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RESEARCH ARTICLE

ROLE OF TRANSESOPHAGEAL ECHOCARDIOGRAPHY (TEE) IN CARDIAC SURGERY

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Abstract

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Introduction:-

Of the many technologies that have been applied to the field of intra operative cardiac monitoring, none has provided as much new information as echocardiography (**Miller, 1994**).

Ultrasound examination of the heart, offers a wealth of anatomical and physiological information without ionizing radiation, patient discomfort or significant risk. It is therefore well studied to the initial assessment of cardiac diseases and to serial studies **(Granger and Allison, 1992).**

Ultrasound creates its image by emitting high frequency acoustic pulses from a piezoelectric crystal transducer and allowing the sonic pulses to travel through soft tissues. Because tissues of various types possess different acoustic properties, each interface causes a small portion of the pulse energy to be reflected as an echo. The return of these echoes to the transducer generates a small voltage signal. Using knowledge of the speed of sound in the tissue (1540m/sec), timing of the return echoes permits estimation of the tissue plane from which the echoes arose **(Putman and Ravin, 1988)**.

As an imaging technology, ultrasound has a number of very significant advantages:

1. Imaging can be repeated at frequent intervals on the same patients, making it an excellent means of monitoring.
2. Since blood is hypo echogenic compared to tissues, cardiac images show excellent contrast at the endocardial blood boundary and valve structures.
3. It permits visualization of virtually all portions of the myocardium at real time rates (>30 images/second).
4. Doppler imaging permits accurate characterization of the direction and pattern of blood flow.

(Putman and Ravin, 1988)

Transesophageal echocardiography (TEE) was introduced for the first time by Frazin et al. in 1976.

They recorded M-mode echocardiogram of the left ventricle and used changes in dimensions to monitor its function .Since that time, improvement in ultrasound technology coupled with miniaturization of transducers and the development of soft flexible tubing have led to a virtual exponential growth in the use of esophageal echocardiography. Although initial reports of the use of TEE were confined to adults and were, for the most part intraoperative in application, development of smaller probe allowed for its application in infants and children **(Snider et al., 1997)**.

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The potential of TEE to provide a valuable imaging tool became widely recognized in the 1980s with advancements in TEE probe technology, including the availability of single-plane phased array transducers and the addition of color flow and continuous wave Doppler imaging technology.

Echocardiography has dramatically reduced the requirement for invasive studies such as cardiac catheterization.

TEE does not supplant transthoracic echocardio-graphy (TTE), however; it is a complementary imaging modality with its own strengths and weaknesses **(Burwash et al., 2002).**

The echocardiographic examination can be used to evaluate cardiac structures in congenital heart lesions, estimate intra cardiac pressures and gradients across stenotic valves and vessels, quantitate cardiac contractile function, determine the direction of flow across a defect, examine the integrity of the coronary arteries and evaluate the presence of vegetations due to endocarditis, pericardial fluid, cardiac tumors or chamber thrombi. Echocardiography may also be used to assist in the performance of pericardiocentesis, balloon atrial septostomy, and endocardial biopsy, and the placement of flow-directed pulmonary arterial (Swan-Ganz) monitoring catheter (**Richard, 2000).**

In early echocardiography, the sound beam was aimed at a fixed direction with the resulting display called motion-mode "M-mode" or "one dimensional" echocardiography with limited informations. In the modern two-dimensional "2-D" imagers, the sound beam sweeps through an arc of 90 degrees and shows the reflecting structures in a plane, each type has its clinical application (**Miller, 1990).**

An extension of the diagnostic and monitoring capabilities of ultrasound is the introduction of color flow mapping providing information about the flow pattern within the heart, and measurement of blood flow velocities using the Doppler principle **(Roeland et al., 1993).**

Satomura in 1957 was the first to report Doppler detection of moving cardiac structures. Subsequently Kaneko et al. (1961) showed that the Doppler shift in the frequency of ultrasound back-scattered from flowing blood. Asberg in 1967 constructed a mechanical scanner which made images of the living heart at seven frames per second. Transesophageal cross-sectional real time imaging was first reported in 1977 by Hisnaga et al.

Transthoracic echocardiography is limited by the presence of adjacent structures, such as bone and lung which present overwhelming obstacles to the conduction of the ultrasound.

So, transesophageal echocardiography (TEE) became attractive alternatives. It has gained significant popularity in anesthesia as a platform for stable, continuous, non-invasive, high quality intraoperative monitoring of global and regional cardiac function **(Miller, 1994).**

Over the past 10 years, specialized echocardiographic techniques had become critical components in the evaluation and treatment of these patients with congenital heart disease during repair in the operating room, so that adequacy of the repair can be assessed and any residual lesions assessed immediately **(Frommlet, 1999).**

Intraoperative TEE can provide detailed information on cardiac anatomy and function not obtainable by other monitoring technologies and it can obtain this information without disrupting the surgical procedure **(Park and Kim, 2000).**

TEE can evaluate global and segmental left ventricular function; detect intraoperative myocardial ischemia, and monitor hemodynamic changes including cardiac output, left ventricular filling pressures, and volume status. The cause of hemodynamic disturbances can be determined and intraoperative complications can be identified. Importantly, the adequacy of valve repairs or replacements and surgical reconstructions for congenital and acquired diseases can be evaluated prior to leaving the operating room **(Park and Kim, 2000).**

In 1996, the American Society of Anesthesiologists published recommendations for performing TEE based on medicine based evidence that TEE improved clinical outcome **(Kolev et al., 1998).**

This essay will throw light on the history of echocardiography. The physics of ultrasound and its instrumentation will be described. Clinical applications of these instruments will be discussed in details with special reference to the importance of TEE in the field of anesthetic practice.

Physical Properties of Ultrasound
A sound wave is a mechanical disturbance that propagates through a liquid, solid or gas medium. Sound waves are produced by vibrating sources which produce vibrations of the adjacent molecules in the medium, Sound waves result in energy being transmitted through the medium but with no net displacement of the medium's particles **(Sabbagha, 1994).**

Sound is characterized by the frequency (f) of the waves in cycles per second or Hertz (Hz) and by wave length (A). These terms are related to the velocity of sound (V) as follows:
A= V/F
(Davis et al., 1995)

What Is Ultrasound?
The normal range of sound that human beings can perceive is 20-20000Hz. A sound wave with a frequency higher than20000 Hz is called ultrasound **(Higashi et al., 1991).**

In order to give an image, the ultrasound wave must be reflected at the interface between materials of different densities representing an acoustic impedance mismatch, the larger this difference, the stronger the echo.
When an ultrasound beam hits an acoustic interface, three main phenomena appear:
1- Specular reflection.
2- Diffuse scattering.
3- Attenuation.
(Poelarert, 2000)

Reflection, Refraction and Scattering:
The principal characteristic of ultrasound is its reflection from surfaces encountered in its path. If the surface is large with respect to the wave length of the sound, then the reflection is specular or mirror-like and the angle of reflection is equal to the angle of incidence of the wave **(Collins and Skorton, 1986).**

Attenuation and Time Gain Compensation:
The degree of attenuation of ultrasound is directly proportional to its frequency. This tends to limit the maximum distance that higher-frequency ultrasound can penetrate before it is completely absorbed since the intensity of ultrasound decreases as it travels through the medium. The Echo apparatus incorporates a mechanism to amplify echoes from greater depth. This mechanism is called time gain compensation (TGC) **(Higashi et al., 1991).**

Resolution:
Resolution refers to the ability to separate two small objects which are placed close to each other. There are two types of ultrasound resolution: axial resolution and lateral resolution.
1. Axial resolution: It is the ability to separate two objects along the path of the ultrasound beam. It depends on the duration of ultrasonic pulse
2. Lateral resolution: it is the ability to separate two objects in a plane perpendicular to the ultrasound beam.

(Higashi et al., 1991)

Doppler Ultrasound:
The Doppler principle states that as sound with a known original frequency interacts with structures in a motion, frequency shift is generated which if measured allows the observer to extract the velocity of motion of the object imposing the shift **(Putman and Ravin, 1988)**.

In order to estimate the blood flow or velocity of an object (v) the Doppler equation states that:

$$v = \frac{C.f_r}{2 f_t . \cos\theta}$$

Where (C) is the speed of sound in blood, (f_r) is the frequency of the reflected sound wave, (f_t) is the frequency of the transmitted sound wave and (θ) is the angle between the sound wave direction and the direction of blood flow. This angle should be as close to zero as possible, angles greater than 25 degrees yield clinically unacceptable quantitative estimates of velocity **(Miller, 1994).**

Imaging modes:

M-mode:

M-mode echocardiography is used principally to view rapidly moving structures, such as valve leaflets, because M-mode transducers can produce up to 1,000 images per second **(Vezina et al.,2005).**

2-D mode:

By using multiple crystals (linear or phased-array transducers) or by rapidly moving a single crystal (mechanical transducer), multiple views can be obtained and collated into a 2-D image. 2-D techniques produce only about 30 images per second. By altering the position or angle of the ultrasound beam, the operator produces multiple cross-sectional (tomographic) images revealing the external and internal anatomy and functionof the heart and great vessels **(Vezina et al., 2005).**

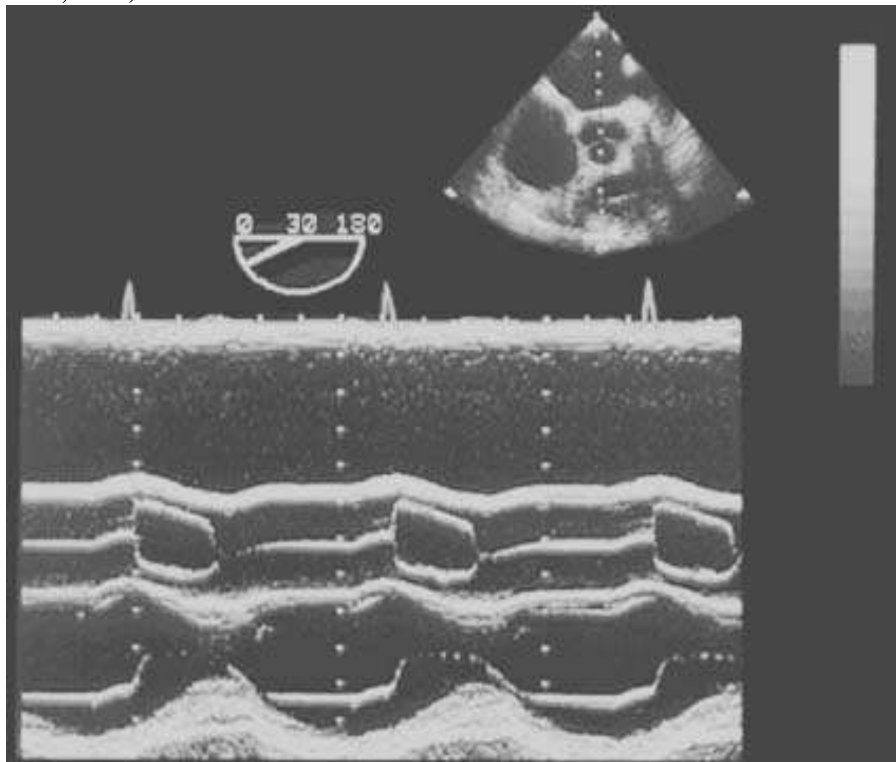


Fig. (1):- M-mode transesophageal echocardiogram of a normal aortic valve. The dotted vertical line through the two-dimensional echocardiogram depicts the single line of sampling provided by the M-mode echocardiogram over time (the horizontal axis for the lower two thirds of the figure). The electrocardiogram defines systole and diastole. Note in the middle of the M-mode image the three tilted rectangles connected by the slightly undulating line. These rectangles and lines are formed by the motion of the leaflets of the aortic valve as they open and close during the cardiac cycles shown. From top to bottom in this M-mode echocardiogram, the structures indicated by the white lines are the posterior wall of the left atrium (just under the electrocardiogram), the posterior wall of the aortic annulus, the aortic valve (as described above), the anterior wall of the aortic annulus, a pulmonary artery catheter, and the myocardium of the right ventricular outflow tract **(Cahalan, 1997)**.

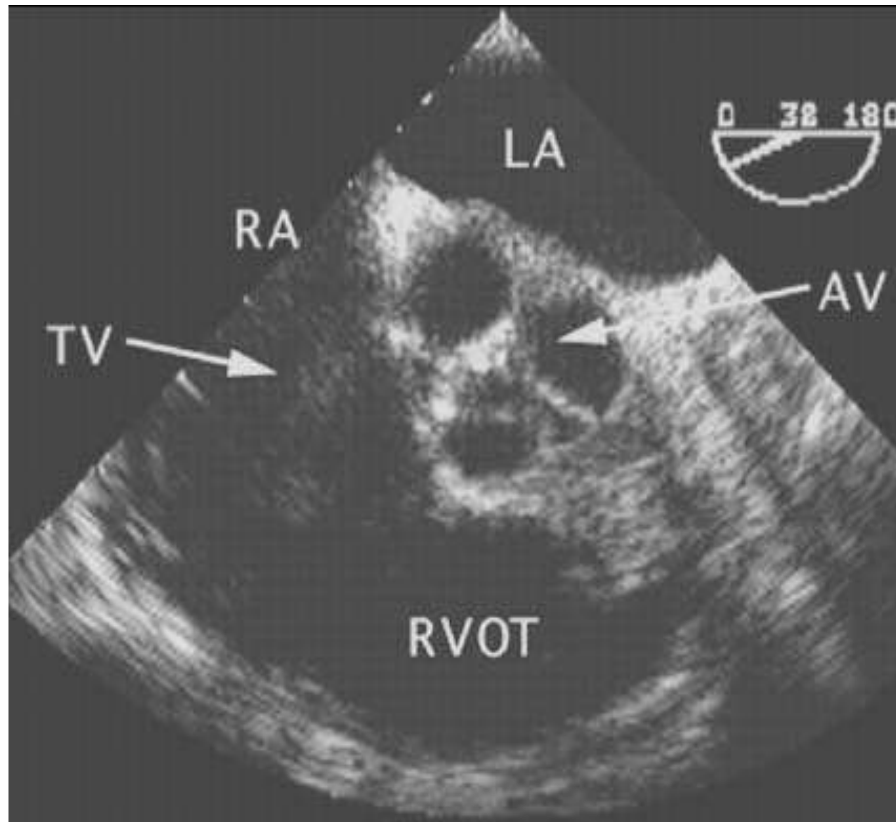


Fig. (2):- Short-axis two-dimensional cross section of a normal aortic valve (AV). This midesophageal short-axis view of the AV reveals the morphology of the three cusps of this normal valve, LA, left atrium; RA, right atrium; RVOT, right ventricular outflow tract and TV, tricuspid valve **(Cahalan ,1997)**.

3-D mode:

Computer is being used for reconstruction of 3-D images. Linker et al. in 1986 used 3-D echocardio-graphy to measure the right ventricular volume. Also Martin and Bashein in 1989 used multiple, precisely controlled 2-D images to reconstruct an actual 3-D volume measurement of stroke volume in a canine model.

Pulsed wave(PW) Doppler mode:

By measuring the Doppler shift, modern ultrasonographs quantify blood flow velocities. The Doppler shift is the shift in frequency of a wave when the source of the wave is moving (in this case it is the wave that reflected by moving red cells) **(Miller, 2000).**

However, two important limitations apply**. First**, the Doppler shift is proportional to the cosine of the angle Q between the ultrasound beam and the direction of the blood cells. **Second**, the maximum velocity of blood flow that can be unambiguously measured is inherently limited ("Nyquist limit"). The Nyquist limit is determined by the pulse repetition frequency, which, in turn, depends directly on the depth of the ultrasound scan and inversely on the ultrasound frequency.

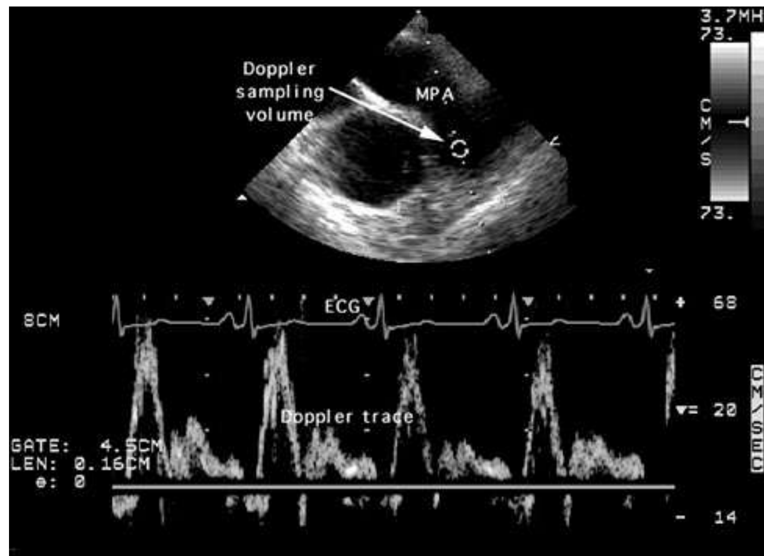


Fig. (3):- Pulsed-wave Doppler echocardiogram of the main pulmonary artery (MPA). At the top of the echocardiogram is a still-frame image of the two-dimensional cross section used to position the Doppler sample volume (the round white sphere). On the bottom two thirds of the echocardiogram is the display in white of the instantaneous blood flow velocities (vertical axis) versus time (horizontal axis) occurring in that sample volume. The electrocardiogram provides timing, and the bold horizontal line is the baseline (zero flow) for the flow velocities. Flow velocities above this line are positive (i.e., toward the transducer) to a maximum of 68 cm/sec. Flow below this line is negative (i.e., away from the transducer) to a maximum of -14 cm/sec **(Cahalan, 1997)**.

If the Nyquist limit is exceeded, sudden apparent flow reversal ("aliasing") will be depicted "Aliasing" is analogous to the sudden apparent reversal of direction in stagecoach wheels visible in old Westerns when the velocity of the wheel spokes exceeds the frame rate of the movie camera. Typically, aliasing of PW Doppler occurs at blood flow velocities of 0.4 to 0.6 m/s. Normal flow within the heart may reach 1.4 m/s, and pathologic flows may be up to 6 m/s. To measure these velocities, continuous-wave (CW) Doppler is needed **(Miller, 2000).**

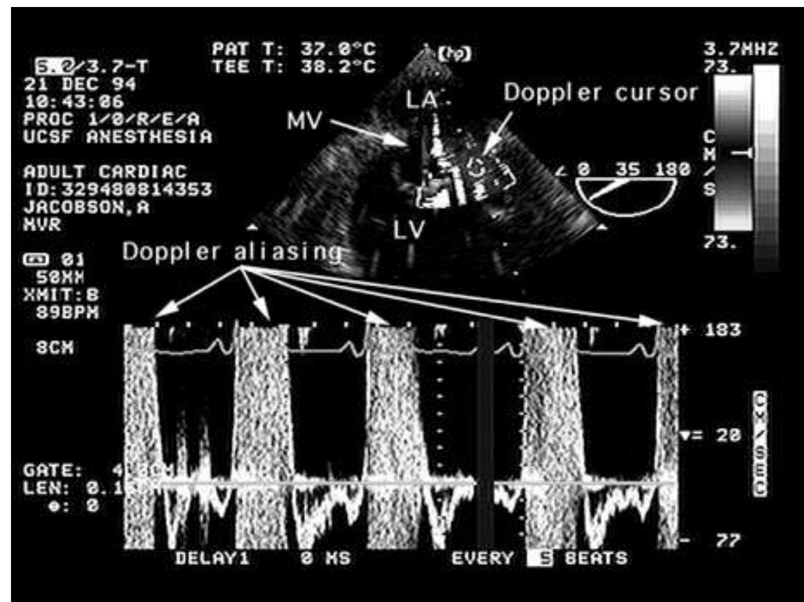


Fig. (4):-Pulsed-wave Doppler with aliasing at high velocities. Pulsed-wave Doppler measurement of blood flow velocities in a mitral valve (MV) orifice during four cardiac cycles is shown. At the top of the figure is a still-frame image of the two-dimensional cross section used to position the Doppler sample volume (the round white sphere). On the bottom two thirds of the figure is the display in white of the instantaneous blood flow velocities (vertical axis)

versus time (horizontal axis) occurring in that sample volume. The electrocardiogram provides timing, and the bold horizontalline is the baseline (zero flow) for the flow velocities. Flow velocities above this line are positive (i.e., toward the transducer) to a maximum of 183 cm/sec. Flow velocities below this line are negative (i.e., away from the transducer) to a maximum of -77 cm/sec. This tracing documents significant mitral regurgitation (the positive systolic velocities) but does not measure the peak velocity of regurgitant flow because it is beyond the Nyquist limit—the systolic velocities off the top of the scale are said to alias, that is, they go off scale and wrap around into the domain of negative velocities LA, left atrium; LV, left ventricle **(Cahalan, 1997)**.

Continuous wave(CW) Doppler mode:
CW Doppler uses two separate crystals: one to emit ultrasound continuously and one to receive it continuously. CW Doppler is basically PW Doppler with an infinite pulse repetition frequency that eliminates the problem of aliasing **(Miller, 2000).**

Color Doppler imaging(CDI) mode:
Color Doppler imaging was developed to permit sampling of the Doppler shift simultaneously in many areas of the sector scan. In color Doppler, a form of PW Doppler, a color code is used to depict flow toward (red) and away (blue) from the transducer **(Cahalan, 2005).**

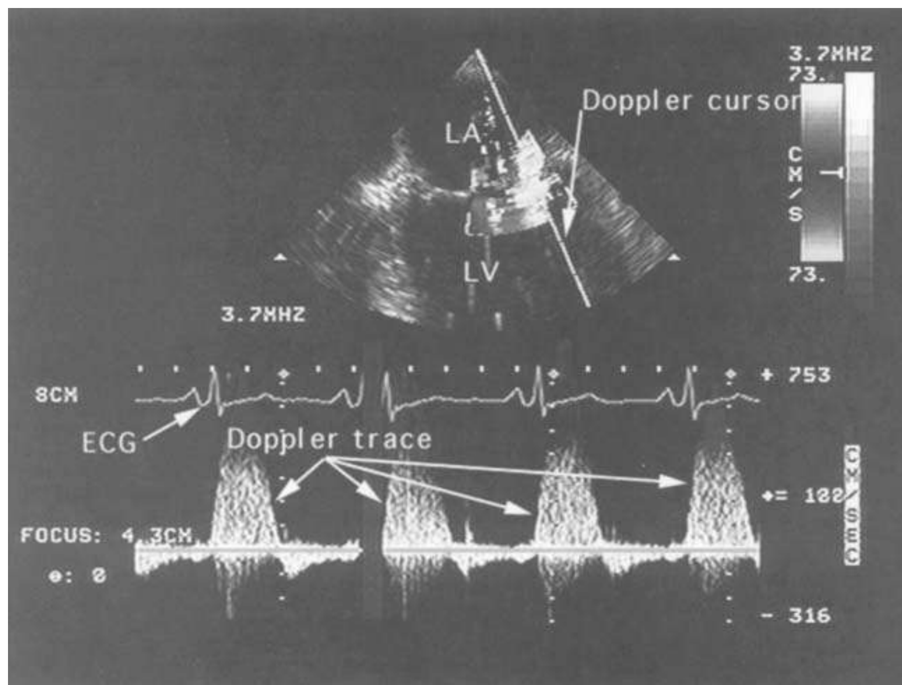


Fig. (5):-Continuous-wave Doppler measures high-velocity flow without aliasing. Continuous-wave Doppler measurement of blood flow velocities in a mitral valve orifice during four cardiac cycles is shown. At the top of the figure is a still-frame image of the two-dimensional cross section used to position the Doppler sample cursor (the diagonal white line). On the bottom two thirds of the figure is the display in white of all the instantaneous blood flow velocities (vertical axis) versus time (horizontal axis) occurring anywhere along that cursor. The electrocardiogram provides timing, and the bold horizontal line is the baseline (zero flow) for the flow velocities. Flow velocities above this line are positive (i.e., toward the transducer) to a maximum of 753 cm/sec. Flow velocities below this line are negative (i.e., away from the transducer) to a maximum of -316 cm/sec. This tracing documents significant mitral regurgitation (the positive systolic velocities) with a peak blood flow velocity of approximately 5 m/sec (each white dot on the vertical axis equals 100 cm/sec or 1 m/sec). LA, left atrium; LV, left ventricle (Cahalan, 1997).

Equipment and imaging technique:
Transducers:
Transducers are made of piezoelectric crystals, which have the particularity of changing shape and expanding when stimulated by an electric current **(Poelarert et al., 2000).**

Two types of 2-D sector scanner transducers are used in echocardiography, mechanical and phased array transducers.

1. Mechanical Transducers:
The simplest type of sector scanners is the oscillating single element transducer. Another mechanical sector scanner consists of a rotating disc with three to five individual transducers. Mechanical transducers have the disadvantages of being some what bulky and the production of a vibrating sensation may be irritating to the patient **(Kotler et at., 1980).**

2. **Electronic Phased Array Transducer:**
A multiplicity of small elements is used to form a single sound beam. Small time delay between individual elements allows the sound beam to be steered electronically. No mechanical motion occurs in this transducer system **(Roelandt et al., 1993).**

TEE Probes:

- **Single plane probe :**

The simplest TEE probe has one phased-array transducer with 64 piezoelectric elements. The transducer is about 40 cm long, 13 mm wide, and 11 mm thick; operates at 5 or 7.5 MHz; and is mounted on the tip of a 9-mm-diameter gastroscope. The ultrasound beam is oriented at right angles to the gastroscope to produce transverse imaging planes of the heart as with standard gastroscopes **(Cahalan, 2005).**

- **Biplane probe:**

Biplane transducers incorporate a second transducer mounted immediately proximal and at right angles to the first to add a longitudinal imaging plane **(Omoto et al., 1990)**.

- **Multiplane probe:**

Multiplane transducers use a single transducer mounted on a rotating device that allows the transducer to spin on its axis from 0 to 180 degrees within the tip of the gastroscope (transducer housing) **(Miller , 2000).**

- **Pediatric probe:**

By reducing the number of crystals and by further miniaturizing transducers, manufacturers have produced single-plane and biplane transducers small enough (6 to 7-mm diameter gastroscopes) for use in infants and neonates **(Miller, 2000).**

Basic examination techniques and cross-sections:
Transesophageal echocardiography is a semi-invasive procedure that should be performed only by a properly trained physician who understands the indications and potential complications of the procedure **(Miller, 2000).**

Cognitive and Technical Skills Required for the Performance of Transesophageal Echocardiography (TEE)
Cognitive Skills:

1. Knowledge of appropriate indications, contra-indications, and risks of TEE.
2. Understanding of differential diagnostic consi-derations in each clinical case.
3. Knowledge of physical principles of echocardio-graphic image formation and blood flow velocity measurement.
4. Familiarity with the operation of the ultra-sonographic instrument,including the function of all controls affecting the quality of the data displayed.
5. Knowledge of normal cardiovascular anatomy, as visualized tomographically.
6. Knowledge of alterations in cardiovascular anatomy resulting from acquired and congenital heart diseases.
7. Knowledge of normal cardiovascular hemodyna-mics and fluid dynamics.
8. Knowledge of alterations in cardiovascular hemodynamics and blood flow resulting from acquired and congenital heart diseases.
9. Understanding of component techniques for general echocardiography and TEE, including when to use these methods to investigate specific clinical questions.
10. Ability to distinguish adequate from inadequate echocardiographic data and to distinguish an adequate from an inadequate TEE examination.
11. Knowledge of other cardiovascular diagnostic methods for correlation with TEE findings.
12. Ability to communicate examination results to patient, other health care professionals, and medical records.

(Burwash, 2002)

Technical Skills:

1. Proficiency in performing a complete standard echocardiographic examination, using all echocardiographic modalities relevant to the case.
2. Proficiency in safely passing the TEE transducer into the esophagus and stomach and in adjusting probe position to obtain the necessary tomographic images and Doppler data.
3. Proficiency in correctly operating the ultrasonographic instrument, including all controls affecting the quality of the data displayed.
4. Proficiency in recognizing abnormalities of cardiac structures and functions as detected from the transesophageal and transgastric windows, distinguishing normal from abnormal findings, and in recognizing artifacts.
5. Proficiency in performing qualitative and quantitative analysis of the echocardiographic data **(Burwash, 2002)**.

Probe Introduction:

Once the patient is anesthetized and the trachea is securely intubated, the contents of the patient's stomach are suctioned. Then the patient's neck is extended, and the well-lubricated TEE probe is introduced into the midline of the hypopharynx with the transducer side facing anteriorly. Usually, with minimal force, the probe will pass blindly into the esophagus, especially if the patient‘s neck is extended. If the probe does not pass blindly, a laryngoscope is used to lift the larynx anteriorly, and the probe is placed into the patient‘s esophagus under direct vision. During transducer insertion or withdrawal, the controls of the gastroscope must be in the neutral or relaxed position to allow the transducer to follow the natural course of the esophagus, thereby potentially minimizing the risk of injury **(Miller, 2000).**

Standard Projections:

Once TEE probe passes 3-5cm down to inferior constrictor (20-25cm from incisors), one starts getting images of great vessels and cardiac chambers.

Basic Transverse Plane Examination:

1. Basal View or Three Chambers View:

In transverse axis at about 25 -30 cm from incisors this view is obtained. One can see aortic valve and sinuses in the center, coronaries, parts of both atria and interatrial septum. This view can be used to study aortic valve anatomy, degree of calcification and measuring aortic cross sectional area. Adjusting the probe little in and out one can focus the pulmonary artery and its main branches **(Poortmans, 2000).**

2. Midesophageal View or Four Chambers View:

Once probe is further enhanced 2-3 cm down (30-35 cm from incisiors), four chambers are seen in a single view. This provides plenimetry of chamber sizes, detection of intracardiac air bubbles after open cardiac surgery, and mitral valve evaluation. Detailed mitral valve examination can be done using different angles to study mitral leaflets, their coaptation and regurgitation in systole. Mitral valve flow studies are done by using pulse wave Doppler or continous wave Doppler and colour flow mapping. This view is very useful judging the adequacy of repair of mitral valve **(Poortmans, 2000).**

3. Short-axis Transgastric View:

This view is obtained by introducing further to 40 cm or so and anteflexing the probe so that the transducer faces towards the apex of heart. This view is very useful for monitoring left ventricular function, studying regional wall motion abnormalities(RWMA), ischemia, LV aneurysm and preload of LV **(Poortmans, 2000).**

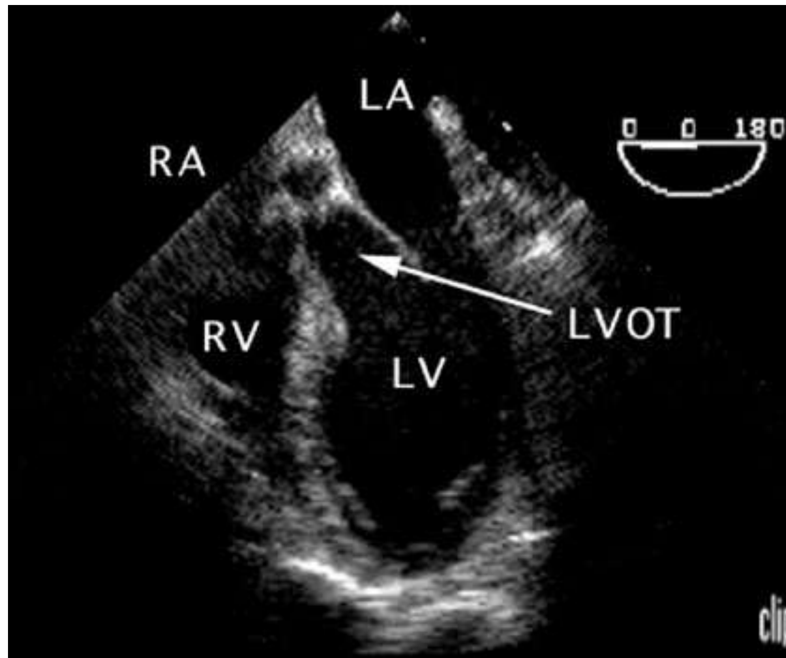


Fig. (6):- Short-axis two-dimensional cross-section of a normal aortic valve (AV). This basal two-dimensional short-axis view reveals the morphology of the three cusps of this normal valve.LA, left atrium; RA, right atrium; RVOT, right ventricular outflow tract; TV, tricuspid valve **(Cahalan,1997)**.

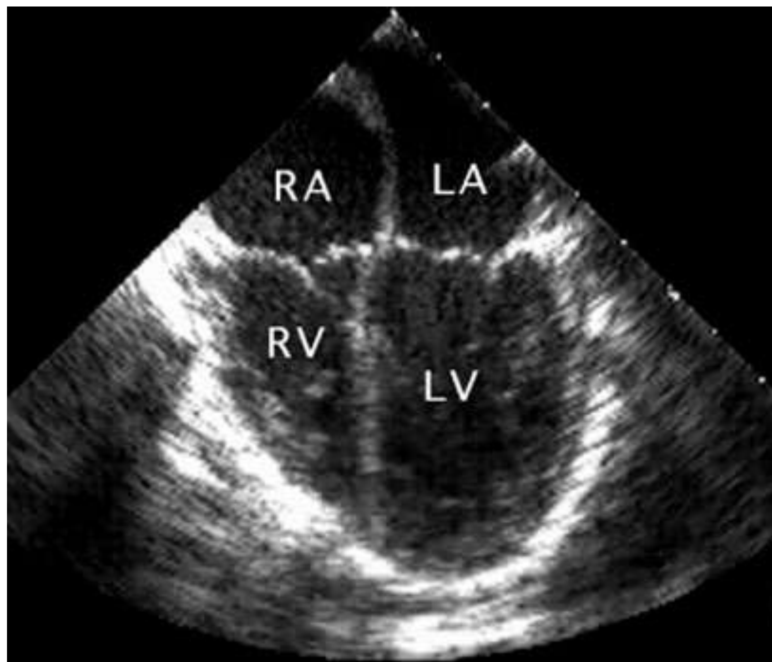


Fig. (7):- Four-chamber echocardiogram rarely reveals the apex of the left ventricle (LV), estimates of filling and ejection derived from these cross-sections usually underestimate LV end-diastolic volume and overestimate ejection fraction. This cross-section is often the best for detection of right ventricular (RV) dysfunction **(Cahlan, 1997)**.

This short-axis cross-section is ideal for monitoring LV filling and ejection. Because all major coronary arteries supply myocardium viewed in this cross-section, changes in preload cause greater changes in the LV short-axis than in the long-axis dimension **(Miller, 2000)**.

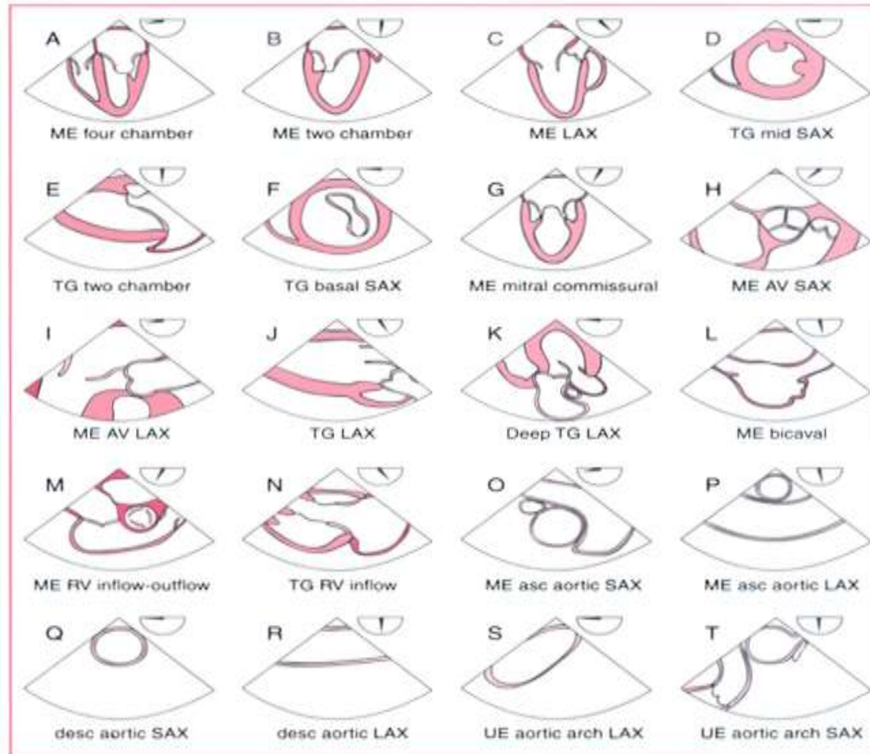


Fig. (8):- TEE cross sections in a comprehensive examination. Twenty standard cross sections and their abbreviated names are depicted by the line drawings. The text describes the probe manipulations required to produce each of the cross sections (Aronson et al., 1999).

Longitudinal Views (90 degrees):

4. **Wrap View or RVOT View:**

At basal level once three chambers view is obtained, the probe is rotated to 60 to 90 degree angles to get the right atrium (RA), right ventricle (RV) and pulmonary trunk in one view. At times one can see the PA catheter transversing to one of the pulmonary arteries at this level.

5. **Midesophageal View:**

This view is obtained by rotating the probe anticlockwise at mid esophageal level and is used to make the detailed evaluation of left atrium, its appendage (LAA), left pulmonary veins and pulmonary venous flow pattern.

6. **Trans gastric View:**

In longitudinal view, it is possible to see longitudinal section of LV, papillary muscles and LA **(Mohan, 1999).**

Essential Precautions:

TEE poses very little risk if it is properly performed. Although anesthesiologists are highly skilled in instrumentation of the airway and esophagus, some special precautions need to be observed to minimize the chances of injury caused by TEE.

1. First, if the history and physical examination suggest esophageal disease, the potential benefits of TEE must clearly outweigh the apparent risks, or TEE should be abandoned.
2. Second, the TEE probe should be inspected prior to each use, and if defects are detected (i.e., cracks in the transducer housing or shaft of the gastroscope), the probe must not be used, but instead sent for repairs. Each manufacturer supplies maintenance and service recommend-dations that should be incorporated into the departmental quality assurance program.
3. Third, when the TEE probe is advanced or withdrawn in the patient‘s esophagus, the control wheels of the gastroscope should be in their neutral positions and left unrestrained. These wheels have locking devices that must be unlocked during probe movements.
4. Fourth, if the probe meets resistance in the esophagus, it should not be forced to advance further.

5. Rarely, repositioning of an abdominal or thoracic retractor relieves the resistance. Otherwise, the operator should suspect esophageal disease and should abandon the TEE examination. Alternatively, esophagoscopy can be performed to determine the safety of persisting efforts to pass the TEE probe.

Last, when the TEE probe is to remain in one position for an extended period, the ultrasound energy (transmitting power of the transducer) and mechanical deflection of the probe tip (i.e., flexion, retroflexion, and angulation) should be minimized. Ideally, the wheels of the gastroscope should not be locked for extended periods, in order to prevent extremes of mechanical deflections from inadvertently persisting **(Miller, 2000).**

Pathophysiology of Cardiac Diseases

A pathophysiologic classification of congenital heart diseases is based upon the answers to several basic questions:

1. Is there an abnormal shuntpathway for blood flow through an intracadiac, extracardiac, or combined defect?
2. Is there an obstructionto or reduction of blood flow?
3. Is there an increase or decrease in pulmonary or systemic blood flow?

1- Pressure overload on the right or left ventrfcle:

1. Aortic stenosis.
2. Pulmonary stenosis.
3. Coarctation of the aorta.
4. Hypoplastic left heart syndrome.

2- Volume overload on the verilricle or atrium:

1. Ventricular septal defect.
2. Patent ductus arteriosus.
3. Endocardial cushion defect.
4. Atrial septal defect.

3- Cyanosis due to obstruction of the pulmonary blood flow:

1. Tetralogy of fallot.
2. Pulmonary atresia,
3. Tricuspid atresia.

4- Cyanosis due to common mixing chamber:

1. Double outlet right ventricle.
2. Single ventricle.
3. Total anomalous pulmonary venous drainage.
4. Truncus arteriosus.

5- Cyanosis due to separation of the systemic and pulmonary circulation:

1. Transposition of great arteries.

(Stephen et al., 1993)

Mitral stenosis:

Mitral stenosis almost always occurs as a delayed complication of acute rheumatic fever. The stenotic process is estimated to begin after a minimum of 2 years following the acute disease and results from progressive fusion and calcification of the valve leaflets.

Pathophysiology

The rheumatic process causes the valve leaflets to thicken, calcify, and become funnel shaped; annular calcification may also be present. The mitral commissures fuse, the chordae tendinae fuse and shorten, and the valve cusps become rigid; as a result, the valve leaflets typically display bowing or doming during diastole on echocardiography **(Park, 2004).**

Significant restriction of blood flow through the mitral valve results in a transvalvular pressure gradient that depends on cardiac output, heart rate (diastolic time), and the presence or absence of a normal atrial kick. Increases in either cardiac output or heart rate (decreased diastolic time) necessitate higher flows across the valve and result in higher transvalvular pressure gradients **(Park, 2004).**

The left atrium is often markedly dilated and promotes supraventricular tachycardias, particularly atrial fibrillation. Blood flow stasis in the atrium promotes the formation of thrombi, usually in the left atrial appendage. Loss of normal atrial systole (which is usually responsible for 20–30% of ventricular filling) necessitates even higher

diastolic flow across the valve to maintain the same cardiac output and increases the transvalvular gradient **(Park, 2004).**

Acute elevations in left atrial pressure are rapidly transmitted back to the pulmonary capillaries. If mean pulmonary capillary pressure acutely rises above 25 mm Hg, transudation of capillary fluid results in pulmonary edema. Chronic elevations in pulmonary capillary pressure are partially compen-sated by increases in pulmonary lymph flow but eventually result in pulmonary vascular changes leading to irreversible increases in Pulmonary Vascular Resistance (PVR) and pulmonary hypertension. Reduced lung compliance and a secondary increase in the work of breathing contribute to chronic dyspnea. Right ventricular failure is frequently precipitated by acute or chronic elevations in right ventricular afterload. Marked dilatation of the right ventricle can result in tricuspid or pulmonary valve regurgitation **(Park, 2004)**.

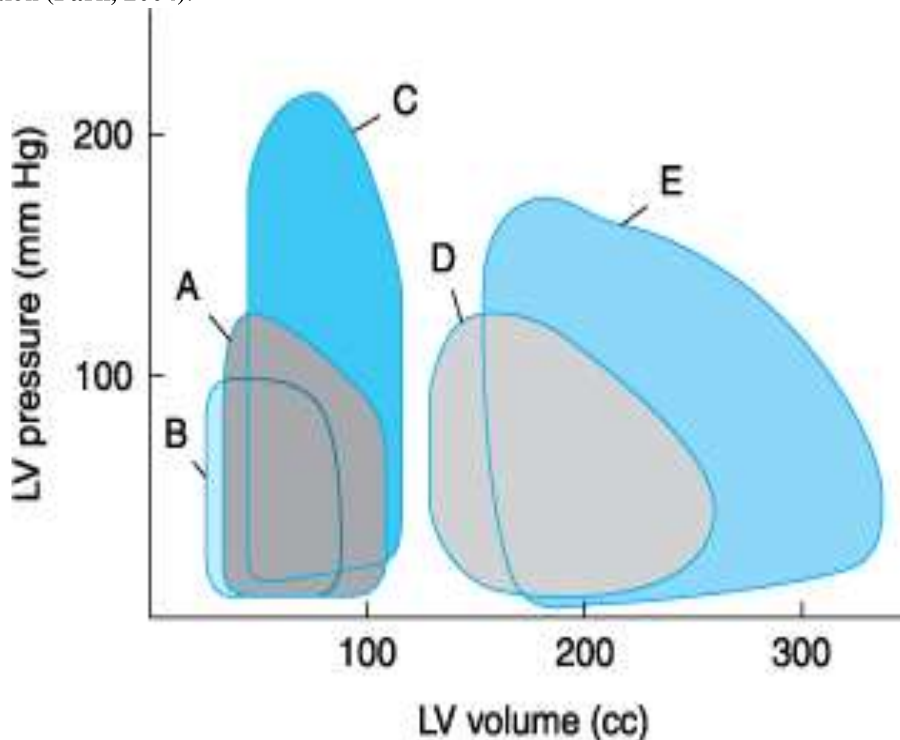


Fig. (9):- Pressure–volume loops in patients with valvular heart disease. A, normal; B, mitral stenosis; C, aortic stenosis; D, mitral regurgitation (chronic); E, aortic regurgitation (chronic). LV left ventricular **(Morgan, 2006)**.

Mitral Regurgitation:

Chronic mitral regurgitation is usually the result of rheumatic fever (often with concomitant mitral stenosis); congenital or developmental abnormalities of the valve apparatus; or dilation, destruction, or calcification of the mitral annulus. Acute mitral regurgitation is usually due to myocardial ischemia or infarction (papillary muscle dysfunction or rupture of a chorda tendinea), infective endocarditis, or chest trauma (**Otto, 2004).**

Pathophysiology

The principal derangement is a reduction in forward stroke volume due to backward flow of blood into the left atrium during systole. The left ventricle compensates by dilating and increasing end-diastolic volume. Regurgitation through the mitral valve reduces left ventricular afterload, which often initially enhances contractility. End-systolic volume thus remains normal but eventually increases as the disease progresses. By increasing end-diastolic volume, the volume-overloaded left ventricle can maintain a normal cardiac output even as ejection fraction decreases **(Otto, 2004).**

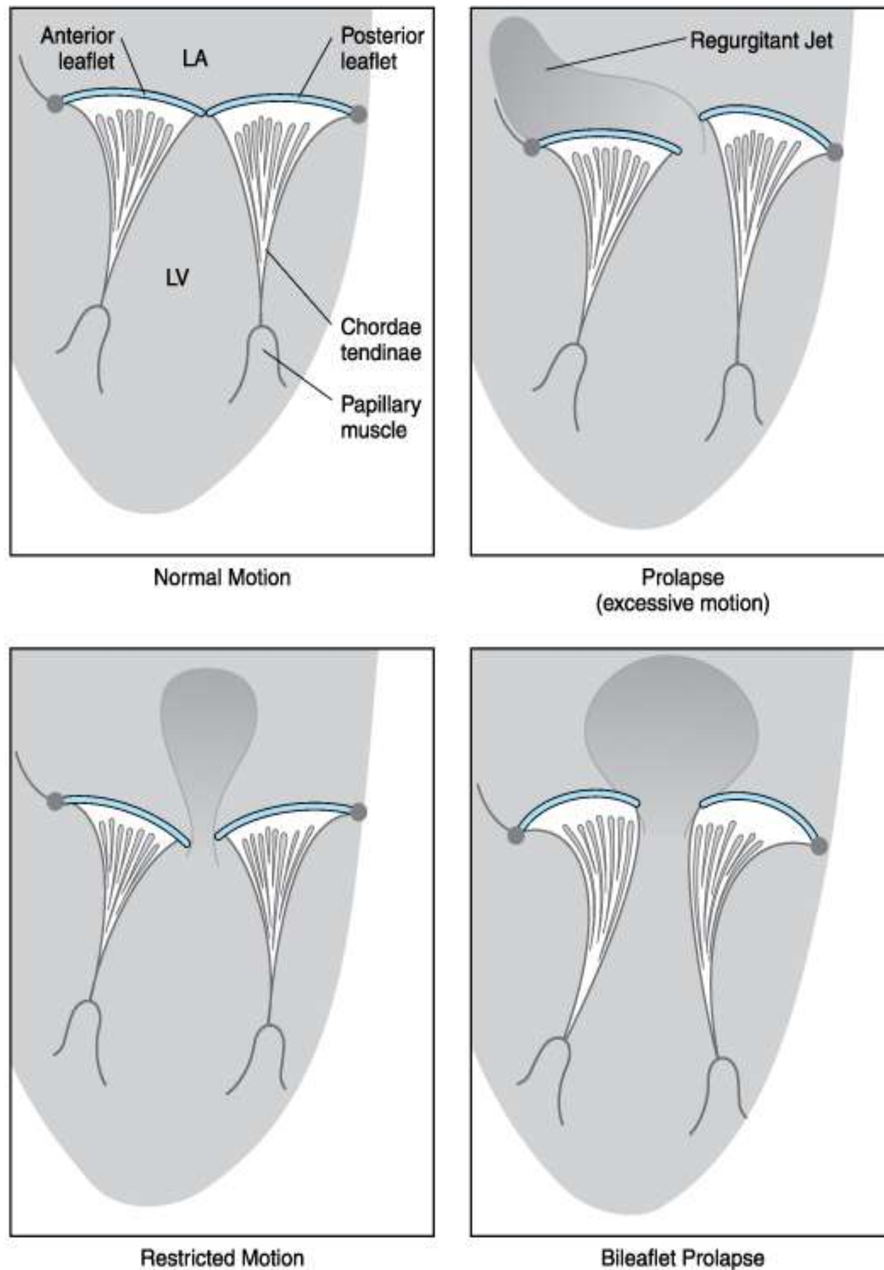


Fig. (10):- Classification of mitral valve leaflet motion (as seen from transesophageal echocardiography). Note that with prolapse, the free edge of the leaflet(s) extends beyond the plane of the mitral annulus producing an eccentric jet. With restricted motion, the leaflets fail to coapt resulting in a central jet **(Morgan, 2006)**.

Hypertrophic cardiomyopathy:

Hypertrophic cardiomyopathy has been referred to by many other names: idiopathic hypertrophic subaortic stenosis, asymmetric septal hypertrophy, hypertrophic obstructive cardiomyopathy, and muscular subaortic stenosis. It is characterized by heterogeneous left ventricular hypertrophy with no obvious cause. The hypertrophied muscle typically displays abnormal cellular architecture **(Eagle et al., 2002).**

Pathophisiology

Affected patients characteristically display diastolic dysfunction that is reflected by elevated left ventricular end-diastolic pressures in spite of often hyperdynamic ventricular function. The diastolic stiffness is presumably due to

the abnormal hypertrophied muscle, which tends to be located in the upper interventricular septum below the aortic valve; rarely, only the ventricular apex is involved **(Eagle et al.,2002).**

Aortic Regurgitation:
Chronic aortic regurgitation may be caused by abnormalities of the aortic valve, the aortic root, or both. Abnormalities in the valve are usually congenital (bicuspid valve) or due to rheumatic fever. Acute aortic insufficiency most commonly follows infective endocarditis, trauma, or aortic dissection**(Morgan, 2006).**

Pathophysiology
1. Regardless of the cause, aortic regurgitation produces volume overload of the left ventricle. The effective forward Stroke Volume (SV) is reduced because of backward (regurgitant) flow of blood into the left ventricle during diastole. Systemic arterial diastolic pressure and Systemic Vascular Resistance (SVR) are typically low.
2. The decrease in cardiac afterload helps to facilitate ventricular ejection. Total SV is the sum of the effective stroke volume and the regurgitant volume **(Morgan, 2006).**
3. With chronic aortic regurgitation, the left ventricle progressively dilates and undergoes eccentric hypertrophy. Patients with severe aortic regurgitation have the largest end-diastolic volumes of any heart disease; the massively dilated heart is often referred to as cor bovinum**(Morgan, 2006)**.

Tricuspid Regurgitation:
Up to 70-90% of patients have mild tricuspid regurgitation on echocardiography; the regurgitant volume in these cases is almost always insignificant

Pathophysiology
1. An increase in end-diastolic volume allows the right ventricle to compensate for the regurgitant volume and to maintain an effective forward flow. Because the right atrium and the vena cava are compliant and can usually accommodate the volume overload, mean right atrial and central venous pressures are generally only slightly elevated **(Howell et al., 2004).**
2. Acute or marked elevations in pulmonary artery pressures increase the regurgitant volume and are reflected by an increase in central venous pressure. Moreover, sudden marked increases in right ventricular afterload sharply reduce the effective right ventricular output, reduce left ventricular preload, and can precipitate systemic hypotension **(Howell et al., 2004).**

Pathophisiology of congenital heart diseases:
Obstructive Lesions:
Congenital aortic stenosis:
Valvular aortic stenosis is the most common cause of obstruction to left ventricular outflow. Left ventricular outflow obstruction is less commonly due to hypertrophic cardiomyopathy, discrete congenital subvalvular stenosis, or, rarely, supravalvular stenosis. Valvular aortic stenosis is nearly always congenital. Abnormalities in the number of cusps (most commonly a bicuspid valve) or in their architecture produce turbulence that traumatizes the valve and eventually leads to stenosis. Obstruction caused by valvular aortic stenosis is almost always gradual, allowing the ventricle, at least initially, to compensate and maintain SV. Concentric ventricular hypertrophy enables the left ventricle to maintain SV by generating a significant transvalvular gradient and to reduce ventricular wall stress **(Morgan, 2006).**

Loss of atrial systole can precipitate congestive heart failure or hypotension in patients with aortic stenosis. Cardiac output may be normal in symptomatic patients at rest, but characteristically, it does not appropriately increase with exertion. Patients may experience angina even in the absence of Coronary Artery Disease (CAD). Myocardial oxygen demand increases because of ventricular hypertrophy, whereas myocardial oxygen supply decreases as a result of the marked compression of intramyocardial coronary vessels caused by high intracavitary systolic pressures (up to 300 mm Hg). Exertional syncope or near-syncope is thought to be due to an inability to tolerate the vasodilation in muscle tissue during exertion. Arrhythmias leading to severe hypoperfusion may also account for syncope and sudden death in some patients. Calcium emboli may occasionally result in neurological complications **(Morgan, 2006).**

Pulmonary Stenosis:

Pulmonary valve stenosis obstructs right ventricular outflow and causes concentric right ventricular hypertrophy. Severe obstruction presents in the neonatal period, whereas lesser degrees of obstruction may go undetected until adulthood. The valve is usually deformed, and is either bicuspid or tricuspid. Valve leaflets are often partially fused and display systolic doming on echocardiography **(Park, 2004)**.

The right ventricle undergoes hypertrophy and poststenotic dilation of the pulmonary artery is often present. With severe stenosis, the pulmonic valve gradient exceeds 60–80 mm Hg, depending on the age of the patient. Right-to-left shunting may also occur in the presence of a patent foramen ovale or atrial septal defect. Cardiac output is very dependent on an elevated heart rate, but excessive increases in the latter can compromise ventricular filling **(Park, 2004).**

Predominantly Left-to-Right (Simple) Shunts:

Simple shunts are isolated abnormal communications between the right and left sides of the heart. Because pressures are normally higher on the left side, blood usually flows across from left to right, and blood flow through the right heart and the lungs increases. Depending on the size and location of the communication, the right ventricle may also be subjected to the higher left-sided pressures, resulting in both pressure and volume overload. Right ventricular afterload is normally 5% that of the left ventricle, so even small left-to-right pressure gradients can produce large increases in pulmonary blood flow **(Park, 2004).**

Large increases in pulmonary blood flow produce pulmonary vascular congestion and increase extravascular lung water. The latter interferes with gas exchange, decreases lung compliance, and increases the work of breathing. Left atrial distention also compresses the left bronchus, whereas distention of pulmonary vessels compresses smaller bronchi **(Park, 2004).**

Ventricular septal defect (VSD):

VSD is one of themost common congenital cardiac lesions accounting for up to 25-35% of congenital heart diseases. The defect may be found in one of several locations on the ventricular septum:

Type I: Located above the crista supra ventricularis under the annulus of the aorta.
Type II: Infra cristal defect.
Type III: Canal type defects accompanies partial A-V canal.
Type IV: Muscular defect.

Pathophysiological effects of VSD include shunting, pulmonary hypertension and heart failure due to volume overload **(Carol, 1993).**

Aterial septal defect (ASD):

Anatomic types:

Patent foramen ovale (PFO), ostium secundum, and sinus venosus.

PFO results from lack of fusion between the septum primum and the secundum and has pathophysiologic significance in only two instances:

a) It may provide a route for air in the RA to enter the LA.
b) It may allow significant right to left shunting in postoperative patients with high right sided pressures such as after right ventriculotomy.

(Rodigas, 1982)

Ostium secondum: the most common type (80%).

The primary pathologic process present in all septal defects is the shunting of blood from one cardiac chamber to another (from LA to RA).

The degree of shunting depends on two factors:

a) The relative compliance of the two cardiac chambers involved.
b) The area of the defect.

(Carol, 1993)

Tetralogy of fallot:

A complex of anatomic malformations characterized by:

1. Underdevelopment of the right ventricular infundibulum and displacement of the infundib-ular septum resulting in right ventricular outflow stenosis or atresia.
2. Large ventricular septal defect (VSD) usualy in the subaortic position,
3. Aortic origin overriding the right ventricle.
4. Right ventricular Hypertrophy (RVH).

Pathophysiology:
The most frequent consequence of the combination of obstruction to pulmonary blood flow and a large VSD is Rt. to Lt. shunting and thus systemic desaturation presenting as cyanosis.

The LV output is determined by the pulmonary venous return and the degree of right to left shunted blood.

The degree of Rt to Lt. shunted blood is determined by the amount of obstruction to pulmonary blood flow at the infundibulum, pulmonary valve anulus, and the pulmonary vasculature. A decrease inpulmonary vascular resistance (PVR) lowers the RV pressure reducing theright to Lt shunting. Decrease in systemic vascular resistance (SVR) may increase the Rt. to Lt. shunting and cyanosis **(Samuelson, 1987).**

Patent Ductus Arteriosus:
Persistence of the communication between the main pulmonary artery and the aorta can produce restrictive or nonrestrictive left-to-right shunts. This abnormality is commonly responsible for the cardiopulmonary deterioration of premature infants, and occasionally presents later in life**(Berger, 2002).**

Tricuspid Atresia:
With tricuspid atresia, blood can flow out of the right atrium only via a patent foramen ovale (or an ASD). Moreover, a PDA (or VSD) is necessary for blood to flow from the left ventricle into the pulmonary circulation. Cyanosis is usually evident at birth and its severity depends on the amount of pulmonary blood flow that is achieved **(Berger, 2002).**

Transposition of the Great Arteries (TGA):
In patients with transposition of the great arteries (TGA), pulmonary and systemic venous return flow normally back to the right and left atrium, respectively, but the aorta arises from the right ventricle and the pulmonary artery arises from the left ventricle. Thus, deoxygenated blood returns back into the systemic circulation and oxygenated blood returns back to the lungs.

Survival is possible only through mixing of oxygenated and deoxygenated blood across the foramen ovale and a PDA. The presence of a VSD increases mixing and reduces the level of hypoxemia **(Berger, 2002).**

Transposition of the great vessels may occur with a VSD and pulmonic stenosis. This combination of defects mimics tetralogy of Fallot; however, the obstruction affects the left ventricle not the right ventricle. Corrective surgery involves patch closure of the VSD, directing left ventricular outflow into the aorta, ligation of the proximal pulmonary artery, and connecting the right ventricular outflow to the pulmonary artery with a valved conduit (Rastelli procedure) **(Berger ,2002).**

Total Anomalous Venous Return:
The absence of a direct connection between the pulmonary veins and the left atrium results in total anomalous venous return. Mixing of deoxygenated and oxygenated blood occurs at or before the right atrial level because the pulmonary veins usually drain into the superior or inferior vena cava, coronary sinus, or ductus venosus. Blood usually reaches the left atrium via the foramen ovale or an ASD **(Sear et al., 2004).**

Obstruction of the pulmonary venous return, which may occur when the blood drains into the ductus venosus and as it begins to close, results in severe pulmonary congestion. Surgical correction involves reanastomosing the common pulmonary venous trunk directly into the left atrium and closure of any ASD **(Sear et al., 2004).**

Truncus Arteriosus:
With a truncus arteriosus defect, a single arterial trunk supplies the pulmonary and systemic circulation. The truncus always overrides a VSD, allowing both ventricles to eject into it. As PVR gradually decreases after birth, pulmonary blood flow increases greatly resulting in heart failure **(Sear et al., 2004).**

If left untreated, PVR increases and cyanosis develops again along with Eisenmenger physiology. Surgical correction closes the VSD, separates the pulmonary artery from the truncus, and connects the right ventricle to the pulmonary artery with a conduit (Rastelli repair) **(Sear et al., 2004)**.

Clinical Implications of TEE
TEE can be performed on patients in the ambulatory setting, intensive care unit, coronary care unit, or operating room. In general, TEE should be employed as the initial diagnostic investigation, as this technique is non invasive and will entail no risk to the patient **(Chan et al., 2002)**.

The American Society of Anesthesiologists (ASA) and the Society of Cardiovascular Anesthesiologists (SCA) published guidelines for preoperative TEE. The guidelines delineate three categories of evidence-based indications for TEE, including category I indications, for which TEE was judged to be frequently useful in improving clinical outcomes in the setting of hemodynamic instability, valvular pathology, cardiac source of emboli, and aortic pathology **(Vezina, 2005)**.

Category I indications:
Supported by the evidence based medicine, TEE is frequently useful in improving clinical outcomes in the following settings and is often indicated, depending on individual circumstances:
1. 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.
2. Intraoperative use in valve repair.
3. Intraoperative use in congenital heart surgery for most lesions requiring cardiopulmonary bypass.
4. Intraoperative use in repair of hypertrophic obstructive cardiomyopathy.
5. Intraoperative use for endocarditis when pre-operative testing was inadequate or extension of infection to perivalvular tissue is suspected.
6. Preoperative use in unstable patients with suspected thoracic aortic aneurysms, dissection, or disruption that needs to be evaluated quickly.
7. Intraoperative assessment of aortic valve function in repair of aortic dissections with possible aortic valve involvement.
8. Intraoperative evaluation of pericardial window procedures.
9. Use in the 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:
Supported by weaker evidence; TEE may be useful in improving clinical outcomes in the following settings, depending on individual circumstances, but appropriate indications are less certain:
1. Perioperative use in patients with an increased risk of myocardial ischemia or infarction.
2. Preoperative use in patients with an increased risk of hemodynamic disturbances.
3. Intraoperative assessment of valve replacement.
4. Intraoperative assessment of repair of cardiac aneurysms.
5. Intraoperative evaluation of removal of cardiac tumors.
6. Intraoperative detection of foreign bodies.
7. Intraoperative detection of air emboli during cardiotomy, heart transplant operations, and upright neurosurgical procedures.
8. Intraoperative use during intracardiac throm-bectomy.
9. Intraoperative use during pulmonary embo-lectomy.
10. Intraoperative use for suspected cardiac trauma.
11. Preoperative assessment of patients with suspected acute thoracic aortic dissections, aneurysms, or disruption.
12. Intraoperative use during repair of thoracic aortic dissections without suspected aortic valve involvement.
13. Intraoperative detection of aortic atheromatous disease or other sources of aortic emboli.

14. Intraoperative evaluation of pericardiectomy, pericardial effusions, or pericardial surgery.
15. Intraoperative evaluation of anastomotic sites during heart and/or lung transplantation.

(Vezina, 2005)

Category III indications:

Little current scientific support; TEE is infrequently useful in improving clinical outcomes in the following settings, and appropriate indications are uncertain.

1. Intraoperative evaluation of myocardial perfusion, coronary artery anatomy, or graft patency.
2. Intraoperative use during repair of cardio-myopathies other than hypertrophic obstructive cardiomyopathy.
3. Intraoperative use for uncomplicated endo-carditis during noncardiac surgery.
4. Intraoperative monitoring for emboli during orthopedic procedures.
5. Intraoperative assessment of repair of thoracic aortic injuries.
6. Intraoperative use for uncomplicated peri-carditis.
7. Intraoperative evaluation of pleuropulmonary diseases.
8. Monitoring placement of intra-aortic balloon pumps, automatic implantable cardiac defibrillators, or pulmonary artery catheters.
9. Intraoperative monitoring of cardioplegia administration.

(Cahalan, 2005)

Applications of echocardiography in anesthetic practice can be summarized as follows:

1- Assessment of Regional Cardiac Function and Detection of Myocardial Ischemia:

Within seconds of the onset of myocardial ischemia, affected segments of the heart cease contracting normally. This fact is the basis for the use of TEE for the detection of myocardial ischemia. For example, in 50 patients undergoing cardiovascular surgery, new severe Segmental Wall Motion Abnormalities (SWMAs) occurred in 24 patients and ischemic ST-segment changes in only 6. In three patients who sustained intraoperative myocardial infarctions, severe SWMAs developed in the corresponding area of myocardium and persisted until the end of surgery, but only one of these three patients had ischemic ST-segment changes intraoperatively **(Vezina, 2005)**.

Subsequent studies in comparable patients confirmed these advantages of TEE over electrocardiographic monitoring. Moreover, when multiple TEE cross sections are monitored (not just the one cross section as was done in the before mentioned studies), the detection rate of SWMAs more than doubles **(Cahalan, 2005)**.

Table (1):- Classes of segmental wall motion and thickening.

Class of Wall Motion	Wall Thickening	Change in Radius
1. Normal or hyperkinesis	Marked	>30% ↓
2. Mild hypokinesis	Moderate	10%–30% ↓
3. Severe hypokinesis	Minimal	<10% or >0% ↓
4. Akinesis	None	No change
5. Dyskinesis	Thinning	↑

(Cahalan, 2005)

Segmental wall thickness (SWT) is examined by comparing the wall thickness (the distance between the endocardium and epicardium) at end-diastole with that at end-systole.

$$\% \, WTh = \frac{WTh_{es} - WTh_{ed}}{WTh_{es}} \, x \, 100$$

Where % WTh is percent wall thickening, WTh_{es} is end-systolic wall thickness, and WTh_{ed} is end-diastolic wall thickness. Normal wall thickening at the interventricular septum is 40% to 80% **(Oka and Goldiner, 1992).**

The short-axis view at the mid-papillary level of the left ventricle is the best single view for routine monitoring of regional motion, since this view includes segments of myocardium supplied by each of the main coronary arteries **(Shah et al., 1991)**.

The use of multiplane TEE, which enhances the ability to observe long-axis shortening and potential RWMA in the apex of the left ventricle, was found to improve the ability of TEE to detect changes in regional cardiac function **(Shah et al.,1991).**

Echocardiographic contrast agents can delineate myocardial blood flow, but to date, they have not proved to be a practical method to differentiate infarcted from acutely stunned myocardium. Fortunately, dobutamine may facilitate this differential diagnosis because it can improve segmental function in stunned, but not infarcted myocardium. For clinical purposes, when stunning, but not infarction, is suspected after cardiopulmonary bypass, graft status should be re-evaluated and segmental myocardial function should be closely monitored for signs of improvement. A trial of low- to moderate-dose dobutamine may improve the function of stunned myocardium **(Vezina, 2005)**.

If worsening occurs, if graft status is questionable, or if the patient's hemodynamics is tenuous, additional revascularization should be considered. Intraoperative stress testing has been evaluated and appears to be safe in the setting of cardiac surgery **(Vezina, 2005).**

2- Assessment of Global Cardiac Function and Measurement of Cardiac Output:

Preload:

The preload of the left ventricle is equivalent to the end-diastolic wall stress, which is mainly determined by the end-diastolic filling volume. Usually filling pressures are determined instead of filling volumes because determination of filling volumes of the left ventricle is not practical in routine clinical practice **(Roelandt et al., 1993)**.

Global Left Ventricular (LV) Contractile Function:

Accurate measurement of left ventricular volume is of primary importance in evaluating global systolic function. Using conventional echocardiography, a number of models have been proposed for this purpose. Ejection Fraction (EF), Stroke Volume (SV), and Cardiac Output (CO) can be calculated using the left ventricular volumes measured at end-diastoleand end-systole by the following equations:

$EF = (EDV - ESV)/EDV$

$SV = EDV - ESV$

$CO = (EDV - ESV) . HR$

Where EDV and ESV are end-diastolic and end-systolic volumes respectively and HR is heart rate.

An ejection fraction below 0.5 is considered to be abnormal. However, normal values change depending on the scanning level **(Oka and Goldiner, 1992)**.

Measuring LV contractility is much more difficult. The fractional area change (FAC) of the left ventricle can be measured by using the transgastric (TG) mid short axis (SAX) or any of the longtidunal axis (LAX) cross sections (provided that the LAX cross sections include the apex of the left ventricle) with the following formula:

$FAC = (EDA - ESA)/EDA \times 100\%$

Where EDA is the cross-sectional area at end-diastole and ESA is the cross-sectional area at end-systole. EDA and ESA are easily measured with the standard software supplied with all ultrasonographs. In the absence of segmental dysfunction, FAC is a reasonable approximation of LV ejection fraction, but the ejection fraction is clearly load dependent and should be viewed cautiously as an index of ventricular function. However, the LV ejection fraction is an excellent predictor of survival in patients with coronary artery disease and is widely used in the perioperative assessment of high-risk patients. Load-independent measures of LV contractility are possible with TEE but are too complex for clinical practice **(Vezina, 2005)**.

Ejection Fraction and Stroke Volume:

Although it is somewhat load dependent and therefore not a pure index of left ventricular function, ejection fraction is often assumed to reflect ventricular contractility. During intraoperative TEE, the fractional area of change measured at the transgastric midpapillary level is often used interchangeably with ejection fraction, although gauging volume in a potentially asymmetric chamber based on the measurement of an area has obvious limitations **(Donald, 2002).**

Cardiac Output:
Real-time images of LV filling and ejection permit qualitative, immediate assessment of marked changes in cardiac output. However, with PW and CW Doppler, TEE can quantify cardiac output. A Doppler measurement of blood flow velocity is combined with a two-dimensional measurement of cross-sectional area:
Cardiac output = VTI - CSA - cos theta - Heart rate

Where VTI is the velocity time integral (the area under the Doppler-derived velocity-versus-time curve per systole), CSA is the cross-sectional area through which the velocity passes, and cos theta is the cosine of the angle between the ultrasound beam and blood flow **(Cahalan, 2005)**.

Contractility:
The end-systolic pressure-volume relationship and resultant end-systolic elastance defines contractility in a load-independent fashion and would therefore be of potential use in the estimation of intraoperative left ventricle contractility and in the quantification of changes resulting from manipulations such as cardiopulmonary bypass **(Vignon et al., 1999).**

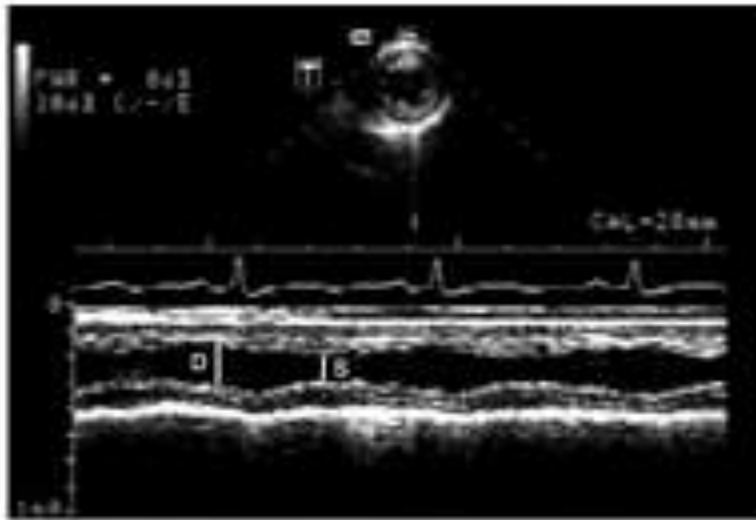


Fig. (11):- Fractional shortening of the left ventricle is derived from an M-mode view of a transgastric mid short axis echocardiogram. The internal diameters of the LV are measured during diastole (D) and systole (S) **(Fox et al., 2003)**.

Left Ventricular Filling:
In the operating room, rapidity is needed in the assessment of preload during periods of hemodynamic instability. Since the introduction of the pulmonary artery catheter in the 1970s, measurement of pulmonary capillary wedge pressure as a surrogate of left ventricular end diastolic volume has been the intraoperative practice standard. TEE has the potential to refine this measurement by allowing Doppler estimation of left atrial pressure, two-dimensional measurement of left ventricular cross-sectional area, and calculation of left ventricular volume **(Mazer et al., 2000).**

Left Atrial Pressure:
Left atrial pressure can be estimated with Doppler TEE by several methods. If mitral regurgitation is present, measurement of the peak velocity of the regurgitant jet and application of the modified Bernoulli equation allows calculation of the left ventriculo atrial pressure gradient; subtraction of this number from the peak systolic blood pressure yields left atrial pressure. Certain mitral inflow and pulmonary venous variables also correlate with left atrial pressure **(Donald, 2002).**

Cheung et al. (1994), Performed an elegant study examining the effect of graded hypovolemia produced by autologous blood collection on hemodynamics and TEE-derived indices of left ventricular preload in patients undergoing coronary artery bypass surgery. Patients with valvular insufficiency, rhythms other than sinus, and overt congestive heart failure were excluded. Patients were stratified on the basis of resting left ventricular function. End diastolic area, end-systolic area, pulmonary capillary wedge pressure, and measures of end-diastolic and end-systolic

wall stress decreased linearly as blood volume was reduced from 0 to 15% in all patients; however, in patients with impaired left ventricular function, only the TEE-derived indices maintained linearity.

Global Right Ventricular (RV) Contractile Function:
Measurement of RV function is more difficult than LV function because of the complex shape of the right ventricle, its large surface area relative to its volume, and its tendency to change shape with changes in loading **(Vezina, 2005).**

Normally, inward motion of the free wall of the right ventricle contributes most to RV ejection; however, some ejection is contributed by contraction of the RV outflow tract and by descent of the base of the heart. Thus, the four-chamber and ME RV inflow-outflow cross sections are the most useful for assessing RV function because they reveal the free wall best (**Vezina, 2005).**

In the four chamber cross section, a normal right ventricle will appear smaller than a normal left ventricle (intra cavitary area roughly two thirds of the LV cavity area) because it is crescent shaped and partially wrapped around the left ventricle. In the ME RV inflow-outflow cross section, the crescent shape of the right ventricle should be most apparent. Although subtle RV dysfunction is hard to diagnose with TEE, severe dysfunction is not. The hallmarks are severe hypokinesis or akinesis of the RV free wall, enlargement of the right ventricle to exceed that of the apparent size of the left ventricle, a change in the shape of the right ventricle from crescent to round, and a flattening or bulging of the intra ventricular septum to the left. These signs may be accompanied by tricuspid regurgitation secondary to tricuspid annular dilatation. With very severe RV failure caused by RV pressure overload, RV dilatation can be so great that it tamponades the left ventricle **(Vezina, 2005).**

In the setting of cardiopulmonary bypass, the evaluation of right ventricular function is important. Right ventricular dysfunction often occurs secondary to the inadequate delivery of cardioplegia and to the embolization of intracardiac air down the right coronary artery following separation from cardiopulmonary bypass. The triangular shape of the right ventricle makes its global function hard to quantitate with TEE and the abnormal septal motion often seen following cardiopulmonary bypass compounds this difficulty **(cheng, 2000).**

Intraoperative RV systolic and diastolic functions were evaluated echocardiographically by assessing Doppler hepaticvenous flow velocity (HVF) patterns before and after CPB. Thenormal HVF pattern is characterized by forward flow in systolethat exceeds the forward flow velocity in early diastole. Thesystolic component is produced by RV contraction with a combinationof atrial relaxation and descent of the TV annulus. Alternatively,the diastolic component is a result of TV opening and RV relaxationand compliance **(cheng, 2000).**

Afterload:
Afterload is equivalent to end-systolic wall stress, and can be determined by end-systolic wall thickness and peak-systolic pressure **(Roelandt et al., 1993).**

To obtain an index for left ventricular (LV) wall stress, 2-D or M-mode echocardiographic assessment of LV dimensions, in the short axis view at mid-papillary muscle level; are combined with measurements of systolic arterial pressure (SAP), which substitutes LV peak systolic pressure.

Greim et al. (1995), measured left ventricular ES pressure-area product as a predictor of ES wall stress. They multiplied systolic arterial pressure with the end-systolic cavity area obtained by TEE. They found a strong correlation between ES pressure-area product and M-mode ES wall stress and with 2-D mode ES wall stress.

3- Assessment of Cardiac Anatomy and Blood Flow Pattern:
Echocardiographic assessment of valvular diseases require a combination of M-mode, 2-D, and Doppler techniques. For regurgitant lesions, the anatomic defect is depicted by 2-D echocardiography, and the location and spatial extent of flow disturbances are semi -quantified by Colour Doppler Imaging (CDI). A combination of 2-D and M-mode echo cardiography is used to assess left ventricular size and function, to help determine the impact of valvular regurgitation on left ventricular performance **(Rippe et al., 1996).**

In valvular stenosis, pulsed and continuous-wave Doppler study is used to measure the peak velocity associated with valvular stenosis and, using the Bernoulli principle, one can estimate peak and mean pressure gradients. These

velocity measurements may also be used to estimate the stenotic valve area in mitral and aortic stenosis. Doppler-derived gradients correlate closely with invasive deter-mination **(Rippe et al., 1996).**

Mitral stenosis:
Mitral stenosis is mostly the result of rheumatic heart disease. 2-D imaging reveals thickened leaflets that dome toward the LV and open poorly. Color Doppler reveals laminar flow acceleration into the stenotic orifice and a turbulent jet emerging into the ventricle. PW and CW Doppler traces display a characteristic flow pattern with increased peak and mean velocities **(Stoddard et al., 1994).**

In addition to the signs noted earlier, severe mitral stenosis always causes marked left atrial enlargement and left atrial spontaneous contrast. Spontaneous contrast is smoke-like appearance of 1-2 mm densities not due to exogenously administrated contrast agents, but to aggregation of red cells in areas of low flow. Whenever left atrial enlargement and spontaneous contrast are noted, thrombus in the left atrium and in particular in the left atrial appendage should be suspected and excluded.

The principal hemodynamic goals in anesthetic management of patients having mitral stenosis are to maintain a sinus rhythm (if present preoperatively), to avoid tachycardia, to avoid large increases in cardiac output, and to avoid both hypovolemia and fluid overload by judicious fluid therapy (**Kranidis et al., 1993**).

Mitral Regurgitation:
The quantitation of valvular regurgitation is important, not only for the early detection of hemodynamically significant lesions but also for monitoring of therapeutic success. It has been suggested that not all patients respond favorably to vasodilator therapy, and quantitative methods can thus assist in differentiating patients by their response to therapeutic interventions **(Heinle, 2002).**

Volumetric Methods:
Regurgitant fraction can be calculated from the difference between flow rates determined at two separate intracardiac sites using the continuity equation. Total stroke volume is measured as antegrade flow across the regurgitant valve, whereas net forward stroke volume is measured as antegrade flow across a competent valve. The combined use of 2-D echocardiography with conventional pulsed-wave Doppler and continuous wave Doppler allows the estimate of volumetric flow across any of the cardiac valves using the following equation:
$SV = CSA \times TVI$

Where SVis stroke volume, CSAis cross-sectional area of the annulus, and TVIis time velocity integral measured as the area under the Doppler spectral velocity curve.

To quantitate mitral regurgitant volume (RV), net forward stroke volume (SV) is measured from the aortic annulus and subtracted from the total stroke volume measured at the mitral annulus, as follows:
$RV = \text{Total SV} - \text{Forward SV}$

Total stroke volume can also be obtained by subtracting end-systolic from end-diastolic volume obtained by two-dimensional echocardiography.

The volumetric method is usually applied to left-sided regurgitant lesions, although it is theoretically possible to substitute flow across a competent pulmonary or tricuspid valve for aortic flow in patients with concomitant aortic insufficiency **(Heinle, 2002).**

Table (2):- Grading of mitral regurgitation based on length of the regurgitant jet in relation to the left atrial area.

Grading of mitral regurgitation	Regurgitant jet relation to left atrium
No MR	0
Jet extends behind the valve.	1+
Jet extends up to one third of length of left atrium.	2+
Jet extends up to two thirds the length of left atrium.	3+
Jet extends more than two thirds into the left atrium.	4+

(Ramesh, 2002)

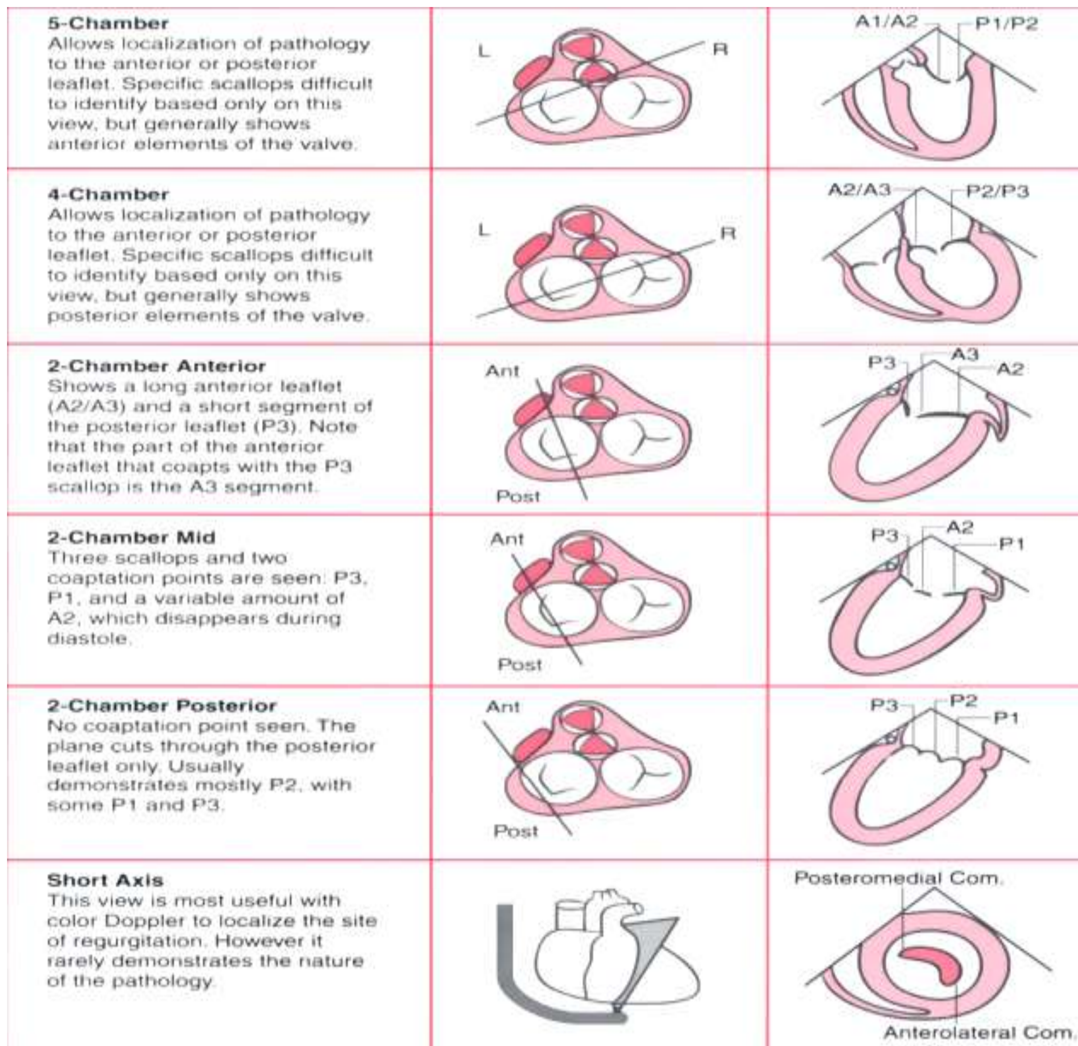


Fig. (12):- Systematic examination of the mitral valve. In this examination, the mitral valve is viewed in multiple cross sections to delineate leaflet anatomy. The "5-chamber" cross section is accomplished by withdrawing the probe slightly from the standard 4-chamber cross section until the left ventricular outflow track is in view. The center column shows the planes of the different cross sections as viewed from directly above the base of the heart. The 2-chamber "anterior," "mid," and "posterior" cross sections are variations of the standard 2-chamber cross section and are accomplished by turning the probe from the patient's right to left. "P1, P2, and P3" refer to the three scallops of the posterior mitral leaflet, and "A1, A2, and A3" refer to the juxtaposed segments of the anterior mitral leaflet. The rightcolumn shows the leaflet segments seen in the corresponding cross section **(Lambert et al., 1999)**.

Aortic stenosis:

Multiplane TEE provides marginally more accurate assessment of anatomy and valve area than single plane TEE because with multiplane TEE the ultrasound beam can be more precisely aligned with the short axis of the aortic annulus than can be done with single plane TEE **(Kim et al., 1997).**

Doppler studies in this cross section reveal turbulence above the valve but they cannot quantity severity because blood flow is perpendicular to the ultrasound beam. In contrast, the transgastric five-chamber cross-section allows excellent alignment of the beam with blood flow for determination of the gradient across the valve **(Blumberg et al., 1997).**

Aortic Regurgitation:

Deceleration Slope:

With increased severity of aortic regurgitation, the diastolic aortic pressure falls rapidly while left ventricular filling pressure rises rapidly, resulting in a steeper deceleration slope on a continuous wave Doppler echocardiogram. Although deceleration slope and pressure half-time both are measured from the continuous wave Doppler curve, deceleration slope is not dependent on the initial pressure gradient. Deceleration slope has been reported to be a better index of regurgitant severity than pressure halftime, demonstrating a close correlation with angiographic grade of regurgitation even in patients with associated aortic stenosis, mitral valve disease, or low cardiac output. A deceleration slope greater than 3 m/sec^2 suggests severe aortic regurgitation. Unfortunately, a deceleration slope less than 3 m/sec^2 can be seen with mild, moderate, or severe regurgitation. Left ventricular compliance influences the reliability of deceleration slope as an index of aortic regurgitant severity **(Heinle, 2002).**

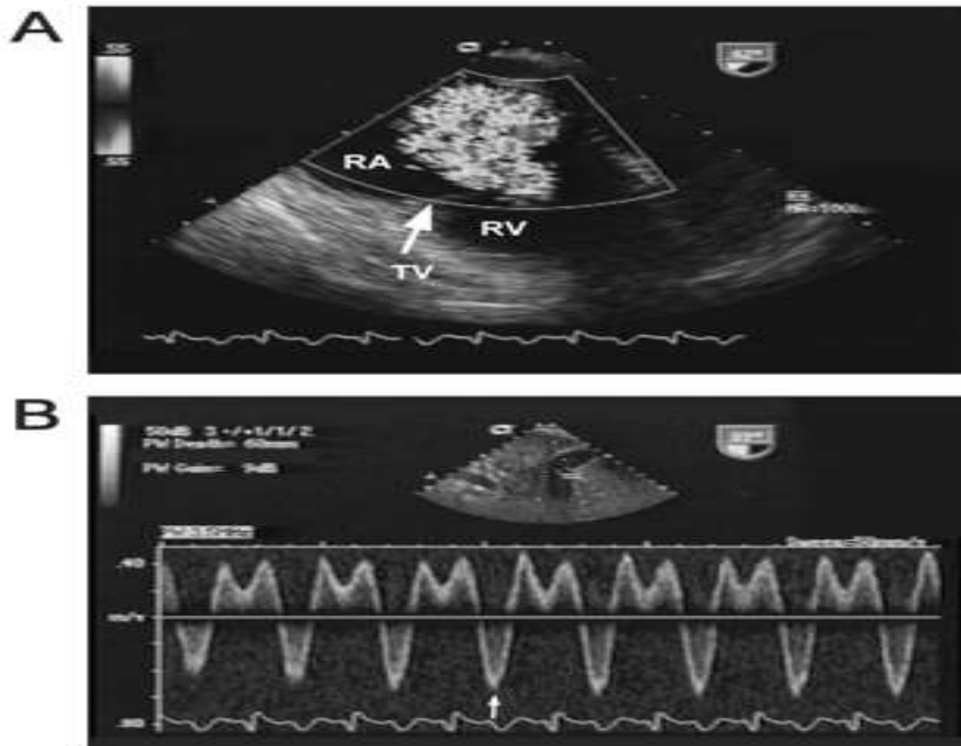
Table (3):- Simplified grading for aortic insufficiency.

	Jet Width at Origin (mm)	Jet Area (% of LVOT)	Jet Depth into LV (cm)
Mild	<2	<50	1-2
Moderate	3-5	50-75	3-5
Severe	>5	>75	>5

(Cahalan, 1996).

Tricuspid Regurgitation:

A reliable marker of severe tricuspid regurgitation is systolic reversal of flow in the hepatic veins and venae cavae. Another index of severe tricuspid regurgitation is an associated annular diameter greater than 34 mm. Although right ventricular systolic pressure can be estimated from continuous wave Doppler interrogation of flow across a regurgitant tricuspid valve, it is of little value in assessing the severity of tricuspid regurgitation, since increased regurgitant severity results in increased right atrial pressure and decreased peak tricuspid velocity and pressure gradient (**Heinle ,2002).**



Severe tricuspid regurgitation. (A) Enlarged right atrium and color flow Doppler evidence of severe tricuspid regurgitation. (B) Hepatic vein Doppler flow velocity profile demonstrating systolic flow reversal (arrow) consistent with severe tricuspic regurgitation (Fox et al., 2003).

4-Assessment of Surgical Repair and Results of Surgery:
a- Valvular Heart Disease:
Valvular abnormalities detected with TEE have important implications. In one study, intraoperative TEE detected mitral regurgitation so severe in 5 of 182 patients scheduled for coronary artery surgery that unscheduled mitral valve repair was performed **(Cahalan, 2005).**

The major challenge in the management of patients with valvular regurgitation is the ability to identify contractile dysfunction and to correct the regurgitant lesion before irreversible contractile dysfunction develops **(Starling et al., 2002).**

Because LV contractility dysfunction is the most important determinant of survival and postoperative outcome in valvular regurgitation, the primary goal guiding the timing of surgical intervention is assumed to be preservation of contractility **(Starling et al., 2002).**

Table (4):- Indications for Intraoperative Echocardiography.

Mitral Disease	To assess feasibility and success of mitral repair for mitral regurgitation. To assess feasibility and success of commissurotomy for mitral stenosis. To determine need for mitral surgery in patients undergoing revascularization or aortic surgery. To assess presence of disease of other valves or other cardiac structures.
Aortic Disease	To assess feasibility and success of aortic valve repair. To assess size of prosthesis. To assess feasibility and success of homograft implantation or Ross procedure.
Tricuspid Disease	To assess need for, feasibility, and success of tricuspid repair.
Prosthetic Function	To determine presence and site of paravalvular leak. To assess perivalvular tissue for abscesses or infection. To assess site and presence of pannus or thrombus.
Revasculari-zation	To assess regional wall motion and global left ventricular function before and after revascularization. To determine sequence of graft placement. To detect and assess complications of infarction (ventricular septal defect, mitral regurgitation).
Surgery on Aorta	To assess size and extent of aneurysm. To determine the mechanism and severity of associated aortic regurgitation. To determine presence and complications of aortic dissection. To determine presence and extent of aortic atheroma.
Transplan-tation/ Devices	To assess left ventricular function and suture lines postoperatively. To assess appropriate sizing, function, and hemodynamic changes with ventricular assist devices.
Congenital Heart surgery	To determine connections (ventriculoarterial, atrioventricular). To assess systemic and nonsystemic ventricular size and function. To assess anatomy of shunts and valvular anatomy.
Monitoring	To assess ventricular volume and function. To monitor drug effects on ventricular function. To diagnose presence and location of ischemia.

(William et al., 2002)

TEE is essential when mitral valve repair is anticipated. It provides a highly accurate anatomic assessment of the mitral valve and is strongly and independently predictive of valve repairability and postoperative outcome **(Omran et al., 2002)**.

The echocardiographic evaluation of the patient with valvular aortic stenosis focuses on quantitation of stenosis severity and assessment of the left ventricular response to chronic pressure overload. The basic clinical echocardiogram includes measurement of maximum aortic jet velocity and calculation of continuity equation aortic valve area. In addition, a more detailed assessment of stenosis severity may be important for understanding the natural history of this disease and for assessment of interventions to slow or reverse disease progression **(Shavelle et al., 2002).**

Several alternative measures of stenosis severity have been proposed, including two-dimensional valve area on trans-esophageal imaging, left ventricular stroke work loss, valve resistance and changes in aortic valve area during the cardiac cycle, three-dimensional valve area, and scoring of valve calcium **(Vignon et al., 1999).**

Prosthetic Valves:
Since its clinical introduction more than a decade ago, transesophageal echocardiography (TEE) has been widely accepted as a tool that allows superior anatomic and functional assessment of native and prosthetic valves. TEE now is a routine diagnostic procedure in assessing prosthetic heart valves. Three-dimensional (3D) echocardiography is an evolving new technology with a wide range of potential clinical applications, and evaluation of prosthetic heart valves, particularly tissue valves **(Zabalgoiti, 2002).**

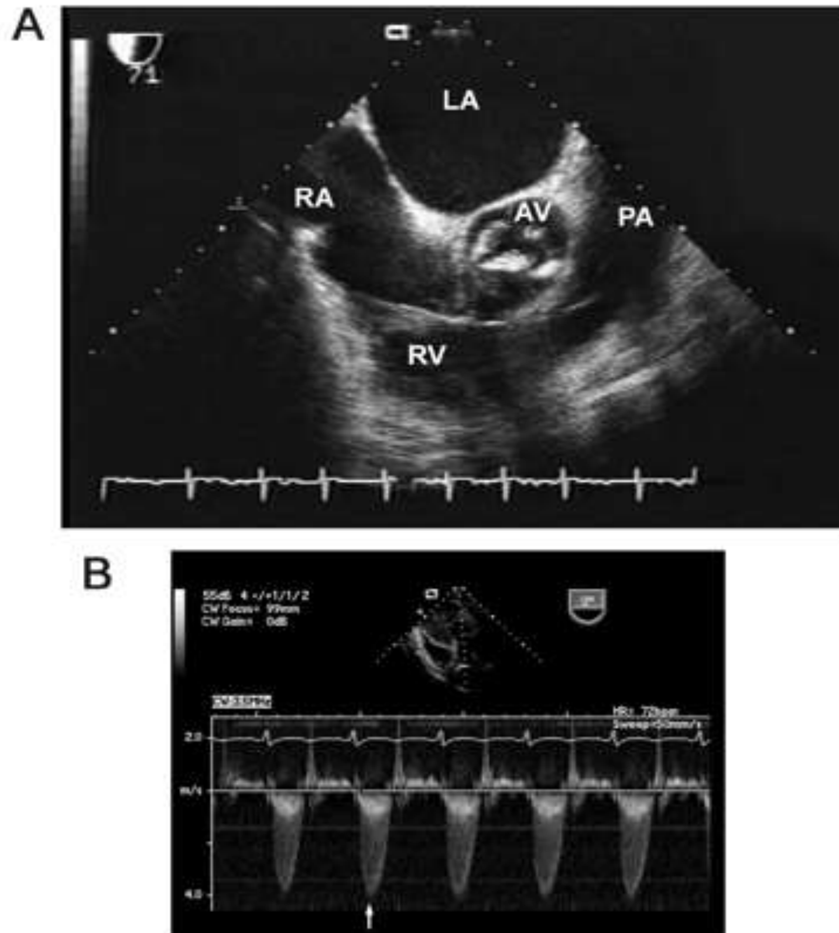
Aortic valve:
For most cases in which the AV is replaced, the pathology hasbeen well delineated by preoperative echocardiography and angiography. In a study by **Nowrangi et al. (2001)**, none of thepatients who underwent AorticValve Replacement (AVR) for Aortic Stenosis (AS) required aortic prosthesis modificationpost–CPB, based on the intraoperative TEE examination. However, in the same study, intraoperative TEE altered theplanned operation in 13% of the patients. The changes in surgicalplan based solely on new data from the intraoperative pre–CPBTEE examination. In addition, intraoperative TEE measurement of aorticannular size, which the investigators were able to do reliably,allowed homografts to be thawed and prepared prior to aortotomy,potentially decreasing the duration of CPB**(Fox et al., 2003).**

Mitral valve:
Echocardiographic assessment of mitral pros-theses includes calculation of the mean pressure gradient and the effective orifice area. Similar to aortic prostheses, the mitral mean pressure gradient correlates very well with the mean gradient derived at the time of catheterization when both data are recorded simultaneously **(Zabalgoiti, 2002).**

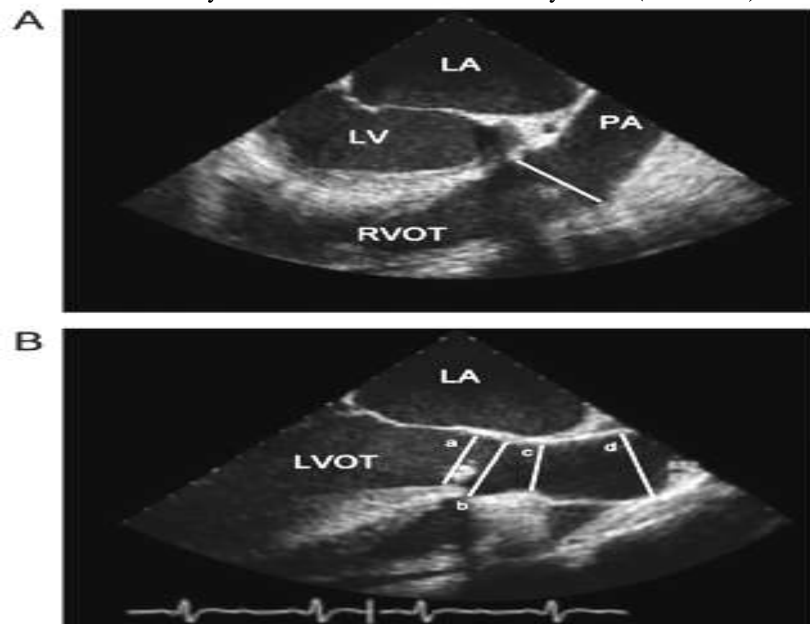
Multiplane TEE approach is the method of choice. This approach is ideally suited for assessing the mitral valve because of its close proximity to the left atrium and the use of high frequency transducer. The exact appearance of the mitral valve depends on the valve's orientation and the degree of left atrial enlargement. During the examination, the valve sewing ring should be carefully searched at the mid-esophageal and transgastric levels. The left atrium and its appendage should be searched for spontaneous echo contrast and thrombus because they may be present in patients with prosthetic mitral valves even if they are in sinus rhythm and have normal left ventricular function **(Tousignant, 1999).**

Tricuspid valve:
Bioprostheses are preferred over mechanical valves because of their high thrombogenic potential in this position. Because flow across the right-sided chambers increases with inspiration, one should expect mild variations in the peak E wave velocity; therefore, three (sinus rhythm) to five (atrial fibrillation) beats should be taken for an average. Severe tricuspid regurgitation is frequently caused by dilation of the native annulus; therefore, annular rings are nowadays preferred over prosthetic valves to correct hemodynamically significant tricuspid regurgitation. TEE plays an important role in these cases by confirming annular dilation as the origin of the regurgitation and not an intrinsic leaflet abnormality **(Fleisher et al., 2002).**

Pulmonary valve:
The more commonly used TEE views include the basal short-axis and the longitudinal views, which may be helpful in choosing the appropriate homograft size. Color flow Doppler examination within the right ventricular outflow tract is essential to document any residual regurgitation **(Fleisher et al., 2002).**



Aortic stenosis: (A) This two-dimensional transesophageal echocardiographic image demons-trates a calcified and stenotic aortic valve. (B) A continuous wave Doppler flow velocity profile is used to measure the velocity (arrow) across the stenotic aortic valve. The velocity across the aortic valve is nearly 4 m/s **(Fox et al., 2003)**.



Pulmonary artery and aortic measurements prior to Ross procedure. (A) Measurement of the pulmonary valve (PV) annular diameter (straight line). (B) Aortic valve and ascending aortic diameters measured in a mid-esophageal, aortic valve long axis transesophageal echocardiographic view. Line a = aortic valve annulus; line b = sinus of Valsalva; line c = sinotubular junction; line d = ascending aorta; RVOT= right ventricular outflow tract; PA= pulmonary artery; LV= left ventricle; LA= left atrium; LVOT= left ventricular outflow tract **(Fox et al., 2003)**.

b- Assessment of Surgical Results:

After the planned surgical intervention, TEE can identify residual defects that need to be addressed to limit morbidity, mortality, and hospitalization costs **(Cahalan, 2005).**

Intraoperative TEE assessment of mitral valve function is predictive of postoperative function and outcome. However, during this assessment, the patient's hemodynamics must be restored to normal values; otherwise, the prognostic value of TEE can be lost. Even with the maturation of valve repair techniques, a significant number of repairs must be immediately revised **(Click et al., 2000).**

During valve replacement surgery, TEE reliably detects periprosthetic leaks (surprisingly common). Although moderate or severe periprosthetic leaks should almost always undergo immediate repair, almost half of small leaks resolve with the administration of protamine (**Morehead et al., 2000).**

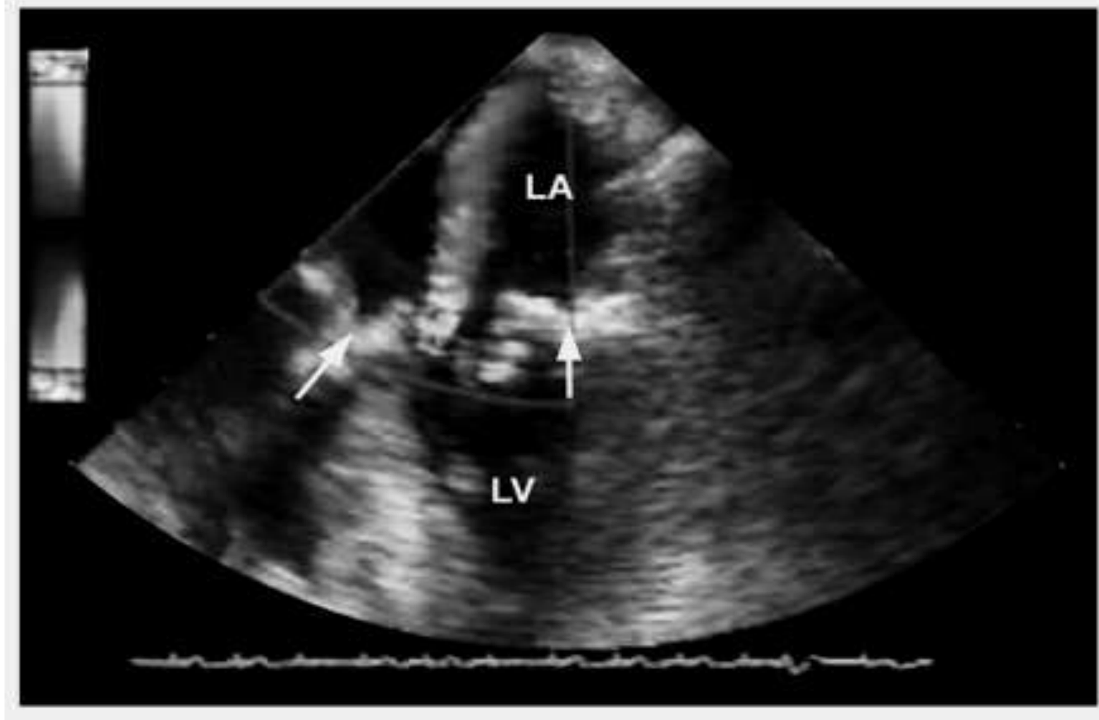
Off-Pump Coronary Bypass Surgery:

The off-pump bypass surgical approach to coronary revascularization involves bypassing coronary arteries without cardiopulmonary bypass, otherwise known as the "beating heart" operation. TEE can detect regional wall motion abnormalities during intermittent coronary occlusion and cardiac lifting, which, if persistent, may necessitate the institution of cardiopulmonary bypass. The use of color kinesis to better define regional wall motion abnormalities intraoperatively has been described but is limited somewhat by cardiac translocation during surgical manipulation **(Watanabe et al., 1999).**

The use of myocardial contrast echocardiography has improved the understanding of the distribution of cardioplegia delivered by both anterograde and retrograde routes. The ability to predict the adequacy of delivery based on knowledge of coronary anatomy and the presence of angiographically demonstrated collateral flow is marginal at best. It is also clear that retrograde cardioplegia does not reliably perfuse the right ventricular free wall **(Vander et al., 2000).**

In the future, the use of myocardial contrast echocardiography may help to differentiate post bypass stunning, which would be treated with cardiopulmonary support, from graft obstruction, which would be treated with surgical correction **(Borger et al., 1999).**

Immediately after valve repair and before the chest is closed, the echocardiographer can determine whether the repair is adequate or if there is residual regurgitation or other complications present, requiring further repair or prosthetic implantation. Making this determination before the chest is closed allows the surgeon to perform further surgical procedures during a second run of cardiopulmonary bypass (a "second pump run") to optimize the surgical outcome. This second pump run eliminates the need for another surgical procedure at a later time **(Stewart et al., 2002).**



Moderate mitral regurgitation is demonstrated in this image following mitral valve repair. The regurgitation jet extends to the back of the left atrium (LA) and is broad-based. The arrows indicate the borders of the ring placed during the repair. LV = left ventricle **(Fox et al., 2003)**.

Table (5):- Intraoperative echocardiographic assessment of repair and reconstructive valve operations

Pre pump	**Post pump**
-To assess severity of stenosis/ regurgitation. -To assess mechanism of regurgitation and potential reparability of valve. -To measure dimensions of annulus, chambers, valves. -To assess whether lesions other than the primary lesion require surgery. -To determine biventricular function. **(Griffin et al., 2002)**	-To assess severity and mechanism of residual regurgitation/stenosis. -To detect systolic anterior motion of the mitral valve and left ventricular outflow obstruction. -To determine change in severity of other valve lesions. -To assess biventricular function. -To detect iatrogenic complications.

The size of the regurgitant orifice area can be derived from Doppler echocardiography techniques in the operating room, using either the antegrade flow difference method or the flow convergence method. The maximum regurgitant orifice area is calculated by dividing regurgitant flow rate by the maximum mitral regurgitant flow velocity (V_{max}) obtained from continuous wave Doppler. The regurgitant orifice area is greater than $0.4cm^2$ in severe mitral regurgitation and greater than $0.25cm^2$ in moderately severe mitral regurgitation **(Griffin et al., 2002).**

The long-axis imaging planes are best for determining which mitral leaflet is involved. Long-axis views of the mitral valve are obtained by imaging from mid-esophageal TEE planes.

The short-axis views also are useful for determining which portion of the anterior or posterior leaflet is involved. These views may be obtained from either the transgastric short-axis view or the epicardial parasternal short axis equivalent view. The posterior leaflet has three divisions or scallops: the medial, middle, and lateral. The anterior leaflet is not segmented but it has a central portion known as the bare areabetween the insertions of the chordae from the anterolateral and posteromedial papillary muscles. In a similar way, the posterior leaflet is also supported. The

papillary muscles and chordae usually are well visualized from the transgastric long-axis views of the left ventricle using biplane or multiplane probes **(Stewart et al., 2002).**

The most appropriate time to image after repair is when the patient is off cardiopulmonary bypass, the intravascular volume is replete, and the loading conditions are similar to those in the ambulatory state. Imaging can be initiated after the aortic cross clamp is off and when the left ventricle is at least partially filled, but abnormal findings at this time may result from abnormal left ventricle geometry. The surgeon should not act on these findings unless they are subsequently confirmed by further imaging after the cessation of cardiopulmonary bypass **(Savage et al., 2002).**

5- Assessment of Congenital Heart Disease in Pediatrics andEfficiency of Repair:
The echocardiographic approach to the diagnosis of complex congenital heart disease involves a segmental analysis of the heart **(Snider, 2002).**

6- Detection of Intracardiac Air:
The extreme difference in acoustic impedance between air and blood causes air bubbles to be strongly reflective of ultrasound. Exceptionally small (2-100**μm**) bubbles can be visualized by echocardio-graphy which makes this technique the most sensitive means of diagnosis of air bubbles in the circulation **(Miller, 1994).**

The common sites of air retention are: (1) the right and left upper pulmonary veins; (2) the left ventricular apex; (3) the left atrium; and (4) the right coronary sinus of valsulva. The three-chamber view is the single best view for monitoring retained intracardiac air, because most of the common locations of air retention and routes of air bubbles are depicted in this view **(Oka and Goldiner, 1992).**

Conventional anesthetic monitoring for pulmonary emboli relies on detecting changes in the capnogram, the pulmonary arterial pressure, and other hemodynamic parameters. These have in common the fact that they monitor the sequelae of a pulmonary embolism rather than the event itself **(Roelandt et al., 1993).**

Contraindications to Transesophageal Echocardiography:
The presence of esophageal disease or injury, the risk is quite low.
Absolute contraindications include:
1. Previous esophagectomy.
2. Severe esophageal obstruction.
3. Esophageal perforation and ongoing esophageal hemorrhage.

Relative contraindications include:
1. Esophageal diverticula.
2. Varices and fistulas.
3. Previous esophageal surgery.
4. History of previous gastric surgery.
5. Mediastinal irradiation.
6. Unexplained swallowing difficulties and other conditions that might be worsened by placement and manipulation of the TEE probe **(Vezina, 2005).**

Complications of Transesophageal Echocardiography:
Transesophageal echocardiography is a relatively safe procedure with a low complication rate. Procedural complications have been observed in 0.47% to 2.80% of patients with successful esophageal intubation, however. The vast majority of complications are minor. Major complications, defined in one study as death, laryngospasm, sustained ventricular tachycardia, or congestive heart failure, occur in approximately 0.3% of patients.

Procedural Complications with Transesophageal Echocardiography:
Major Complications:
1. Death.
2. Esophageal rupture.
3. Laryngospasm or bronchospasm.
4. Congestive heart failure or pulmonary edema.

5. Sustained ventricular tachycardia.

Minor Complications:
1. Excessive retching or vomiting.
2. Sore throat.
3. Hoarseness.
4. Minor pharyngeal bleeding.
5. Blood-tinged sputum.
6. Nonsustained or sustained supraventricular tachycardia.
7. Atrial fibrillation.
8. Nonsustained ventricular tachycardia.
9. Bradycardia or heart block.
10. Transient hypotension.
11. Transient hypertension.
12. Angina.
13. Transient hypoxia.
14. Parotid swelling.
15. Tracheal intubation**.** **(Burwash and Chan, 2002).**

Summary

Ultrasound examination of the heart offers a wealth of anatomical and physiological information with minimal risk to patient, the new development of transesophageal approach facilitates the continuous use of echocardiographic assessment of heart during anesthesia and surgery.

Echocardiography has dramatically reduced the requirement for invasive studies such as cardiac catheterization. M-mode echocardiography offers a very good assessment of the extent and velocity of movement of objects, it also useful in obtaining quantitative measurement of chamber size and wall thickness.

Intraoperative TEE is essential and its routine use in open cardiac surgery should no longer be a matter of choice. It allows early and rapid assessment of cardiac structures and functions.

TEE is a semi-invasive investigation that can be performed quickly and with minimal risk even in critically ill-patient intraopratívly TEE has the advantage of providing continues stable views of the heart and great vessels. TEE is more sensitive than ECG and pulmonary wedge pressure for detection of myocardial ischemia.

The echocardiography examination can be used to evaluate cardiac structure in the congenital heart lesions, estimate intra cardiac pressures and gradients across stenotic valves and vessels, quantitate cardiac contractile function, determine the direction of flow across a defect, examine the integrity of the coronary arteries and evaluate the presence of vegetations due to endocarditis, pericardial fluid, cardiac tumors or chamber thrombi. Echocardiography helps to diagnose the cause of congestive heart failure and also take a significant role in the diagnosis of myocardial infarction prior to the availability of enzymatic changes.

TEE can evaluate global and segmental left ventricular function; detect intraoperative myocardial ischemia, and monitor hemodynamic changes including cardiac output, left ventricular filling pressures, and volume status. The cause of hemodynamic disturbances can be determined and intraoperative complications can be identified. Importantly, the adequacy of valve repairs or replacements and surgical reconstructions for congenital and acquired diseases can be evaluated prior to leaving the operating room.

TEE is also used to diagnose pulmonary embolism and to optimize the use of PEEP when mechanical ventilation is considered.

TEE is a useful monitor preoperatively and intraoperatively during cardiac operations. Also TEE is specially valuable in the ICU setting in the cardiac surgery cardiac patient under going non-cardiac surgery and non-cardiac undergoing surgery where marked fluid shift, acute ischemia, mechanical ventilation, changes in heart rate and use of drugs and anesthetics that affect the cardiovascular system.

So, it should be a routine monitor. Also adequate training of the anesthesiologists for proper use of the TEE.

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