ABSTRACT

Transesophageal echocardiography is commonly used to evaluate the mitral valve during perioperative period. It delineates the morphology of normal as well as diseased mitral valve. Transesophageal echocardiography (TEE) has also significantly contributed in achieving the excellent results after repair of mitral valve. Furthermore, the use of echocardiography after surgery led to early diagnosis and management of complications after repair and replacement of mitral valve. In order to achieve the higher degree of accuracy, it is important to understand the anatomy of the mitral valve and its correlation with various echocardiographic views. This article has been divided into parts. Transesophageal echocardiographic evaluation of the mitral valve—Part I—covers the anatomy of the mitral valve, echocardiographic views to assess the mitral valve, and evaluation of the mitral regurgitation. On the other hand, Part II would cover the echocardiographic evaluation of mitral stenosis, after mitral valve replacement, and assessment of surgical results after mitral valve repair.

Keywords: Mitral valve, Transesophageal echocardiography, Mitral stenosis, Mitral regurgitation.


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MITRAL VALVE ANATOMY

Assessment of the mitral valve (MV) using transesophageal echocardiography (TEE) needs thorough understanding of its anatomy. It is one of the most complex structures of the human heart due to its multifaceted anatomy. MV comprises the anterior and posterior leaflets, the subvalvar apparatus (chordae tendinae and papillary muscles), and the fibrous annulus. MV complex include all components of MV, left atrium (LA), left ventricle (LV), and aorto-mitral curtain (Fig. 1). The function of MV depends on the coordinated action of these anatomical components. Failure of the normal function of any of these components may lead to mitral regurgitation (MR).

MITRAL ANNULUS

Mitral annulus is the circular area where the MV leaflets attach at the intersection of the LA and LV. It is the concept and not an anatomical well-defined structure. At the level of the LA-LV junction, there is fibrous structure common to aortic valve (AV) and MV anteriorly (aorto-mitral curtain). This fibro-elastic tissue extends posteriorly from the left and right fibrous trigones forming a partial ring, which is completed by myocardium posteriorly. Thus, posterior part of the annulus has little fibrous tissue. Normal MV is saddle shaped and hyperbolic paraboloid with two-directional curvature making two highest points at the mid portions of the anterior and posterior leaflets and two lowest points at the commissures.

MITRAL VALVE LEAFLETS

There are two leaflets—anterior mitral leaflet (AML) and posterior mitral leaflet (PML).

- Anterior mitral leaflet: AML is in continuity with the left and noncoronary cusps of the AV. It is located directly beneath the left ventricular outflow tract (LVOT). Its close relation to AV is helpful in identifying the leaflet during TEE examination. AML occupies only one-third of the annular circumference and has smaller length but more width as compared to the posterior leaflet. Margin of the AML is smooth with no clefts and scallops.

- Posterior mitral leaflet: PML occupies the remainder two-third of the annular circumference. It is narrower and presents a scalloped appearance with three or more segments separated by clefts. It is crescent-shaped and dilates more commonly in degenerative disease due to little fibrous tissue on the posterior annulus.

There are three-segmental nomenclatures commonly used to describe the anatomy of the MV leaflets, the American Society of Echocardiography (ASE), Society of Cardiovascular Anesthesiologists (SCA), i.e. Carpentier’s, the Anatomic, and the Duran. Amongst them, ASE-SCA classification is most commonly used and well accepted. This classification divides posterior leaflet of the mitral valve into three segments due to presence of two scallops.
as P1, P2, P3 and the corresponding segments of the AML are labelled as A1, A2 and A3 respectively. A1 and P1 join at anterolateral commissure (AC), and A3 and P3 join at posteromedial commissure (PC).

**PAPILLARY MUSCLES**

There are two papillary muscles, posteromedial (PM) and anterolateral (AL). The AL papillary muscle is located on the anterio-lateral free wall of the LV whereas, PM located at the junction of the posterior LV free wall and the muscular ventricular septum. The AL papillary muscle is more commonly supplied by two separate arteries: the first obtuse marginal arising from the left circumflex artery (LCX) and the first diagonal arising from the left anterior descending artery. The PM receives blood supply from only the posterior descending artery or a branch of the LCX artery. Therefore, the PM papillary muscle is more susceptible to infarction and rupture than the AL.

**CHORDAE TENDINAE**

The chordae tendineae are fibrous strings radiating from the papillary muscles or the LV free wall (posterior leaflet only) and attaching to the mitral leaflets in an organised manner (Fig. 2). Chordae tendineae from AL papillary muscle insert into A1, P1, AC, and one part of the A2 and P2 segments of the mitral leaflet whereas, segments A3, P3, PC, and other part of A2 and P2 receives chordae tendineae from PM papillary muscle (Fig. 3). It is now well accepted by all the classifications that chordae tendineae from the head of both AL and PM papillary muscles attach to the corresponding half of the both AML as well as PML.

Chordae tendineae are also labelled as primary, secondary, and tertiary based on their site of attachment. Primary chords are those that attach to the edge of the leaflet. Secondary chords attach to the underside of the leaflet. Tertiary chords (only the PML) attach to the undersurface of the leaflet directly from the ventricular wall instead of from the papillary muscle. The papillary-chordal-annular continuity maintains the dynamic shape of the LV. The primary chordae of the AML appear to be more involved in MV competence, whereas, the secondary chordae maintain LV geometry and function.

**TRANSESOPHAGEAL ECHOCARDIOGRAPHIC ASSESSMENT OF MITRAL VALVE**

**Intraoperative Examination (Prior to Onset of Cardiopulmonary Bypass)**

Echocardiographer must document following points while evaluating the MV.

1. Whether the MV is normal or abnormal?
2. If abnormal, then whether it is MR or mitral stenosis (MS)?
3. If MS, then what is the cause and severity? Does it need replacement?
4. In case of MR, what is its severity and mechanism?
   a. Whether this valve is repairable?
   b. In case of MV repair, whether the patient is at high risk of systolic anterior motion (SAM) after repair?
5. Assessment of LA for chamber size and presence of any clot/thrombus.
6. Assessment of LV and right ventricle (RV) systolic function.
Transesophageal Echocardiographic Views to evaluate the Mitral Valve

While performing TEE examination, it is important to understand the relationship of imaging plane and MV (Fig. 4).

1. **Midesophageal five chamber (0°)** (Fig. 5): In this view, imaging plane passes through the anterior portion of the MV. Therefore, A1/A2 segments of the AML and P1/P2 segments of PML are seen. The AML is on the left side of the display and PML on the right side. As the LVOT is seen, this view is also good to assess the SAM, such as aorto-mitral angle, distance from the coaptation point to septum (C-sept distance) and length of AML and PML.

2. **Midesophageal four chamber view (0°)** (Fig. 6): This view is obtained from five chamber by gentle retroflexion or slight insertion of the probe till LVOT disappears. This view is used to evaluate the posterior portion of the MV, i.e. A2-A3 and P2-P3 (from left side of the display to right side).

3. **Midesophageal mitral commissural view (60-80°)** (see Fig. 3): This view is obtained by moving the cursor from 0° to 60-80° and counterclockwise rotation of the probe toward the patient’s left. In this view, two coaptation points are visualised between P3 and A2 and between A2 and P1. Thus, from left to right P3-A2-P1 segments of the MV leaflets are visualised. Presence of two flow orifices and multiple regurgitation jets on color Doppler imaging should not be mistaken for commissural points and a perforated AML. In addition, one should not assess the severity of MR in this view, because imaging plane...
intersects the MV at multiple points. Clockwise rotation of the probe towards patient’s right shows AML whereas, counterclockwise rotation of the probe toward the patient’s left shows PML of the MV (P3-P2-P1).

4. **Midesophageal Two chamber view (80-100°)** (Fig. 7): In this view, AML is seen on the right side and PML on the left side. Rotating the probe clockwise towards the patient’s right until the commissure is no longer visible reveals the base of the AML. Gradual counterclockwise rotation of the probe back towards the patient’s left shows small portion of the PML (P3) and a large part of the AML, A3-A2.

5. **Midesophageal long axis view (120-160°)** (Fig. 8): Here, imaging plane intersects the highest portion of the AML and PML at only one point. Section of the AML and PML should be labelled as A2 and P2 respectively. This view is excellent for evaluating SAM and mid posterior and anterior leaflet pathology.

6. **Transgastric basal short axis view of left ventricle (0°)** (Fig. 9): The probe is then advanced into the stomach and anteroflexed to obtain the transgastric (TG) basal short-axis view. In this view, the MV can be seen as C-shaped orifice. The AML is seen on the left side of the display and the PML towards the right. PC is seen at the upper part of the screen, and the AC at the lower part. The use of colour flow imaging at this level is useful to demonstrate the exact origin of the MR jet(s). Planimetry method can be used to measure the mitral valve area (MVA) by tracing the MV leaflets in diastole. However, this method may not be accurate because the imaging plane may be oblique as well as above or below the MV leaflets, thus overestimating the MVA.

7. **Transgastric two-chamber view (80-100°)** (Fig. 10): This view is particularly helpful to evaluate the subvalvular apparatus, particularly the papillary muscles, the chordae tendineae, and their insertions on the leaflets margins. Moving the probe towards patient’s left, the AL papillary muscle can be bottom of the image away from transducer, whereas moving the probe toward the patient’s right will bring the PM papillary muscle on the top of the image.

8. **Transgastric midpapillary short-axis view (0°)** (Fig. 11): From the TG basal view, slight release from full anteroflexed probe brings papillary muscles in view. PM papillary muscle is on the top of the image whereas, AL...
papillary muscle away from the transducer. This view is helpful in defining where torn papillary muscle chordae originate from and for assessing papillary muscle contractile function. The view is excellent for measuring LV systolic and diastolic dimensions as well as LV and RV systolic function.

Close inspection of the MV anatomy by 2D examination would localise the pathology in terms of annular dilatation, mitral annular calcification (MAC), leaflet excessive or restrictive motion, subvalvular apparatus (normal or fused), and any rupture chordate. The pathology is further confirmed by using Doppler imaging, such as colour Doppler, pulse wave (PW) Doppler, and continuous wave (CW) Doppler.

**MITRAL REGURGITATION**

Mitral regurgitation is one of the commonly encountered valve lesions in present day practice. In Western countries, the aetiology of MR is usually degenerative causing excessive leaflet motion (45%), rheumatic diseases causing restrictive leaflet motion and commissural fusion (12%), and ischemic causing rupture chordae tendinae or LV dysfunction (27%). Whereas in India, rheumatic heart disease is the most common cause of MR. Other causes of MR include infective endocarditis (leaflet destruction), drugs (fenfluramine), congenital heart disease (mitral cleft and double orifice MV), and dilated cardiomyopathy.

**Functional Classification of MR (Carpentier’s Classification)**

The functional classification of the MR has been described by Alain Carpentier:

**Normal Leaflet Motion**

Due to annular dilatation, perforation, or cleft in the MV leaflet.

**Excessive Leaflet Motion**

It is due to degenerative mitral prolapse, ruptured chordae to infarction or ischemia. In case of leaflet prolapse, either one or both leaflets partly or as whole move into the LA, but leaflet tips point towards the LV. The coaptation point is > 2 mm above the mitral annular level as measured on ME four-chamber and ME long axis view. The jet is eccentric, directed away from the prolapsing leaflet. If the coaptation point of the MV is situated at or below the annular plane but the middle part of the leaflet is bulging into the LA, it is called billowing. On the other hand, if leaflet tip moves into the LA with ventricular surface of leaflet looks towards the LA during systole, it is termed as flail segment and usually associated with rupture chordae or papillary muscle (Fig. 12).

**Restricted Leaflet Motion**

*During diastole and systole (rheumatic):* The leaflets are held back below the coaptation plane in systole by remodelling due to rheumatic disease.

*During systole (ischemic):* Due to systolic wall motion abnormality or LV dilatation.

The severity of MR and echocardiographic appearance vary depending upon loading conditions and use of anaesthetics or vasoactive agents. It is always advisable to maintain the hemodynamics as they were prior to induction. One must be aware of the different behaviour of different mechanisms of MR due to hemodynamic variations. For example, MR would decrease in presence of hypovolemia, decreased systemic afterload or increased inotropy but similar conditions would increase MR in case of a MV prolapse (ruptured chordae tendineae). Under anaesthesia, severity of MR decreases by one grade because of the
decrease in sympathetic tone, decrease in venous return, and secondary to mechanical ventilation.

The evaluation of the severity of MR is best achieved by using an appropriate combination of: 2D echocardiography, the color Doppler, PW Doppler, and CW Doppler techniques.

**2D echocardiography:** MV leaflets are systematically examined in ME four-chamber, two-chamber, mitral commissural view, ME long-axis view, TG basal, and midpapillary view. Thickness of leaflets (>5 mm), presence of calcification, any mal-coaptation, prolapsed or flail segment, MAC, and presence of any vegetation are documented during examination.

In addition, chamber size of LA, LV, and RV are measured. Anterior-posterior diameter of LA more than 55 mm suggests dilated LA. LV as well as RV dimensions and systolic function are important prognostic factors. LV gets dilated due to volume overload and end-systolic diameter more than 55 mm predicts high risk for surgery.

**DOPPLER IMAGING**

- **Colour Doppler** (Fig. 13): The definitive diagnosis of MR relies mainly on colour Doppler.\(^4\) It is important to remember that the colour Doppler is a mapping of blood velocities but does not represent an actual blood volume. Based on the colour Doppler, techniques used to assess the severity of MR include Jet area mapping, Jet area/LA area ratio, and Vena contracta. Assessment of the severity based on just eyeballing the dimensions of the turbulent systolic colour flow can be misleading. Jet area mapping is achieved by tracing the regurgitant jet area in LA during systole. However, its correlation with the regurgitant volume (RV) is usually not good. One must adjust appropriate colour gain and Nyquist limit prior to colour Doppler use. A high Nyquist limit will decrease the regurgitant area while, a low Nyquist limit will increase the regurgitant area. It is better to keep Nyquist limit between 40 and 50 cm/sec and optimise the colour gain. Ratio of jet area and LA area is not very popular method inside the operating room, because whole LA area is not visualised due to its close proximity to the transducer. This is in contrast to transthoracic echocardiography where entire LA area can be measured and thus more popular among cardiologists.

- **Vena contracta**\(^5\) (see Fig. 13): The cross-sectional area of the regurgitant jet immediately below MV level or within MV leaflets represents the EROA and is called the vena contracta (VC). It is the narrowest portion of the jet at the level of MV leaflets. The flow is laminar and its width is directly proportional to the dimension of the EROA on this plane. VC method has an advantage over the PISA in presence of eccentric jets, because the VC is affected less by the eccentricity of the jet. In this method also, appropriate Nyquist limit and colour gain settings should be ensured.

- **Direction of the jet** (Fig. 14): Direction of the jet can be central, anterior or posterior. An eccentric jet may adhere to and flow around the LA wall with loss of energy (coanda effect). This may underestimate severity of MR by the up to 40%.

- **Continuous-wave Doppler** (Fig. 15): CW Doppler across the MV will produce a large, full, rounded-shaped, high velocity (>5 m/s) trace. If LV function is depressed, the...
peak velocity (< 4 m/s), and the ascending slope are decreased. LV systolic function can also be assessed by calculating LV dP/dt using CW Doppler across the MR jet.

- **Pulsed-wave Doppler (Fig. 16):** PW Doppler across the MV inflow supports the presence of MR if E wave velocity is more than 1.5 m/s. PW Doppler is also used to interrogate the pulmonary vein flow. In case of moderate MR, the systolic wave (S) of pulmonary venous flow is lower than diastolic wave (D) and would reverse in case of severe MR. A complete systolic flow reversal is pathognomonic of severe MR. However, severe MR may occur without systolic flow reversal in presence of large and highly compliant LA. Sometimes, pulmonary venous flow may be falsely negative due to eccentric MR jets; therefore, all the four pulmonary veins (right upper, right lower, left upper, and left lower) should be interrogated.

- **PISA (Proximal isovelocity surface area)** (Fig. 17): As regurgitant jet moves from the LV to LA, blood flow forms hemispherical shells of increasing blood velocity and decreasing surface area (proximal flow convergence). The principle of mass conservation assumes that the volume of blood in any of the isovelocity hemisphere is equal to the volume passing through the regurgitant orifice.

From this principle, the following equations are derived:

\[
\text{Effective regurgitant orifice (ERO)} = \frac{2\pi r^2 \times V_r}{V_{\text{MR max}}}
\]

where, ERO in cm²; \( r \) is the measured radius of the hemispheric shell of the aliased velocity; \( V_r \) is the aliased velocity at the radius \( r \), identified as the Nyquist limit (in cm/sec); and \( V_{\text{MR max}} \) is the maximal MR velocity across the orifice, obtained by CW Doppler (in cm/sec).

Mitrval RV is obtained by multiplying ERO with time velocity integral of MR jet (ERO_{MV} \times TVI_{MR} where ERO is the effective regurgitant orifice (in cm²); and TVI_{MR} is the time velocity integral (in cm) of the MR signal obtained by CW Doppler). Another method where aliasing radius \( r \) is achieved by changing colour Doppler scale to 40 cm/sec and the peak velocity of MR jet is more than 500 cm/sec. Formula for ERO can then be simplified to \( \text{ERO} = r^2/2 \).

To obtain the ERO and the RV, four parameters are required:

1. **Radius \( r \) of the hemispheric shell of the aliased velocity \( (V_r) \):** In the ME four chamber view, colours Doppler across the MV is used to obtain view with good vena contracta (VC), zoom the view, and adjust the colour scale in such a way to generate a good hemispheric shell. The \( r \) is measured from the edge of the hemispheric shell where the colour scale changes (from one edge of the spectrum to the other) to the base of the shell, i.e. at the plane of the leaflets. The annular plane is best visualised by activating the icon ‘colour suppress’ after freezing the frame. The range of \( V_r \) for this measurement is usually between 25 and 40 cm/sec.
2. \( V_r \) is the velocity at which the hemispheric shell is obtained.
3. \( V_{\text{MR}} \) is the maximum velocity of the MR jet obtained by CW Doppler across the MV.
4. Tracing the MR jet would measure the time velocity integral of MR jet, i.e. TVI_{MR}.

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**Fig. 15:** Transesophageal long axis view with continuous Doppler across the mitral regurgitation jet and obtained the dense spectral envelope suggesting moderate-severe regurgitation. Peak velocity is 428 cm/sec and pressure gradient 73 mm Hg. Left atrial pressure (LAP) can be calculated using systolic blood pressure-4 (Peak MR velocity)^2

**Fig. 16:** Pulse wave Doppler across the left upper pulmonary vein showing velocity of S wave lower than D wave that is blunt S wave suggesting of moderate mitral regurgitation. However, blunted S wave can be found in pseudo-normal pattern of diastolic dysfunction, even in absence of mitral regurgitation. S: Systolic wave, D: Diastolic wave
The PISA method is more accurate for central jets than for eccentric jets, and multiple jets. ERO is a more sensitive as compared with colour Doppler and planimetry. It is less altered with changing hemodynamic conditions. However, it is time consuming and needs practice. One must be careful as any error in measuring ‘r’ would magnify to its squared value.

**Regurgitant volume:** The mitral RV may also be obtained by the continuity equation using volumetric flow calculation. Mitral RV = SVMV – SVAV, where SVMV is stroke volume across the MV and SVAV is the stroke volume across AV. The stroke volume across the aortic valve (SVAV) is given by the following equation: 

\[ \text{SVAV} = 0.785 \times d^2 \times TVI_{AV} \]

where \( d \) is the diameter (in cm) of the LVOT; and \( TVI_{AV} \) is the time velocity integral (in cm) by PW Doppler. The diameter of the LVOT is measured through a zoomed-in view of the aortic valve in the ME long axis view from the base of the right coronary cusp to the base of the opposite cusp (from inner edge to inner edge). The TVI of the LVOT is best obtained by PW Doppler interrogation through the deep transgastric view tracing the peak (outer edge of the) velocity Doppler signal envelope.

The regurgitant fraction (RF) is calculated by the following equation:

\[ \text{RF} (\%) = \frac{\text{mitral RV (ml)}}{\text{total stroke volume (ml)}} \times 100 \]

The RV is obtained either by the PISA method or through the continuity equation. Stroke volume can be obtained by thermodilution method or using continuity equation. Advantage of calculating RV and ERO through the continuity equation is that the technique can be used even in the presence of very eccentric jets or multiples jets, where the

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**Table 1:** Parameters to assess the severity of MR and criteria to assess the severity as mild, moderate, and severe

<table>
<thead>
<tr>
<th>Method</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
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<tr>
<td>CW signal</td>
<td>Faint</td>
<td>Moderate</td>
<td>Dense</td>
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<tr>
<td>Area mapping (cm²)</td>
<td>&lt;4</td>
<td>4-10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Jet area/left atrial area (%)</td>
<td>&lt;20</td>
<td>20-40</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Vena contracta (mm)</td>
<td>&lt;3</td>
<td>4-6</td>
<td>&gt;7</td>
</tr>
<tr>
<td>Pulmonary venous Doppler (S wave)</td>
<td>Normal</td>
<td>Blunt</td>
<td>Reverse</td>
</tr>
<tr>
<td>PISA radius (r)</td>
<td>&lt;4 mm</td>
<td>4-10 mm</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Regurgitant volume (cc)</td>
<td>&lt;30</td>
<td>30-60</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Regurgitant fraction (%)</td>
<td>&lt;30</td>
<td>30-50</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Effective regurgitant orifice area (cm²)</td>
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<td>0.20-0.39</td>
<td>&gt;0.40</td>
</tr>
</tbody>
</table>

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**Fig. 17:** Effective regurgitant orifice (ERO) = \( 2\pi r^2 \times V_{Vr} \times V_{MR\ max} \) where ERO in cm²; \( r \) is the measured radius of the hemispheric shell of the aliased velocity; \( V_r \) is the aliased velocity at the radius \( r \), identified as the Nyquist limit (in cm/sec); and \( V_{MR\ max} \) is the maximal MR velocity across the orifice, obtained by CW Doppler (in cm/sec). Mitral regurgitant volume can also be calculated by multiplying the velocity time integral of regurgitant jet (TVI_{MR}) with ERO obtained by PISA method. Mitral Regurgitant Volume (RV) = ERO_{MR} \times TVI_{MR}, where ERO is the effective regurgitant orifice (in cm²); and TVI_{MR} is the time velocity integral (in cm) of the MR signal obtained by CW Doppler.
PISA and VC methods can be erroneous. However, these calculations are time-consuming and require careful execution which may be sometimes difficult to perform in the operating room.

Table 1 summarises the parameters to assess the severity of MR and criteria’s to assess the severity as mild, moderate, and severe.

**CONCLUSION**

Thorough understanding of the MV anatomy and its relation with echocardiographic views is necessary to evaluate the MV. MV pathology is an area where TEE plays an important role in evaluation of the mechanism of the disease and can alter the nature of surgery during intraoperative period. However, one must be careful while evaluating the MR in patients under anaesthesia as one tends to underestimates the severity of regurgitation during intraoperative period. Therefore, haemodynamics should be adjusted as per baseline values to evaluate the MR.

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