Basic Mitral Valve Anatomy and TEE Imaging Planes

The mitral valve (MV) apparatus is a very complex structure, consisting of two leaflets (anterior and posterior), a fibrous annulus, chordae tendinae, two papillary muscles (anterolateral and posteromedial), and adjacent myocardium. It is important to understand that all of these components must work together for proper valve function. Mitral regurgitation can occur when any one of these elements fails.

Orientation and nomenclature of the MV can be confusing since there is more than one system in use. Per the ASE/SCA guidelines, it will be assumed that the patient is supine with the probe in the esophagus and the observer’s right and left are reversed relative to the patient.\(^1\) The posterior (or mural) leaflet takes up approximately 2/3 of the annular circumference and contains indentations known as scallops. The Carpentier nomenclature system, which is most commonly used in echocardiography, numbers the scallops P1, P2, and P3, moving from the anterolateral to posteromedial commissure. The anterior (or aortic) leaflet is associated with the aortic valve and has more ‘height’ than the posterior leaflet, although is about equal in surface area due to having less annular circumference. Although the anterior leaflet does not have scallops, the Carpentier system divides it into 3 sections labeled A1, A2, and A3 which correspond to the posterior leaflet segments found opposite of them.
There are four midesophageal views used to examine the leaflets of the mitral valve. At the mid esophageal 4 chamber view (ME 4C), the posterior leaflet will be to the right of the screen and the anterior leaflet to the left of the screen. Depending upon probe depth, the coaptation line is cut at either the 1st or 2nd segments (i.e. likely A1/P1 in the “5-chamber view” and A2/P2 as probe is advanced and the LVOT disappears). Rotating the omniplane angle 90 degrees to this (ME 2C view) will reverse the relationship and put the posterior leaflet on the left side of the image display and the anterior leaflet on the right side. It is often difficult to identify specific scallops due to variable transducer depth and variation in the amount of probe flexion.

However, when the posteromedial papillary muscle is well-visualized, the coaptation line is generally divided close to the posteromedial commissure (i.e. A3/P3). The midesophageal long axis view cuts thru the middle of the valve at the A2/P2 coaptation point and little, if any, papillary muscle is seen. The midesophageal commissural view cuts thru both commissures (and both papillary muscles), and P1 is seen at the right of the screen, P3 at the left, with A2 in the center, typically moving in and out of the imaging plane.

The two transgastric views used to image the MV are the transgastric basal short axis and transgastric two chamber views. The basal short axis gives an en face view of the MV as viewed from the apex of the heart. It is often used to detect clefts in the MV. The TG 2C view does not typically provide useful leaflet information, but papillary muscle and chordae tendinae are usually well-visualized.
Causes and Mechanisms of Mitral Regurgitation

The *cause* of MR refers to the underlying disease process that the patient has. The two most common causes seen in cardiac surgical patients are degenerative processes (i.e. fibro-elastic dysplasia or Barlow’s syndrome) and ischemia.² The *mechanism* of MR, however, describes how the coaptation defect is formed. The two terms are not synonymous and any particular cause can result in more than one mechanism. Ischemia, for example, can result in an acute infarction leading to papillary muscle disruption and excessive leaflet motion. However, ischemia could also result in a dilated cardiomyopathy, leading to annular dilatation, which is a different type of mechanism requiring a different surgical intervention. Essentially, the cause of MR is a pathological diagnosis while the mechanism is an echocardiographic finding.

MR can be broadly classified as either *organic* (i.e. primary), meaning an intrinsic valve problem, or *functional* (i.e. secondary), occurring as a result of ventricular remodeling. However, a more descriptive classification of mechanism was developed by Carpentier based upon the movement of the leaflets being normal, excessive, or restricted.³ These mechanisms are summarized below in Table 1. It should be noted that mechanisms can be combined. For example, annular dilatation is often seen with restricted leaflet movement (type I and type IIIb), so-called “ischemic MR.”

*Table 1: Mechanisms of MR by leaflet motion with commonly seen clinical examples*

| Type I: Normal Motion | Annular dilatation  
|                       | Clefts  
|                       | Leaflet perforations  
| Type II: Excessive Motion | Prolapse  
|                       | Flail chordae tendinae  
|                       | Ruptured papillary muscle  
| Type III: Restricted Motion | IIIa: Commissural fusion due to rheumatic heart disease  
|                        | IIIb: Chordal tethering  
|                        | Papillary muscle displacement  

*Causes of MR seen in surgical patients*
The initial assessment of mitral regurgitation begins with a systematic 2D examination of all leaflet segments. Specifically, each segment is evaluated for excessive or restricted movement in order to begin to define the mechanism of regurgitation and localize pathology. Taking a systematic approach to segment identification by using the above views has been well described and can correctly identify normal versus abnormal movement >95% of the time.4

Coaptation of the anterior and posterior leaflets normally occurs below the level of the annular plane. Excessive leaflet movement causes the leaflets to rise above this level, usually creating a coaptation defect. Prolapse is defined as the leaflet tip rising above the annular line, but still pointing toward the left ventricle. In severe myxomatous degeneration, both leaflets may prolapse above the annulus. Flail segments usually involve a ruptured chordae tendinae, causing the leaflet tip to point toward the left atrium. The term billowing is often used when part of the leaflet body rises above the annular level, but coaptation still occurs at or below the annular line.

Restricted movement refers to the reduced excursion of one or both leaflets, causing a coaptation defect to be formed. Unlike excessive movement, there is no advancement above the annular line. The leaflet tips often curl inward due to tethering of the chordae tendinae. Restricted movement should prompt the search for signs of rheumatic disease or annular dilatation.

In addition to identifying the leaflets’ movement, the morphology should be noted as well. If the underlying cause of the regurgitation is myxomatous degeneration, the leaflets will appear thickened and redundant on 2D examination. Calcification of the leaflets and the annulus is another common finding and can have significant impact on the repairability of the valve.

The left atrium is pliable and dilates in response to chronic volume / pressure overload. Therefore, measurement of the left atrial size can provide some insight into
how long the MR has been occurring. Unfortunately, because of where the TEE probe is located, complete visualization of the left atrium is often not possible in most views. Additionally, the assessment of atrial size by volume, rather than diameter, is now the preferred method of quantification.\(^5\) That said, measurement of left atrial diameter in the ME AV LAX view seems to correlate the best with transthoracic anterior-posterior measurement, of which <4.0cm is considered normal and >5.2cm severely dilated.\(^6\)

**Assessment of Mitral Regurgitation**

Color flow Doppler should be applied only after a thorough 2D examination. If *excessive* movement in a segment is found, the resulting jet of regurgitation will be directed *away* from that segment. In the case of *restricted* movement, the MR jet will be directed *toward* the pathological segment. If leaflet movement is normal, or there is a similar degree of pathology present in both leaflets, the MR jet will appear to be directed centrally. In this way, color flow Doppler is used to confirm the findings of the initial 2D examination.

![Diagram showing color flow Doppler](image)

*Excessive movement creates jets away from pathology*

*Restricted movement creates jets toward pathology*

Color flow Doppler can also help to localize the pathology if findings on 2D examination are not obvious. In the ME commissural view, it can be determined whether the jet originates from the anterolateral commissure (i.e. involving the 1\(^{st}\)/2\(^{nd}\) segments) or the posteromedial commissure (i.e. involving the 2\(^{nd}\)/3\(^{rd}\) segments). If both commissures appear to have jets originating from them, there is either multiple jets or regurgitation is occurring across the entire line of coaptation.

![Diagram showing commissural views](image)

*The majority of MR is originating from the PM commissure, indicating the 2\(^{nd}\)/3\(^{rd}\) segments are involved*
Quantification of Mitral Regurgitation

Table 2: Parameters for quantifying severity of mitral regurgitation.7

<table>
<thead>
<tr>
<th>Specific signs of severity</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small central jet &lt; 4 cm² or &lt; 20% of LA area</td>
<td>Signs of MR &gt; mild present, but no criteria for severe MR.</td>
<td>Venous contracta width ≤ 0.7 cm with large central MR jet (area &gt; 40% of LA) or with a wall-impinging jet of any size, swirling in LA</td>
</tr>
<tr>
<td>Vena contracta width &lt; 0.3 cm</td>
<td></td>
<td>Large flow convergence</td>
</tr>
<tr>
<td>No or minimal flow convergence</td>
<td></td>
<td>Systolic reversal in pulmonary veins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prominent fluid MV leaflet or ruptured papillary muscles</td>
</tr>
</tbody>
</table>

Supportive signs

- Systolic dominant flow in pulmonary veins
- A wave dominant mitral inflow
- Soft density parabolic CW Doppler MR signal
- Normal LV size

Intermediate signs/findings

- Dense, triangular CW Doppler MR jet
- B wave dominate mitral inflow (E > 1.2 m/s)
- Enlarged LV and LA size, particularly when normal LV function is present.

Quantitative parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>R Vol (ml/beat)</td>
<td>&lt; 30</td>
<td>30-40</td>
<td>45-50</td>
</tr>
<tr>
<td>RF (%)</td>
<td>&lt; 30</td>
<td>30-39</td>
<td>40-49</td>
</tr>
<tr>
<td>EROA (cm²)</td>
<td>&lt; 0.30</td>
<td>0.20-0.39</td>
<td>0.30-0.39</td>
</tr>
</tbody>
</table>

Semi-quantitative methods for evaluating MR include regurgitant jet area and vena contracta. In theory, the size of the color flow Doppler tracing should reflect the regurgitant volume. By planimetricing the MR jet area and comparing it to the left atrial area, the severity of MR can be estimated. If the regurgitant jet area fills less than 20% of the left atrium, it is considered mild and if it takes up more than 40%, the MR is considered severe. Although this method is commonly done when “eye-balling it,” there are substantial limitations. Patient hemodynamics have a significant effect and the severity of eccentric jets is underestimated because of the Coanda effect.

The vena contracta is the narrowest portion of the regurgitant jet occurring at or just downstream of the orifice and theoretically correlates with the effective regurgitant orifice area (EROA). It is less dependent on flow than regurgitant jet area. For MR, a vena contracta width <0.3 cm is considered mild and a width ≥0.7 cm is severe. On TEE, the ME mitral commissural view should not be used to measure vena contracta since it will overestimate severity.
Of the quantitative parameters, EROA is most often used in the OR and obtained using proximal isovelocity surface area (PISA) and the continuity equation. This method has been extensively reviewed. Briefly, the concept of PISA is based upon the idea that blood must accelerate and converge thru the regurgitant orifice area, which creates a series of isovelocity shells. The velocity of the shell when the color flow Doppler aliases (usually from yellow to blue) is known since that is the Nyquist limit. The flow at each shell layer must equal the flow at the regurgitant orifice (RO). Since flow is cross-sectional area (CSA) multiplied by velocity (V), the following equation is produced:

\[ \text{CSA}_{\text{PISA}} \times V_{\text{PISA}} = \text{CSA}_{\text{RO}} \times V_{\text{RO}} \]

The CSA of the PISA is \(2\pi r^2\), and the radius can easily be measured from the outer edge of the PISA (with known velocity) to the regurgitant orifice. Placing CW Doppler thru the MR jet will provide the \(V_{\text{RO}}\), which will be the maximum velocity obtained. Rearranged equation:

\[ \text{CSA}_{\text{RO}} = \frac{2\pi (r_{\text{PISA}})^2 \times V_{\text{PISA}}}{V_{\text{RO}}} \]

In practice, the Nyquist limit is usually set to about 40 cm/s and the \(V_{\text{RO}}\) is assumed to be 500 cm/s, further simplifying the equation to \(\text{CSA}_{\text{RO}} = \frac{(r_{\text{PISA}})^2}{2}\). There are, of course, some limitations to the PISA method, perhaps the largest being that it is assumed the regurgitant orifice is circular. If the PISA hemisphere is too flat, the radius will be underestimated and if it is too cone shaped, the radius will be overestimated. Additionally, if the base of the hemisphere is not flat (which often occurs with restricted leaflets), the angle of coaptation (\(\alpha\)) needs to be estimated and the \(\text{CSA}_{\text{RO}}\) needs to be multiplied by \(\alpha/180\).

**Key Points**

- The mitral valve consists of two leaflets – anterior and posterior
- The Carpentier nomenclature system divides each leaflet into 3 segments
- Leaflet movement should be classified as either normal, excessive, or restricted
- Excessive movement results in MR jets away from the affected segment
- Restricted movement causes the MR jet to move toward the affected segment
- Central jets are the result of either normal movement or bilateral leaflet pathology
- MR severity should be assessed using both supportive signs and quantitative parameters
References


