrical leakage testing unit before high-level disinfection
- Step 5: The probe is left inside the high-level disinfectant solution of recommended concentration. Glutaraldehyde 2% solution, which is available as Cidex®, is the commonly used disinfectant solution. It kills all the bacteria, viruses and spores in 20 minutes. In United Kingdom, this substance is banned. Ortho-phthalaldehide 0.55% solution (HOSPAL-OPA®) is alternatively used, and the probe is kept immersed for 12 minutes. The minimum required concentration can be checked by using test strips. The solution is usually changed once in 14 days and earlier if it fails during the test
- Step 6: The disinfected probe should be rinsed with clean water thrice, for one minute duration each time, to remove any disinfectant
- Step 7: The probe is then wiped dry and kept inside a disposable sterile cover ready for use in the next patient
- Step 8: The probe is then stored in a cabinet hanging vertically down [Figure 2], the cabinet should be dry and in a high-efficiency particulate absorbing (HEPA) filter clean space
- Step 9: The probe must be carefully transported inside and outside the hospital by keeping it in a carrying case
- Step 10: The metallic part of the probe and connector's external surface may be sprayed and wiped clean with 70% isopropyl alcohol or using sanitary wipes soaked in alcohol. Care should be taken to ensure that no liquid enters any unsealed joints near the control knobs. Entry of liquids may produce corrosion and electrical damage.

Steps 4, 5, and 6 may be undertaken in a microprocessor controlled automated endoscope reprocessor system which checks the probe for electrical leakage, does high-level disinfection and rinses the probe with filtered water. This offers some advantages in terms of reducing manual labor and reduces the time to complete the process. It also reduces human error and human exposure to the disinfectant. A printout of the results of disinfection process can be obtained and stored for auditing.

The bite guard also should be cleaned and sterilized in the same manner as described for the probe.

Tips for proper handling

The TEE probe should be transported without re-contaminating it and without dropping or impacting the probe (scan head and connector) against any hard surface or sharp objects which could result in damage. The tip should not be moved manually, and it should be done only by rotating the control knobs. The flexible portion of the shaft should not be bent too much and the diameter of the circle should be more than 12 inches when kept inside the disinfectant tray. The probe should not be left inside the carrying case for more than 48 hours, as this will affect the flexibility. The tip of the probe which contains the crystals and lens should always be covered with a protective cap.

Patient Selection

Indications for performing transesophageal echocardiography

TEE has several advantages over TTE and other cardiovascular imaging modalities. Due to the close proximity of the TEE probe to heart from esophagus and upper gastric region, TEE has virtually no challenge of limited access window or poor acoustic window, encountered frequently during TTE.[12] Furthermore, TEE can utilize high frequency ultrasound beam (5-8 MHz) to generate high resolution images with high signal-to-noise ratio and with least reverberation or shadowing artefacts. Also, TEE can achieve 180° scanning via electronic plane rotation due to least acoustic impedance from soft tissue around the probe.

For these reasons, TEE invariably yields high diagnostic quality images of posterior cardiac structures such as left atrium (LA), right atrium (RA), opening of the pulmonary and systemic veins into atria, interatrial septum, atrial appendages, aortic root, descending thoracic aorta and aortic arch, and right pulmonary artery to specify. The greatest advantage of TEE is however, in the comprehensive and real-time evaluation of MV structure and function by 2D and 3D imaging modes, which is not possible by any other cardiac imaging modality.[13]

Being real time, portable and far from the operating field or vascular access sites, TEE is also the imaging modality of choice

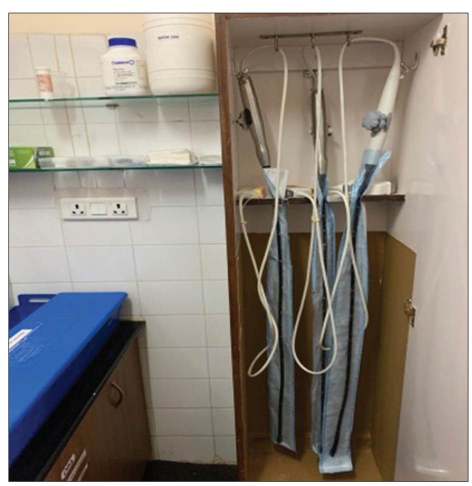

Figure 2: Probe storage cabinet

for cardiac surgery or catheter interventions. It can leverage the advantages of all the different cardiac ultrasound modalities like color Doppler, spectral Doppler, tissue Doppler imaging, speckle tracking, ultrasound contrast and 3D echocardiography.

Following are the common indications for performing TEE[14]

1. If TTE is non-diagnostic due to poor acoustic window despite the use of ultrasound contrast, or when more critical information is required about posterior cardiac structures
2. Infective endocarditis-
   a. In patients with clinical suspicion of infective endocarditis, especially when TTE is negative. TEE has higher resolution to diagnose smaller vegetations. There is generally a low threshold to perform TEE in cases of clinically suspected prosthetic valve/conduit or pacemaker endocarditis
   b. In acutely ill patients with infective endocarditis, there is a low threshold to perform TEE to pick up early para-valvular abscesses, valve perforations, prosthetic valve dehiscence or other structural damage caused by the infection
   c. Surveillance TEE is indicated in infective endocarditis if there is no response to treatment or deterioration in clinical condition.
3. To exclude LA/LAA clot in patients with atrial fibrillation (AF) who are scheduled to undergo electrical cardioversion or radiofrequency (RF) ablation
4. Valve lesions-
   a. In mitral or aortic valve regurgitation, to assess the mechanism of regurgitation and feasibility of repair
   b. In mitral stenosis (MS), to diagnose LAA clot before balloon mitral valvotomy or when the patient presents with a cardioembolic event
   c. In aortic stenosis (AS), TEE may be useful for diagnosis of subaortic membrane, direct planimetry of aortic valve area, accurate measurement of left ventricular (LV) outflow tract (LVOT) diameter or cross-sectional area, and the size of aortic sinuses or ascending aorta
   d. In patients with prosthetic valve dysfunction, especially in case of mitral prosthetic valve, TEE invariably provides incremental information over TTE and fluoroscopy by improved visualization of thrombus, pannus, paravalvular regurgitation.
5. In cryptogenic stroke, TEE is essential to exclude right-to-left shunt across patent foramen ovale (PFO) (aided by saline bubble contrast with Valsalva maneuver), to visualize mobile atheromas in the arch of aorta and to detect other unsuspected cardiac sources of embolism[15]
6. Congenital heart diseases-
   a. TEE is useful in adults with TTE evidence of unexplained RA and right ventricular (RV) dilatation with or without pulmonary hypertension (PH). In such cases, TEE helps to diagnose pre-tricuspid shunts such as sinus venosus atrial septal defect (ASD) and partial anomalous connection of pulmonary veins. In adult patients with TTE diagnosis of ostium secundum ASD, TEE is frequently performed for assessing suitability for device closure. Similarly, in case of suspected primary PH, TEE is frequently performed before planning cardiac catheterization
   b. TEE is often useful for evaluation of RV outflow tract/LVOT stenosis, sub-valvular and valvular pulmonary stenosis/ AS, and the function of conduits in adult patients with congenital heart disease.
7. In cases of cardiac masses, TEE is frequently performed if TTE is unable to delineate the attachment, infiltration, spatial extension, and hemodynamic impact of the mass
8. TEE is immensely useful in the cardiac catheterization lab for guiding various interventional procedures such as device closures (ASD, ventricular septal defect, ruptured sinus of Valsalva aneurysm, paravalvular regurgitation, etc.), percutaneous valve implantation or repair, interatrial septal puncture, RF ablation of pulmonary veins, LAA closure, and insertion of ventricular assist devices (VAD) and extracorporeal membrane oxygenation cannulas
9. Role in the operating room-
   a. TEE has an important role in the cardiac operating room, especially during the surgery for valvular or congenital heart diseases.[16-18] After induction, a quick TEE examination re-confirms the diagnostic findings and often provides additional information to guide the surgical planning. After release of the cross-clamp, once the ventricles start ejecting and the weaning from the cardiopulmonary bypass starts, a quick assessment of LV preload, ventricular recovery and intracardiac air bubbles can be performed with TEE. After achieving adequate systemic blood pressure (BP), adequacy of structural repair or functioning of the implanted valves can be thoroughly assessed. The crucial decision at this moment regarding the need for a second run of cardiopulmonary bypass for inadequate repair heavily depends on meticulously gathered semi-quantitative TEE data[16]
   b. Even during the non-cardiac surgeries, TEE may be required in case of unexplained hypotension, hypoxia, or hemodynamic instability. In such circumstances, TEE can provide a quick assessment of ventricular function, volume status and intracardiac hemodynamics.
10. In hemodynamically unstable, post myocardial infarction or post-operative patients in cardiac ICU, TEE is indicated when the cardiac cause of deterioration is suspected and TTE is either non-diagnostic or not feasible due to the presence of chest dressings and drainage tubes and/or unfavorable patient position because of mechanical ventilation. TEE is useful in recognizing new-onset or worsening LV systolic dysfunction, aortic dissection, LA thrombus, ruptured papillary muscle, cardiac-aortic source of embolism, intracardiac vegetation, acute native or prosthetic valve dysfunction, which are frequently missed during TTE in such patients[19,20]

11. In patients with severe chest pain with normal cardiac biomarkers and non-diagnostic electrocardiogram (ECG), and with suspected acute aortic syndrome, TEE may be considered if cardiac CT is not immediately available
12. TEE is more sensitive in detecting intrapulmonary shunt in patients with cirrhosis of liver. The detection rate for intrapulmonary shunt in patients with PaO2 <80 mmHg or dyspnea is 56% and 50%, respectively, with TEE and 33% and 25% with TTE.[21]

Appropriate use criteria

The clinical use of TEE as a first or supplemental test is deemed appropriate in the following clinical situations[22]

1. Non-diagnostic TTE
2. Surveillance of LA thrombus or valvular vegetation for resolution on optimal treatment, and for modifying or stopping therapy
3. For guiding transcatheter device therapy
4. Acute aortic syndrome
5. Evaluation for valve repair surgery
6. Diagnosis of infective endocarditis when pre-test probability is moderate to high
7. Evaluation of cryptogenic or suspected cardioembolic stroke
8. Patients with AF scheduled to undergo electrical cardioversion or RF ablation.

Conversely, the use of TEE as a first or supplemental test is deemed inappropriate in the following clinical situations[22]

1. After good quality TTE with diagnostic information optimal for therapeutic decision-making
2. Surveillance of LA clot or valvular vegetation on optimal treatment when no change in treatment is anticipated
3. Asymptomatic patient after pulmonary vein isolation by RF ablation
4. Diagnosis of infective endocarditis when pre-test probability is low
5. Evaluation of cardioembolic stroke with known source on TTE
6. AF patients on anticoagulation not considered for electrical cardioversion.

Contraindications

Definite contraindications for TEE are few and are clinically obvious-

1. Recent oropharyngeal or esophageal surgery
2. Obstructive pathology of pharynx or esophagus like neoplasm or stricture
3. Suspected esophageal perforation or traumatic injury
4. Diverticulum of esophagus
5. Active bleeding from esophageal ulcer or varices.

The relative contraindications are as follows-

1. Loose teeth or gum injury
2. Agitated and uncooperative or delirious patient
3. Inability to open mouth widely
4. History of radiation to head, neck, or mediastinum
5. History of Barrett's esophagus
6. Non-bleeding ulcers or grade 1 or 2 esophageal varices with no recent variceal bleeding- TEE can be performed safely, avoiding lower esophageal and transgastric views[23]
7. Hiatus hernia
8. History of odynophagia or dysphagia
9. Cervical spine arthritis or instability
10. Prolonged partial thromboplastin time or thrombocytopenia
11. Bleeding diatheses but no active bleeding
12. Obstructive sleep apnea/airway compromise during intravenous (IV) sedation.

Patient Set-up, Anesthesia, Intra-procedure Monitoring Considerations

Patient preparation

The patient scheduled for TEE should be instructed to come fasting for at least 4-6 hours. If the patient is on warfarin and the prothrombin time/international normalized ratio is in therapeutic range, there is no need to stop warfarin. The patient should bring all relevant medical records, including previous TTE report. A consent form is required to be signed before the procedure.

To reduce the patient's anxiety, the physician or the assistant should explain the TEE procedure in simple terms. A detailed history about potential contraindications to TEE should be obtained. History of allergies, current use of alcohol or drug addictions should be reviewed. Any removable dentures should be taken out, and the oral cavity and oropharynx examined for any pathology and to assess the Mallampatti score.[24]

The baseline saturation, heart rate and BP are measured and recorded. A cardiac monitor would be helpful. An IV line is preferred, especially if the need for IV sedation is anticipated. The IV line should be placed in the left arm if saline bubble contrast study is planned for PFO, considering that persistent left superior vena cava (SVC) has been reported in roughly 4% patients referred for cardiac evaluation.[25]

The patient lies down on the examination couch in left lateral or right lateral position to reduce the chances of aspiration during the procedure. It should be noted that the pulmonary venous (systolic flow) return from the corresponding dependent lung increases in the lateral position.[26] Disposable chest electrodes are applied and connected to the echocardiography machine's ECG cable. A finger probe pulse oximeter is also connected. For patients needing supplemental oxygen or IV sedation, a nasal cannula is set up and connected to the oxygen source. It is optional to place a non-invasive BP cuff for automatic periodic BP monitoring. The availability of a trained or knowledgeable assistant makes the procedure safer and more efficient.

Local anesthesia and sedation for out-patients

Pharyngeal anesthesia

Pharyngeal anesthesia is used to suppress the gag reflex during TEE and the pain associated with esophageal intubation.

Aerosol spray or viscous gargles of benzocaine or lidocaine are commonly used to anaesthetize the pharynx. The patient is asked to open the mouth wide, saying "ahh", and the anesthetic agent is sprayed aiming at the soft palate and posterior pharyngeal wall. About 3-4 puffs of lidocaine local anesthetic spray should result in numbness and heaviness in the pharyngeal region. The spray may get inadvertently inhaled leading to stressful coughing or laryngeal anesthesia and increased risk for aspiration. This should be avoided but if it happens, delaying the procedure for some time may be needed. The anesthetic effect lasts for 30 minutes to 1 hour.[27] Excess spraying of lidocaine may cause toxicity in a very small percentage of patients. There are reports of benzocaine induced methemoglobinemia and therefore, benzocaine should be avoided in patients with a history of methemoglobinemia or known glucose-6-phosphate dehydrogenase deficiency.

Intravenous sedation

IV sedation is uncommonly required for TEE, either in the young, uncooperative patients or if the patient is agitated. Pre-sedation assessment of Mallampati score is performed by the anesthetist for judging the difficulty in intubation if required in case of emergency. The modified Mallampati classification is a simple scoring system that relates the amount of mouth opening to the size of the tongue and provides an estimate of space available for oral intubation by direct laryngoscopy.[24,28] According to this system, class I is assigned when the soft palate, uvula, and pillars are visible; class II when the soft palate and the uvula are visible; class III when only the soft palate and base of the uvula are visible; and class IV when only the hard palate is visible. Most patients will need either minimal sedation (anxiolysis, normal response to verbal commands) or moderate sedation (conscious sedation, purposeful response to verbal commands or tactile stimulation) which does not require maintenance of patent airway or ventilation or does not cause cardiovascular depression.[29] However, oxygen supply, oral suction, an emergency crash cart, oral airways, and Ambu bag must be available in the echocardiography lab. Nasal oxygen supplementation maybe prophylactically needed in case of mild desaturation during TEE.

Sedation for TEE is achieved with IV benzodiazepines (preferably midazolam), alone or in combination with opiates (Fentanyl), as is done during gastrointestinal endoscopic procedures.[30] Midazolam has good sedative, amnestic, anxiolytic but non-analgesic properties and its effect is easily reversed with flumazenil. Midazolam is administered as IV bolus of 0.02 to 0.03 mg/kg (1 to 2 mg) over 2-3 minutes and its effect starts within 1-2 minutes and may last up to 15-80 minutes. Fentanyl has good sedative and analgesic but non-amnestic properties with rapid onset of action and clearance and is reversed with naloxone. Fentanyl is administered as IV bolus of 0.5 to 1 mcg/kg over 3-4 minutes and its effect starts within 2-3 minutes and may last up to 30-60 minutes.[29] The patients receiving IV sedatives require an extended monitoring after the procedure.

Monitoring

Since most patients undergoing TEE have significant cardiovascular disease, their oxygen saturation and hemodynamics should be closely monitoring during the TEE examination.

- Non-sedated and lightly sedated patients will not be able to communicate verbally during TEE examination due to esophageal intubation. Therefore, the patients should be instructed in advance to use hand gestures to communicate the level of discomfort (tolerable or intolerable)
- The operator and the assistant should remain vigilant about obvious warning signs such as facial expression of discomfort, cyanosis of lips and fingers, cold clammy extremities, fast and thready pulse or changes in breathing rate and pattern
- The pulse oximeter should be closely watched for any desaturation. Supplemental oxygen should immediately be provided through nasal cannula in case of fall in the saturation or hypoventilation in a deeply sedated patient. The test should be terminated if the saturation does not improve or worsens
- The heart rate and rhythm are automatically monitored by the echocardiography machine (provided ECG cable is connected) and are displayed on the monitor. One should watch for significant sinus tachycardia, bradycardia or arrhythmias which may result in hemodynamic instability
- For ICU patients or those receiving IV sedation, non-invasive BP monitoring with cuff inflation time set at every 5 minutes at least is mandatory. Those on naso-gastric tube should have it aspirated and preferably, removed before the TEE probe is inserted
- Frequent suctioning of the oropharyngeal secretions should be performed if TEE is being performed under IV sedation.

Postprocedure instructions

Procedure performed under local pharyngeal anesthesia

After removal of the TEE probe and the bite guard, the probe should be checked for any blood streaks. The patient should be asked to expectorate the throat secretions in the kidney tray and any fresh blood streaks suggestive of oropharyngeal or esophageal mucosal injury should be watched for. The patient should rinse the mouth and gargle the throat with lukewarm water at the wash basin inside the echocardiography room. The patient should be instructed to take fluids (but avoid cold or hot beverages) orally after at least half an hour and soft food after one hour. The patient should also be informed that the dysphagia and sore throat feeling may persist for 12-24 hours and should not cause worry. However, if there is persistent dysphagia for longer duration or hemoptysis, hematemesis, breathing difficulty or persistent cough during the first 24 hours, this should be immediately reported to the echocardiography lab.

Procedure performed with intravenous sedation

A through suction of throat secretions should be performed through the bite guard. Oxygen saturation on pulse oximeter should be checked, and if satisfactory, the bite guard can be removed. The anesthesiologist should examine the patient and decide whether the sedation effect has completely reversed and if it is safe to allow the patient to get off the bed and do throat gargles. The IV line should be removed after half an hour. The patient should be instructed as above but disallowed to self-drive home.

Complications

The complications of TEE examination in the hands of trained physicians are rare, if the test is performed diligently and patiently. A single-center study of 10,000 consecutive patients undergoing TEE demonstrated a very low risk of esophagogastric trauma (hypopharyngeal perforation 0.01%, cervical esophageal perforation 0.02%, and gastric perforation 0%), when the test was performed by an experienced operator.[31] The very low risk of complications was also confirmed in a multicenter study from 15 European centers with 10,419 TEE examinations, carried out by 54 physicians.[32] Only one mortality (mortality rate, 0.0098%) was reported, which occurred due to esophageal bleeding from a malignant lung tumor with esophageal infiltration. In only 90 (0.88%) of 10,218 TEE studies, the examination had to be interrupted because of the patient's intolerance of the TEE probe (65 cases); or pulmonary (8 cases), cardiac (8 cases), or bleeding complications (2 cases); or for other reasons (7 cases). TEE has also been shown to be safe as a bedside procedure even in critically ill patients in the ICU.[19] Some illnesses may affect esophageal tissue, such as previous thoracic radiation, achalasia cardia and systemic illnesses like scleroderma with esophageal involvement. In such cases, there is an increased risk for perforation during TEE, which should be kept in consideration.

The major and minor side effects of TEE are summarized below;[33] these should be closely watched for once the test is over.

Major complications:

1. Lung aspiration
2. Tooth (native or implanted) dislocation and displacement into airway
3. Pharyngeal hematoma causing upper airway compromise[34]
4. Laryngeal injury due to probe entering the trachea
5. Esophageal perforation or Mallory-Weiss tear
6. Mediastinitis due to unsuspected perforation at cricopharyngeal junction or in the esophagus
7. Bleeding from upper gastroesophageal ulcers or varices
8. Methemoglobinemia- The incidence of methemoglobinemia due to the local anesthetic spray is low (1 case per 1499) and has a good outcome if promptly recognized (cyanosis, fall in saturation with normal PaO2) and treated with IV methylene blue (1% solution, 1 to 2 mg/kg IV slowly over 5 min). Clinical factors associated with the development of methemoglobinemia are sepsis, anemia, and hospitalization.[35]

Minor complications:

1. Mucosal laceration with streaky bleeding while coughing or spitting
2. Dysphagia, odynophagia
3. Sore throat
4. Vomiting
5. Bronchospasm, laryngospasm
6. Transient ventricular arrhythmia, AF
7. Heart failure
8. Dislodgement of endotracheal tube in patients on mechanical ventilation
9. Dental injury.

There is virtually no risk of transient bacteremia from pathogenic oral flora after non-traumatic TEE.[36] Hence, infective endocarditis prophylaxis is not indicated before TEE.[37]

When used for guiding the interventional procedures, the incidence of TEE-related complications is less during transcatheter aortic valve replacement (overall 0.9%, major 0.6%) compared to MitraClip implantation or para-valvar leak closure (overall 6.1%, major 2.8%). Procedural time requiring TEE-manipulation is an independent predictor of major complications. The patient related factors associated with increased risk are lower body weight, history of gastrointestinal bleeding and the use of chronic steroids/immunosuppressive medications.[38]

Technique of Probe Insertion

To be able to insert the TEE probe smoothly and safely into the patient's esophagus, the operator must be familiar with the basic anatomy of the oropharynx, esophagus, and stomach. Beyond the base of the tongue and the soft palatal arch, the oropharyngeal cavity makes a 90° downward turn into thyropharyngeal and cricopharyngeal cavity. In this portion, the epiglottis and the larynx are situated anteriorly, whereas the cricopharyngeal muscle (upper esophageal sphincter) is situated posterior to the vocal cords. There are 2 different techniques for introducing the TEE probe blindly. The probe should never be advanced with excessive force. The operator should withdraw the probe if resistance is felt and reinsert it with another attempt.

In the first technique, the patient is asked to hold the bite guard in between the teeth. The operator holds the handle of the TEE probe in the left hand with the knobs facing the patient and holds the distal end of the lubricated TEE shaft in the right hand. The patient is asked to flex the head forward. With the right hand, the probe is glided through the bite guard over the tongue till it reaches the soft palate of the pharynx, which the operator can easily make out as it usually induces a gag (in well-anesthetized patients, the experienced operators can judge it by the tactile feeling). During this process, care should be taken to keep the probe exactly in the centre of the oral cavity to avoid deflecting it into the recesses of the pharyngeal cavity. Subsequently, the probe is anteflexed by operating the flexion wheel at the handle with left hand and is advanced slightly. The patient is asked to make a swallowing attempt to open the cricopharyngeal sphincter, which produces a tug on the TEE probe. At that moment, the probe tip should be brought back to neutral position (i.e. remove anteflexion) and gently advanced into the esophagus. Once the probe tip enters the esophagus, further advancing the probe to lower esophagus is usually easy and occurs without any resistance.

In the second technique, the bite guard is slid up the lubricated TEE probe shaft. The patient is asked to open the mouth and flex the neck. The physician puts 2 fingers (middle and index) of left hand over the patient's tongue and glides to reach the posterior wall of the anesthetized pharyngeal cavity and then bends them down by 90°. With the right hand holding the distal end of the TEE probe, the physician glides the probe into the patient's mouth till the tip reaches and is caught between the distal end of 2 fingers in the pharyngeal cavity. This ensures the probe remains in the centre of the oropharynx and the two fingers catching the probe tip can guide it further towards the cricopharyngeal sphincter. The patient is then asked to make a swallowing attempt to open the cricopharyngeal sphincter and with gentle firmness the probe is pushed forward in the upper esophagus. Once the physician removes the fingers, the bite guard is positioned between the patient's teeth.

Esophageal intubation of TEE probe requires a different technique for ICU patients on mechanical ventilation through endotracheal tube. It is a recommended practice to remove the nasogastric tube, increase the depth of sedation and administer skeletal muscle relaxing agent. The patient's neck is extended, and the TEE probe introduced under direct vision using a laryngoscope. Rarely, deflation of the endotracheal cuff may be required for easy passage of the TEE probe through the cricopharyngeal region.[39] Support of the anesthesiologist or the critical care specialist will facilitate the procedure.

In the aforementioned European multi-centre survey of 10,419 TEE examinations, insertion of the TEE probe was unsuccessful in 201 cases (1.9%), either because of the lack of patient cooperation and/or operator inexperience (98.5%) or because of anatomical reasons (1.5%).[32]

Technical Aspects of Probe Manipulation and Image Display

The basic principles of the imaging plane orientation and its display on the echocardiography monitor are described below-

Horizontal planes: The horizontally oriented imaging planes are displayed on the monitor in such a way that the left-sided and right-sided cardiac structures are shown on the right-hand and left-hand side of the imaging display, respectively [Figure 3].

Vertical planes: The vertically oriented imaging planes are displayed on the monitor in such a way that the cranial and caudal structures are shown on the right-hand and left-hand side of the imaging display, respectively [Figure 3].

The TEE probe can be manipulated in the following different ways during the examination-

A. Advancing and withdrawing the probe ('in' and 'out' motion)

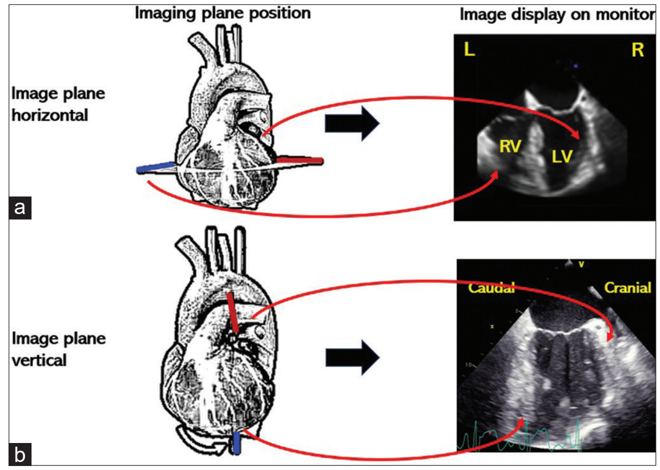

Figure 3: Orientation of cardiac structures in relation to image display on the monitor. (a) Imaging plane horizontal, (b) Imaging plane vertical

The TEE probe can be gently 'advanced' or 'pushed in' or can be gradually 'withdrawn' or 'pulled out'. If the imaging plane is in horizontal orientation, advancing or withdrawing the probe will transect the heart at different levels in craniocaudal direction [Figure 4]. Conversely, with vertically oriented imaging planes, this movement will result in greater visualization of more caudal or cranial structures [Figure 4]. If a more cranial structure (displayed towards the right margin of the image sector) needs to be visualized, then the probe should be gently withdrawn. In contrast, if the structures at the left margin of the image sector (i.e., more caudal structures) need to be evaluated, then the probe should be gently advanced

B. Clockwise and anticlockwise torque

The TEE probe can be gently and gradually rotated (torqued) either clockwise or anticlockwise (assuming the patient's face to represent the clock face). Small degrees of torque adjustment can be done with the hand holding the shaft of the probe. However, large angle of torquing is achieved more easily by rotating the handle of the TEE probe

The clockwise torque of the TEE probe turns the imaging plane towards right-sided cardiac structures, while the anticlockwise torque turns the imaging plane towards the left-sided structures. If the imaging plane is oriented vertically, then torquing the probe will move the imaging plane sideways, transecting the heart vertically at different positions [Figure 5]. However, if the imaging plane is horizontal, then anticlockwise torque of the probe brings the left-sided structures (i.e., those displayed towards the right margin of the image sector) towards the center of the display [Figure 5]. Conversely, a clockwise torque results in the right-sided cardiac structures (those displayed towards the left margin of the image sector) coming towards the center of the image display

C. Electronic rotation of the imaging plane

The TEE imaging plane can be electronically rotated, using the buttons on the probe handle (and in some machines, using the controls on the monitor), around an imaginary

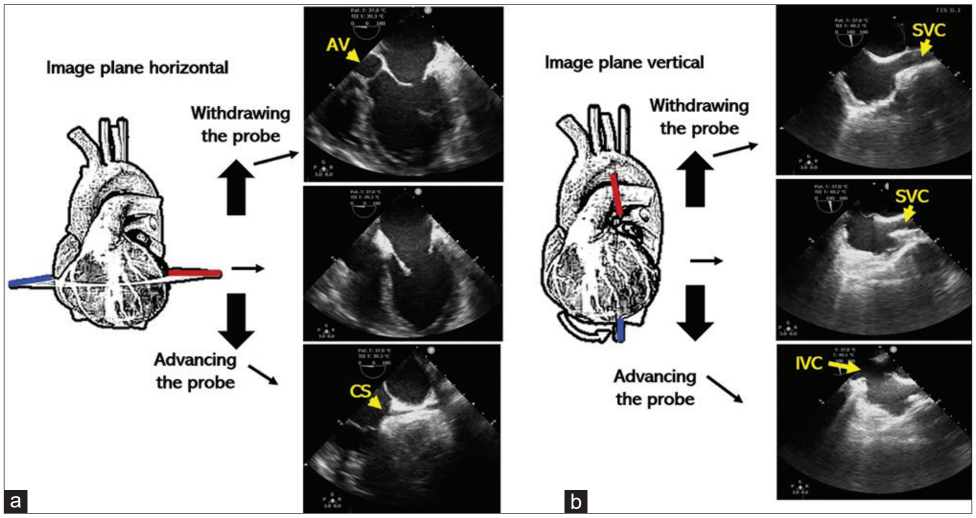

Figure 4: The effect of advancing or withdrawing the probe on the image display. (a) Horizonal imaging plane, (b) vertical imaging plane. AV: Aortic valve, CS: Coronary sinus, IVC: Inferior vena cava, SVC: Superior vena cava

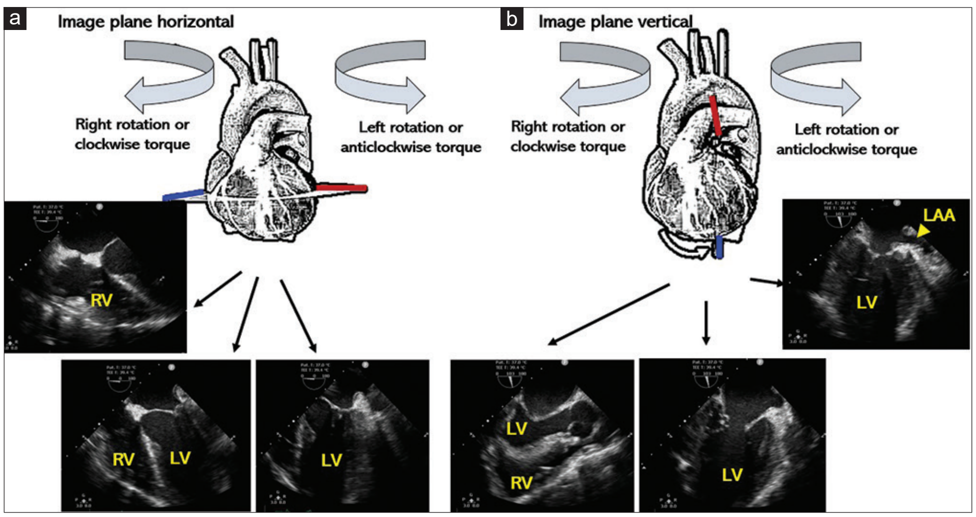

Figure 5: The effect of clockwise and anticlockwise rotation or torque of the probe on the image display. (a) Horizonal imaging plane, (b) Vertical imaging plane. LAA: Left atrial appendage, LV: Left ventricle, RV: Right ventricle

anteroposterior axis (with respect to the patient's chest). The plane rotates by each degree unit, in anti-clockwise direction (when viewed from the front of the chest), starting from 0° (horizontal or axial plane) all the way through 30°-60º [short-axis (SAX) plane], 90º (vertical or sagittal plane), 120°-135º (long-axis plane) to 180º (horizontal, mirror image) [Figure 6]. The rotation angle and location of the plane are shown on the monitor in the form of a dial displayed at the left or right upper corner of the image display

D. Flexion of the distal tip

Two separate wheel-like knobs are situated on the control handle using which the distal end of the TEE probe can be flexed antero-posteriorly (bigger wheel) or rightward or leftward (smaller wheel) [Figure 7]. The operator should be aware that excessive movements can cause discomfort to the patients

Anteflexion: Anterior flexion of the TEE probe bends the tip forwards, tilting the transducer lens cranially. If there are air bubbles trapped in front of the transducer lens, the gentle anteflexion helps in achieving good contact between transducer lens and anterior esophageal wall, thereby improving the image quality. For transgastric views, anteflexion is a rule, to achieve good contact between the transducer lens and the roof of the fundus to get adequate trans-diaphragmatic views. The horizontal imaging plane gets tilted cranially by anteflexion. This maneuver is particularly useful for obtaining outflow tract view, from transgastric SAX views. This outflow tract view allows parallel alignment of the Doppler beam with the blood flow and is ideal for measuring gradients

Retroflexion: Retroflexion of the TEE probe bends the tip backwards and tilts the transducer lens caudally. The horizontal imaging plane gets tilted caudally by retroflexion. This maneuver is particularly useful for imaging LV apex in the mid-esophageal (ME) 4-chamber view. In the lower esophageal view, the inferior vena cava (IVC) margin of ASD

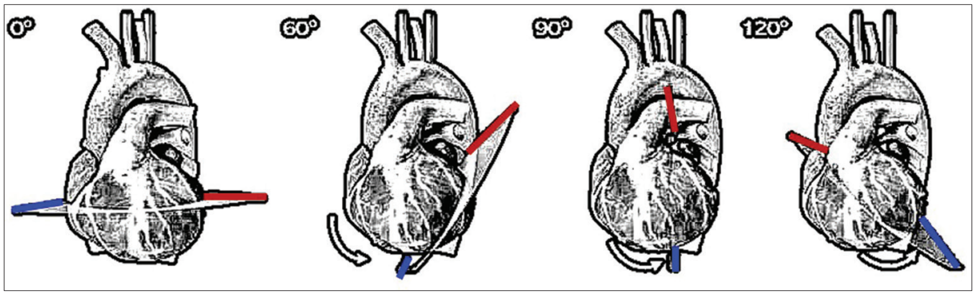

Figure 6: Orientation of the imaging plane at different multi-plane angles

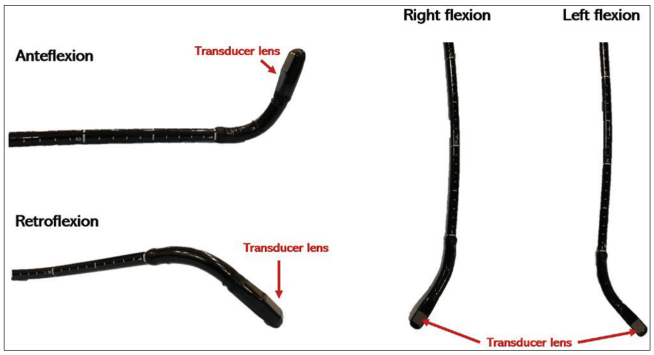

Figure 7: Anteflexion, retroflexion and sideways flexion of the probe

invariably falls in the apical clutter of the image sector. The retroflexion maneuver is useful to move gastroesophageal junction away from the base of the heart, thereby moving the IVC margin of the ASD out of the apical clutter

Side-by-side flexion: This maneuver used to be helpful in the era of monoplane and biplane TEE to get intermediate angulations from horizontal or vertical imaging planes. Currently, with the availability of multiplane TEE, use of sideways flexion is limited but may sometimes be necessary during transgastric imaging, especially when right or left side structures are being imaged.

Imaging Windows

Most of the TEE examination is performed from the following four imaging windows [Figure 8]

A. ME window: The ME view is at the level of cardiac chambers. It is the most utilized view with maximum information. This view is useful for detailed evaluation of the following structures- LA cavity, LAA, interatrial septum, all the four pulmonary veins, multiplanar imaging of MV apparatus, multiplanar imaging of aortic valve and aortic root, LV in all the three long-axis views, RV inflow and outflow tract, RA cavity, in-flow portions of SVC and IVC, tricuspid valve (TV), ascending aorta up to the level of posterior crossing of right pulmonary artery

B. Lower esophageal window: The lower esophageal view is at the level of gastroesophageal junction. This view is useful for following structures- additional evaluation of the TV (especially for acquisition of 3D data set of the TV), evaluation of coronary sinus, visualization of upper hepatic portion of IVC and hepatic vein tributary, IVC margin of the ASD, Eustachian valve, distal part of descending thoracic aorta, and the evaluation of pleural spaces for any effusion

C. Transgastric window: The transgastric views are acquired by gradually advancing the probe from gastroesophageal junction to the distal part of the fundus and intermittently ante-flexing the tip at different levels (care should be taken to avoid advancing or withdrawing the probe with its tip anteflexed to avoid mucosal injury). This window provides three SAX images of the LV from base to apex. These SAX images are helpful in wall motion analysis of all the 16 segments of the LV. The basal SAX view also shows *en face* view of the MV orifice. Anteflexion from apical position allows visualization of LVOT and measurement of LV outflow velocity and gradient. The long-axis views from transgastric window are useful for assessing LV inflow and outflow tract. The long-axis views are also useful for evaluation of RV inflow and outflow tracts

D. Upper esophageal window: The upper esophageal view is useful for detailed evaluation of following structures- main pulmonary artery, right pulmonary artery, SVC, right superior pulmonary vein, descending thoracic aorta, entire arch of aorta and origins of the arch branches.

The approximate distance of TEE probe tip from the incisors for different TEE windows is as follows-

- Upper esophageal window- 20 to 22 cm
- ME window- 28 to 30 cm
- Lower esophageal (gastroesophageal junction) window- 38 to 40 cm
- Deep transgastric (fundus) window- 42 to 45 cm.

General Principles of Imaging

Based on the clinical query and the information derived from TTE, the operator should develop an idea about the additional information sought or likely to be obtained from the planned TEE study. This helps in tailoring the examination for the specific clinical requirements of the patient to ensure maximum yield from the study. It also helps in salvaging the study in case a full comprehensive TEE imaging is not feasible for some reason. The sequence of imaging should be planned beforehand, based on the following principles-

- The study goal should be to increase the diagnostic yield in a time-efficient manner, with least discomfort and risk to the patient

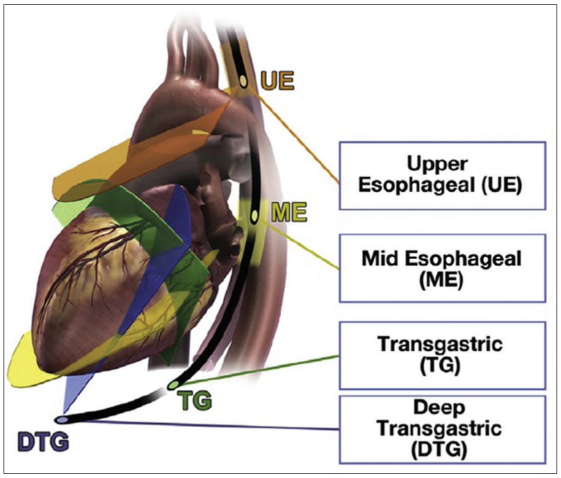

Figure 8: Standard imaging windows. Reproduced with permission from: Hahn RT, Abraham T, Adams MS, Bruce CJ, Glas KE, Lang RM, *et al*. Guidelines for performing a comprehensive transesophageal echocardiographic examination: recommendations from the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. J Am Soc Echocardiogr 2013;26:921-64

- Minimum manipulation of TEE probe by sequential selection of TEE views and TEE windows. The TEE probe 'in and out' or 'torquing' movements should be done gently and in gradual increments
- Visualize the expected pathological structure first and perform less important imaging later. This can salvage the study in case of premature termination of the test due to patient discomfort or instability
- Focus on one structure of interest at a time to avoid missing inconspicuous pathologies
- The transgastric views need extreme anteflexion and are prone to cause discomfort to the conscious patients. These views should be obtained in conscious patients only if additional information, not available on TTE or from esophageal TEE windows, is required
- The Valsalva maneuver, used for detecting right-to-left shunt across PFO using saline bubble contrast, requires patient's effort and cooperation. It should be performed as the penultimate step
- High esophageal arch imaging should be performed at the last as it causes patient discomfort and often leads to termination of the test.

A comprehensive TEE imaging of any cardiac structure of interest should include the following[15]

- Positioning the structure of interest in the centre of the imaging sector,
- Careful setting of probe frequency, focus position, gain and compression,
- A thorough multiplanar electronic sweep of imaging plane from 0°-120° at gradual (5°-10°) increment to evaluate the pathology found,
- To image the structure thoroughly, perform a gentle "clockwise-anticlockwise torque" and a gentle "inward-outward push-pull" of TEE probe at every imaging plane (at approximately 0°, 30°, 60°, 90°, and 120°),
- Color flow mapping and pulsed-wave (PW) or continuous-wave (CW) Doppler interrogation at appropriate locations, and
- Use of tissue Doppler imaging and 3D echocardiography whenever required.

General Workflow of Comprehensive Imaging and Main Views

This section describes in detail the technique of acquisition of all the important TEE views with their advantages in different clinical situations. Each described view is represented in an accompanying anatomical figure and illustrated TEE image. As described earlier in general principles of TEE imaging, one should formulate the strategy to choose appropriate views as per the clinical requirement. In each patient, these views will require further optimization, which can be achieved by constant manipulation of the probe and the imaging plane using the controls described above. These manipulations should be gentle and in small increments to minimize discomfort to the patient and to avoid causing sudden shift in the imaging plane.

The main TEE views are summarized in Table 1.[1] The usual transducer location from incisor level as well as various maneuvers and probe manipulations required to obtain each view are also described. However, final adjustments of the transducer angle and probe position in each view will have to be guided by the adequacy of the visualization of the desired anatomic structure(s).

Principles of Three-dimensional Data Set Acquisition

The 3D dataset is always acquired in zoomed and multi-beat format to improve spatial resolution and to maintain temporal resolution (except during real time guidance for transcatheter procedures). One should ensure that the entire 3D extent of the structure is captured inside the 3D pyramidal dataset. It is imperative to have anatomical landmarks included in the acquired 3D dataset to permit spatial orientation and to allow displaying the structures in the guidelines-directed manner.[40] Following are the general recommendations for 3D dataset acquisition during TEE-

1. While planning the zoomed capture of a structure, select the best TEE imaging plane showing the structure, pathological highlight, and an adjacent important anatomical landmark. For example, for MV 3D capture, 120º is a good plane to begin with, with the addition of aortic root as an anatomical landmark. Thereafter, adjust the zoom window in multiplane mode or simultaneous biplane to ensure that the entire structure is included in the 3D dataset. A real-time multi-slice mode at this juncture to ensure that full circumferential extent is included may help

Table 1: Recommended transesophageal echocardiographic views, cardiac structures visualized and the techniques for obtaining those views

View	Maneuver	Visualized structures	Doppler	Clinical utility	Figure/Video number
ME 0° five-chamber	TEE probe advanced to approximately 28-30 cm from incisor level	Aortic valve, LVOT, LA, LV, IVS, LV anterolateral wall, RV, AML (A2-A1), PML (P1)	Color flow mapping for MV and LVOT	To evaluate MR and AR jets, mitral vegetations, aorto-mitral intervalvular fibrosa abscess, good view for diagnosing sigmoid septum and for evaluating basal septum in patients with hypertrophic cardiomyopathy	[Figure 9 and Video 1]
ME 0° four-chamber	From view 1, gradually advance the probe further to get the four-chamber view	LA, RA, LV, RV, AML (A3-A2), PML (P2), TV, IAS, IVS, inferior septum, LV anterolateral wall, RV free wall	Color flow mapping of MV and TV, PW/CW Doppler for mitral flow, MR and TR, mitral annular TDI	To evaluate MV pathologies and MR, TR, mitral inflow and annular velocities, PASP by TR jet, LV RWMA, RV TAPSE, pericardial effusion, tamponade, MV and TV vegetations, ASD device relation with atrioventricular valves	[Figure 10 and Video 2]
ME LV bi-commissural view	From view 2, keep LV in the centre, rotate the plane electronically to 45°-75° approximately, slight withdrawal may be needed	LA, LV, MV (P3-A2-P1), both commissures and corresponding chordae and papillary muscles, coronary sinus	Color flow mapping of MV	To evaluate commissural MR and other pathologies	[Figure 11 and Video 3]
ME LV two-chamber	From view 3, rotate the plane electronically to 70°-90° approximately	LA, LV, inferior and anterior walls of LV, LAA, coronary sinus, MV (P2/P3 junction-A2, A1)	Color flow mapping of MV	To evaluate MR jets, LV RWMA, LAA clot	[Figure 12 and Video 4]
ME LV LAX (three-chamber)	From view 4, rotate the plane electronically to 120°-135° approximately	LA, LV, MV (P2-A2), LVOT, AV, aortic sinuses, proximal ascending aorta, RVOT SAX, anterior septum, inferolateral wall	Color flow mapping of MV, LVOT, AV	To evaluate MV and AV pathologies (especially MR, AR jets), systolic anterior motion of MV, dynamic LVOT obstruction, LV RWMA	[Figure 13 and Video 5]
ME LAX Zoom LV inflow-Outflow	In view 5, slightly withdraw the probe and zoom the area encompassing LV inflow-outflow	LA, LV inflow, MV (P2-A2), LVOT, AV, aortic sinuses, proximal ascending aorta	Color flow mapping of MV, LVOT, AV	To evaluate mechanism of AR, MR, vegetation on AV, MV, aorto-mitral intervalvular fibrosa abscess	[Figure 14]
ME ascending aorta LAX with RPA SAX	From view 5, gradually withdraw the probe and rotate the plane electronically to 100°-110° approximately	Ascending aorta LAX and RPA SAX	Color flow mapping of ascending aorta	To evaluate ascending aorta size, dissection flap, ascending aorta atheroma	[Figure 15 and Video 6]
UE 0° MPA and RPA LAX	From view 1 (0° plane), gradually withdraw the probe until RPA LAX is seen	MPA LAX, ascending aorta SAX, RPA LAX, SVC SAX	Color flow mapping of MPA, ascending aorta	To evaluate pulmonary emboli in MPA, RPA; ascending aorta atheroma	[Figure 16 and Video 7]
UE 0° RSPV LAX, SVC SAX	From view 8, gently advance the probe until RSPV is seen entering LA	RSPV entering LA behind SVC (seen in SAX), ascending aorta SAX	Color flow mapping of RSPV	To evaluate anomalous drainage of RSPV to SVC	[Figure 17 and Video 8]
UE 30°-60° RSPV-RIPV	From view 9, rotate the plane electronically to 30°-60° and torque the probe clockwise (rightwards)	RSPV and RIPV entering LA with carina between the two ostia	Color flow mapping of RSPV-RIPV	To evaluate anomalous drainage of RIPV and pulmonary venous stenosis	[Figure 18 and Video 9]

Contd...

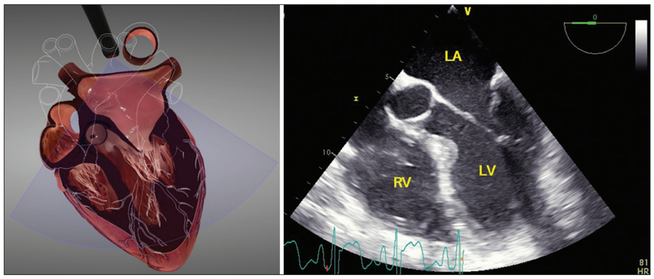

Figure 9: Mid-esophageal 0° five-chamber view. LA: Left atrium, LV: Left ventricle, RV: Right ventricle

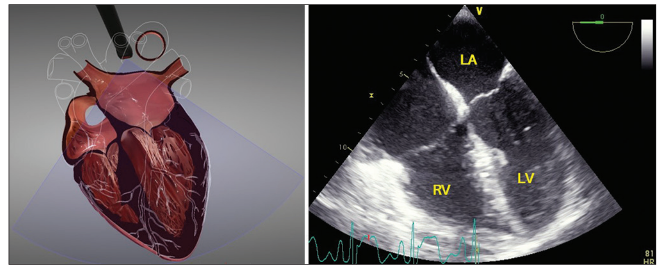

Figure 10: Mid-esophageal 0° four-chamber view. LA: Left atrium, LV: Left ventricle, RV: Right ventricle

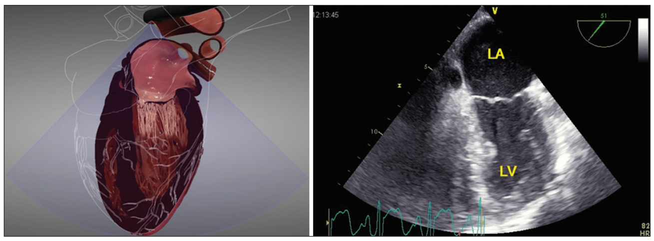

Figure 11: Mid-esophageal bi-commissural view. LA: Left atrium, LV: Left ventricle

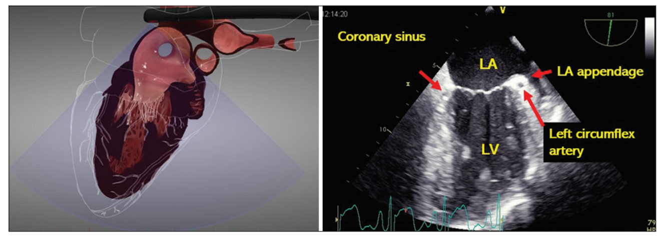

Figure 12: Mid-esophageal two-chamber view. LA: Left atrium, LV: Left ventricle

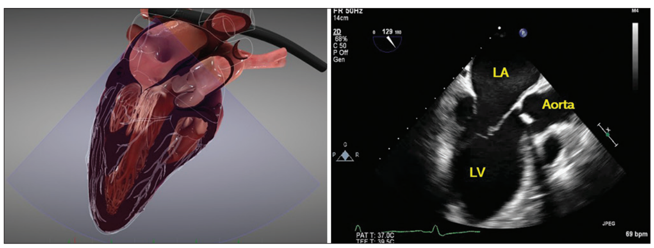

Figure 13: Mid-esophageal long-axis view. LA: Left atrium, LV: Left ventricle

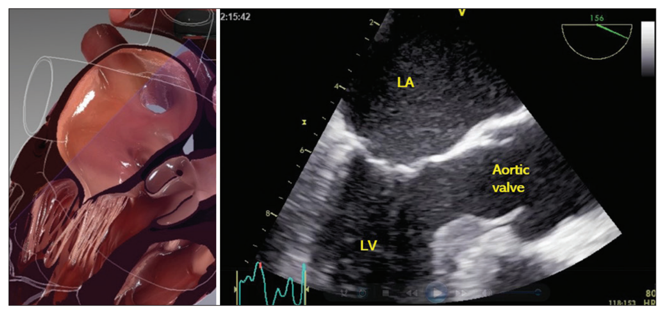

Figure 14: Mid-esophageal zoomed left ventricular inflow-outflow view. LA: Left atrium, LV: Left ventricle

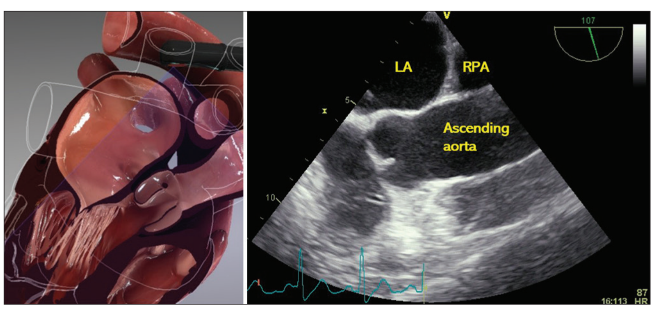

Figure 15: Mid-esophageal ascending aorta long-axis with right pulmonary artery short-axis view. LA: Left atrium, RPA: Right pulmonary artery

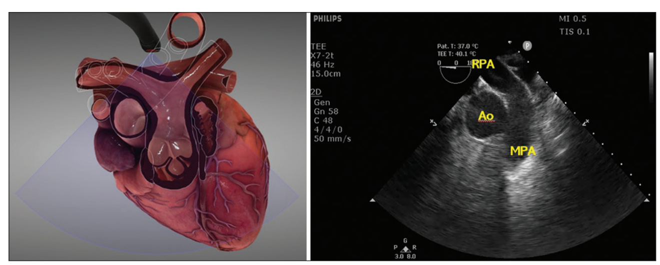

Figure 16: Upper-esophageal 0° main and right pulmonary artery long-axis view. Ao: Ascending aorta, MPA: Main pulmonary artery, RPA: Right pulmonary artery

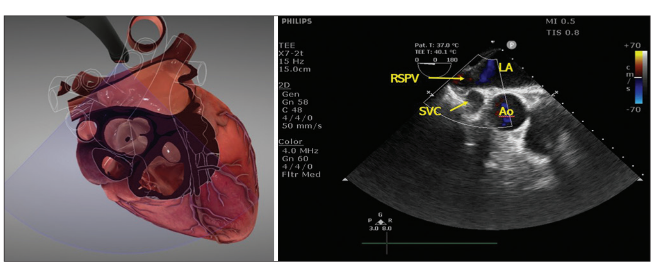

Figure 17: Upper-esophageal 0° right superior pulmonary vein long-axis and superior vena cava short-axis view. Ao: Ascending aorta, LA: Left atrium, RSPV: Right superior pulmonary vein, SVC: Superior vena cava

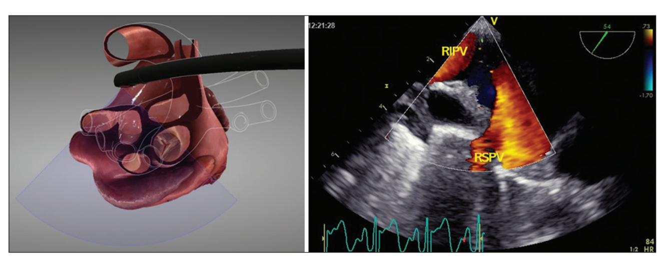

Figure 18: Upper-esophageal 30°–60° right superior and inferior pulmonary vein view. RIPV: Right inferior pulmonary vein, RSPV: Right superior pulmonary vein

Table 1: Contd...

View	Maneuver	Visualized structures	Doppler	Clinical utility	Figure/Video number
UE 0° RAA, SVC, ascending aorta	From view 9, gently advance the probe further; SVC will be seen merging with RA	RAA, ascending aorta SAX, SVC SAX merging into RA	Color flow mapping of SVC	To detect SVC type sinus venosus ASD	[Figure 19 and Video 10]
ME 45°-60° SAX AV and RV inflow-outflow	From view 1, keeping the aortic root in the centre, advance the probe and rotate the plane electronically to 45°-60° with mild clockwise torque	LA, RA, IAS, AV in SAX with 3 cusps and sinuses, TV, RV inflow, RVOT, PV, ostia of both coronary arteries	Color flow mapping of TV, RVOT, perimembranous septum, PV, AV	To evaluate aortic cuspal pathology, AV planimetry, RSOV, TR, VSD, ASD, RVOT stenosis, PV stenosis	[Figure 20 and Video 11]
ME 70°-90° IVC-RA junction	From view 12, torque the probe clockwise, rotate the plane electronically to 70°-90° approximately, gently advance the probe to visualize IVC opening into RA	LA, RA, IAS, IVC opening, hepatic segment of IVC and first hepatic vein opening, Eustachian valve	Color flow mapping of IVC, ASD	To evaluate IVC rim of ASD; to follow the catheters entering through IVC. Also, a good view for assessing TR and TR gradient (will require slight withdrawal of the probe to bring TV in center)	[Figure 21 and Video 12]
ME 90°-110° degree SVC-RA junction	From view 13, rotate the plane electronically to 70°-90° approximately, gently withdraw the probe to see SVC opening into RA	LA, RA, IAS, SVC opening, RAA, with more clockwise torque RSPV	Color flow mapping of SVC, ASD, RSPV	To evaluate for SVC type sinus venosus ASD, anomalous drainage of RSPV, catheters and leads entering through SVC	[Figure 22 and Video 13]
ME 60° LAA-LSPV	From view 12, with 60° imaging plane, torque anticlockwise and gently advance the probe to image LAA	LAA, Coumadin ridge between LAA-LSPV, LSPV opening	Color flow mapping of LAA and PW Doppler at LAA ostium for LAA function	After identifying LAA evaluate for LAA anatomy or LAA clot by sweeping imaging plane from 0° to 135°, very useful for evaluating pulmonary vein flow pattern	[Figure 23 and Video 14]
ME 120° LSPV-LIPV	From view 15, keep LSPV in center, rotate the plane electronically to 120°-135° approximately and torque the probe extreme anticlockwise to see LSPV-LIPV, a little retroflexion may help	LSPV and LIPV opening into LA with carina in between the two ostia	Color flow mapping of LSPV-LIPV	To evaluate anomalous drainage of LSPV-LIPV and pulmonary venous stenosis	[Figure 24 and Video 15]
LE coronary sinus view	From view 2, advance the probe to gastroesophageal junction (approximately 38-40 cm from incisors)	Coronary sinus in LAX	Color flow mapping of coronary sinus	To evaluate anomalous drainage of pulmonary veins, position of retrograde cardioplegia cannula, guiding coronary sinus catheter placement	[Figure 25 and Video 16]
LE pleural spaces	From view 17, torque the probe extreme clockwise or anti-clockwise to see right and left pleural spaces respectively	Right side liver and pleural space; left side lung field and pleural space	Nil	To evaluate pleural effusions, lung consolidation (however, loculated effusions can be missed)	[Figure 26 and Video 17a and b]
Transgastric basal LV SAX	From view 17, with imaging plane at 0°, advance the probe into stomach and anteflex in fundus	Basal LV SAX, MV end-on view of AML-PML coaptation line, RV free wall	Color flow mapping of MV orifice	To evaluate LV RWMA in basal six segments, en face view of MR jet origin, MV orifice size (e.g., in MS, or before and during MitraClip procedure)	[Figure 27 and Video 18]
Transgastric mid LV SAX	From view 19, with imaging plane at 0°, advance the probe further in the fundus, anteflexion needed	Mid LV SAX, both papillary muscles	Nil	To evaluate LV RWMA in six mid segments, MV subvalvular apparatus	[Figure 28 and Video 19]

Contd...

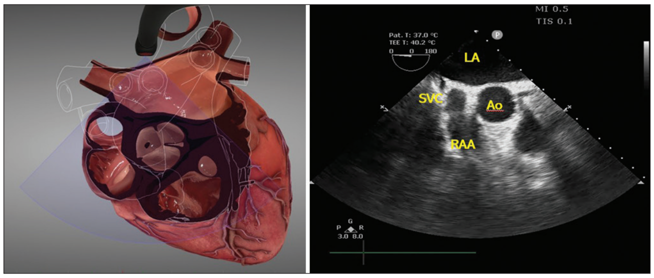

Figure 19: Upper-esophageal 0° right atrial appendage, superior vena cava and ascending aorta view. Ao: Ascending aorta, LA: Left atrium, RAA: Right atrial appendage, SVC: Superior vena cava

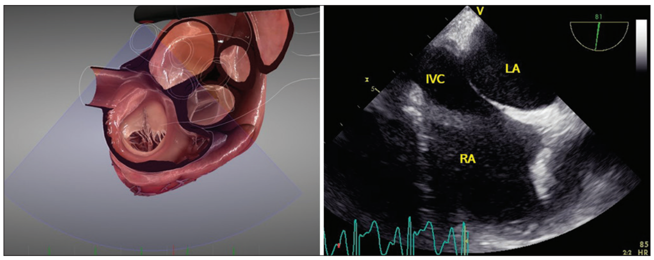

Figure 21: Mid-esophageal 70°–90° inferior vena cava right atrial junction view. IVC: Inferior vena cava, LA**:** Left atrium, RA: Right atrium

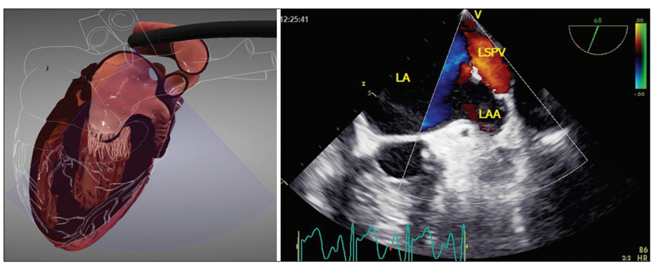

Figure 23: Mid-esophageal 60° left atrial appendage left superior pulmonary vein view. LA: Left atrium, LAA: Left atrial appendage, LSPV: Left superior pulmonary vein

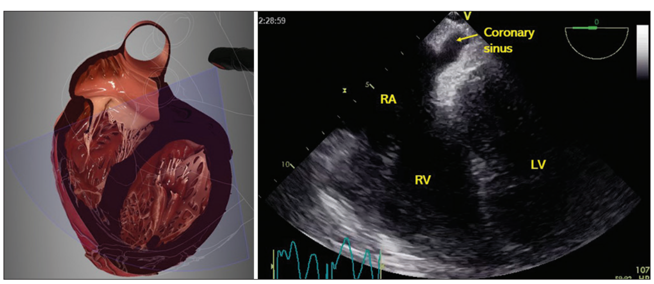

Figure 25: Lower-esophageal coronary sinus view. LV: Left ventricle, RA: Right atrium, RV: Right ventricle

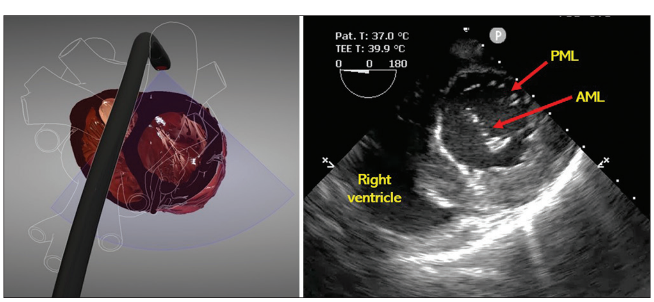

Figure 27: Transgastric basal left ventricular short-axis view. AML: Anterior mitral leaflet, PML: Posterior mitral leaflet

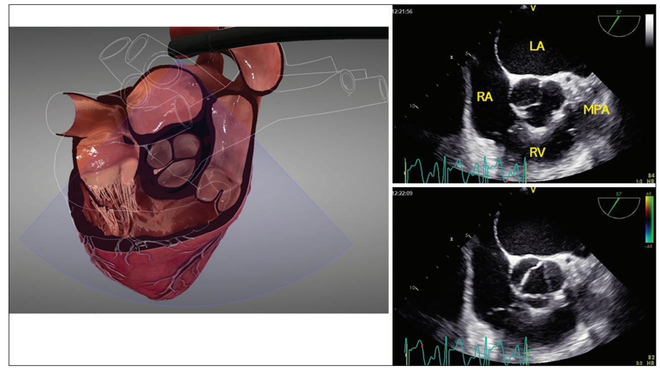

Figure 20: Mid-esophageal 60° aortic valve short-axis and right ventricular inflow-outflow view. LA**:** Left atrium, MPA: Main pulmonary artery, RA: Right atrium, RV: Right ventricle

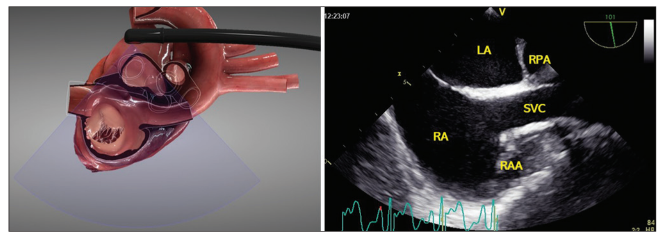

Figure 22: Mid-esophageal 90°-110° superior vena cava right atrial junction view. LA**:** Left atrium, RA: Right atrium, RAA: Right atrial appendage, RPA: Right pulmonary artery, SVC: Superior vena cava

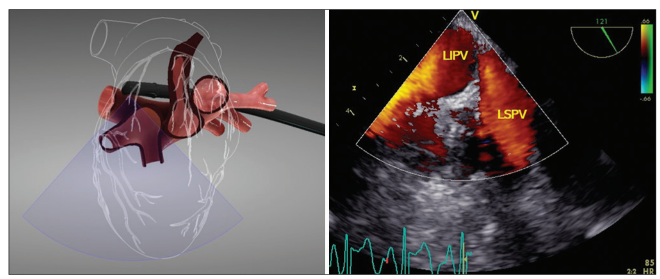

Figure 24: Mid-esophageal 120° left superior and inferior pulmonary vein view. LIPV: Left inferior pulmonary vein, LSPV: Left superior pulmonary vein

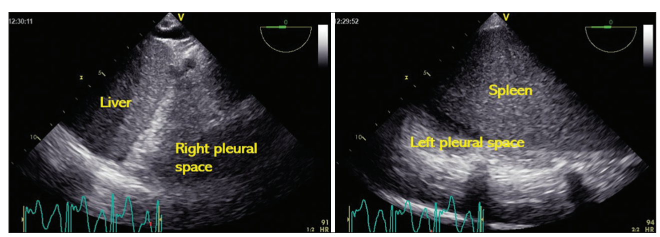

Figure 26: Lower-esophageal pleural spaces

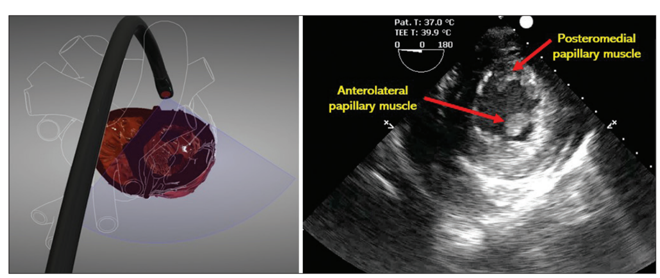

Figure 28: Transgastric mid left ventricular short-axis view

Table 1: Contd...

View	Maneuver	Visualized structures	Doppler	Clinical utility	Figure/Video number
Deep transgastric LV apical SAX	From view 20, with imaging plane at 0°, advance the probe further in the fundus (approximately 42-45 cm from incisors), anteflexion needed	Apical LV SAX	Nil	To evaluate LV RWMA in four apical segments	[Figure 29 and Video 20]
Deep transgastric LV SAX outflow views	From view 20-21, with imaging plane at 0°, gradually anteflex the probe to see RVOT first followed by further anteflexion and left flexion to visualize LVOT	RVOT, TV end-on, PV, following further anteflexion and leftward flexion LVOT, AV in far field	Color flow mapping of RVOT, PV, LVOT and AV; in this view, CW Doppler cursor can be positioned parallel to LVOT-AV flow	To evaluate native/ prosthetic aortic valve gradient, paravalvular AR, residual RVOT gradient postsubvalvular resection and trans-annular patch	[Figure 30 and Video 21a and b]
Transgastric LV LAX two-chamber	From view 20, electronically rotate the plane to 90°, keeping it ante-flexed	LV, LA, MV, LAA	Color flow mapping of MV	To evaluate LV RWMA of anterior and inferior wall, MR jet, mitral subvalvular apparatus	[Figure 31 and Video 22]
Transgastric RV inflow LAX view	From view 23, torque the probe clockwise keeping it ante-flexed and electronic plane at 90°, (while clockwise torqueing from view 23, the RVOT gets scanned before reaching the RV inflow view)	RA, RAA, RV inflow, RV inferior and free wall, TV, Part of RVOT	Color flow mapping of TV	To evaluate RV free wall recovery (postoperative), RV function, TV pathologies, TR and residual RVOT obstruction	[Figure 32 and Video 23]
Transgastric LV LAX inflow-outflow	From view 23, electronically rotate the plane to 110°-120°, keeping it ante-flexed	LA, LV MV, AML, PML, LVOT, AV	Color flow mapping of MV and LVOT, AV	To evaluate MR jets, systolic anterior motion of MV, dynamic LVOT obstruction, LV RWMA, AV gradient, AR jets	[Figure 33 and Video 24]
ME descending aorta SAX and LAX	From view 2, torque the probe extreme anticlockwise to see the SAX of DTA. Pull out the probe gently to scan entire length of DTA. Rotate the plane electronically to see LAX of DTA	Entire DTA	Color flow mapping of descending aorta	To evaluate DTA for dissection. Atheromas, balloon position in case of IABP	[Figure 34 and Video 25a and b]
UE aortic arch SAX (three views with opening of each arch vessel) and UE aortic arch LAX	From view 26, Keeping imaging plane at 90° gently withdraw the probe outward until the DTA lumen turns into a blind end in UE (20-24 cm from incisors). Then torque the probe clockwise gradually with mild ante-flexion. The arch of aorta is seen in SAX with ostia of arch vessels on right hand side of the image display. Following are visualized successively LSA opening LCC opening and MPA LAX, and finally RIA opening and LAX of distal ascending aorta	Entire arch of aorta and ostia of arch vessels (LSA, LCC, RIA), Left innominate vein, MPA LAX, PV, distal ascending aorta	Color flow mapping of arch of aorta	To evaluate arch of aorta for dissection, mobile/ulcerated atheromas, atherosclerotic lesions of arch vessels ostia	[Figure 35 and Video 26a-c]

Contd...

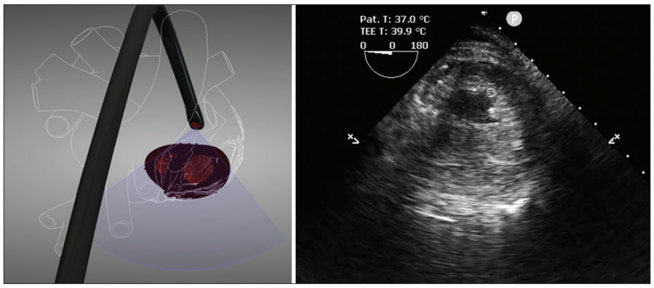

Figure 29: Deep transgastric left ventricular apical short-axis view

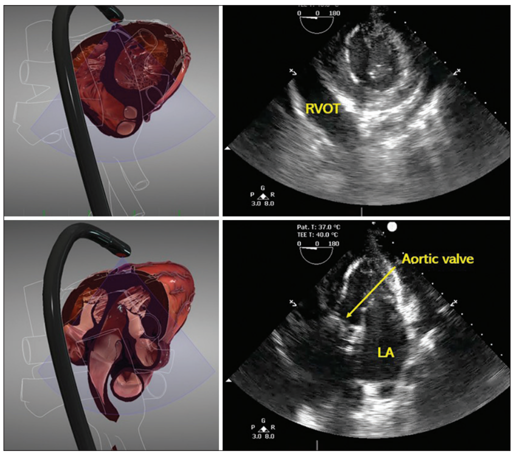

Figure 30: Deep transgastric left ventricular short-axis outflow views. Upper panel- right ventricular outflow view; lower panel- left ventricular outflow view. LA: Left atrium, RVOT: Right ventricular outflow tract

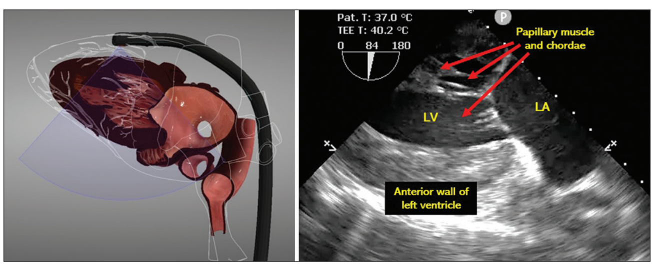

Figure 31: Transgastric left ventricular long-axis two-chamber view. LA: Left atrium, LV: Left ventricle

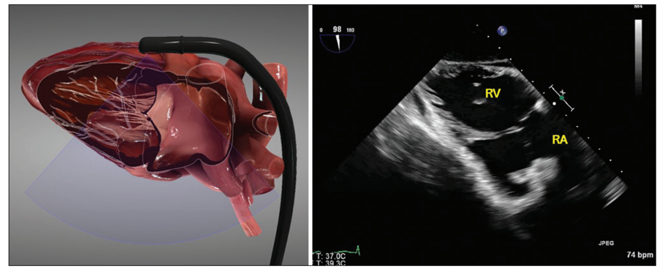

Figure 32: Transgastric right ventricular inflow long-axis view. RA: Right atrium, RV: Right ventricle

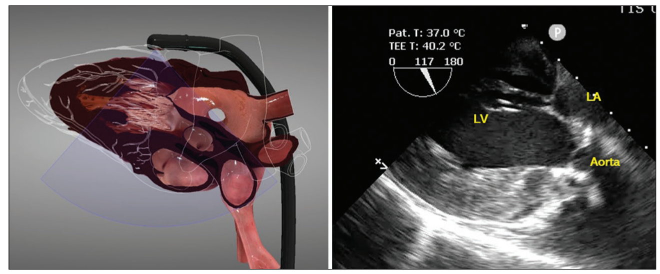

Figure 33: Transgastric left ventricular long-axis inflow-outflow view. LA: Left atrium, LV: Left ventricle

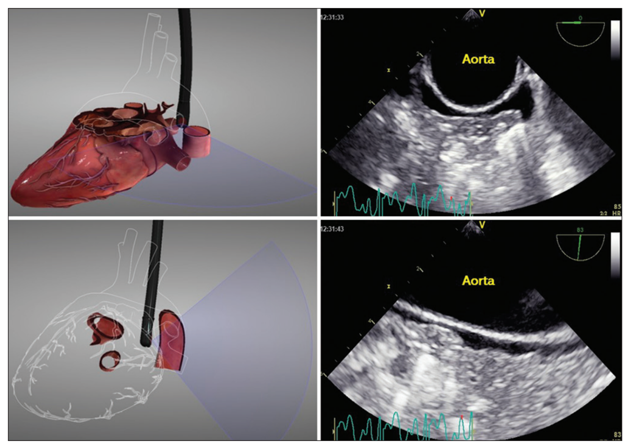

Figure 34: Mid-esophageal descending aorta short-axis (upper panel) and long-axis (lower panel) views

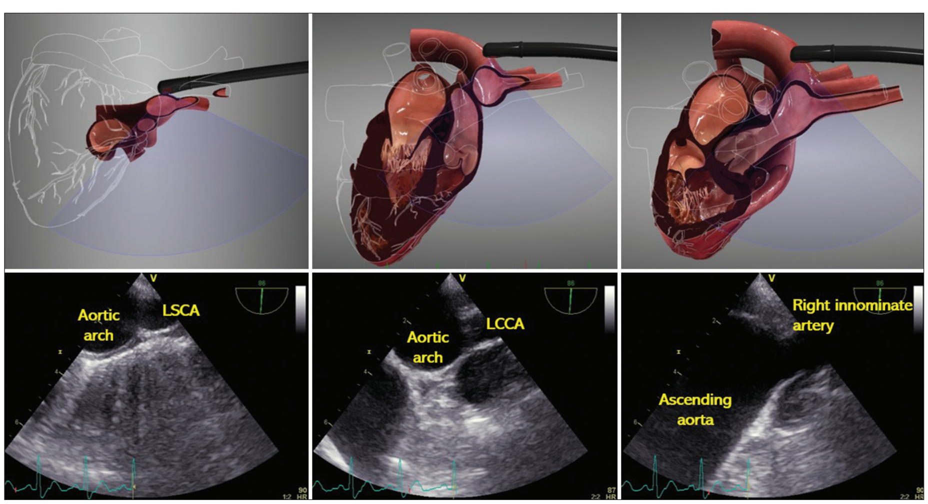

Figure 35: Upper esophageal aortic arch short- and long-axis views with branch vessels. LCCA: Left common carotid artery, LSCA: Left subclavian artery

Table 1: Contd...

View	Maneuver	Visualized structures	Doppler	Clinical utility	Figure/Video number
Biplane imaging	In each view, biplane mode can be activated, as required. The orthogonal imaging plane angle can be steered as required	Images of two orthogonal planes displayed simultaneously	Color flow mapping of two orthogonal planes displayed simultaneously	A structure, mobile mass or valve scallop or tentative artefact seen in one plane can be simultaneously evaluated in real time by positioning the cursor of the steerable orthogonal image plane through the object of interest	[Figure 36 and Video 27]

AML: Anterior mitral leaflet, AR: Aortic regurgitation, ASD: Atrial septal defect, AV: Aortic valve, CW: Continuous wave, DTA: Descending thoracic aorta, IABP: Intra-aortic balloon pump, IAS: Interatrial septum, IVC: Inferior vena cava, IVS: Interventricular septum, LA: Left atrium, LAA: Left atrial appendage, LAX: Long-axis, LCC: Left common carotid, LE: Lower esophageal, LIPV: Left inferior pulmonary vein, LSA: Left subclavian artery, LSPV: Left superior pulmonary vein, LV: Left ventricle, LVOT: Left ventricular outflow tract, ME: Mid esophageal, MPA: Main pulmonary artery, MR: Mitral regurgitation, MV: Mitral valve, PASP: Pulmonary artery systolic pressure, PML: Posterior mitral leaflet, PV: Pulmonary valve, PW: Pulsed-wave, RA: Right atrium, RAA: Right atrial appendage, RIA: Right innominate artery, RIPV: Right inferior pulmonary vein, RPA: Right pulmonary artery, RSOV: Ruptured sinus of valsalva, RSPV: Right superior pulmonary vein, RV: Right ventricle, RVOT: Right ventricular outflow tract, RWMA: Regional wall motion abnormality, SAX: Short-axis, SVC: Superior vena cava, TAPSE: Tricuspid annular plane systolic excursion, TDI: Tissue Doppler imaging, TR: Tricuspid regurgitation, TV: Tricuspid valve, UE: Upper esophageal, VSD: Ventricular septal defect, MS: Mitral stenosis

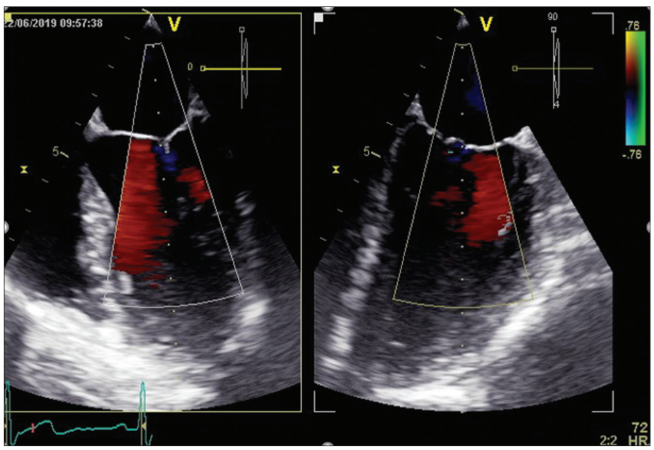

Figure 36: Simultaneous biplane imaging

2. Adjust the biplane zoom window to minimum size but encompassing the entire structure and accompanying anatomical landmark. Keep the gains setting to 60% and uniform throughout the field. Train the patient beforehand to hold breath for 6-8 seconds and to follow operator's instructions for breath hold and release. With the operator keeping his hand holding the probe shaft steady and the patient (when conscious and co-operating) holding the breath, try to choose maximum number of cardiac cycles[6-7] to acquire multi-beat 3D dataset without stitch artefacts. The stitch artefacts can be examined in the image pane which is perpendicular to the primary view
3. Acquire multiple datasets by changing the viewing angle while using the same principle as described above.

Post-processing can be easily performed by auto-dissecting the 3D dataset in steerable tri-plane (XY-YZ-XZ) 2D views to identify various structures and to choose an appropriate viewing plane [Figure 37]. The viewing plane is the plane which provides *en face* visualization of the structure of interest. The remaining two planes are designated as orthogonal longitudinal planes. Both orthogonal longitudinal planes should be adjusted (by displacement and axial rotation) to dissect the structure through the center forming a crosshair in the viewing plane. Subsequently, the viewing plane is adjusted perpendicular to both the orthogonal longitudinal planes to get *en face* 3D perspective of the structure.

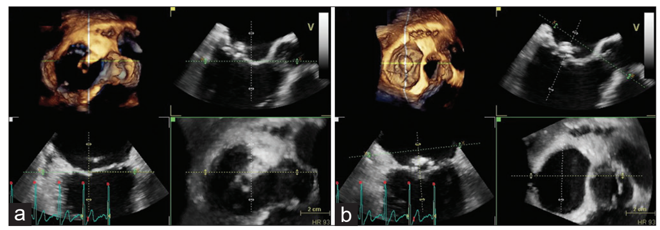

Figure 37: Postprocessing of three-dimensional echocardiographic dataset. (a) Auto dissection of three-dimensional data set into 3 orthogonal planes. The yellow, white and green dotted lines show the plane orientation and yellow, white and green corner square markings show the two-dimensional image in the corresponding plane; (b) For viewing the mitral valve *en face,* the green plane is chosen as the viewing plane and the yellow and white planes are the orthogonal planes. The orthogonal planes are steered to dissect the mitral valve longitudinally through the center of the mitral orifice. The viewing plane (green) is then steered to be perpendicular to the crosshair formed by the orthogonal planes (yellow and white) so that it is perfectly parallel to the mitral valve. By using "flip crop" and axial "z" rotation of the viewing plane, the prescribed surgeon's view can be shown

Focused Imaging of Specific Cardiac Structures

Mitral valve

TEE has great advantage in MV imaging. The valve can be imaged in virtually any plane in 360º space, with high spatial resolution facilitated by fluid filled LA as the only structure between the probe and the MV. When available, TEE 3D imaging of MV provides comprehensive diagnostic information in a format suitable for communication with the surgeon or the interventionist [Figure 38 and Video 28]. However, multiplanar 2D imaging remains the mainstay for a more detailed diagnostic evaluation [Figure 39].

The MV should be positioned in the center of the imaging sector and the sector depth and width and focus position are adjusted for optimal viewing of mitral leaflets, annulus, proximal chordae and part of adjacent aortic root and LAA. The step-by-step approach described below can be followed for comprehensive analysis of the MV apparatus[41,42] [Figure 39]. The MV scallops are described according to the classification proposed by Carpentier *et al*.[43]

1. At ME 0-30º viewing plane (four-chamber view), anterior and posterior mitral leaflets (AML and PML, respectively) are displayed in observer's left to right orientation on the monitor. The AML is formed by A3-A2 scallops in base-to-free edge direction. The PML is formed by mainly P2 or P1-P2 scallops in base-to-free edge direction

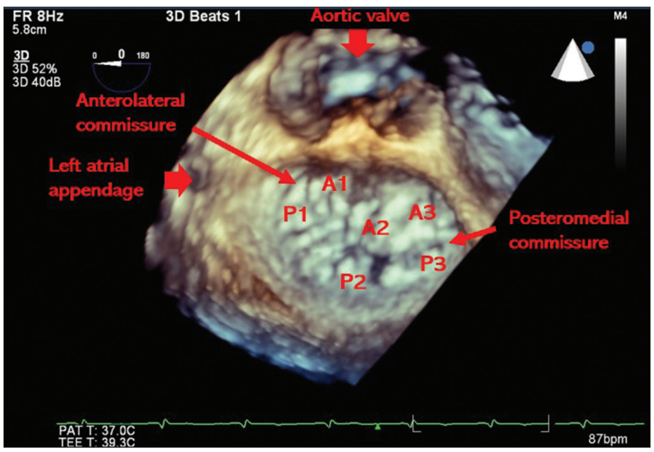

Figure 38: Three-dimensional transesophageal echocardiographic visualization of the mitral valve from the left atrial side (i.e., the "surgeon's view"). A1, A2, A3, P1, P2, and P3 are scallops of anterior and posterior mitral valve leaflets, respectively

2. From ME 0º viewing plane, if the TEE probe is gradually withdrawn to develop five-chamber view, A1 and P1 scallops can be visualized and further withdrawing the probe brings the anterolateral commissure of the MV in the view [Figure 40]. This maneuver is useful for analyzing fusion, calcification and commissural regurgitation involving the anterolateral commissure. Conversely, advancing the transducer visualizes A3 and P3 scallops [Figure 40]
3. At ME 45°-75º viewing plane showing the bi-commissural view, the medial and lateral commissures are displayed in observer's left to right orientation on the monitor. Three MV segments are visualized in this view viz. P3-A2-P1 (sometimes P3-A3A2A1-P1), displayed in left to right direction on the monitor. From this view, with clockwise torque (rightward) the imaging plane successfully cuts through entire AML, from free edge to base to aorto-mitral inter-valvular fibrosa. Similarly, with anti-clockwise torque (leftward), entire PML can be visualized from free edge to base [Figure 40]
4. At ME 90º viewing plane, PML-AML are displayed in observer's left to right orientation on the monitor. The AML is formed by A1-A2 scallops in base-to-free edge direction. The PML is formed by mainly P3 or P3-P2 junction. From this view, with clockwise torque (rightward), the imaging plane successively cuts through the posteromedial commissure. This maneuver is useful for analyzing fusion, calcification and commissural regurgitation involving the posteromedial commissure
5. At ME 120°-135º viewing plane, PML-AML are displayed in observer's left to right orientation on the monitor. The AML is formed by A2 and PML by P2, with the imaging plane passing through the center of the MV orifice. With

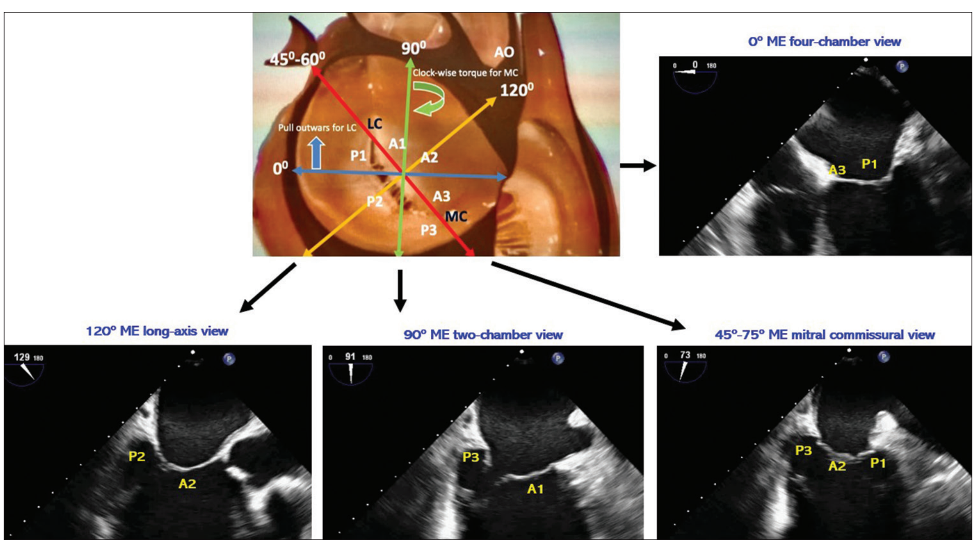

Figure 39: Two-dimensional transesophageal echocardiographic visualization of the mitral valve in different views. A1, A2, A3, P1, P2, and P3 are scallops of anterior and posterior mitral valve leaflets, respectively. Ao: Aorta, LC: Lateral commissure, MC: Medial commissure, ME: Mid-esophageal

clockwise (rightward) and anti-clockwise (leftward) torque, the imaging plane moves sideways, cutting through remaining parts of the leaflets and the medial and lateral commissures, respectively

6. At every viewing plane, color Doppler interrogation (and if needed PW or CW Doppler) can be performed to visualize the mitral regurgitation (MR) jets. The MR jets due to AML pathology are generally directed posteriorly, whereas jets due to PML pathology are directed anteriorly. The regurgitant jets due to lateral commissural pathology are directed medially towards interatrial septum and those due to medial commissural pathology are directed laterally towards LAA. In case of non-coaptation of the central part of the MV leaflets or PML clefts, the MR jets are generally directed centrally towards the LA roof.

Guiding transcatheter edge-to-edge repair of mitral valve

TEE plays central role in patient selection, procedural planning and performance of trans-catheter edge-to-edge repair (TEER) of MV using the commercially available MitraClip®.

Patient selection

TEER is performed for surgically very high-risk patients with-

1. Carpentier type II (A2/P2 prolapse/flail) MR, or
2. Secondary MR

The ideal MV anatomy identified by TEE for the choice of TEER is as follows[44]

- Non-rheumatic valve/no infective endocarditis
- Leak at A2-P2
- Grade III/IV MR
- Single/dominant central jet
- No calcium at the grasping site
- In case of secondary MR: leaflet coaptation depth <11 mm, coaptation length >2 mm [Figure 41]
- In case of Carpentier type II (A2/P2 prolapse/flail) MR: nontethered PML >10 mm, flail width <15 mm, flail gap <10 mm [Figure 42]
- MV area (MVA) >4 cm^2 on 3D TEE
- Baseline MV mean gradient <3 mmHg
- LV cavity size <65 mm
- Trans-septal crossing height from mitral annulus >4 cm.

The above parameters indicate ideal anatomy for TEER but with increasing experience, properly selected patients with less favorable anatomy can also undergo successful TEER.

Contraindications for TEER are as follows-

- Carpentier IIIA abnormality (i.e., rheumatic heart disease)
- Infective endocarditis
- LA/LAA clot
- Calcification of leaflets at grasping area
- MV mean gradient >5 mmHg
- MVA < 3 cm^2 on 3D TEE
- Severe RV dysfunction and PH unrelated to MR
- ASD closure device
- IVC thrombosis.

Procedural details

Following are the steps involved in TEE-guidance of MV TEER procedure[44,45]

- Define the leaflet target,
- Trans-septal puncture and safe steering of steerable guiding catheter (SGC) and clip delivery system (CDS) in the LA,
- Proper clip alignment,
- Grasping the leaflets,
- Assessment of MR reduction, and
- Exclusion of significant MS and assessment of interatrial shunt.

Trans-septal puncture and safe steering of the guide catheter and the clip delivery system

The TEE views/steps typically used for guiding trans-septal puncture are-

- The trans-septal puncture should be performed through

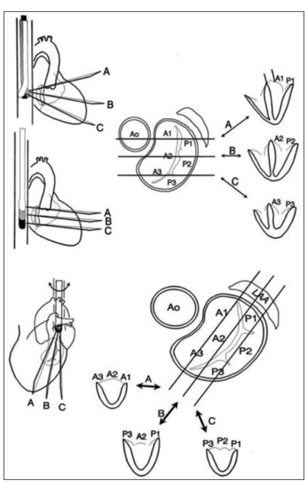

Figure 40: Upper panel shows mitral valve structures visualized as the transesophageal echocardiography probe is advanced or withdrawn from the mid-esophageal 0° four-chamber view. The lower panel shows the effect of clockwise and counterclockwise rotation of the probe in bi-commissural view. Reproduced from: Chen C, Okoh A, Garg A, Russo M. Catheter-based mitral intervention imaging and procedural TEE; November 2020. Available from: https://www.ctsnet.org/article/catheter-based-mitral-intervention-imaging-and-procedural-tee. [Last accessed on 2021 Jul 09]

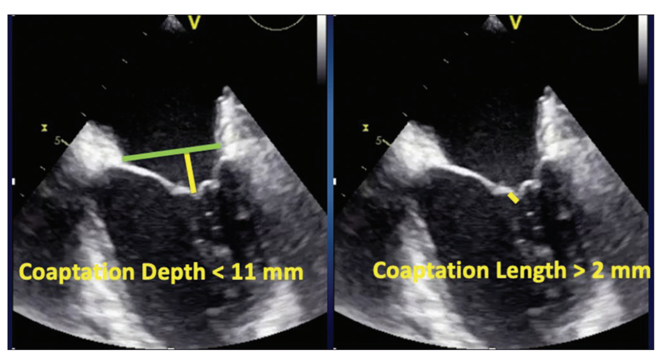

Figure 41: Preferred anatomic criteria for transcatheter mitral valve edge-to-edge repair in secondary mitral regurgitation

the posterior-mid aspect of the fossa. This is confirmed by simultaneous biplane imaging at approximately 45° for anteroposterior orientation (puncture site posteriorly) and 90° for superior-inferior orientation (puncture site in mid-fossa) [Figure 43 and Video 29]

- At the same time, the puncture height should be at least 4-4.5 cm above the mitral annulus; this is confirmed in 2D 4-chamber view (0°-20°) [Figure 43]. Less than 4 cm may be acceptable when coaptation is deeper in the LV, whereas >4.5 cm is often necessary when flail leaflet is the underlying pathology
- Sharp tenting of the interatrial septum should be seen in both 45° and 90° views before puncturing the septum
- Following septal puncture, a guidewire is positioned in the left upper pulmonary vein
- SGC is introduced into the LA, under fluoroscopy and TEE guidance in 45° SAX view and live 3D imaging. CDS is introduced subsequently in the same manner. It is important to ensure that the SGC and CDS tips are away from the surrounding tissues
- The CDS is flexed towards the MV, while the device tip is followed in the 45° SAX view and four-chamber view.

Proper clip alignment

For guiding proper clip alignment, following views are used-

- Simultaneous biplane imaging with bi-commissural view (60°) for medial-lateral orientation and the LVOT view (135°-150°) for anteroposterior orientation [Figure 44 and Video 30], and
- 3D TEE LA aspect *en face* MV view [Figure 44 and Video 31] or the transgastric basal SAX view for aligning the clip perpendicular to the coaptation line.

First, the clip is positioned centrally over the valve with respect to anterior-posterior and medial-lateral directions. The distal tip of the clip should be at least 1 cm above the leaflets.

The clip arms are then opened and meticulously aligned. The goal is to ensure that the clip splits the MR jet in both antero-posterior and medial-lateral directions. In addition, the clip arms should be exactly perpendicular to the mitral coaptation line.

Grasping the leaflets

After verifying proper clip orientation multiple times, the clip arms are closed to 60° and the clip is then advanced into the LV, approximately 2 cm below the valve leaflets.

The clip arms are opened to 180°, and proper orientation is confirmed once again and readjustment done as needed, in the same views as above [Figure 45 and Video 32]. Lowering of gain in 3D *en face* view is needed to visualize the clip arms through the MV leaflets to ensure perpendicularity to the coaptation line.

The clip arms angle is reduced to 120° (grasping angle) and the clip is retracted towards the valve to grasp the leaflets. This is performed under TEE guidance in the LVOT view [Figure 46].

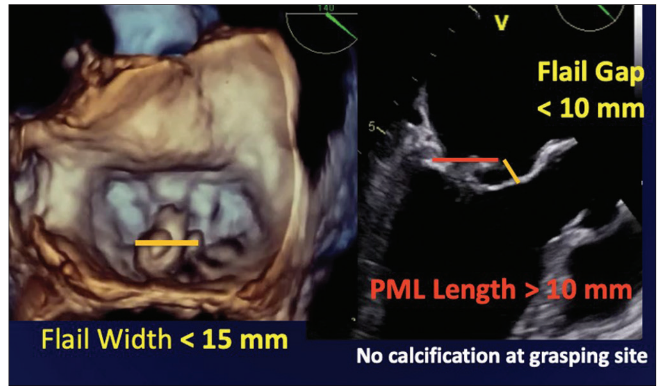

Figure 42: Selection criteria for transcatheter mitral valve edge-to-edge repair in degenerative mitral regurgitation

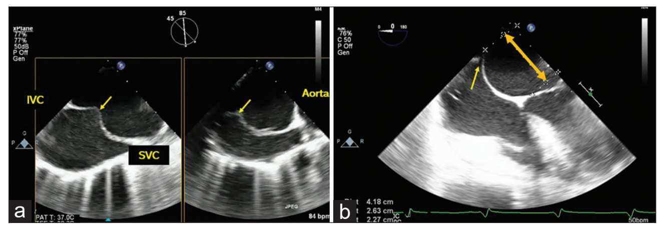

Figure 43: Transseptal puncture for transcatheter mitral valve edge-to-edge repair. (a) Biplane imaging to ensure that the puncture is done in mid-fossa (left image) and away from the aortic valve (right image). (b) The puncture height (orange arrow) should be 4–4.5 cm above the mitral annular plane. Yellow arrows point to the site of septal tenting just prior to the puncture. IVC: Inferior vena cava, SVC: Superior vena cava

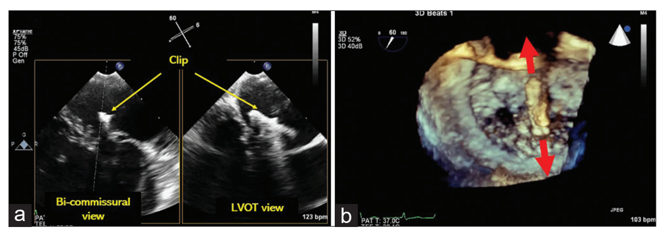

Figure 44: Aligning the clip in relation to the mitral valve. (a) Biplane imaging is used to simultaneously orient the clip in medial-lateral direction (bi-commissural view, left image) as well as anteroposterior direction (LVOT view). (b) Three-dimensional *en face* view is used for orientating the clip perpendicular to the coaptation line. LVOT- left ventricular outflow tract

The clip is closed to 60° and proper grasp is confirmed in multiple views (bi-commissural view, LVOT views, 3D *en face*, four-chamber). It should be ensured that-

- Both leaflets are captured and are fully inserted to the base of 'V' between gripper and arms,
- There is non-existent or limited leaflet motion relative to the clip arms,
- On the medial and lateral sides of the clip, the leaflets enter at the same level,
- Clip arms are perpendicular to the line of coaptation, and the clip is not biased towards the anterior or posterior leaflet, and
- There is satisfactory reduction of MR.

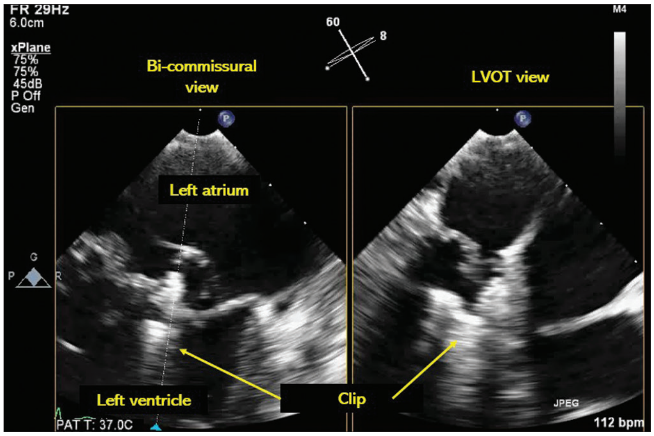

Figure 45: Aligning the clip once it has been advanced into the left ventricle. The principles of imaging are same as in Figure 44. LVOT: Left ventricular outflow tract

Assessment of mitral regurgitation reduction

It is essential to confirm that the procedure has resulted in satisfactory reduction of MR. Assessment of residual MR severity can be performed by looking at-

- MR jet size in 2D TEE color-flow Doppler in all the standard views and 3D TEE color-flow Doppler,
- Pulmonary vein flow pattern (no systolic flow reversal with restoration of systolic forward flow or improvement in systolic forward flow from baseline), and
- Increase in LVOT velocity/LV stroke volume (quantified from the 2D TEE transgastric view).

Formal quantitative parameters such as vena contracta and effective regurgitant orifice area derived using proximal isovelocity surface area have not been validated.

One should look for significant jet either side of the clip. In case of residual MR, evaluation with clip arms loosened and retightened should be performed. If the clip position is unsatisfactory and/or there is significant residual MR, the grasp is released, clip withdrawn into the LA and the process is repeated to reposition the clip. In some cases, additional clip may also be needed once the first clip is deployed.

Once the satisfactory clip position and MR reduction are achieved, the clip is deployed, and a final assessment of MR is performed.

Residual interatrial shunt and mitral stenosis

- Exclude significant MS by measuring transmitral gradient (2D TEE CW Doppler) and MVA (2D TEE transgastric basal SAX view, 3D TEE). For an optimal result, transmitral gradient should be <4 mmHg
- Look for residual interatrial shunt and the defect size. In case of a large shunt, device closure may be needed
- Confirm that there is no pericardial effusion or no increase in pre-existing pericardial effusion.

Interatrial septum and pulmonary veins

TEE is superior to TTE in providing high quality images of interatrial septum which are helpful to confirm the diagnosis of ASD, to accurately measure the size of the defect, to assess the rims and to identify additional defects missed by TTE. In case of an ostium secundum ASD, 2D multiplanar TEE examination should systematically evaluate the entire margin of the defect, as described below. Careful attention should be given to the gain, dynamic range and compression setting and operational frequency so that the softer echoes of the thin septal margins are adequately recorded. Any additional echo dropout in the septum should be interrogated with color flow mapping at low Nyquist limit to confirm the presence of a true defect or cribriform septum.

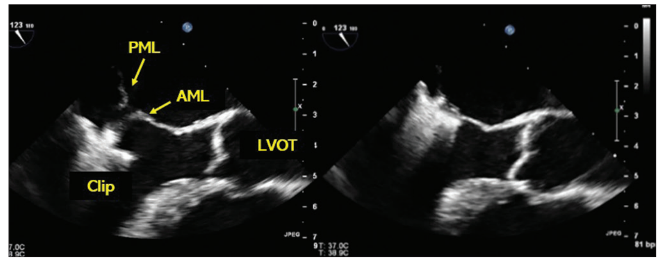

Figure 46: Grasping of the mitral valve leaflets is performed in the LVOT view. AML: Anterior mitral leaflet, LVOT: Left ventricular outflow tract, PML: Posterior mitral leaflet

The edges of the ASD margins may appear bulbous due to blooming effect. The IVC margin of ASD invariably falls into apical clutter artefact and switching to harmonics and retro-flexion of the probe may improve its visualization. The size of the margins should be carefully measured at multiple locations from the edge of the defect to the relevant anatomic landmark such as atrial wall, mitral annulus, aortic root, or SVC/IVC opening. The ASD margins are divided into the following six rims- SVC rim, atrial or posterior rim (divided into posterosuperior and posteroinferior rims), IVC rim, mitral rim, and the aortic rim [Figures 47 and 48].[46-48]

Careful attention should be given to characterize the margins as either thin and floppy or thick and sturdy by visualizing their movement. In an Amplatzer® septal occluder (ASO) device, the LA disc is 5 mm longer and RA disc 4 mm longer radially than the waist in case of smaller devices (4-10 mm size devices), and 7 and 5 mm longer respectively in case of larger devices.[49,50] Hence, margins <5 mm in a contiguous arc of 45^0 are considered inadequate for device closure (except for aortic margin) and <3 mm as virtually absent.[48] In the presence of very thin and floppy margins, the distance between the sturdy rims of the defect is measured for judging the device size. In the presence of multiple defects, if the distance between two defect margins is more than 7 mm (more than the ASO LA disc overhang), then the defects are classified as widely separated needing two devices.[51]

During TEE, a systematic evaluation of ASD margins and pulmonary venous drainage should be performed as described below [Figure 48].

1. In 0º ME four-chamber view [Video 33], the imaging plane passes caudal to insertion of right superior pulmonary vein

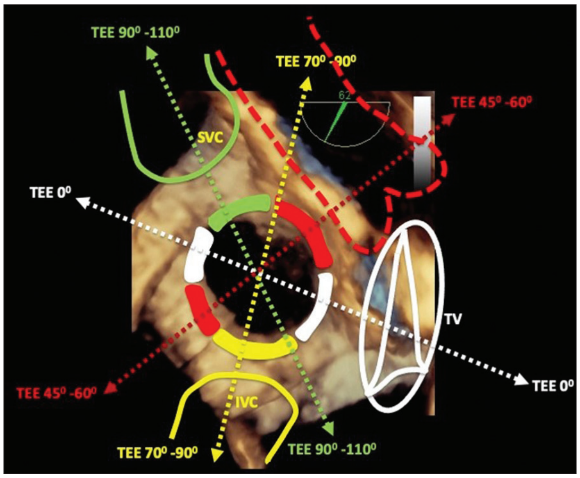

Figure 47: Schematic diagram showing an ostium secundum type of atrial septal defect and its margins, as visualized from the right atrial side. Different TEE multiplane angles are shown, along with the rims seen in those views. Green - SVC rim; red - aortic rim anteriorly and posteroinferior atrial rim posteriorly; white - mitral rim anteriorly and posterosuperior atrial rim posteriorly; yellow - IVC rim. IVC: Inferior vena cava, SVC: Superior vena cava, TEE: Transesophageal echocardiography, TV: Tricuspid valve

and shows posterosuperior atrial rim (left side of image display, measured from posterior wall of LA to the edge of ASD) and the mitral rim (right side of image display, measured from hinge point of AML to the edge of ASD). The largest anteroposterior diameter of ASD and the total anteroposterior length of the septum can also be measured

2. At 0º, withdrawing the probe to SVC-RA junction level with clockwise (rightward) rotation of the probe, opening of the right superior pulmonary vein can be seen [Video 34]. At this level, electronic plane rotation to 30°-40º degrees shows both superior and inferior pulmonary veins opening into the LA with carina between the two openings
3. The anomalous right sided pulmonary vein draining into SVC, SVC-RA junction or RA free wall can be visualized at 0º imaging plane with the probe rotated extreme rightwards (clockwise) and slightly withdrawn. The probe is then gradually advanced deeper starting from the long-axis view of right pulmonary artery, carefully scanning entire length of SVC to SVC-RA junction to RA free wall
4. From 0º ME four-chamber view, gradual sweep to 30º-60° visualizes the entire posterior atrial margin of the ASD on the left side of the image display [Videos 35 and 36]. At approximately 60° (SAX view), the anticlockwise (leftward) rotation of the probe shows the opening of the left superior pulmonary vein into LA, adjacent to LAA. Keeping the left superior pulmonary vein positioned in the center of the image and electronically rotating the imaging plane to 120°-130° with extreme anticlockwise (leftward) rotation of the probe, both left superior and inferior pulmonary veins opening into LA can be seen together, with the carina between the two openings

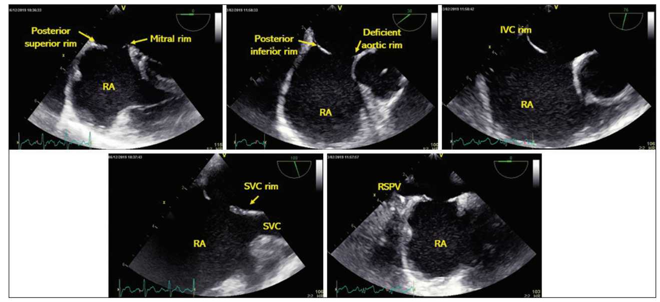

Figure 48: Two-dimensional transesophageal echocardiographic visualization of an ostium secundum atrial septal defect. IVC: Inferior vena cava, RA: Right atrium, RSPV: Right superior pulmonary vein, SVC: Superior vena cava

5. Left-side pulmonary veins draining anomalously into vertical vein can be visualized in 90° imaging plane with leftward rotation of TEE probe and then slowly withdrawing the transducer from LA level to SAX view of arch of aorta. With this maneuver one can trace the vertical vein coursing anterior to left pulmonary artery and draining into innominate vein anterior to aortic arch. The anomalously draining left pulmonary veins into coronary sinus can also be visualized by first identifying the SAX view of coronary sinus posterior to MV annulus in 90° imaging plane and then rotating the TEE probe to the left
6. The ME 60° view shows the aortic rim on the right side of the image display [Video 36]. This view (cable axial view) is useful during TEE guidance of ASD device closure. When the interventionist grounds the device delivery sheath in the left superior pulmonary vein, one can track the opening and deployment of the LA disc when it is hitched towards the ASD. If the aortic root margin is completely absent, the large LA disc may get oriented perpendicular to the septum with the anterior lip of the disc prolapsing through the ASD. This would prompt the interventionist to adopt a different strategy for device deployment
7. At 70°-90°-110°, the imaging plane sweeps the interatrial septum vertically with the posteroinferior atrial rim of the ASD seen on the left side of the image display
8. At 60°-80°, the probe can be advanced deeper towards gastroesophageal junction with gentle clockwise (rightward) rotation to image the IVC in its long-axis opening into the RA. The IVC rim of the defect is seen near the apex of the image sector and Eustachian valve is seen anterior to the IVC opening. It is usually difficult to profile the IVC rim well in this view, because of the proximity of the IVC to the lower esophagus. To overcome this, the TEE probe may be advanced further into the stomach and retroflexed and then gently withdrawn back to the gastroesophageal junction level. This maneuver helps in moving the probe and also esophagus away from the IVC, improving visualization of the IVC rim of the ASD in 60°-80° imaging plane.[46] The rim length is measured from the posteroinferior wall of the

LA to the inferior edge of the ASD, keeping IVC opening in sight. The supero-inferior diameter of the ASD and the total supero-inferior septal length are also measured in this view. ASDs with the absent posteroinferior and/or IVC rims are usually larger and are associated with greater chances of failure of the device closure and device embolization

9. At 90°-110° imaging plane, the probe can be withdrawn with gentle clockwise (rightward) torque to visualize the SVC opening into the RA, SVC rim of the ASD (on the right side of the image display) and the RA appendage (seen anteriorly) [Video 37]. With further clockwise rotation, the right superior pulmonary artery is seen in cross-section behind the SVC. The normal opening of the right superior pulmonary vein into LA can also be seen (may need increasing the angle to 110º-120º) and when it is anomalously connected to SVC, the same can be diagnosed in this view. The SVC rim length is measured from the superior edge of the ASD to the insertion of the septum posterior to SVC opening, just opposite to where right pulmonary artery crosses the SVC
10. Finally, if 3D TEE is available, the same can be used to permit *en face* visualization of the entire ASD [Figure 49].

Evaluation of patients with suspected cardioembolic stroke

In 2018, the Indian Academy of Echocardiography had published a practice guideline for the performance of TEE for evaluation of patients with suspected cardioembolic stroke.[15] This document describes in detail the indications for TEE, systemic segmental approach for performing TEE, and TEE evaluation of individual pathologies which could result in an embolic stroke. The readers are encouraged to refer to this document for a more detailed discussion.

Left atrial appendage

LAA is a finger-like projection at the junction of LA and LV free wall. There is considerable variation in the size, shape and number of the lobes of the LAA.[52-54] It may have a chicken wing, windsock, cauliflower or cactus shape [Figure 50]. The ostium of LAA may be circular, elliptical, triangular, waterdrop like or shoe like.

LAA lies within the pericardium and acts as a decompression chamber during ventricular systole and when the LA pressure is raised. It becomes dilated when there is LA dilatation, as occurs in patients with MV disease, AF and cardiac failure. LAA also helps in maintenance of heart rate and fluid balance through secretion of atrial natriuretic peptide, 30% of which is secreted from the LAA.[52,53]

At least 15% of all strokes are cardioembolic in origin.[55] LAA is the commonest source of embolism in the presence of AF, MV disease or both [Figure 51 and Video 38]. LAA thrombus may also form in sinus rhythm, especially in patients with heart failure. Anticoagulation, surgical LAA occlusion during MV surgery and percutaneous LAA exclusion are used for minimizing cardioembolic stroke risk in appropriately selected patients.

There are several indications for which imaging of LA and LAA is required, as outlined previously. During TEE, LAA is commonly imaged in ME SAX view at 30°-60° and ME two-chamber view at 80°-90°. However, it is not enough to visualize the LAA in these two views alone because it has got a complex 3D anatomy with different shapes, size and lobes. Hence, the operator should scan through the entire LAA in complete detail to diagnose or exclude any LAA thrombus. This can be achieved by keeping the LAA in the centre of the ME SAX view and scanning from 30°-135° while simultaneously adjusting the probe orientation to keep the LAA in view [Figure 52]. This sequence cuts through the LAA in different angles and helps to completely visualize it.

If TEE is performed using a 3D TEE probe, multiplane imaging along two orthogonal planes with simultaneous adjustment of elevational plane should be used. A full-volume

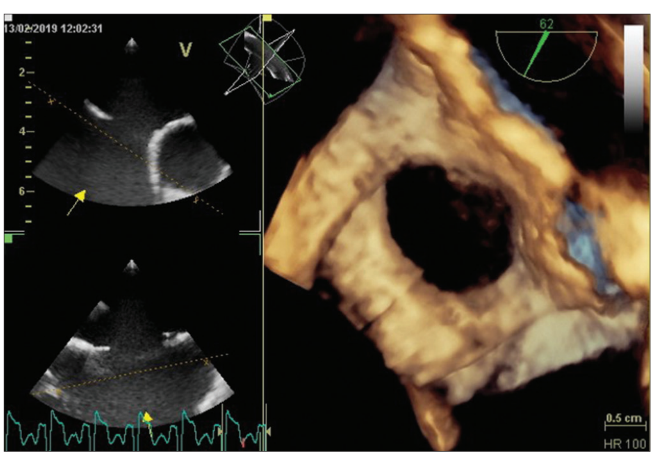

Figure 49: Three-dimensional transesophageal echocardiographic visualization of an ostium secundum atrial septal defect from right atrial side

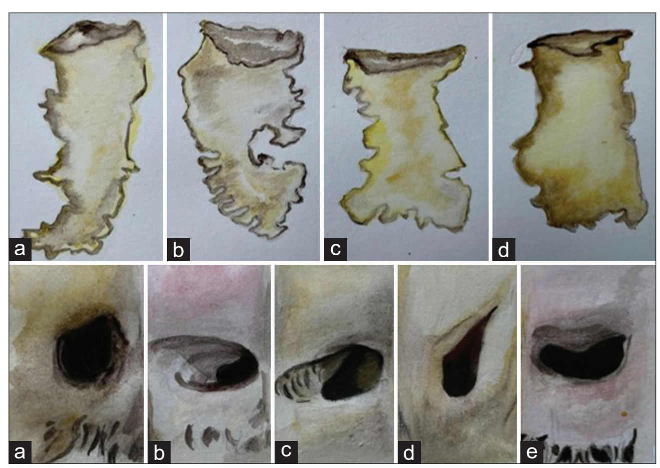

Figure 50: Upper panel - Different shapes of left atrial appendage. (a) Windsock, (b) chicken-wing, (c) cactus, and (d) cauliflower shape. Lower panel - Different shapes of the ostium of left atrial appendage. (a) Circular, (b) elliptical, (c) triangular, (d) water drop like, (e) foot like

image acquisition at ME 45° is recommended. 3D zoom mode may be used when required. 3D TEE can visualize the entire LAA, helping to study the shape, size and the mouth of the LAA along with better interrogation of pectinate muscles and volume quantifications. The short- and long-axis assessment is also more accurate, especially when multiple slice method is used.

The sensitivity and specificity of TEE for diagnosing LAA thrombus has been reported to be as high as 100% and 99%, respectively.[56] Pectinate muscles and spontaneous echo contrast may be mistaken for a thrombus [Figure 51 and Videos 38, 39]. Contrast opacification of LAA helps to resolve this and improves the diagnostic accuracy. Apart from the anatomic assessment, complete imaging of LAA should also include color flow imaging and PW Doppler assessment of the emptying velocity.[57]

TEE is indispensable in the planning and guiding percutaneous device closure of the LAA.[58,59] Pre-procedure, TEE is performed for assessment of LAA anatomy and size and to exclude LA/LAA thrombus, which is an absolute contraindication to the procedure. Specific set of measurements need to be obtained, depending on the type of device being used. The actual procedure is performed under complete TEE guidance, which is used for guiding the trans-septal puncture, verifying position of the delivery sheath, aiding delivery and deployment of the device at the LAA ostium, confirming successful deployment and stability of the device, and to rule out any procedural complications [Figure 53].

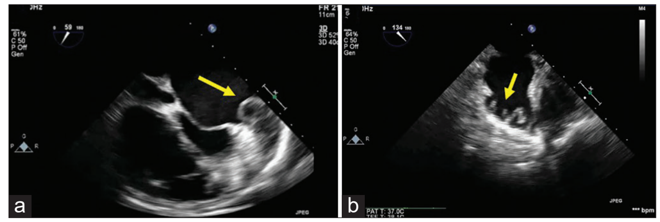

Figure 51: (a) A large left atrial thrombus (arrow). (b) Comb-like parallelly arranged pectinate muscles (arrow)

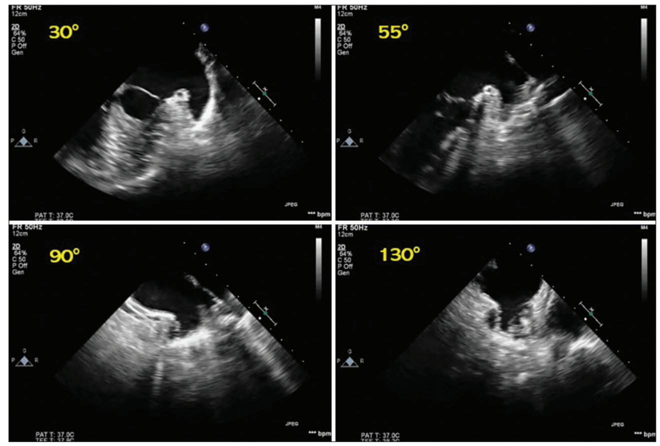

Figure 52: Visualization of the left atrial appendage in different imaging planes

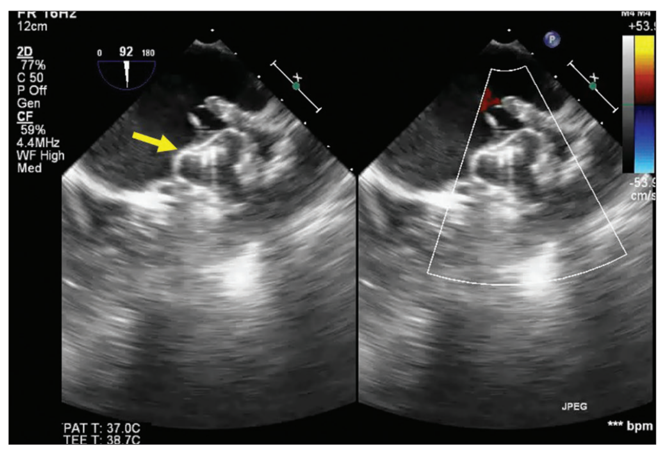

Figure 53: A Watchman® left atrial appendage occlusion device in place (arrow). The right-side image shows color Doppler evaluation to rule out any residual peri-device leak

Patients undergoing transcatheter aortic valve implantation

Accurate sizing of the aortic annulus is a very important measure for a successful outcome of transcatheter aortic valve implantation (TAVI). Conventionally, cardiac CT is used for this purpose because of its greater accuracy. Routine 2D TEE is unreliable since a single linear measurement in one view cannot accurately reflect the annulus which frequently is oval in shape. When compared to cardiac CT, it consistently underestimates the annulus size. In comparison, 3D TEE fares better, but again undersizes the annulus.[60] Though the difference in values is about 9.6%, the absolute value is small and has a reasonable correlation. 3D underestimates because of its lower resolution, with the difference more for area than perimeter. However, 3D TEE can be a useful alternative whenever cardiac CT is not possible for some reason (e.g. renal dysfunction). There have been some studies reporting good correlation of 3D TEE with cardiac CT. Additionally, 3D TEE can measure the length of the aortic leaflet and the distance of the left main ostium from the aortic annulus, which is not possible with 2D TEE. However, dropouts due to significant calcification are a frequent problem.

Following is the recommended technique for TAVI-specific aortic valve assessment using 3D TEE[61] [Figures 54-56 and Video 40a, b].

- Optimize 2D image in the 3-chamber long-axis view
- Use 3D zoom
- Include LVOT and the aortic root till the sinotubular junction completely
- Acquire in 3D mode
- Align the sagittal and coronal lines to get the long-axis of the LVOT and aorta
- Then align the transverse line below the hinge point perpendicular to the above 2 lines
- Measure aortic annulus area or diameter
- Distance of left and right coronary arteries from the annulus can also be measured
- Leaflet length can be measured.

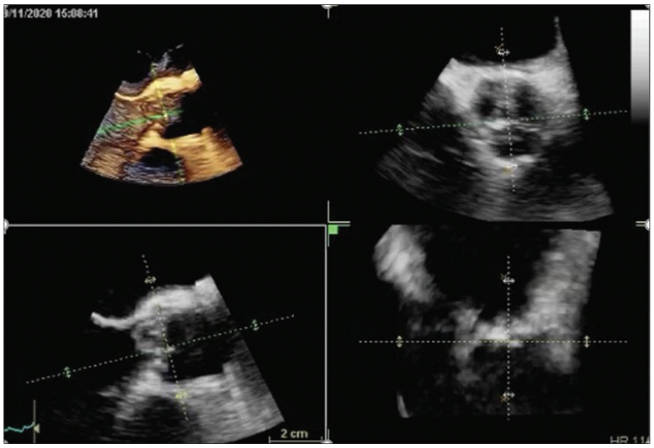

Figure 54: Use of three-dimensional echocardiography with multiplanar reconstruction for selecting appropriate image plane for obtaining various aortic measurements

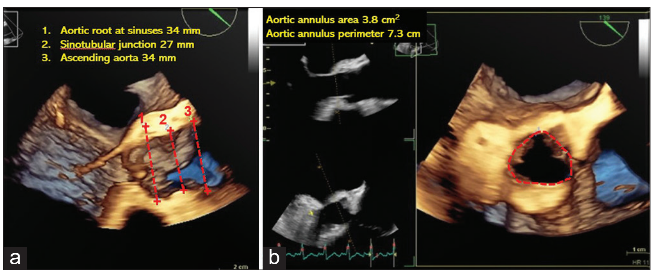

Figure 55: Three-dimensional transesophageal echocardiographic measurement of aortic root dimensions. (a) Diameter measurement of aortic root at the sinus of valsalva, sinotubular junction and ascending aorta, (b) Measurement of aortic annular area and perimeter

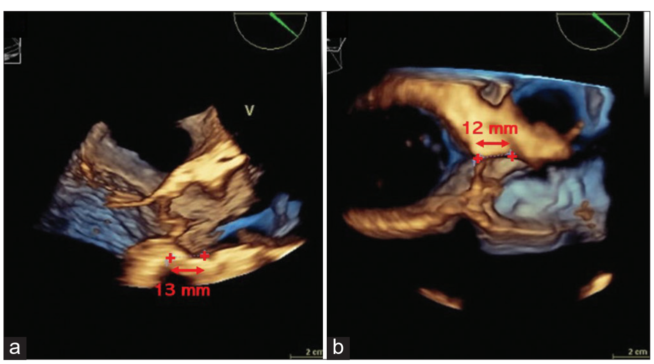

Figure 56: Three-dimensional transesophageal echocardiography for the measurement of coronary ostial height from the aortic annulus. (a) Right coronary ostial height, (b) Left coronary ostial height

Intraprocedural fusion imaging, combining fluoroscopy with 3D TEE has been reported to be feasible for valve deployment and successful outcome. Although the use of intraprocedural TEE in TAVI is now limited, it does have its advantages when used. It has been shown to reduce procedure times and lower outcomes of kidney injury. An added advantage TEE provides compared to fluoroscopy is its ability to assess ventricular function, associated valve disease, especially the MV disease, and procedural complications such as pericardial effusion.

Tricuspid valve and interventions

Ideally, imaging of the TV for transcatheter or surgical interventions requires both 2D and 3D TEE for better understanding of the valve. TTE is superior in many patients, but TEE is more flexible and provides for more viewing planes at mid- and lower-esophageal plus transgastric levels. During the intervention, TEE is preferred because imaging can be done without any restrictions or limitations to the operator while guiding the interventionist.

Challenges in TEE evaluation of TV when compared to MV are:

- TV is a more distant structure
- Lower-esophageal view is less clear due to the curve of the esophagus
- TV has thin leaflets and hence more dropouts
- Limited imaging windows available for TV visualization.
- TV is more prone for artifacts originating from other structures like atrial septum

2D TEE imaging of TV starts at the level of ME 0° four-chamber view [Figure 57] with focus on septal leaflet (which is a constant structure).[62] Anterior or posterior leaflets vary depending on the level and angle at which imaging is done. The anterior tricuspid leaflet (ATL) is seen when the transducer is withdrawn slightly and the aortic valve which is at a higher level comes into view, while a lower level will show the posterior tricuspid leaflet (PTL). A biplane on a 3D TEE transducer in ME 0° four-chamber view provides for accurate identification of these two leaflets, where the ATL can be identified due to its proximity to the aorta in the orthogonal view with the opposite leaflet being the PTL.[63] Additional views are at SAX [Figure 58] and bicaval views [Figures 59 and 60]. Lower-esophageal level just before the gastro-esophageal junction is the preferred view for an uninterrupted view of the annulus, its sizing and leaflet imaging (structural and color Doppler). The PTL is seen close to the coronary sinus and the opposite leaflet is the ATL. Next is the upper transgastric view with all three leaflets [Figure 61] and commissures seen in a transverse cut, seen between 0° to 30°, with the posterior annulus in the near field. It is then followed by a deep transgastric view with rightward and anterior flexion in which all three leaflets with 2 commissures can be seen [Figure 62]. The septal leaflet is close to the atrial septum, the ATL in the middle and PTL being the other. Off-axis views [Figure 63] are encouraged so that maximum information is obtained at all levels with varying angles and rotations.

3D TEE has become a highly accurate and reliable imaging approach for TV evaluation [Figures 64-66].[64] The axial resolution is generally better than the lateral and elevation resolution, hence the ideal imaging plane should be first identified and thereafter multiple datasets should be acquired. It is important to include adjacent structures

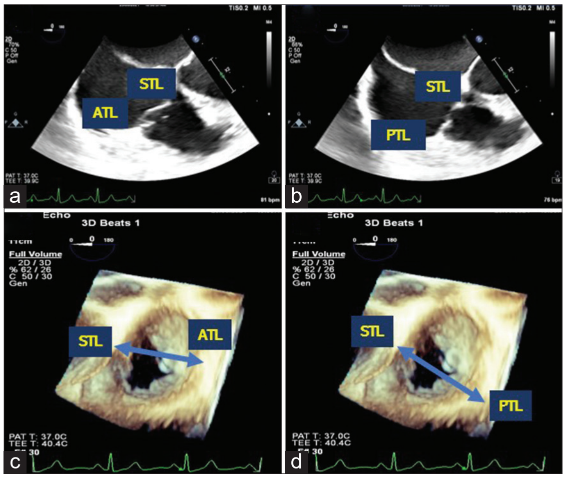

Figure 57: Two-dimensional mid-esophageal four-chamber view of tricuspid valve at a higher level with ATL viewed (a), and at a lower level with PTL viewed (b). (c and d) Three-dimensional image of tricuspid valve with arrows showing the angles it has been imaged to obtain STL, ATL and PTL. ATL: Anterior tricuspid leaflet, PTL: Posterior tricuspid leaflet, STL: Septal tricuspid leaflet

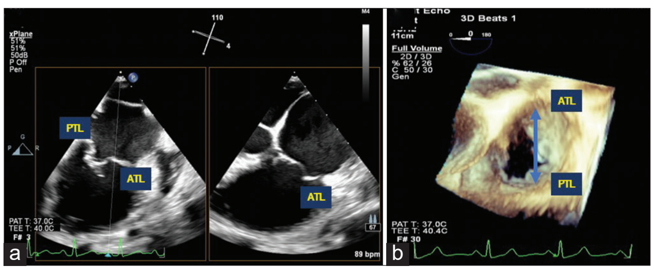

Figure 59: (a) Two-dimensional mid-esophageal bicaval view of tricuspid valve in left image, with corresponding orthogonal view in the right image. (b) Three-dimensional image of tricuspid valve with arrow showing the angle it has been imaged to obtain ATL and PTL. ATL: Anterior tricuspid leaflet, PTL: Posterior tricuspid leaflet

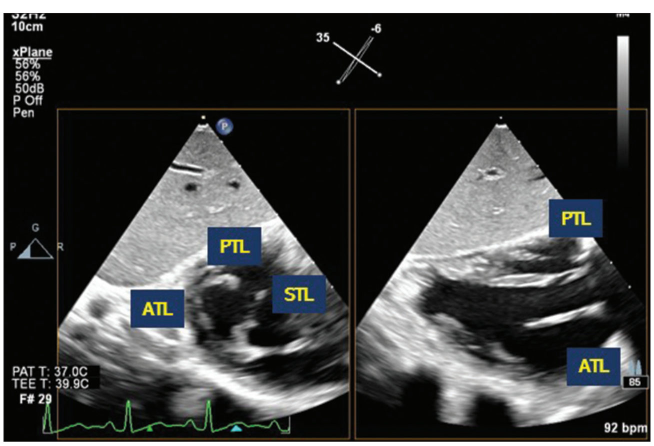

Figure 61: Two-dimensional transgastric biplane view. All three leaflets of tricuspid valve are seen in the left image, while the corresponding image on right shows PTL and ATL. ATL: Anterior tricuspid leaflet, PTL: Posterior tricuspid leaflet, STL: Septal tricuspid leaflet

[Figures 67 and 68] during acquisition for better anatomic understanding of the TV anatomy (aorta for ATL and atrial

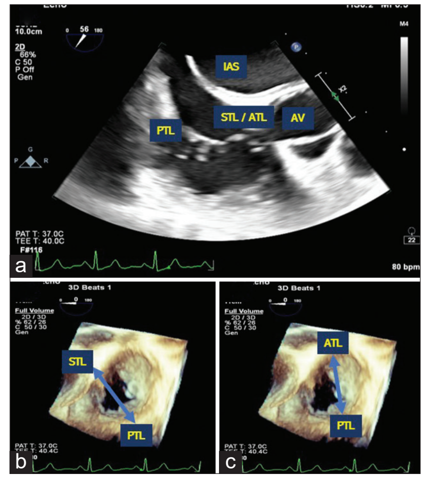

Figure 58: (a) Two-dimensional mid-esophageal short-axis view of tricuspid valve. (b and c) Three-dimensional image of tricuspid valve with arrows showing the angles it is to be imaged to obtain STL, ATL and PTL. ATL: Anterior tricuspid leaflet, AV: Aortic valve, IAS: Interatrial septum, PTL: Posterior tricuspid leaflet, STL: Septal tricuspid leaflet

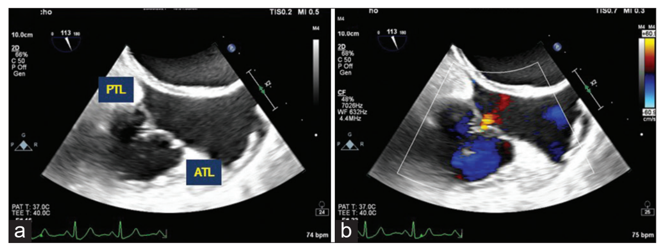

Figure 60: (a) Two-dimensional mid-esophageal bicaval view of tricuspid valve showing ATL and PTL. (b) Mild tricuspid regurgitation. ATL: Anterior tricuspid leaflet, PTL: Posterior tricuspid leaflet

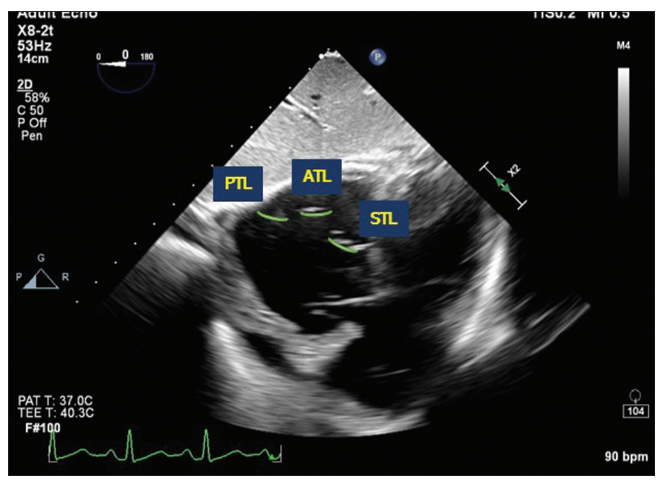

Figure 62: Two-dimensional deep transgastric view of all three leaflets of tricuspid valve. ATL: Anterior tricuspid leaflet, PTL: Posterior tricuspid leaflet, STL: Septal tricuspid leaflet

septum for septal leaflet). The coronary sinus entry is usually located near the commissure between the posterior and septal leaflets from the atrial side. When acquired from lower-esophageal four-chamber view, from the atrial side, the septal, posterior and anterior leaflets can be identified along

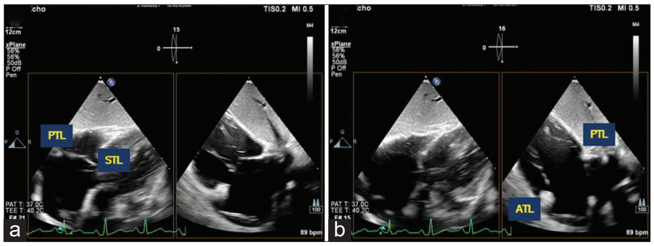

Figure 63: Two-dimensional deep transgastric view of tricuspid valve in systole (a) and diastole (b). Four-chamber view is seen in the left image and two-chamber view in the right image. ATL: Anterior tricuspid leaflet, PTL: Posterior tricuspid leaflet, STL: Septal tricuspid leaflet

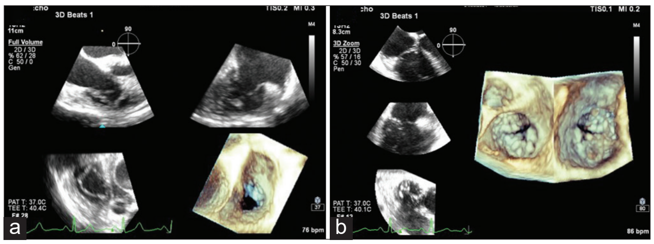

Figure 65: Three-dimensional view of tricuspid valve, from atrial (a) and ventricular (b) sides

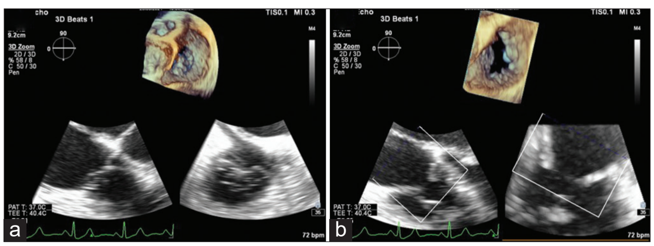

Figure 66: Three-dimensional view of tricuspid valve in systole (a) and diastole (b)

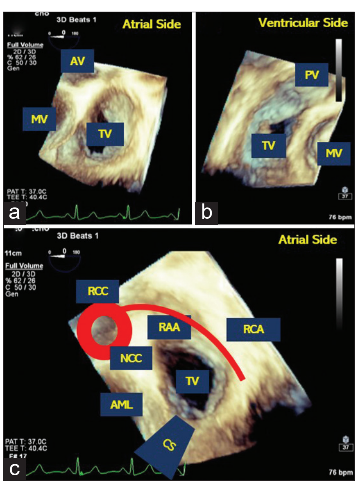

Figure 68: Three-dimensional view of TV, showing various adjacent structures from atrial and ventricular sides. (a) AV and MV, (b) PV and MV, (c) RCC and NCC of AV, AML, CS, RAA and RCA. AML: Anterior mitral leaflet, AV: Aortic valve, CS: Coronary sinus, MV: Mitral valve, NCC: Noncoronary cusps, PV: Pulmonary valve, RAA: Right atrial appendage, RCA: Right coronary artery, RCC: Right coronary cusps, TV: Tricuspid valve

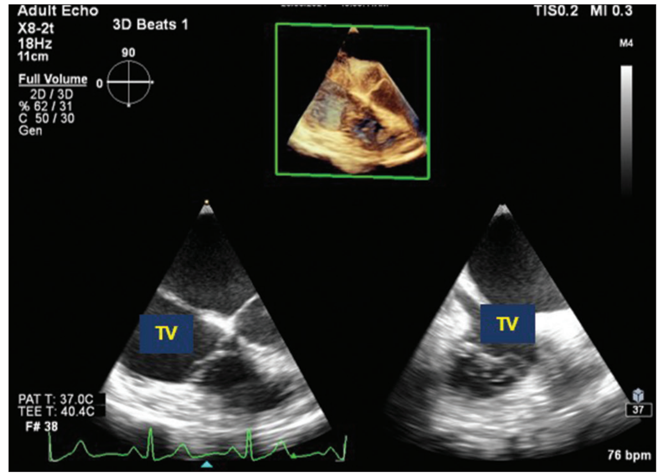

Figure 64: Initial scout three-dimensional view of tricuspid valve. Left image is at 0º mid-esophageal view with corresponding bicaval view in the right image

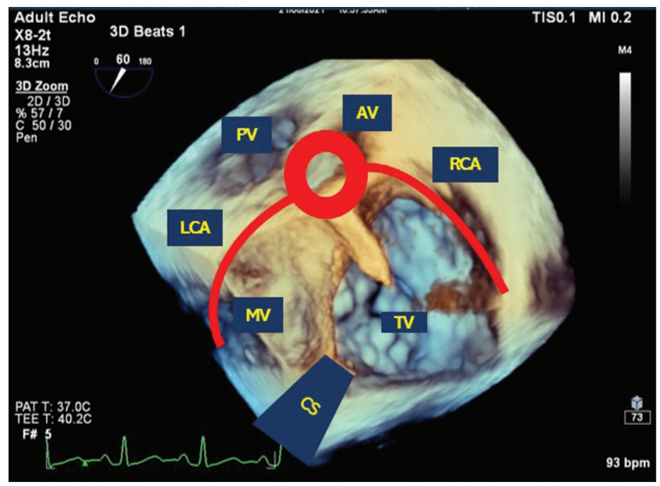

Figure 67: Three-dimensional view of all the valves, coronary arteries and coronary sinus. AV: Aortic valve, CS: Coronary sinus, LCA: Left coronary artery, MV: Mitral valve, PV: Pulmonary valve, RCA: Right coronary artery, TV: Tricuspid valve

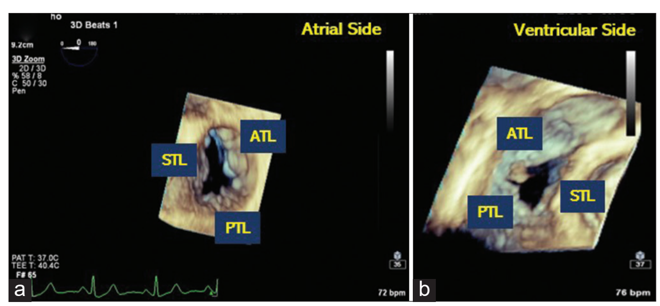

Figure 69: Three-dimensional view of tricuspid valve, from atrial (a) and ventricular (b) sides showing the three leaflets. ATL: Anterior tricuspid leaflet, PTL: Posterior tricuspid leaflet, STL: Septal tricuspid leaflet

with their corresponding commissures [Figures 69 and 70]. The valve should be imaged from both atrial and ventricular sides [Figure 71]. Alternative approach is to acquire TV 3D dataset from the bicaval view.

Pre procedural imaging for interventions includes assessing the annulus, its size, its shape, leaflet morphology, leaflet function, amount of calcification, coaptation, commissures, severity of tricuspid regurgitation (TR) and anatomical relation of TV to adjacent structures.

MitraClip®, and more recently TriClip®, by trans-jugular approach have been employed for TV edge-to-edge repair in patients with severe TR.[65] It is important to align the annular plane as perpendicular as possible to the ultrasound beam. Lower-esophageal four-chamber view with simultaneous biplane imaging is ideal for imaging the TR, optimizing device placement and grasping of leaflets. This same view in 2D TEE can be used for measuring gradients. Deep transgastric views are best to assess for clip positioning. 3D TEE provides for better imaging structurally and for assessing TR. Avoid deep transgastric view for TR after clip is in place due to the shadowing from the device.

Forma® and Trialign® are the other repair devices. In the Forma® device implantation, the landing zone is identified, the route of the anchor is monitored in RV and TR severity is assessed.[66] During implantation, TEE is crucial in guiding the catheter, tracing path of device catheter, anchor deployment at the RV wall for stabilizing the device and for confirming optimal position of the device. In Trialign®, pledgeted sutures are used across the posterior annulus and 3D TEE provides for accurate placing of pledgets. The Cardioband® is a system that is employed along the annulus and 3D TEE is invaluable for providing *en face* view of the annulus and its size. This can be obtained from the ME RV inflow-outflow view at 50° to 70°. Supplementary views are ME four-chamber view and transgastric views.

Role in Special Settings

Point-of-care ultrasound

The use of point-of-care ultrasound (POCUS) as a diagnostic assist in many scenarios is rapidly rising. It is now increasingly being used by anesthesiologists, critical care teams and in emergency rooms. Its utility lies in quick diagnostics and monitoring in the care of cardiac and non-cardiac patients. Transthoracic POCUS is now routinely applied in many areas but use of TEE for this purpose is still a slowly progressing field. The scope of practice and application of PCOUS TEE are still not defined clearly, but the requirement is very much there. Paradoxically, the success rate of good images obtained is more in TEE than TTE.[67,68]

POCUS TEE is broadly based on 5 essential views for easy, quick and practical application-

- ME four-chamber view at 0°,
- ME SAX view of aortic valve at 45°-60°,
- ME LV two-chamber view at 90°,
- ME LV long-axis view at 110°,
- ME bicaval view at 90°.

Additionally, transgastric SAX views of LV and aortic views are also being evaluated.

TTE images can be suboptimal in about 50 percent of patients due to trauma, ventilatory support, body habitus, surgical bandages and due to lung diseases. POCUS TEE can be invaluable in such situations targeting ventricular size and function, volume status, status of pericardial effusion and guiding pacemakers, cannulations, and other procedures. POCUS TEE has also been demonstrated to be of much utility in cardiopulmonary resuscitation,[69] as discussed subsequently.

Presently, the interest is on how quickly TEE can be integrated into POCUS for improved patient management with a simplified and effective protocol.

Temporary mechanical circulatory support

Intra-aortic balloon pump

Before insertion of an intra-aortic balloon pump (IABP), TTE or TEE is done to exclude significant aortic regurgitation (AR),

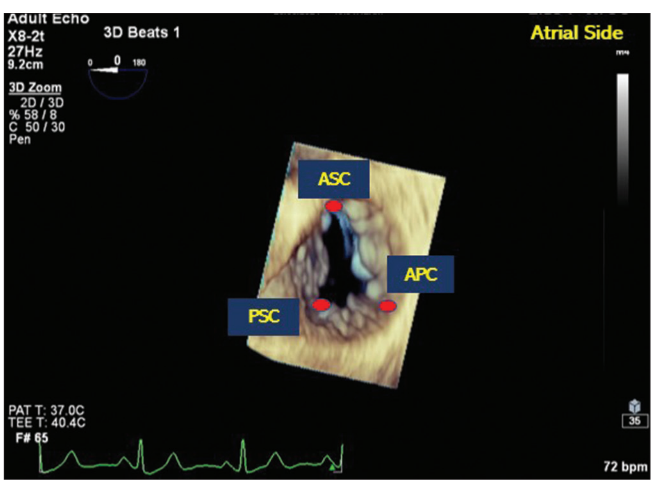

Figure 70: Three-dimensional view of tricuspid valve, from atrial side showing the three commissures. APC: Anteroposterior commissure, ASC: Anteroseptal commissure, PSC: Posteroseptal commissure

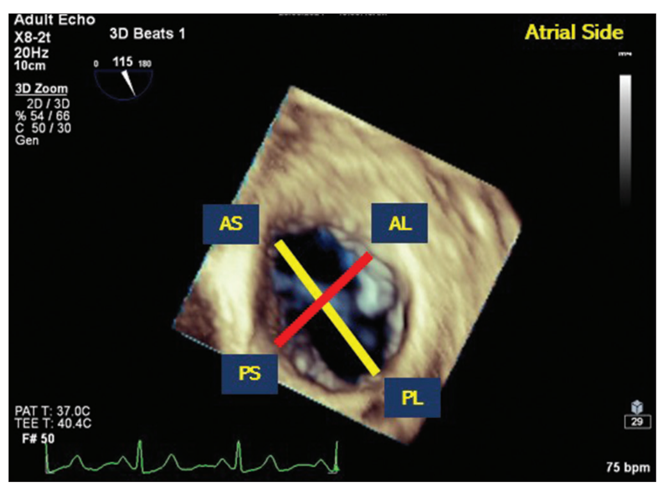

Figure 71: Three-dimensional view of tricuspid annulus, from atrial side. Yellow line is the high point, while the red line is the low point of the saddle shaped annulus. AL: Anterolateral, AS: Anteroseptal, PL: Posterolateral, PS: Posteroseptal

aortic dissection, or aneurysm, which are contraindications to IABP insertion. Though not regularly used, TEE can be helpful in certain situations. In hemodynamically unstable patients with poor acoustic window, TEE may be needed to obtain adequate images. Moreover, TEE is generally superior to TTE for assessment of aortic valve and aortic pathologies. TEE may also demonstrate mobile aortic atheroma, which may be relevant for IABP insertion. ME aortic valve and ascending aorta long-axis views provide good visualization of aortic root and ascending aorta, whereas ME descending aorta long- and short-axis views permit visualization of entire descending thoracic aorta [Table 1]. At upper esophageal level, aortic arch short- and long-axis views can show openings of all the three arch vessels.

During IABP insertion, position of the guidewire is confirmed in the descending aorta. The balloon is then inserted and advanced till the tip is about 2-5 cm below the left subclavian artery [Video 41a and b]. In unusual situations like aortic dissection or a graft, IABP will have to be positioned at different sites. Monitoring includes LV function assessment, severity of AR, changes in location of atheroma or an appearance of dissection.

Ventricular assist device

The main purpose of TEE is to guide implantation and to detect immediate post-procedural complications. Though there are different types of VAD, the overall concept is same when it comes to the use of TEE in pre-, intra- and post-procedural imaging.

Before the procedure, TEE can be used for confirming the need for VAD and to evaluate for contraindications like significant aortic valve disease, MS, intracardiac thrombus, aortic dissection, pulmonary stenosis or intracardiac shunt.[70] The required TEE views include ME four-chamber view, ME short- and long-axis views for aortic valve along with deep transgastric views and views for ascending and descending aorta imaging.

At the time of insertion, TEE can guide positioning of the inflow cannula at the LV apex [Figures 72-74] or in the LA, while the outflow cannula is placed in the ascending aorta.[71-74] Depending on the device used, atrial septum is assessed for septal puncture. Once the device is in place, it is evaluated for its flow and functioning of aortic, tricuspid, and mitral valves, presence of air, shift of interventricular septum, RV and LV dilatation, size and function, tamponade, and flow problems (kinking or obstruction).

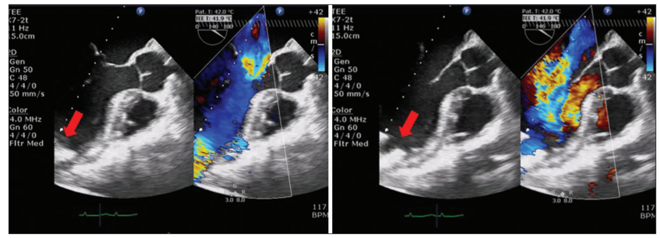

Figure 72: Left ventricular assist device inflow cannula is seen at the left ventricular apex (red arrows). Color flow is seen coming from mitral valve and entering the inflow cannula

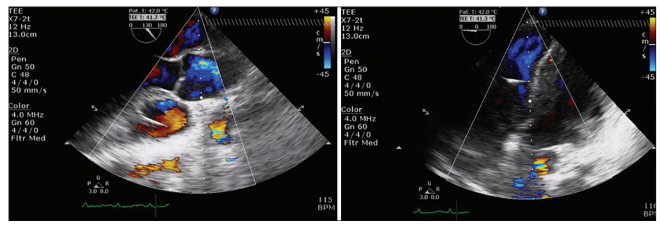

Figure 73: Characteristic finding of continuously closed aortic valve in a patient on left ventricular assist device support. The flow from the inflow cannula bypasses the aortic valve and directly enters the ascending aorta via the outflow cannula

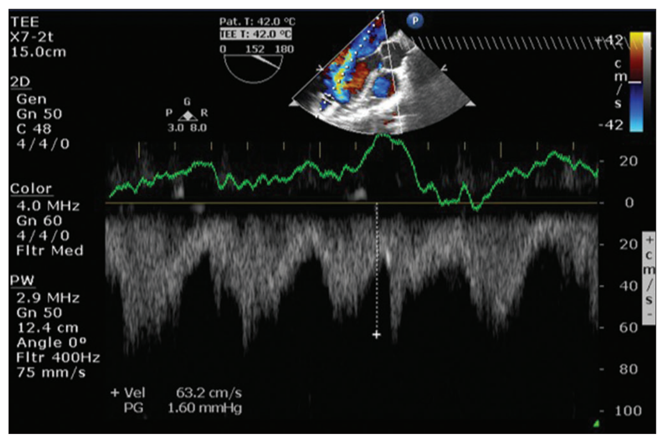

Figure 74: Doppler sampling at the inflow cannula, with normal flow velocities

Cardiopulmonary resuscitation

TEE has emerged as a useful imaging modality during cardiopulmonary resuscitation (CPR). There are several ways in which TEE can be helpful-

1. TEE in cardiac arrest has been shown to be helpful in identifying presence or absence of intrinsic cardiac contraction and distinguishing pulseless electrical activity from true asystole,
2. It helps in the dynamic evaluation of effectiveness of chest compressions,[75]
3. In as many as 20% of cases, it can identify the cause of arrest such as severe hypovolemia, cardiac tamponade, massive pulmonary embolism, aortic dissection, and myocardial rupture.

A major advantage of TEE in this setting is that it does not come in the way of the resuscitating team and allows the CPR team to continue and maintain effective CPR. At the same time, it provides crucial images of ventricular function and pericardial effusion in real time, which have great diagnostic and prognostic value.

Imaging protocol

CPR TEE protocol comprises of only 6 views[68]

- ME four-chamber view,
- ME two-chamber view,
- ME long-axis view,

- ME bicaval view,
- Transgastric SAX view, and
- Descending aorta views.

In our opinion CPR TEE can be performed by anyone (cardiologist or non-cardiologist) who has performed 50 independent elective TEEs in the echocardiography lab/operating room/ICU.

Safety and contraindications

Apart from all contraindications for elective TEE, the specific contraindication for TEE during CPR are-

- Possibility of esophageal or gastric rupture, and
- Lack of definitive airway.

No study has been performed to address the safety of CPR TEE. However, in a case series,[76] TEE was shown to be safe without any added complication risk compared to elective TEE and allowed the patients to be shocked when the TEE probe was in place. A literature review of 55 publications involving 277 patients undergoing TEE during CPR concluded that TEE during CPR was helpful in guiding resuscitation and could be used even by non-cardiology physicians safely.[77] It added valuable incremental diagnostic and prognostic information which in select cases could be lifesaving.

Micro-transesophageal echocardiography

The micro-TEE probe was primarily designed for application in pediatric patients. But over time it has been used in adults in certain clinical scenarios. The overall aim has been to keep the probe small, not too invasive, and less injurious to the patient. The standard TEE probe tip generally measures approximately 10-15 mm in thickness while the 3D probe is about 1.5 mm thicker. To a large extent, this thick probe is well tolerated but during intubation and while imaging it always carries the risk of injury to the mucosal lining of the oral cavity, esophagus, and stomach. In contrast, the micro-TEE probe measures about 7.5 mm in thickness at its tip and about 5 mm at the shaft, which is half the size of the adult probe.[78,79] This ensures easy intubation, less mucosal injury, less hemodynamic compromise with lower complication rates [Table 2]. In India where most TEEs are done under local anesthesia, this would be a boon to the operator and the patient. However, the tradeoff means that the thin probe holds less crystals which in turn results in suboptimal resolution and quality of images, though not affecting the accuracy of the images visualized. The lower resolution can be a challenge when used for imaging difficult/deeper structures, complex pathologies, and for transcatheter heart interventions and in peri-operative TEE. Optimal images are better at 6 to 7 cm depth with loss of image quality in the far field. Accuracy of measurements are acceptable, but with slight underestimation.

Micro-TEE probe has about 32 elements, phased-array, providing grey scale imaging, M-mode, color and spectral Doppler (both PW and CW) but 3D imaging is not possible. It has a frequency range of 3.2 to 7.4 MHz, capable of good frame rates, multiplane 180° imaging, angle display, antero-posterior movements, temperature check and a locking mechanism. Probe manipulation is the same as that for regular TEE probe.

The micro-TEE probe is inserted either by the nasal route (with a drawn mandible, either by blind introduction or by laryngoscope guidance) or orally, as per standard TEE intubation methods.[80] Epistaxis can happen occasionally during nasal approach, but it is usually minimal. Imaging done is as per routine protocol as followed with standard TEE probe. There are single use probes, but these are expensive.

Use of micro-TEE has been explored in transcatheter heart interventions where it has shown promise and feasibility for some select procedures (PFO closure, ASD closure, LAA closure, MitraClip® implantation, aortic valve implants, guiding septal punctures, AF ablation, and pediatric cardiac surgeries).[81] They were done under local anesthesia, thus reducing procedural time, reducing cost and causing less discomfort to the patient. However, suboptimal imaging was a frequent challenge faced, especially with deeper structures, along with slight undersizing of device implants. It can be used as an alternative in certain situations in adults. Quality of 2D and color Doppler images are better in neonates and children, especially in underweight children.[82] Larger esophagus in adults and older children leads to reduced stability of the thin transducer often requiring additional flexion for good images. Though it has been in clinical use for a decade, availability of the probe is still limited.

Role of Training on Mannequin Simulator

TEE is a semi-invasive procedure and is associated with patient discomfort and rarely, minor and major complications. For these reasons, TEE is not as easily repeatable as TTE. Therefore, the goal of any TEE examination is to ensure maximum yield in the

Table 2: Advantages and limitations of micro-transesophageal echocardiography probe

Advantages	Limitations
Easy intubation	Lower spatial resolution
Less discomfort and better tolerated over prolonged period of time	Lower acoustic coupling due to its small size in the esophagus
Less traumatic	No 3D imaging
Can be done under local anesthesia	
Less complications	
Can be used in infants and children	
Superior imaging and lower cost when compared to intracardiac echocardiography	

3D: Three-dimensional

shortest possible time and with minimum patient discomfort and risk. The skillset required to meet these objectives is demanding. Considerable amount of hands-on-training and observership are required to relearn the cardiac structural orientation from the perspective of esophageal or transgastric access and to learn TEE probe manipulations needed to acquire optimum images from a variety of imaging windows.

There are only a limited number of targeted TEE studies being done in most of the echocardiography labs and therefore, there is limited access to hands-on training for the cardiology fellows. Furthermore, in conscious patients or in emergency situations, only a limited time is available for TEE study and most often the study is performed by senior faculty to reduce examination time and increase the yield of the study. In cardiac operation theatre, however, the situation is ideal to learn and practice TEE imaging as the patient is under general anesthesia and there is no time-pressure, unlike in a busy echocardiography lab. However, quite often, there is 'professional competition' or 'turf war' for training and ownership between cardiovascular anesthesiologists and cardiology fellows, impeding learning opportunities for the latter.

In this context, the development of computer simulation in medicine has been a great boon. The availability of highly sophisticated TEE simulator mannequins has created an excellent opportunity to thoroughly learn and practice TEE hands-on, under expert guidance, and at one's own pace of learning [Figure 75].

A typical TEE simulator has a life size mannequin torso and a real size dummy TEE probe with all the regular control knobs on the handle. The TEE probe is connected to a fast-processing computer with the advanced simulation software. Just like a real-life TEE, the probe can be inserted in the mannequin's mouth and can be moved up or down, torqued and the imaging plane can be rotated from 0°-180° electronically. The computer memory has a comprehensive 3D data of human heart structure and function derived from 3D CT and magnetic resonance imaging datasets of normal hearts to create realistic, anatomically accurate, animated images of a human heart which is fully interactive.

The mannequin is mostly empty inside and has a magnetic field. There are tiny electromagnetic sensors embedded in the dummy TEE probe. The sensors track the position of the transducer lens of the dummy TEE probe in real time within the mannequin torso, just like a global positioning system that can track the location of a moving object. From the position of the probe and from the electronic feedback from the sham controls of the dummy probe, exact imaging plane is determined. Interaction between this information and the 3D anatomical model of the heart stored in the computer memory generates real time cross-sectional 'echocardiographic' images on the monitor. The operator gets an experience like that of performing real life, real-time imaging, with quick feedback from operating controls and manipulation of the probe inside the mannequin. The virtual, animated, 3D anatomical heart model is also displayed on the computer monitor next to a simulated echocardiography image. The side-by-side display of the actual anatomical section and the simulated echocardiography images allows learner to develop a much better spatial-anatomical orientation for all the imaging planes. This feature greatly helps in improving conceptual understating of TEE imaging as to why particular structures are visualized in any given view.

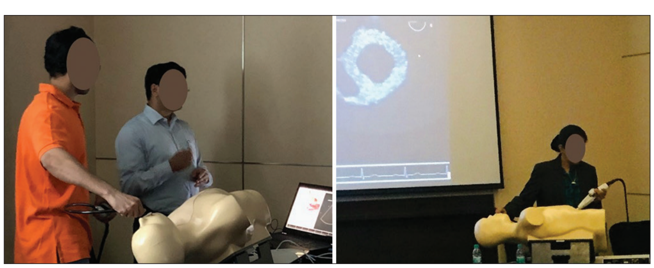

Figure 75: The use of mannequin simulator for imparting "hands-on" training in transesophageal echocardiography

Certain common pathologies can also be programmed in the computer for practicing focused views required for better delineating those pathologies. Various echocardiographic modalities such as M-mode, color Doppler, PW Doppler and CW Doppler along with measurement calipers can be added to the software to permit quantification as well. In a small study, cardiology fellows, who were first trained for one month on mannequin simulator before joining traditional on-patient training, were found to be more proficient in performing TEE on patients than the fellows trained only by traditional on-patient training.[83] The mannequin trained fellows could obtain a greater number of TEE views on the patients without assistance, could perform TEE in a shorter duration of time, had more comfort level in handling the TEE probe and consistently scored higher on formal assessment.

Conclusions

TEE is an immensely useful cardiac diagnostic modality. However, it requires technical expertise to ensure maximum diagnostic yield with minimum patient discomfort and the risk of complications. Thorough understanding of echocardiographic-anatomic orientation from TEE perspective and adequate hands-on training are essential to gain competency in TEE. Additionally, paying careful attention to patient preparation and periprocedural monitoring and following a systematic protocol for image acquisition are helpful in achieving the best outcomes with this modality.

Acknowledgements

The authors gratefully acknowledge the support of GE Education, India for providing the 'HeartWorks'® (Intelligent Ultrasound®) mannequin for teaching and training purpose and for deriving the anatomical drawings of standard TEE views.

The authors are also thankful to Ms UK Janani Priyadarsini and Ms Shruti Bansal for their help in preparing artwork for this document.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Video legends

Video 1: Mid-esophageal 0° five-chamber view.

Video 2: Mid-esophageal 0° four-chamber view.

Video 3: Mid-esophageal bi-commissural view.

Video 4: Mid-esophageal two-chamber view.

Video 5: Mid-esophageal long-axis view.

Video 6: Mid-esophageal ascending aorta long-axis with right pulmonary artery short-axis view.

Video 7: Upper-esophageal 0° main and right pulmonary artery long-axis view.

Video 8: Upper-esophageal 0° right superior pulmonary vein long-axis and superior vena cava short-axis view.

Video 9: Upper-esophageal 30°–60° right superior and inferior pulmonary vein view.

Video 10: Upper-esophageal 0° right atrial appendage, superior vena cava and ascending aorta view.

Video 11: Mid-esophageal 60° aortic valve short-axis and right ventricular inflow-outflow view.

Video 12: Mid-esophageal 70°–90° inferior vena cava right atrial junction view.

Video 13: Mid-esophageal 90°–110° superior vena cava right atrial junction view.

Video 14: Mid-esophageal 60° left atrial appendage left superior pulmonary vein view.

Video 15: Mid-esophageal 120° left superior and inferior pulmonary vein view.

Video 16: Lower-esophageal coronary sinus view.

Video 17: Lower-esophageal pleural spaces. (a) Right pleural space, (b) left pleural space.

Video 18: Transgastric basal left ventricular short-axis view.

Video 19: Transgastric mid left ventricular short-axis view.

Video 20: Deep transgastric left ventricular apical short-axis view.

Video 21: Deep transgastric left ventricular short-axis outflow views. (a) Right ventricular outflow view, (b) left ventricular outflow view.

Video 22: Transgastric left ventricular long-axis two-chamber view.

Video 23: Transgastric right ventricular inflow long-axis view.

Video 24: Transgastric left ventricular long-axis inflow-outflow view.

Video 25: Mid-esophageal descending aorta views. (a) Short-axis view, (b) long-axis view.

Video 26: Upper esophageal aortic arch short- and long-axis views with branch vessels. (a) origin of left subclavian artery, (b) origin of left common carotid artery, (c) origin of the innominate artery.

Video 27: Simultaneous biplane imaging.

Video 28: Three-dimensional zoomed transesophageal echocardiographic view of the mitral valve, as visualized from the left atrial side (i.e., the "surgeon's view"). The A2 scallop of the anterior mitral leaflet appears to be flail with ruptured chordae seen attached to it.

Video 29: Simultaneous biplane imaging for guiding transseptal puncture for transcatheter mitral valve edge-to-edge repair. The left images shows bicaval view for superior-inferior orientation while the right image shows basal short-axis view for anteroposterior orientation. IVC: Inferior vena cava, SVC: Superior vena cava.

Video 30: Aligning the clip in relation to the mitral valve. Biplane imaging is used to simultaneously orient the clip in medial-lateral (bi-commissural view, left image) as well as anteroposterior (left ventricular outflow tract view, right image) directions.

Video 31: Three-dimensional *en face* view for orientating the clip perpendicular to the mitral leaflets coaptation line.

Video 32: Aligning the clip once it has been advanced into the left ventricle.

Video 33: Atrial septal defect as visualized in the 0° mid-esophageal four-chamber view. Posterosuperior atrial rim is seen on the left side of image display, whereas the mitral rim is seen on the right side of image display.

Video 34: At 0°, withdrawing the probe to superior vena cava- right atrial junction level with clockwise rotation can visualize the opening of the right superior pulmonary vein into the left atrium.

Video 35: Atrial septal defect as visualized in the mid-esophageal 30° view.

Video 36: Atrial septal defect in the mid-esophageal 60° view. Posteroinferior atrial rim is on the left side and the aortic rim on the right side.

Video 37: Atrial septal defect in the bicaval view.

Video 38: Left atrial appendage thrombus.

Video 39: Comb-like pectinate muscles in the left atrial appendage.

Video 40: The use of three-dimensional transesophageal echocardiography for measuring coronary ostial height. (a) Left main ostium, (b) right coronary ostium.

Video 41: Intra-aortic balloon pump is seen in descending aorta short-axis view (a) just distal to the origin of left subclavian artery, and in long-axis view (b).

References

1. Hahn RT, Abraham T, Adams MS, Bruce CJ, Glas KE, Lang RM, *et al.* Guidelines for performing a comprehensive transesophageal echocardiographic examination: Recommendations from the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. J Am Soc Echocardiogr 2013;26:921-64.
2. Ryan T, Berlacher K, Lindner JR, Mankad SV, Rose GA, Wang A. COCATS 4 Task Force 5: Training in echocardiography. J Am Coll Cardiol 2015;65:1786-99.
3. Wiegers SE, Ryan T, Arrighi JA, Brown SM, Canaday B, Damp JB, *et al.* 2019 ACC/AHA/ASE Advanced Training Statement on Echocardiography (Revision of the 2003 ACC/AHA Clinical Competence Statement on Echocardiography): A Report of the ACC Competency Management Committee. J Am Coll Cardiol 2019;74:377-402.
4. Prabhu M, Raju D, Pauli H. Transesophageal echocardiography: Instrumentation and system controls. Ann Card Anaesth 2012;15:144-55.
5. Kanagala P, Bradley C, Hoffman P, Steeds RP, British Society of Echocardiography. Guidelines for transoesophageal echocardiographic probe cleaning and disinfection from the British Society of Echocardiography. Eur J Echocardiogr 2011;12:i17-23.
6. Rutala WA, Weber DJ, and the Healthcare Infection Control Practices Advisory Committee. Guideline for Disinfection and Sterilization in Healthcare Facilities; 2008. Update: May, 2019. Available from: https://www.cdc.gov/infectioncontrol/guidelines/disinfection/. [Last accessed on 2021 Jun 25].
7. American Institute of Ultrasound in Medicine. Guidelines for Cleaning and Preparing External- and Internal-Use Ultrasound Transducers and Equipment Between Patients as well as Safe Handling and Use of Ultrasound Coupling Gel. Available from: https://www.aium.org/officialStatements/57. [Last accessed on 2021 Jun 25].
8. Spach DH, Silverstein FE, Stamm WE. Transmission of infection by gastrointestinal endoscopy and bronchoscopy. Ann Intern Med 1993;118:117-28.
9. Philips Ultrasound. Care and Cleaning of Ultrasound Systems and Transducers. Available from: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwi555Hcy7DxAhWsumMGHQO-Au4QFjAAegQIAxAD&url=https%3A%2F%2Fwww.philips.com%2Fc-dam%2Fb2bhc%2Fmaster%2Fwhitepapers%2Fultrasound-care-and-cleaning%2Fcare-and-cleaning-manuals%2FCC-US.pdf&usg=AOvVaw2q9YfidC7eR9UHPtX62nej. [Last accessed on 2021 Jun 25].
10. Healthcare Ultrasound U.S. Accessories and Supplies. Available from: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact =8&ved=2ahUKEwj3ooHdzLDxAhVyILcAHVD0D_kQFjAAegQIAxAD&url=https%3A%2F%2Fwww.gehealthcare.com%2F-%2Fmedia%2F29ac5632d79f445ab2f5703cdf3daded.pdf%3Fla%3Den-us&usg=AOvVaw1DF9wHXY-w3cr6QA6Qoxan. [Last accessed on 2021 Jun 25].
11. 10 Steps to Successful TEE Probe Reprocessing. Available from: https://www.csmedicalllc.com/tee-complete-care. [Last accessed on 2021 Jun 25].
12. Frazin L, Talano JV, Stephanides L, Loeb HS, Kopel L, Gunnar RM. Esophageal echocardiography. Circulation 1976;54:102-8.
13. Zaroff JG, Picard MH. Transesophageal echocardiographic (TEE) evaluation of the mitral and tricuspid valves. Cardiol Clin 2000;18:731-50.
14. Khandheria BK, Seward JB, Tajik AJ. Transesophageal echocardiography. Mayo Clin Proc 1994;69:856-63.
15. Burkule N, Govind SC, Sola S, Bansal M. The Indian Academy of Echocardiography practice guideline for the performance of transesophageal echocardiographic evaluation of a patient with cerebrovascular stroke. J Indian Acad Echocardiogr Cardiovasc Imaging 2018;2:1-18.
16. American Society of Anesthesiologists and Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. Practice guidelines for perioperative transesophageal echocardiography. An updated report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. Anesthesiology 2010;112:1084-96.
17. Patil T, Ambli S, Badge V. Trans-esophageal echocardiography during off-pump coronary artery bypass grafting. J Indian Acad Echocardiogr Cardiovasc Imaging 2019;3:12-6.
18. Pollak A, Swaminathan M. Intraoperative assessment of mitral regurgitation. J Indian Acad Echocardiogr Cardiovasc Imaging 2019;3:66-70.
19. Pearson AC, Castello R, Labovitz AJ. Safety and utility of transesophageal echocardiography in the critically ill patient. Am Heart J 1990;119:1083-9.
20. Foster E, Schiller NB. The role of transesophageal echocardiography in critical care: UCSF experience. J Am Soc Echocardiogr 1992;5:368-74.
21. Vedrinne JM, Duperret S, Bizollon T, Magnin C, Motin J, Trepo C, *et al.* Comparison of transesophageal and transthoracic contrast echocardiography for detection of an intrapulmonary shunt in liver disease. Chest 1997;111:1236-40.
22. American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Society of Echocardiography, American Heart Association, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, *et al.* ACCF/ASE/AHA/ASNC/HFSA/HRS/SCAI/SCCM/SCCT/SCMR 2011 Appropriate Use Criteria for Echocardiography. A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Society of Echocardiography, American Heart Association, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Critical Care Medicine, Society of Cardiovascular Computed Tomography, and Society for Cardiovascular Magnetic Resonance Endorsed by the American College of Chest Physicians. J Am Coll Cardiol 2011;57:1126-66.
23. Spier BJ, Larue SJ, Teelin TC, Leff JA, Swize LR, Borkan SH, *et al.* Review of complications in a series of patients with known gastro-esophageal varices undergoing transesophageal echocardiography. J Am Soc Echocardiogr 2009;22:396-400.
24. Samsoon GL, Young JR. Difficult tracheal intubation: A retrospective study. Anaesthesia 1987;42:487-90.
25. Fraser RS, Dvorkin J, Rossall RE, Eidem R. Left superior vena cava: A review of associated congenital heart lesions, catheterization data and roentgenologic findings. Am J Med 1961;31:711-6.
26. Tanabe K, Yoshitomi H, Oyake N, Asanuma T, Ohta T, Ishibashi Y, *et al.* Effects of supine and lateral recumbent positions on pulmonary venous flow in healthy subjects evaluated by transesophageal Doppler echocardiography. J Am Coll Cardiol 1994;24:1552-7.
27. Evans LT, Saberi S, Kim HM, Elta GH, Schoenfeld P. Pharyngeal anesthesia during sedated EGDs: Is "the spray" beneficial? A meta-analysis and systematic review. Gastrointest Endosc 2006;63:761-6.
28. American Society of Anesthesiologists Task Force on Sedation and Analgesia by Non-Anesthesiologists. Practice guidelines for sedation and analgesia by non-anesthesiologists. Anesthesiology 2002;96:1004-17.
29. Cohen LB, Delegge MH, Aisenberg J, Brill JV, Inadomi JM, Kochman ML, *et al.* AGA Institute review of endoscopic sedation. Gastroenterology 2007;133:675-701.
30. McQuaid KR, Laine L. A systematic review and meta-analysis of randomized, controlled trials of moderate sedation for routine endoscopic procedures. Gastrointest Endosc 2008;67:910-23.
31. Min JK, Spencer KT, Furlong KT, DeCara JM, Sugeng L, Ward RP, *et al.* Clinical features of complications from transesophageal echocardiography: A single-center case series of 10,000 consecutive examinations. J Am Soc Echocardiogr 2005;18:925-9.
32. Daniel WG, Erbel R, Kasper W, Visser CA, Engberding R, Sutherland GR, *et al.* Safety of transesophageal echocardiography. A multicenter survey of 10,419 examinations. Circulation 1991;83:817-21.
33. Hilberath JN, Oakes DA, Shernan SK, Bulwer BE, D'Ambra MN, Eltzschig HK. Safety of transesophageal echocardiography. J Am Soc Echocardiogr 2010;23:1115-27.
34. Saphir JR, Cooper JA, Kerbavez RJ, Larson SF, Schiller NB. Upper airway obstruction after transesophageal echocardiography. J Am Soc Echocardiogr 1997;10:977-8.
35. Kane GC, Hoehn SM, Behrenbeck TR, Mulvagh SL. Benzocaine-induced

methemoglobinemia based on the Mayo Clinic experience from 28 478 transesophageal echocardiograms: Incidence, outcomes, and predisposing factors. Arch Intern Med 2007;167:1977-82.
36. Steckelberg JM, Khandheria BK, Anhalt JP, Ballard DJ, Seward JB, Click RL, *et al.* Prospective evaluation of the risk of bacteremia associated with transesophageal echocardiography. Circulation 1991;84:177-80.
37. Wilson W, Taubert KA, Gewitz M, Lockhart PB, Baddour LM, Levison M, *et al.* Prevention of infective endocarditis: Guidelines from the American Heart Association: A guideline from the American Heart Association Rheumatic Fever, Endocarditis, and Kawasaki Disease Committee, Council on Cardiovascular Disease in the Young, and the Counc il on Clinical Cardiology, Council on Cardiovascular Surgery and A nesthesia, and the Quality of Care and Outcomes Research Interdisciplinary Working Group. Circulation 2007;116:1736-54.
38. Freitas-Ferraz AB, Rodés-Cabau J, Junquera Vega L, Beaudoin J, O'Connor K, Turgeon PY, *et al.* Transesophageal echocardiography complications associated with interventional cardiology procedures. Am Heart J 2020;221:19-28.
39. Fleischer DE, Goldstein SA. Transesophageal echocardiography: What the gastroenterologist thinks the cardiologist should know about endoscopy. J Am Soc Echocardiogr 1990;3:428-34.
40. Lang RM, Badano LP, Tsang W, Adams DH, Agricola E, Buck T, *et al.* EAE/ASE recommendations for image acquisition and display using three-dimensional echocardiography. J Am Soc Echocardiogr 2012;25:3-46.
41. Foster GP, Isselbacher EM, Rose GA, Torchiana DF, Akins CW, Picard MH. Accurate localization of mitral regurgitant defects using multiplane transesophageal echocardiography. Ann Thorac Surg 1998;65:1025-31.
42. Omran AS, Woo A, David TE, Feindel CM, Rakowski H, Siu SC. Intraoperative transesophageal echocardiography accurately predicts mitral valve anatomy and suitability for repair. J Am Soc Echocardiogr 2002;15:950-7.
43. Carpentier AF, Lessana A, Relland JY, Belli E, Mihaileanu S, Berrebi AJ, *et al.* The "physio-ring": An advanced concept in mitral valve annuloplasty. Ann Thorac Surg 1995;60:1177-85.
44. Gheorghe LL, Mobasseri S, Agricola E, Wang DD, Milla F, Swaans M, *et al.* Imaging for native mitral valve surgical and transcatheter interventions. JACC Cardiovasc Imaging 2021;14:112-27.
45. Zamorano JL, Badano LP, Bruce C, Chan KL, Gonçalves A, Hahn RT, *et al.* EAE/ASE recommendations for the use of echocardiography in new transcatheter interventions for valvular heart disease. J Am Soc Echocardiogr 2011;24:937-65.
46. Vaidyanathan B, Simpson JM, Kumar RK. Transesophageal echocardiography for device closure of atrial septal defects: Case selection, planning, and procedural guidance. JACC Cardiovasc Imaging 2009;2:1238-42.
47. Prokselj K, Kozelj M, Zadnik V, Podnar T. Echocardiographic characteristics of secundum-type atrial septal defects in adult patients: Implications for percutaneous closure using Amplatzer septal occluders. J Am Soc Echocardiogr 2004;17:1167-72.
48. Mathewson JW, Bichell D, Rothman A, Ing FF. Absent posteroinferior and anterosuperior atrial septal defect rims: Factors affecting nonsurgical closure of large secundum defects using the Amplatzer occluder. J Am Soc Echocardiogr 2004;17:62-9.
49. Cooke JC, Gelman JS, Harper RW. Echocardiologists' role in the deployment of the Amplatzer atrial septal occluder device in adults. J Am Soc Echocardiogr 2001;14:588-94.
50. Mazic U, Gavora P, Masura J. The role of transesophageal echocardiography in transcatheter closure of secundum atrial septal defects by the Amplatzer septal occluder. Am Heart J 2001;142:482-8.
51. Podnar T, Martanovic P, Gavora P, Masura J. Morphological variations of secundum-type atrial septal defects: Feasibility for percutaneous closure using Amplatzer septal occluders. Catheter Cardiovasc Interv 2001;53:386-91.
52. Al-Saady NM, Obel OA, Camm AJ. Left atrial appendage: Structure, function, and role in thromboembolism. Heart 1999;82:547-54.
53. Beigel R, Wunderlich NC, Ho SY, Arsanjani R, Siegel RJ. The left atrial appendage: Anatomy, function, and noninvasive evaluation. JACC Cardiovasc Imaging 2014;7:1251-65.
54. Agmon Y, Khandheria BK, Gentile F, Seward JB. Echocardiographic assessment of the left atrial appendage. J Am Coll Cardiol 1999;34:1867-77.
55. Strandberg M, Marttila RJ, Helenius H, Hartiala J. Transoesophageal echocardiography in selecting patients for anticoagulation after ischaemic stroke or transient ischaemic attack. J Neurol Neurosurg Psychiatry 2002;73:29-33.
56. Manning WJ, Weintraub RM, Waksmonski CA, Haering JM, Rooney PS, Maslow AD, *et al.* Accuracy of transesophageal echocardiography for identifying left atrial thrombi. A prospective, intraoperative study. Ann Intern Med 1995;123:817-22.
57. Bansal M, Kasliwal RR. Echocardiography for left atrial appendage structure and function. Indian Heart J 2012;64:469-75.
58. Wunderlich NC, Beigel R, Swaans MJ, Ho SY, Siegel RJ. Percutaneous interventions for left atrial appendage exclusion: Options, assessment, and imaging using 2D and 3D echocardiography. JACC Cardiovasc Imaging 2015;8:472-88.
59. Saw J, Lempereur M. Percutaneous left atrial appendage closure: Procedural techniques and outcomes. JACC Cardiovasc Interv 2014;7:1205-20.
60. Bleakley C, Monaghan MJ. The pivotal role of imaging in TAVR procedures. Curr Cardiol Rep 2018;20:9.
61. Bleakley C, Eskandari M, Monaghan M. 3D transoesophageal echocardiography in the TAVI sizing arena: Should we do it and how do we do it? Echo Res Pract 2017;4:R21-32.
62. Hahn RT. State-of-the-art review of echocardiographic imaging in the evaluation and treatment of functional tricuspid regurgitation. Circ Cardiovasc Imaging 2016;9:e005332.
63. Wunderlich NC, Landendinger M, Arnold M, Achenbach S, Swaans MJ, Siegel RJ, *et al.* State-of-the-art review: Anatomical and imaging considerations during transcatheter tricuspid valve repair using an annuloplasty approach. Front Cardiovasc Med 2021;8:619605.
64. Khalique OK, Cavalcante JL, Shah D, Guta AC, Zhan Y, Piazza N, *et al.* Multimodality imaging of the tricuspid valve and right heart anatomy. JACC Cardiovasc Imaging 2019;12:516-31.
65. Winkel MG, Brugger N, Khalique OK, Gräni C, Huber A, Pilgrim T, *et al.* Imaging and patient selection for transcatheter tricuspid valve interventions. Front Cardiovasc Med 2020;7:60.
66. Ro R, Tang GH, Seetharam K, Khera S, Sharma SK, Kini AS, *et al.* Echocardiographic imaging for transcatheter tricuspid edge-to-edge repair. J Am Heart Assoc 2020;9:e015682.
67. Arntfield R, Pace J, McLeod S, Granton J, Hegazy A, Lingard L. Focused transesophageal echocardiography for emergency physicians-description and results from simulation training of a structured four-view examination. Crit Ultrasound J 2015;7:27.
68. Nazerian P, De Stefano G, Albano G, Gaspari V, Bevilacqua S, Campagnolo V, *et al.* Transesophageal echocardiography (TEE) in cardiac arrest: Results of a hands-on training for a simplified TEE protocol. Ultrasound J 2020;12:41.
69. Long B, Alerhand S, Maliel K, Koyfman A. Echocardiography in cardiac arrest: An emergency medicine review. Am J Emerg Med 2018;36:488-93.
70. Hulde N, Koster A, von Dossow V. Perioperative management of patients with undergoing durable mechanical circulatory support. Ann Transl Med 2020;8:830.
71. Peura JL, Colvin-Adams M, Francis GS, Grady KL, Hoffman TM, Jessup M, *et al.* Recommendations for the use of mechanical circulatory support: Device strategies and patient selection: A scientific statement from the American Heart Association. Circulation 2012;126:2648-67.
72. Stainback RF, Estep JD, Agler DA, Birks EJ, Bremer M, Hung J, *et al.* Echocardiography in the management of patients with left ventricular assist devices: Recommendations from the American Society of Echocardiography. J Am Soc Echocardiogr 2015;28:853-909.
73. Ayub-Ferreira SM. Executive summary-Guidelines for mechanical circulatory support of the Brazilian Society of Cardiology. Arq Bras Cardiol 2018;111:4-12.
74. Kirkpatrick JN, Wiegers SE, Lang RM. Left ventricular assist devices and other devices for end-stage heart failure: Utility of echocardiography. Curr Cardiol Rep 2010;12:257-64.
75. van der Wouw PA, Koster RW, Delemarre BJ, de Vos R,

Lampe-Schoenmaeckers AJ, Lie KI. Diagnostic accuracy of transesophageal echocardiography during cardiopulmonary resuscitation. J Am Coll Cardiol 1997;30:780-3.

76. Blaivas M. Transesophageal echocardiography during cardiopulmonary arrest in the emergency department. Resuscitation 2008;78:135-40.
77. Parker BK, Salerno A, Euerle BD. The use of transesophageal echocardiography during cardiac arrest resuscitation: A literature review. J Ultrasound Med 2019;38:1141-51.
78. Stec S, Zaborska B, Sikora-Frac M, Kryński T, Kułakowski P. First experience with microprobe transoesophageal echocardiography in non-sedated adults undergoing atrial fibrillation ablation: Feasibility study and comparison with intracardiac echocardiography. Europace 2011;13:51-6.
79. Zyblewski SC, Shirali GS, Forbus GA, Hsia TY, Bradley SM, Atz AM, *et al.* Initial experience with a miniaturized multiplane transesophageal probe in small infants undergoing cardiac operations. Ann Thorac Surg 2010;89:1990-4.
80. Hascoët S, Peyre M, Hadeed K, Alacoque X, Chausseray G, Fesseau R, *et al.* Safety and efficiency of the new micro-multiplane transoesophageal probe in paediatric cardiology. Arch Cardiovasc Dis 2014;107:361-70.
81. Nijenhuis VJ, Alipour A, Wunderlich NC, Rensing BJ, Gijsbers G, Ten Berg JM, *et al.* Feasibility of multiplane microtransoesophageal echocardiographic guidance in structural heart disease transcatheter interventions in adults. Neth Heart J 2017;25:669-74.
82. Toole BJ, Slesnick TC, Kreeger J, Border WL, Ehrlich AC, Ferguson ME, *et al.* The miniaturized multiplane micro-transesophageal echocardiographic probe: A comparative evaluation of its accuracy and image quality. J Am Soc Echocardiogr 2015;28:802-7.
83. Damp J, Anthony R, Davidson MA, Mendes L. Effects of transesophageal echocardiography simulator training on learning and performance in cardiovascular medicine fellows. J Am Soc Echocardiogr 2013;26:1450-6.e2.