

## **Basics of Echocardiography For Anesthesiologists**

*Dr. Thomas Koshy*, Professor in Cardiac Anesthesiology, Sree Chitra Tirunal Institute for Medical Sciences and Technology, Trivandrum, Kerala

Echocardiography – the use of ultrasound to examine the heart- is a safe, powerful, non-invasive and painless technique. The introduction of transesophageal echocardiography (TEE) has provided a new acoustic window to the heart and mediastinum. High-quality images of most cardiovascular structures can be obtained readily. TEE has revolutionized cardiac anesthesia and has become increasingly important in the management of patients in the ICU and during certain non-cardiac surgical procedures as well. As we view the field of echocardiography in the current decade, it is almost impossible to conceive of a state-of-the-art cardiac OR without an echo machine.

### **HOW ECHO HELPS IN OR/ICU**

- Augment preoperative evaluation
- Surgical decision planning
- Evaluation of surgical results
- Hemodynamic assessment/ Differential diagnosis of hypotension

TEE is associated with a long learning curve because the complexities of transducer positioning, imaging sector alignment and the three dimensional cardiac anatomy, that are not familiar to most beginners.

## **PHYSICS OF ULTRASOUND**

### **BASIC PRINCIPLES**

In TEE, the heart and great vessels are insonated with ultrasound from probe inside the esophagus, which is sound above the human audible range (frequency above 20,000 Hz). Frequency within the range of human hearing (20-20,000 Hz) are referred to as audio frequencies, while those above this range are referred to as ultrasonic frequencies. Echocardiography machines commonly operate in the frequency range of 2-10 million cycles per second (2-10MHz). The ultrasound is partially reflected by the cardiovascular structures. From these reflections, distance, velocity and density of objects within the chest are derived.

### **FORMING THE IMAGE**

#### **INTERACTION OF ULTRASOUND WAVES WITH TISSUES**

The formation of an ultrasonic image is dependent upon wave reflections occurring at the interfaces between different media. The strength of reflection at an interface depends upon the difference in acoustic impedance between the two media. For example, a blood-fat interface produces a stronger reflection than a blood-muscle interface, because there is a greater difference in density between blood and fat than between blood and muscle.

When an ultrasound wave is propagated through a living tissue, it is partly absorbed, partly reflected, and partly scattered. Attenuation refers to the loss of ultrasound power as it transverses tissue. Ultrasound reflection, scattering and absorption

are responsible for tissue attenuation. A high percentage of ultrasound is absorbed by the tissues and is converted to heat, the higher the frequency the greater the absorption. The greater the ultrasound reflection and scattering, the less ultrasound energy is available for penetration and resolution of deeper structures. Water, blood and muscle have low tissue impedance resulting in low ultrasound attenuation, whereas air and bone have very high tissue ultrasound impedance, limiting the ability of ultrasound to transverse these structures. Because sound waves travel through soft tissue at a constant velocity, the length of time for the ultrasound beam to be returned back to the transducer can be used to calculate the precise distance between the transducer and the object being interrogated.

## ULTRASONIC TRANSDUCERS

A transducer is a device that converts energy from one form into another. Ultrasonic transducers use piezoelectric crystals to emit and receive high-frequency sound waves. These transducers convert electrical energy from the ultrasound instrument into acoustic energy when transmitting, and they convert acoustic energy reflected from the tissues into electrical energy, that is used by the instrument to form the image.

A transducer with a mechanism to sweep the ultrasound beam automatically in a fan-like fashion is called a mechanical sector scanner. In a phased array scanner, the ultrasonic beam is formed and steered by firing an array of small closely spaced transducer elements in a sequence. A TEE probe typically has 64 elements. (fig 1)

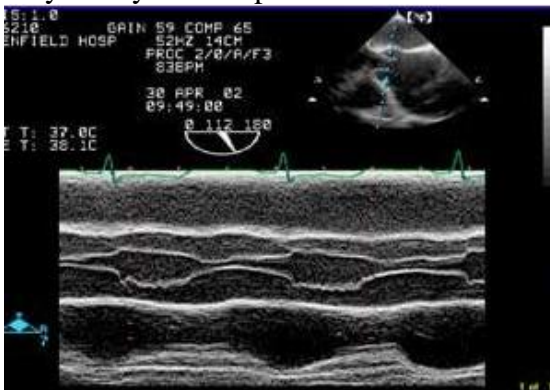


*Fig 1: A pediatric TEE probe inside the esophagus in the OR*

## IMAGING TECHNIQUES

### M MODE

This is the most basic form of ultrasound imaging. In this mode, the density and position of all tissues in the path of a narrow ultrasound beam (i.e., along a single line) are displayed (fig 2). M-mode is not currently used as a primary imaging mode because only a very limited part of the heart is being observed. However this mode is useful for

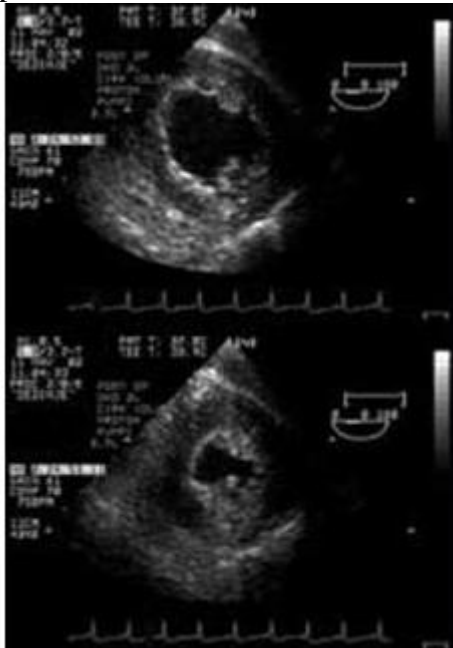


**Fig 3:** A TEE M-mode image taken across the aortic root (box like structure) having regurgitation. Note the gap between the aortic valves during diastole

the precise timing of events within the cardiac cycle. Because M-mode images are updated 1000 times per second, they provide greater temporal resolution than 2D echo, thus, more subtle changes in motion or dimension can be appreciated. The ultrasound signal should be aligned perpendicularly to the structure being examined. Finer analysis of valve motion or thickness and motion of cardiac chambers are best done in this view.

#### TWO-DIMENSIONAL ECHO (2D ECHO)

The acquired image which resembles an anatomic section of the heart is easily interpreted (fig 3). This 2D echo image (“live” real image) is obtained by rapid, repetitive scanning along many different radii within an area in the shape of a fan (sector). Information on structures and motion in the plane of a 2D scan is updated 30 to 60 times per second.



**Fig 3:** 2D TEE image of the left ventricle in diastole and systole

#### DOPPLER ULTRASOUND

Doppler echo uses the reflection of ultrasound by moving red blood cells. The reflected ultrasound has a frequency shift relative to the transmitted ultrasound, determined by the velocity and direction of blood flow. The Doppler effect is defined as the apparent change in the frequency of waves occurring when the source and observer are in motion relative to each other, with frequency increasing when the source and observer approach each other and decreasing when they move apart. To obtain sufficient signal strength and penetration for a good Doppler signal, higher ultrasonic intensity levels and lower frequencies are used than for 2-D imaging.

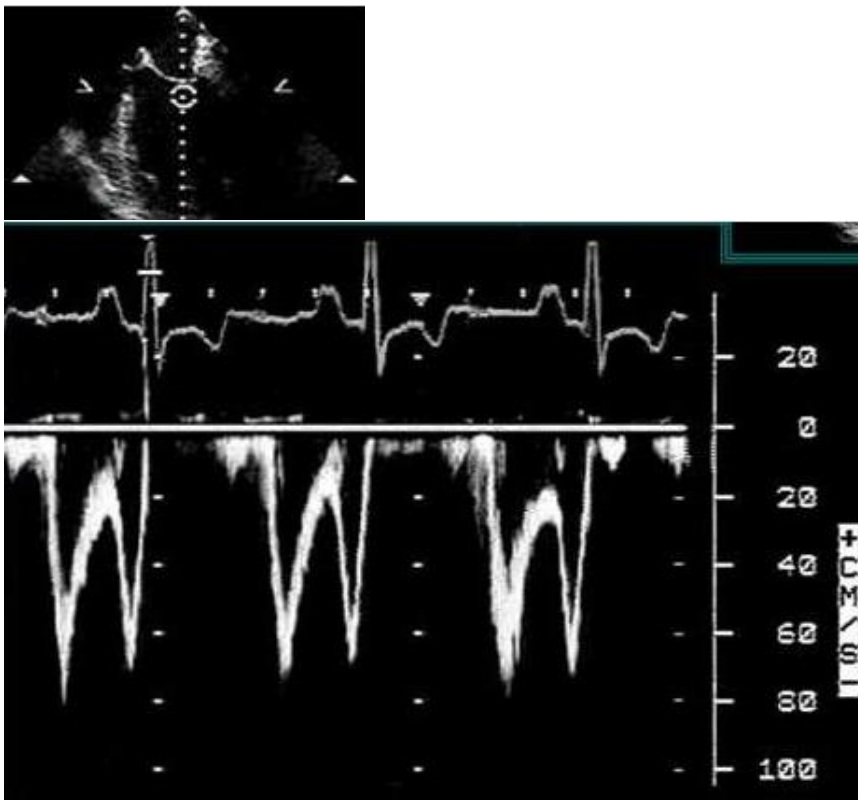
All modern echo machines combine Doppler capabilities with 2D imaging facilities. After the desired view of the heart has been obtained by 2D echo, the Doppler beam, represented by a cursor, is superimposed on the 2D image. The operator positions the cursor as parallel as possible to the assumed direction of blood flow. In clinical

practice, a deviation from parallel of up to 20 degrees can be tolerated, because this only results in an error of 6% or less.

Doppler echo is used to measure the severity of valvular stenosis, quantify valvular regurgitation and it can also show intracardiac shunts. Doppler technology is usually used in three different ways to measure blood velocities: pulse wave, continuous wave and color flow.

#### PULSED WAVE DOPPLER

This allows a flow disturbance to be localized or blood velocity from a small region to be measured (fig 4). A single crystal is used to transmit an ultrasound signal and then to receive after a pre-set time delay. There is a limit to the maximum velocity that can be accurately detected, before a phenomenon known as 'aliasing' occurs usually at velocities in excess of 2 m/s



*Fig 4: Pulse wave Doppler of the mitral inflow*

#### CONTINUOUS WAVE DOPPLER

Two crystals are used-one transmitting continuously and one receiving continuously. This technique is useful for measuring high velocities but its ability to localize precisely a flow signal is limited since the signal can originate at any point along the length or width of the ultrasound beam.

#### COLOR FLOW DOPPLER

Color flow Doppler uses pulsed-wave technology to measure blood flow velocity at multiple sites. Here real time blood flow is displayed within the heart as colors, while also showing 2D images in black and white. The velocities and directions of blood flow

are color encoded. Color flow Doppler Velocities away from the transducer are in blue, those towards it in red.

### TRANSTHORACIC ECHO

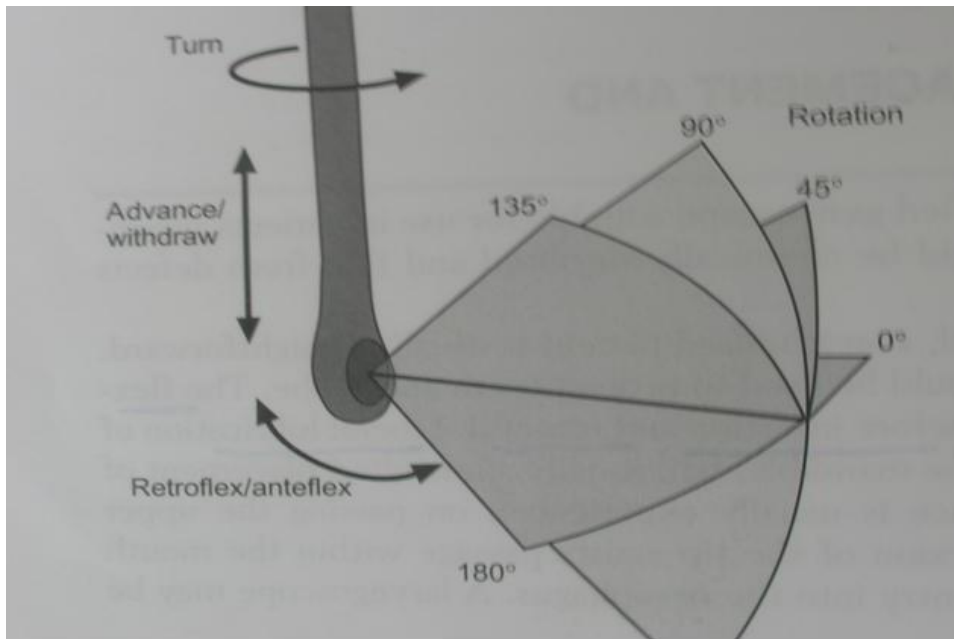
Routine echocardiography examination begins with transthoracic two-dimensional (2D) scanning from four standard transducer positions: the parasternal, apical, subcostal (subxiphoid), and suprasternal windows. The parasternal and apical views usually are obtained with the patient in the left lateral decubitus position and the subcostal and suprasternal notch views, with the patient in the supine position. From each transducer position, multiple tomographic images of the heart relative to its long and short axes are obtained by manually rotating

### TRANSESOPHAGEAL ECHO

Trans thoracic echocardiogram views are particularly difficult to obtain in patients with obesity, emphysema, or abnormal chest wall anatomy because bone, fat and air containing lung interfere with ultrasonic penetration. To avoid these problems, TEE transducers were developed. They are mounted on modified probe similar to those used for upper gastrointestinal endoscopy. Sound waves emitted from an esophageal transducer only have to pass through the esophageal wall and the pericardium to reach the heart, improving image quality and increasing the number of echocardiographic windows. Other advantages of TEE include the stability of the transducer position and the possibility of obtaining continuous recordings of cardiac activity for extended periods of time (for eg: during cardiac surgery). Majority to TEE probes uses ultrasound between 3.5 and 7 MHz. Two types of probes are available in the market. The adult probe has a shaft length of 100 cm and a diameter of around 12 mm. This can be introduced in patients up to 20-25 Kgm. The pediatric probe measures approximately 7 mm in diameter and the company recommends its use in patients weighing upto 4 Kgm.

### MOVEMENTS OF THE TEE PROBE

The TEE probe produces a  $90^{\circ}$  imaging sector which can be directed by a variety of maneuvers (fig 5). The shaft of the probe may be *advanced* into or *withdrawn* from the esophagus and *turned to the right* (clockwise) or to *the left* (anticlockwise). The tip of the probe may be *anteflexed* (anteriorly) or *retroflexed* (posteriorly) by rotating the large control wheel on the handle of the probe. Rotating the small control wheel flexes the tip of the probe to the *left or to the right (lateral flexion)*. This facility (lateral flexion) may not be available in pediatric probe because of the size limitation. All modern TEE probes are multiplane as compared to older biplane probes and the scanning plane can be *rotated* from  $0^{\circ}$  to  $180^{\circ}$ . At  $0^{\circ}$  the sector scan lies in the transverse image plane and runs perpendicular to the shaft of the probe. At  $90^{\circ}$  the sector scan lies in the longitudinal or vertical plane and runs parallel to the shaft of the probe.



**Fig 5: Movements of the TEE probe**

A transducer icon which indicates the degrees of imaging sector rotation is located at the upper right hand corner of the image display. It allows tracking the degrees of forward or backward multiplane angle rotation.

#### PREPARATION FOR TEE EXAMINATION

Anaesthesiologists may need to insert the TEE probe in awake or anaesthetized patients. In both scenarios, the probe needs to be well lubricated. One need to be very careful in patients with history of dysphagia, hematemesis, operations on GIT and cervical spine disease. Introduction of TEE probe into the esophagus in intubated patients under general anesthesia may be difficult at times and alternative maneuvers are described in literature. An awake patient must be fasting for at least 4-6 hours before the procedure. Blood pressure and heart rate are measured. Dentures and oral prostheses should be removed. Airway, oxygen delivery system, bite guard, suction, standard crash cart should be immediately available. An intravenous access is generally established before TEE examination.

#### PREMEDICATION

Awake patients are usually premedicated for the following reasons:

- *Topical anesthesia:* of oropharynx and hard and soft palates diminishes gag reflex. It can be produced by an aerosol local anesthetic like lidocaine solution or viscous lidocaine.
- *Sedation:* is carried out intravenously to decrease anxiety and discomfort, with administration of a sedative belonging to the benzodiazepines group (e.g. diazepam or midazolam).
- *Drying agents:* lessen salivary and gastrointestinal secretions reducing the risk of aspiration (e.g. glycopyrrolate)

*Antibiotics:* help prevent infective endocarditis in selected high-risk patients. The issue of endocarditis prophylaxis during TEE remains controversial. Since the procedure is similar to that of endoscopic examinations, there may be some merit to administering bacterial endocarditis prophylaxis.

## TECHNIQUE OF INTRODUCTION

The pharynx is anesthetized with a topical anesthetic spray. The patient is placed in the left lateral position and the neck slightly flexed to allow better oropharyngeal entry. Introduction of the probe can also be performed with the patient in the supine position and if necessary in the upright sitting position. A bite guard is essential to allow manipulation and protection of the TEE probe. Distal portion of the transducer is coated with lubricating jelly. The echographer passes the probe tip through the bite guard and over the tongue maintaining it in the midline. The tip is advanced until resistance is encountered, then the patient is asked to swallow and with gentle forward pressure the transducer is advanced into position behind the heart. When TEE procedure is over, the precautions that should be taken by the patient include not to drink any hot liquid until oropharyngeal anesthesia has worn off (1-2 hours), not to eat until gag reflex returns (1-4 hours) and not to drive for 12 hours (if a sedative was given).

## STANDARD IMAGE DISPLAY

It is imperative that an examiner be comfortable with imaging sector orientation and the resulting image display. These are key concepts. Mastering them will allow to predict the images which will result from the various probe manipulations and to display a desired cross-section.

The apex of the sector scan is shown at the top of the echo screen, which displays posterior cardiac structures (parts closer to the probe in the esophagus). In the transverse imaging plane (transducer at  $0^{\circ}$ ), the left of the image is towards patient's right, and the right of the image is towards the patient's left. In the vertical image plane ( $90^{\circ}$ ), the left side of the image is inferior and points towards the patient's feet and right side of the image is anterior and points towards the patient's head.

## CENTERING THE IMAGE

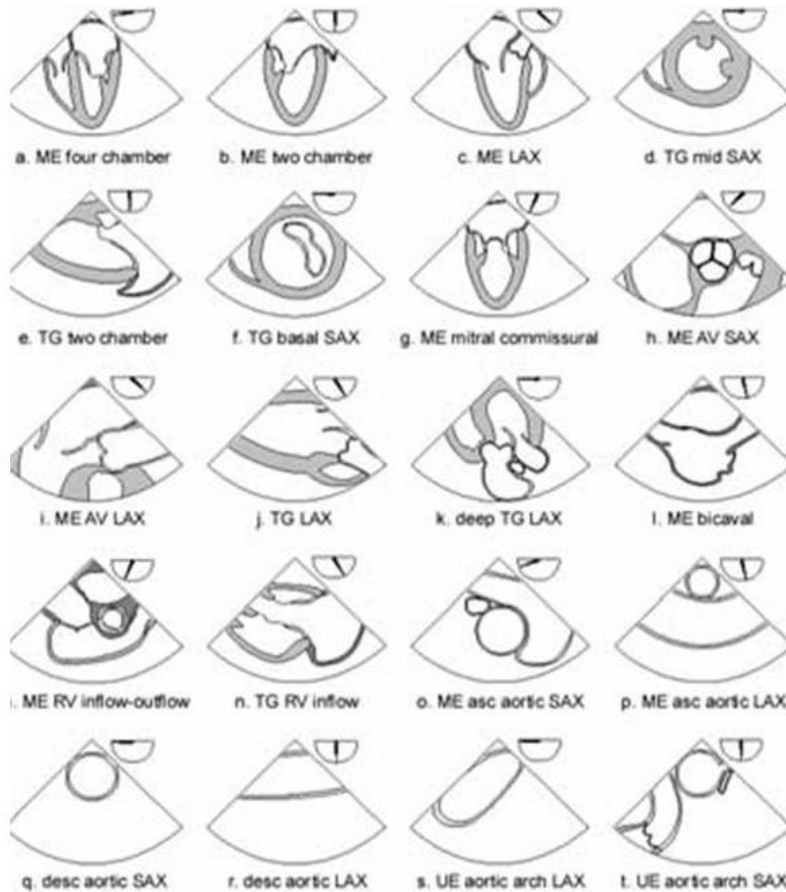
Once we centre a cardiac structure in one image plane, it will continue to remain there as the transducer is rotated from  $0^{\circ}$  to  $180^{\circ}$  facilitating the three-dimensional assessment of that particular structure. To centre a structure in the transverse imaging plane ( $0^{\circ}$  rotation), the shaft of the probe should be turned to the left or to the right so that the structure of interest is aligned in the middle of the display. If the probe is in the vertical image plane ( $90^{\circ}$  rotation) advancing or withdrawing the probe will achieve the same result.

## STANDARD VIEWS AND SYSTEMATIC EXAMINATION

Patient details are usually entered and the machine controls are adjusted for optimal resolution before starting the examination. Images are collected at four depths:

- Upper esophageal
- Mid esophageal
- Transgastric
- Deep transgastric

The American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists had published guidelines for comprehensive intraoperative multiplane TEE examination. They recommend 20 standard images. They are shown below(fig 6).



**Fig 6:** Standard images for a systematic TEE examination

Various views and images will be presented in the conference. The great majority of images are obtained at mid esophageal and transgastric levels. The goal is not to get all 20 views in all patients. The goal is to elucidate the structure and function of the heart and great vessels. The transducer is first moved into the desired depth, and then the probe is manipulated to orient the imaging plane to obtain the desired cross-sectional image. This is achieved by watching the image develop as the probe is manipulated, rather than by relying on the depth markers on the probe or the multiplane angle icon.

#### MID ESOPHAGEAL VIEWS

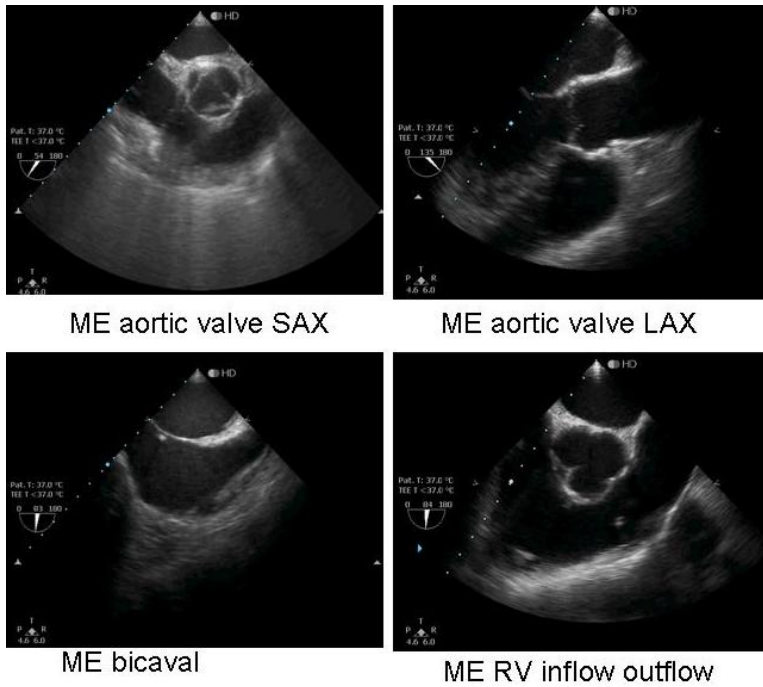
The mid-esophageal (ME) views fall into two groups: ME aortic views and ME ventricular views.

#### Mid-esophageal aortic views

These views image the aortic valve and proximal ascending aorta. Six views are obtained at this level: ME aortic valve short axis (SAX), ME aortic valve long axis (LAX), ME right ventricle inflow-outflow view, ME bicaval view, ME ascending aorta

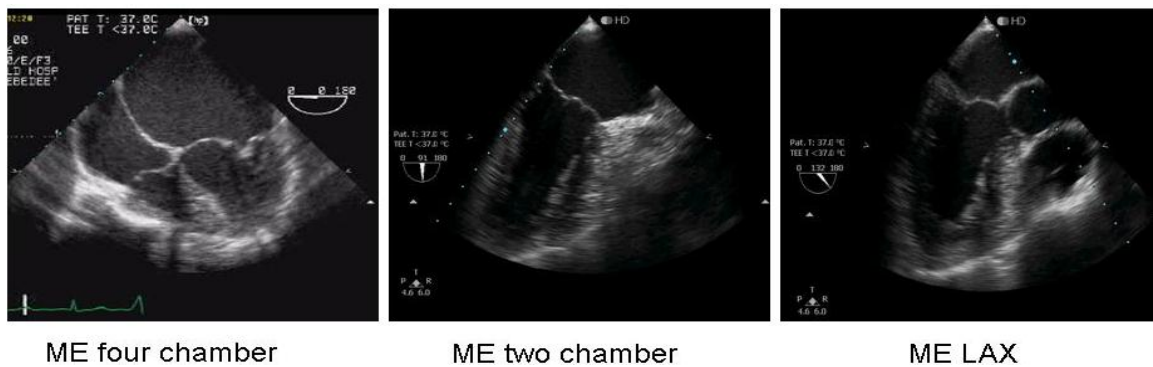


SAX and ME ascending aorta LAX. The aortic root, aortic valve cusps, inter atrial septum, right ventricle, tricuspid valve, and the vena cavae are assessed with these views. (fig 7)



**Fig 7:** Important mid esophageal aortic views

### Mid-esophageal ventricular views

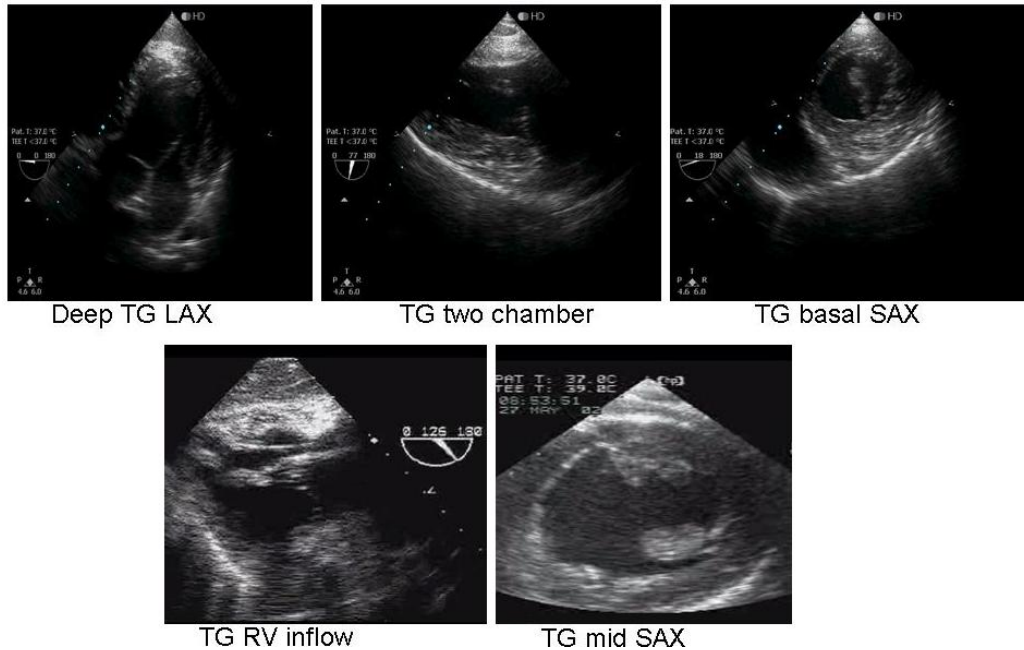


**Fig 8:** Commonly used mid esophageal ventricular views

These views (four-chamber, two-chamber, commissural, and LAX) are important in the assessment of mitral valve, left ventricle, inter ventricular septum and both atrium(fig 8). Progressive rotation of the transducer from the four-chamber view ( $0^0$ ) to long-axis view ( $130^0$ ) allows visualization of all segments of anterior and posterior mitral leaflets and a complete evaluation of left ventricular wall motion.

### Transgastric views

From the mid-esophageal position the TEE probe is further advanced into the stomach and anteflexed (to keep it apposed to the diaphragmatic surface of the stomach) to develop the transgastric (TG) views (fig 9). The five views (TG mid SAX, TG two chamber, TG basal SAX, TG LAX, TG RV inflow) obtained at this level are useful in the assessment of the mitral valve and left and right ventricles. In particular the transgastric mid SAX view is very commonly used by the anesthesiologists in the assessment of LV function, ejection fraction and volume status.

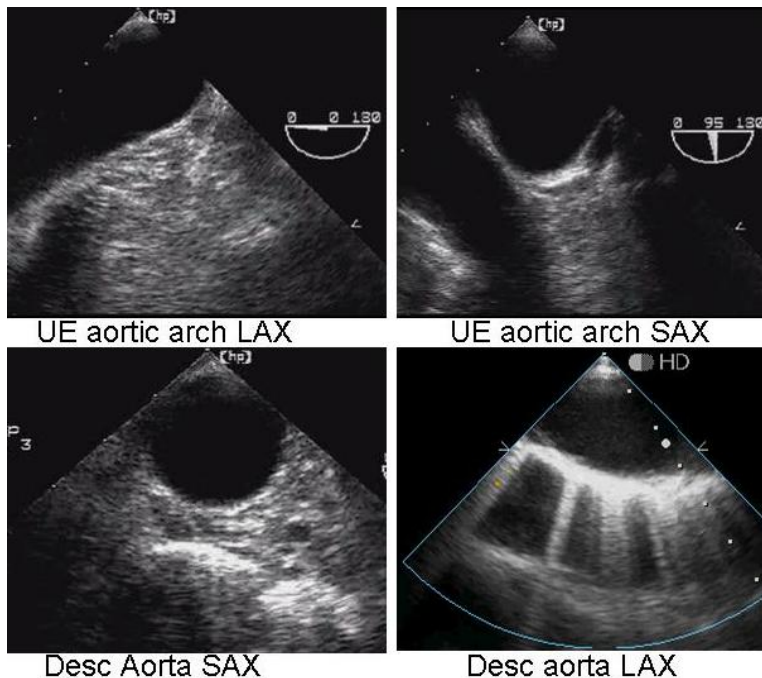


**Fig9 :** *Transgastric and Deep transgastric views*

To obtain deep TG LAX view, the probe is advanced further into the stomach and then slowly withdrawn with tip sharply anteflexed until it contacts the diaphragmatic surface of stomach wall. This view shows all four cardiac chambers, aortic valve and the left ventricular outflow tract. Since the ultrasound beam is parallel to the blood flow through the aortic valve, this image is ideal for estimation of velocity through the AV and cardiac output.

### **Descending thoracic aorta, Aortic arch views**

TEE can image both aortic arch and descending aorta with four standard views (Upper esophageal aortic arch SAX & LAX, Descending aortic SAX & LAX) (fig 10).



**Fig 10:** Long axis and short axis views of Aortic arch and Descending aorta

## INDICATIONS

Intraoperative TEE imaging enabled anesthesiologists and surgeons to diagnose myocardial ischemia, confirm the adequacy of valve reconstruction and other surgical repairs, determine the cause of hemodynamic disorders and other intraoperative complications, and provide diagnostic information that could not be obtained preoperatively. Real-time access to this information has enabled surgeons to correct inadequate repairs before patients leave the operating room, has reduced the need for reoperation, and has facilitated the prevention and early treatment of perioperative complications. Anesthesiologists use TEE increasingly to evaluate and treat unstable patients in OR as well as ICU, as it provides important hemodynamic parameters. TEE examination is generally safe, but manipulation of the probe can compress important neighbouring structures or produce injuries.

Recommendations for performing TEE are intended for those anesthesiologists who use TEE, rather than for all anesthesiologists. The recommendations are divided into three categories based on the strength of supporting evidence or expert opinion that the technology improves clinical outcomes. *Category I* indications are supported by the strongest evidence or expert opinion; TEE frequently is useful in improving clinical outcomes in these settings and often is indicated. *Category II* indications are supported by weaker evidence and expert consensus; TEE may be useful in improving clinical outcomes in these settings. *Category III* indications have little current scientific or expert support; TEE infrequently is useful in improving clinical outcomes in these settings, and appropriate indications are uncertain.

### Category I indications:

- Intraoperative evaluation of acute, persistent, and life-threatening hemodynamic disturbances in which ventricular function and its determinants are uncertain and have not responded to treatment

- Intraoperative use in valve repair
- Intraoperative use in congenital heart surgery for most lesions requiring cardiopulmonary bypass
- Intraoperative use in repair of hypertrophic obstructive cardiomyopathy
- Intraoperative use for endocarditis when preoperative testing was inadequate or extension of infection to perivalvular tissue is suspected
- Preoperative use in unstable patients with suspected thoracic aortic aneurysms, dissection, or disruption who need to be evaluated quickly
- Intraoperative assessment of aortic valve function in repair of aortic dissections with possible aortic valve involvement
- Intraoperative evaluation of pericardial window procedures
- Use in intensive care unit for unstable patients with unexplained hemodynamic disturbances, suspected valve disease, or thromboembolic problems (if other tests or monitoring techniques have not confirmed the diagnosis or patients are too unstable to undergo other tests)

**Category II indications:**

- Perioperative use in patients with increased risk of myocardial ischemia or infarction
- Perioperative use in patients with increased risk of hemodynamic disturbances
- Intraoperative assessment of valve replacement
- Intraoperative assessment of repair of cardiac aneurysms
- Intraoperative evaluation of removal of cardiac tumors
- Intraoperative detection of foreign bodies
- Intraoperative detection of air emboli during cardiectomy, heart transplant operations, and upright neurosurgical procedures
- Intraoperative use during intracardiac thrombectomy
- Intraoperative use during pulmonary embolectomy
- Intraoperative use for suspected cardiac trauma
- Preoperative assessment of patients with suspected acute thoracic aortic dissections, aneurysms, or disruption
- Intraoperative use during repair of thoracic aortic dissections without suspected aortic valve involvement
- Intraoperative detection of aortic atheromatous disease or other sources of aortic emboli
- Intraoperative evaluation of pericardiectomy, pericardial effusions or evaluation of pericardial surgery
- Intraoperative evaluation of anastomotic sites during heart and/or lung transplantation
- Monitoring placement and function of assist devices

**Category III indications:**

- Intraoperative evaluation of myocardial perfusion, coronary artery anatomy, or graft patency
- Intraoperative use during repair of cardiomyopathies other than hypertrophic obstructive cardiomyopathy
- Intraoperative use for uncomplicated endocarditis during noncardiac surgery
- Intraoperative monitoring for emboli during orthopedic procedures

- Intraoperative assessment of repair of thoracic aortic injuries
- Intraoperative use for uncomplicated pericarditis
- Intraoperative evaluation of pleuropulmonary diseases
- Monitoring placement of intraaortic balloon pumps, automatic implantable cardiac defibrillators, or pulmonary artery catheters
- Intraoperative monitoring of cardioplegia administration

## HEMODYNAMIC PARAMETERS

TEE allows the anesthesiologist to obtain multiple hemodynamic parameters to guide in the care of the patient. Some of them are listed below.

- Right ventricular systolic pressure
- Pulmonary artery diastolic pressure
- Left atrial pressure
- Left ventricular end diastolic pressure
- Cardiac output
- Stenotic valve orifice areas
- Regurgitant valve orifice areas

## COMPLICATIONS

Complications resulting from TEE can be separated into two groups:

1. Injury from direct trauma to the airway and esophagus
  - Esophageal bleeding, burning, tearing
  - Dysphagia
  - Laryngeal discomfort
  - Bacteremia
  - Vocal cord paralysis
2. Indirect effects of TEE
  - Hemodynamic and pulmonary effects of airway manipulation
  - Distraction from patient

## CONTRAINDICATIONS

Absolute contraindications to TEE in intubated patients include esophageal stricture, diverticula, tumor, recent suture lines and known esophageal interruption. Relative contraindications include symptomatic hiatal hernia, esophagitis, coagulopathy, esophageal varices, and unexplained upper gastrointestinal bleeding.

## SAFETY GUIDELINES

To ensure continued safety of TEE, the following points may be noted. The TEE probe should be inspected prior to each insertion for cleanliness and structural integrity. It should be inserted gently and if resistance is met, the procedure should be aborted. The image is frozen when not in use and the probe should be left in the neutral, unlocked position to prevent prolonged pressure on the esophageal mucosa.

## CONCLUSION

TEE has become the cornerstone in the non-invasive diagnostic evaluation and monitoring of patients with suspected cardiovascular diseases or hemodynamic

instability. Further TEE is an image based technology and is best learned through printed materials, video loops and regular hands-on training.

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