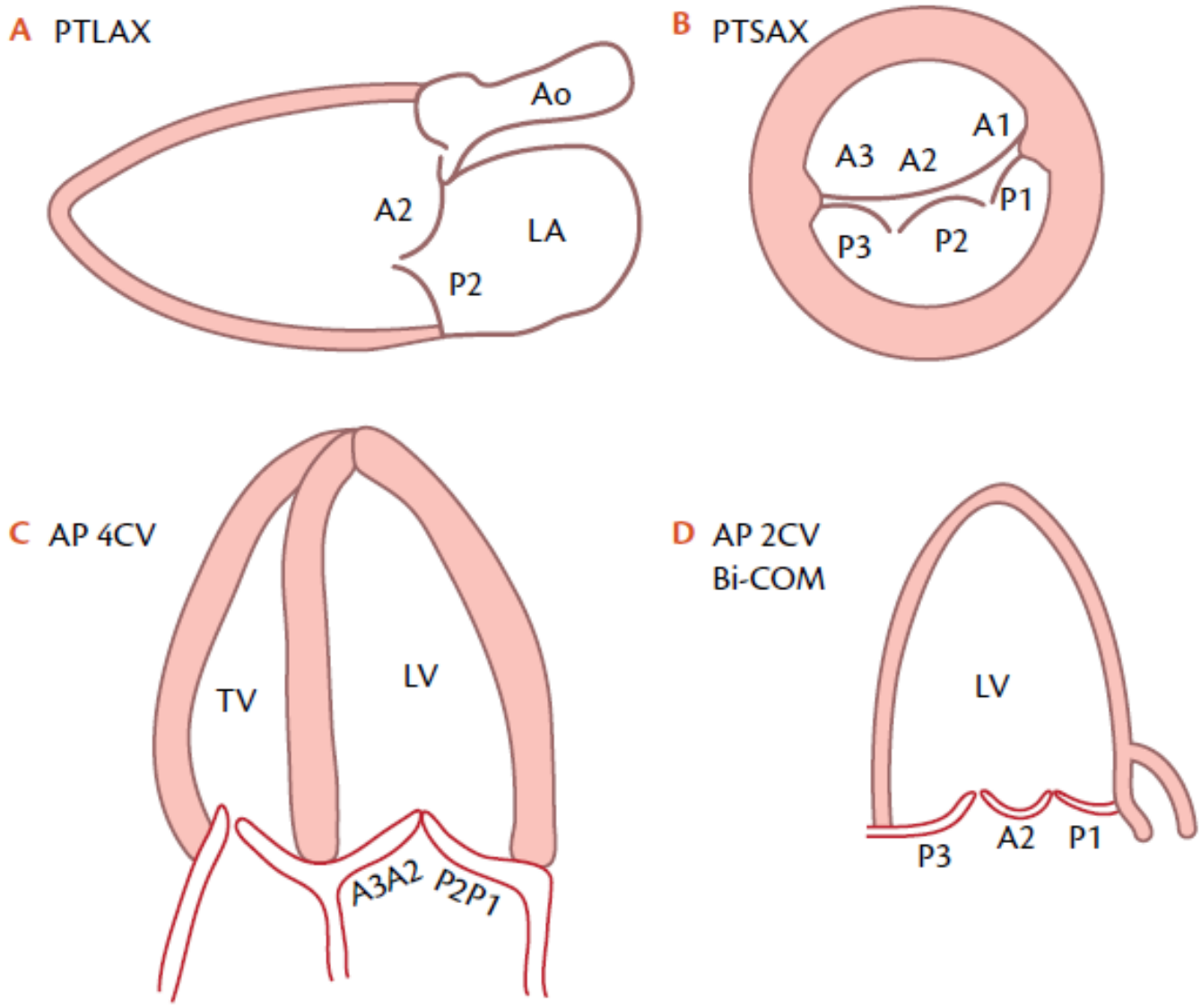
# MITRAL VALVE ANATOMY

**The MV consists of**

1. 2 Leaflets: large anterior leaflet and the crescent shaped posterior leaflet. The anterior leaflet is the larger leaflet by area but it is the posterior leaflet that subtends the larger annular circumference of the two. Each leaflet is divided into 3 scallops: lateral ($A_1$&$P_1$), middle ($A_2$/$P_2$), and medial ($A_3$/$P_3$). The two leaflets are joined at the anterolateral and posteromedial commissures, each of which is associated with a corresponding papillary muscle. The anterior leaflet is in fibrous continuity with the AV.
2. Annulus
3. Chordae tendinae
4. 2 Papillary muscles (AL and PM)



# MITRAL STENOSIS

## CAUSES OF MS

- **Rheumatic valve disease** (childhood rheumatic fever): can affect any of the heart valves (or several in combination), but most commonly affects the mitral valve (the most common cause of MS, followed by calcific disease). Echocardiographic features include:
  - The characteristic feature is fusion of the mitral leaflets along their edges, starting from the mitral commissures restricting their ability to open → fish mouth appearance in PSAX during diastole. The leaflet edges become thickened, although there can be thickening and/or calcification elsewhere too.
  - As the main body of each leaflet usually remains relatively pliable, the leaflets are seen to "dome" during diastole, with the rising LA pressure causing the leaflet body to bow forwards towards the ventricle. This gives the leaflets what is described as a "hockey stick" appearance.
  - Rheumatic MS also affects the chordae, causing fibrosis, shortening and calcification of the subvalvular apparatus.
- **Mitral annular calcification**- is relatively common in older patients (but can also be seen in younger patients with renal failure)
- **Congenital mitral stenosis**
- **Systemic lupus erythematosus**
- **Rheumatoid arthritis**
- **Carcinoid syndrome**
- **Infective endocarditis**.
- Beware of conditions that can cause obstruction of the mitral valve orifice and mimic mitral stenosis, such as **left atrial myxoma**, infective endocarditis with a **large vegetation**, **ball thrombus** or **cor triatriatum**.

## ECHO ASSESSMENT OF MS

## ASSESSMENT OF SEVERITY OF MS

| | Normal | Mild | Moderate | Severe |
|---|---|---|---|---|
| **Valve area ($cm^2$)** | ≥ **4** | | 1.5-**1** *(AS 1.4-1)* | <1 |
| **Pressure half time (ms)** | ≤ **70** | | **140**-220 *(AR 500-250)* | >220 |
| **Mean pressure drop (mmHg)** (at HR 60-80 bpm in sinus rhythm) | | | **5-10** *(AS 25-40)* | |
| **PAP** | | <30 | 30-50 | >50 |

## M-MODE

Marked thickening of the mitral valve leaflets

Flat mitral E-F slope during diastole.

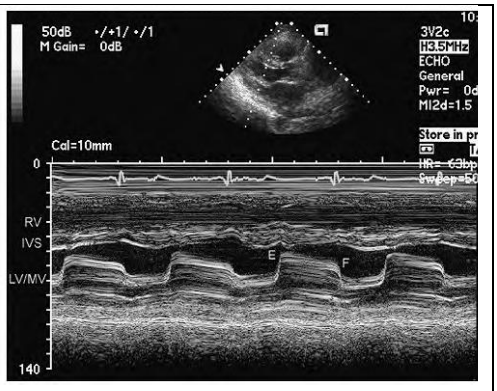
Posterior leaflet appears to move anteriorly in diastole as well (both leaflets move in concert).

Mitral leaflets open at early diastole

Rheumatic mitral stenosis, showing

- Marked thickening of the mitral valve leaflets
- Flat E-F slope during diastole- is seen on M-mode across the MV in MS but does not correlate well with severity as it is affected by annular motion and fibrosis among other factors.
- Posterior leaflet appears to move anteriorly in diastole as well. i.e. both leaflets move in concert. This is because of commissural fusion → tethering of the posterior leaflet tips to the larger anterior leaflet → paradoxical anterior diastolic motion of the posterior leaflet tips

*Note that The mitral leaflets open at early diastole.*



**2D ECHO**

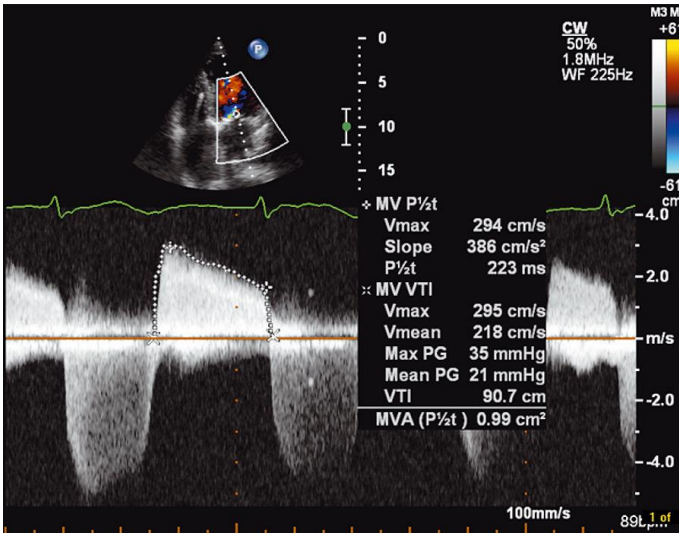
- **Measuring the mitral orifice area by planimetry** in the PSAX is gold standard method for evaluation of severity of AS if the image quality is good. Remember that a stenosed mitral valve, when open, is funnel shaped, so be careful to ensure that you are measuring the ”funnel” at its narrowest point, i.e. the level of the leaflet tips. One should scan from the apex to the first point that the MV tips appear, this is the narrowest part of the valve orifice (Biplane 3D echo can help aligning the beam accurately at the level of the leaflet tips and avoiding foreshortening of the orifice). Once you’ve recorded a loop at the level of the tips, scroll the images back and forth until you find the one that shows the orifice at its widest point in the cardiac cycle (mid diastole). Take your measurement from this image, tracing around the inner edge of the leaflets If you angle the probe too far upwards (towards the LA) you will overestimate the orifice area. Importantly, if the gains are too high, the valve will appear to be thicker than it is, with the luminal edges seemingly encroaching into the orifice; planimetry may thus cause the valve area to be underestimated. Planimetry has been well validated against cardiac catheter data, but is not accurate when image quality is poor, as visualisation of the orifice is suboptimal. Valve area <1.5 $cm^2$ indicates haemodynamically significant MS and <1 $cm^2$ indicates severe MS
- **Wilkins’ score for amenability for valvuloplasty (percutaneous mitral commissurotomy, PMC):**
  - Leaflet mobility (1 = Mobile, 4 = Immobile)
  - Leaflet thickening (1 = thickening < 5mm, 4 = thickening > 8-10mm)
  - Leaflet calcification (1 = No bright echoes, 4 = Extensive brightness)
  - Subvalvar involvement (1 = Minimal thickening below leaflet tips; 4 = Thickening of all chordal structures)

  Combined score > 8 suggests the valve may not be amenable to valvuloplasty**.** A low Wilkins’ score suggests a good candidate for valve commissurotomy (or valvuloplasty).

- **Cormier score for assessment of mitral valve anatomy:**

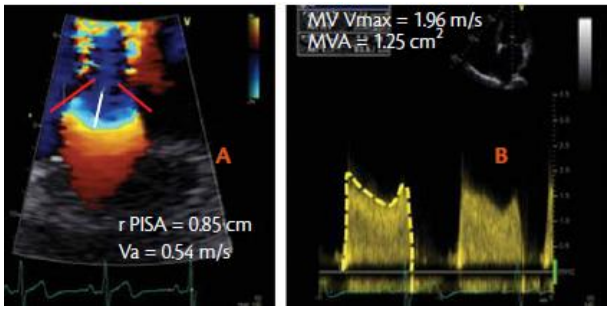
**Group 1** Pliable non-calcified anterior mitral leaflet and mild subvalvular disease (i.e. thin chordae <10 mm long)
**Group 2** Pliable non-calcified anterior mitral leaflet and severe subvalvular disease (i.e. thickened chordae ,10 mm long)
**Group 3** Calcification of mitral valve of any extent, as assessed by fluoroscopy, whatever the state of subvalvular apparatus

**DOPPLER ECHO-** use CW Doppler to obtain a trace of forward flow through the mitral valve from an apical 4C (other apical views can also be used). Ignore traces obtained from ectopic beats (and the beat following an ectopic), and if the patient is in AF (as is often the case) take an average measurement from several beats. The position of the probe is crucial for accurate assessment by Doppler and must be parallel to the forward flow through the mitral valve.




1. **MV area can be calculated using the PHT** method by measuring the downward slope of the E wave of the mitral valve inflow. The deceleration slope should ideally be linear though this is not always attainable. Occasionally, mitral velocity has two different deceleration slopes; PHT should be measured from the early trans-mitral flow (In cases with two distinct slopes, the measurement is done on the slowest of the slopes, i.e., the slope with the longer duration). PHT is a measure of the rate of fall in pressure across the valve. The narrower the valve, the longer it takes for the pressure gradient to fall and hence the longer the PHT. Studies have shown that a MV area of 1 $cm^2$ has PHT of approximately 220 ms, and that the relationship between PHT and valve area is linear. It is therefore possible to estimate MV area from PHT using the equation: MV area = 220 / PHT. PHT is unreliable in the presence of:
   - MR (slightly affected)
   - AR and ASD (alter compliance in LA/LV, hence shorten PHT overestimating MV area)
   - Eccentric jet of AR (may overestimate MS due to added functional MS, which would prolong the PHT)
   - Prosthetic MV
   - Up to 72 h post mitral valvuloplasty (due to the alter compliance in LA/LV)
   - AS/LVH

2. **Measure the mean mitral pressure drop** by tracing the VTI of the mitral inflow from any apical window. Unlike pressure half-time, the mean pressure gradient is dependent upon flow across the valve. Therefore, conditions that increase transmitral flow such as tachycardia, exercise, anaemia, pregnancy, sepsis, thyrotoxicosis, coexistent MR and other high cardiac output conditions will increase the gradient, overestimating the severity of the MS.
3. **MV area can also be calculated using the continuity equation**. **$Area_{MV} = Area_{LVOT} \times VTI_{LVOT} \div VTI_{MV}$** [remember $Area_{LVOT} = \pi (r^2)$]. Calculation of MVA by continuity equation relies on the volume of blood entering the LV via the MV during diastole (transmitral stroke volume) being equal to the volume of blood leaving the LV via the LVOT during systole. This calculation cannot therefore be used in the presence of significant MR, AR or AF). PA can replace the LVOT in this equation (with the same precautions).This method is tedious and therefore not used routinely unless there is discrepancy between the valve area measurements by planimetry and by PHT.
4. **PISA method-** can be used to calculate MV area in case of MS and is not affected by presence of MR or AR. However, MVA calculated by PISA method (in presence of MS) should be multiplied by angle correction factor ($\alpha^0 /180^0$) to correct for the funnel angle formed due to doming of the mitral leaflets in MS. This method is technically demanding and requires multiple measurements. The use of colour M-mode improves its accuracy, enabling simultaneous measurement of flow and velocity.




$MVA = (2\pi r^2) \times (V_{aliasing} / V_{max}) \times (\alpha^0 /180^0)$
$2\pi r^2$ = PISArea at a radial distance r from the orifice
$V_{aliasing}$ = Aliasing velocity at the radial distance r (cm/s)
$V_{max}$ = Peak mitral stenosis velocity by CW (m/s)
$\alpha^0$ = Angle between two mitral leaflets on the atrial side (red lines)
Some labs use fixed $\alpha^0$ angle value of 100°

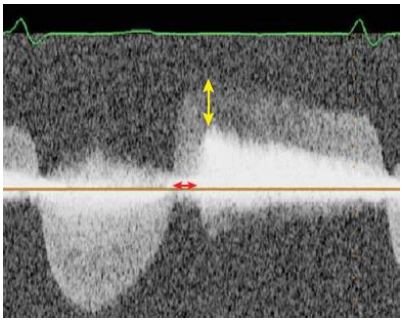
**Associated features**

- Most patients are female, and most will have coexistent MR or other coexistent valve disease.
- Evidence of blood stasis in the LA: spontaneous echo contrast or LA thrombus even in sinus rhythm (TOE is mandatory prior to valvuloplasty as it has a higher sensitivity and specificity for detecting thrombus in the LAA than TTE).
- LA dilatation (indirect indicator of severe MS). LA M-mode diameter > 50 mm or/and LA indexed volume > 60 $mL/m^2$ should prompt the initiation of anticoagulation in MS patients (class IIa, level of evidence C)
- Pulmonary hypertension (indirect indicator of severe MS)
- Increased chronic PASP leads to RV hypertrophy and dilatation and ultimately, to RV dysfunction and failure. The presence of RV systolic dysfunction does not preclude PMC or surgery in a patient with MS, but it reflects a higher mortality rate.
- Coexisting leaflet thickening may be suggestive of aetiology but is not a marker of severity
- AF is a complication of MS but is not a marker of severity
- Diastolic closure of the MV is later than normal in MS because the persistent gradient from LA to LV in diastole keeps the valve open for longer.

**PITFALLS IN THE ECHO ASSESSMENT OF MS**

- **Preferred method:**
  - **Direct planimetry** of mitral valve orifice is the preferred method for rheumatic MS and MS with associated MR.
    - Angulating the probe too far upwards (towards the LA) → failure to planimeter the mitral leaflets at their tips→ overestimates the MVA by planimetry → underestimate the severity of MS calculated by planimetry
    - High gain → underestimates the MVA by planimetry → overestimates the severity of MS calculated by planimetry
    - Heavy calcification of the mitral leaflet edges → inaccurate planimetry of the MVA.
  - **Continuity equation** is accurate for MVA calculation, and is the preferred method in the absence of MR/AR (even in presence of associated AS)**,** but is invalid in the presence of associated MR or AR (or AF) as this equation relies on the equality of the transmitral stroke volume (during diastole) and the LVOT stroke volume (during systole), which is inaccurate because of added regurgitant flow the increases the anterograde flow through the MV or LVOT. Stroke volume can, alternatively, be estimated from the pulmonary artery; however, this is rarely performed in practice because of limited acoustic windows. Remember: continuity equation is valid for calculating the AVA in presence of MR**.**

- **PISA method can be used** to calculate MV area in case of MS and is not affected by presence of associated MR or AR. However, MVA calculated by PISA method (in presence of MS) should be multiplied by angle correction factor ($\alpha^o$ /180$^o$) to correct for the funnel angle formed due to doming of the mitral leaflets in MS. Some labs use fixed $\alpha^o$ angle value of 100°
- PHT is unreliable in the presence of:
  - MR (slightly affected) – direct planimetry is the preferred method
  - AR & ASD (alter compliance in LA/LV, hence shorten PHT overestimating MV area) -direct planimetry is preferred
  - Eccentric jet of AR (may overestimate MS due to added functional MS, which would prolong the PHT)
  - Prosthetic MV
  - Up to 72 h post mitral valvuloplasty (due to the alter compliance in LA/LV)
  - AS/LVH (continuity equation can be used)
- Associated AS, LVH, recent valvuloplasty and the presence of associated ASD will also affect the **PHT**
- Low flow low gradient MS (paradoxical or not) is not infrequent in presence of associated AS
- In general, using Doppler to assess valve area is dependent on HR because at high HRs, LA filling per beat is reduced as the cardiac cycle is shorter and transmitral flow terminates earlier as diastole is shorter.
- On using the PW Doppler, the sample volume should typically be located in-between the tips of the MV leaflets
- On using CW Doppler, the Doppler beam should be aligned with the flow through the valve.
- In presence of AF, you should obtain the average of several readings (5-10).
- MS jet should not be mistaken for associated AR jet (MS has a lower velocity and a later onset)



**ECHO SURVEILLANCE**

- Patients with asymptomatic but significant mitral stenosis should be advised to report symptoms immediately and should have annual clinical and echo evaluations.
- **ACC**: annual echo for moderate-severe valvular stenosis/regurgitation and every three years for mild valvular stenosis/regurgitation

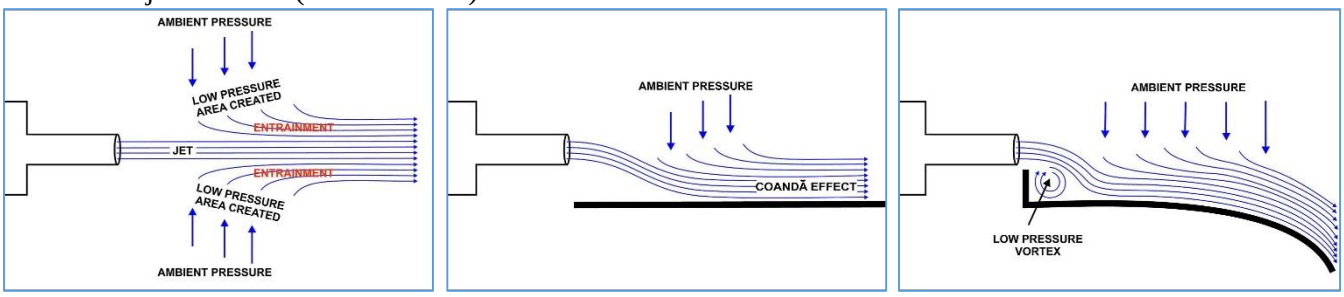
# MITRAL REGURGITATION

**CAUSES OF MR:** Mitral regurgitation is the most common cardiac valvular regurgitation

- **Myxomatous degeneration/mitral valve prolapse (MVP)**. Diagnose MVP when any part of either leaflet moves >2 mm behind the plane of the mitral annulus in the **PLAX** or the coaptation point of the leaflets moves behind the annular plane in the apical 4C. However, due to saddle shaped mitral valve apparatus, the apical 4C projection erroneously misinterprets the anatomy of the valve as prolapsing and, therefore, EACVI recommends PLAX only for diagnosing MVP. Prolapse of the TV and AV is seen in approximately 20% patients with MVP. MVP is associated with other conditions, such as Marfan's syndrome, Ehlers–Danlos syndrome and osteogenesis imperfecta. MVP can be present with and without MR. Isolated MVP carries an excellent prognosis, and such patients should have follow-up scans every 3–5 years.
- **Rheumatic valve disease-** Regurgitant rheumatic valves are oedematous with fibrous thickening and minimal calcification, non-fused commissures, annular dilatation, and anterior chordal elongation
- **Infective endocarditis** (Perforation of the leaflets implies endocarditis as the aetiology).
- **Mitral annular dilatation (Secondary MR)**:
  - Secondary MR develops despite a structurally normal mitral valve in the context of ischaemic heart disease, dilated cardiomyopathy, or severe LA dilatation.
  - It results from increased tethering forces (due to LV remodeling) and decreased MV closing forces, leading to stretching of the mitral annulus and non-coaptation or apical displacement of the coaptation point, resulting in central jet.
  - A number of anatomic measurements can be made that reflect the pathophysiology of functional MR, including (Fig.):
    - Global and regional LV remodelling (apical displacement of the papillary muscle)
    - Altered geometry of the mitral valve apparatus
      1. Tenting area (the area between the mitral annulus and the mitral leaflets body from PLAX or apical view). Systolic tenting area >2.5 $cm^2$ *(> 1.7 for TV repair)* is preoperative indicators of failure of functional MR repair
      2. Coaptation distance (distance between the mitral annular plane and the point of coaptation in mid-systole from apical 4C). Coaptation distance >1 cm is preoperative indicators of failure of functional MR repair.
      3. postero-lateral angle (the angle between the PL leaflet and the annular plane). postero-lateral angle > $45^o$ is preoperative indicators of failure of functional MR repair
- **Ischaemic heart disease**- Mitral regurgitation in ischaemic heart disease can be intermittent, only occurring when an episode of myocardial ischaemia affects a papillary muscle, or it may be permanent following a myocardial infarction. Multiple mechanisms may account for MR complicating acute MI. These include (1) dilation of the mitral valve annulus as a result of LV dilation; (2) ischemic papillary muscle dysfunction; and (3) rupture of the chordae or papillary muscle. Rupture of the chordae or papillary muscle is more common with inferior MI, affecting the posteromedial papillary muscle, resulting in flail posterior leaflet. This is because the posteromedial papillary muscle receives blood supply solely from the PDA, whereas the anterolateral papillary muscle has dual blood supply from LAD and CX arteries. Similarly, Ischemic papillary muscle dysfunction and associated tethered posterior leaflet is more common with infero-posterior MI
- **Collagen disorders**, for example, Marfan syndrome (associated with long redundant anterior leaflet, MVP, MR and MV calcification) and Ehlers Danlos syndrome
- **Congenital** (e.g. cleft mitral valve, which may be associated with a primum ASD)- A cleft MV looks anatomically similar to the TV and indeed can be difficult to distinguish from the TV in the presence of congenital heart disease.
- **SLE**
- **Osteogenesis imperfecta**
- **Mitral annular calcification (MAC)**
- **Balloon valvuloplasty**: as the stenotic valve is dilated with the balloon, the leaflets can be torn leading to a regurgitant valve. Moreover, during balloon valvuloplasty, the LA is accessed via a trans-septal puncture from the RA, which can leave an ASD.

**DIRECTION OF THE REGURGITANT JET:**

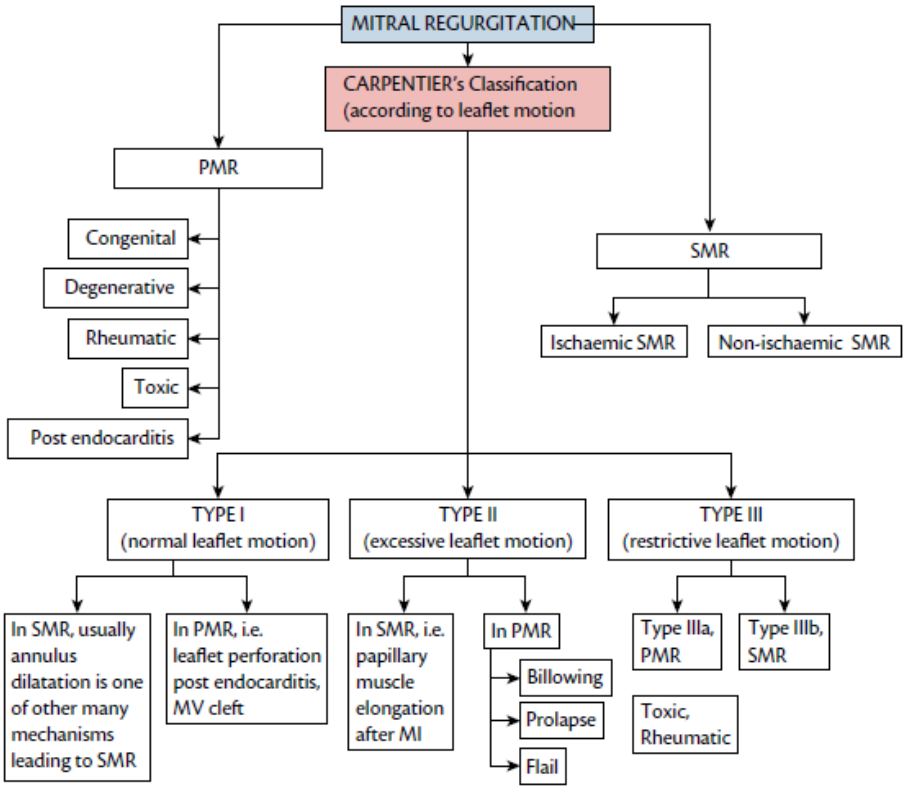
The direction of the jet may give an indication of aetiology but is not a marker of severity per se. However, Central jets can appear more severe than they really are on colour Doppler because, in free surroundings, the regurgitant jet entrains the blood cells on the side of the jet as it flows away from the orifice. whereas, eccentric jets that impinge on the LA wall can appear less severe than they are, because they cannot entrain blood cells on the side of the jet that hits the wall; instead, the jet attaches itself to the nearby wall and remains attached even when the surface curves away from the initial jet direction (Coanda effect).




- **Prolapsed leaflet/Flail/SAM** → the jet direction is opposite to that of the involved leaflet. Prolapse or flail posterior leaflet → jet is directed anteriorly and medially towards the IVS.
- **Restricted (tethered) leaflets (due to ischemia/infarction)** → the jet direction is similar to that of the restricted leaflet
- **Bileaflet prolapse**, **restricted physiology of both leaflets** and **annular dilatation** → central jet. Annular dilatation causes a rather symmetric displacement of the leaflets. Thus, the direction of the jet will be central (with increased coaption depth).
- **SAM** pulls the anterior leaflet away from the posterior leaflet, but also distorts the posterior leaflet and causes an opening channel that directs the jet in posterior and lateral direction
- Apical 4C or 3C are used to visualize the direction of the jet associated with MVP; however, PLAX is superior view for assessment of degree of MVP as the MV annulus is saddle-shaped and the lowest portion of it is not seen in the apical 4C. In general, the direction of the jet, as well as, annular calcification can be assessed in the PLAX and PSAX

**Carpentier's** classification is usually used to classify MR according to its mechanism (% Fig. 36.2). This classification uses the pattern of leaflet motion and categorizes MR into

- **Type I**—MR with normal leaflet motion (i.e. annular dilatation)
- **Type II**—MR due to excessive leaflet motion (i.e. MV prolapse/flail; see z Video 36.1)
- **Type III**—MR due to restrictive leaflet motion
  - **IIIa** systolic and diastolic restrictive leaflet motion (such as in rheumatic MR)
  - **IIIb** with restrictive motion only in systole (such as in secondary MR).



**ASSESSMENT OF SEVERITY OF MR**

| | Mild | Moderate | Severe |
|---|---|---|---|
| **Vena contracta width (cm)** | < 0.3 | **0.3** - 0.7 (AR **0.3 - 0.6**) | > 0.7 (AR>0.6) |
| **PISA radius (Nyquist 40 cm/s)** | < 0.4 | **0.4 - 1** | > 1 |
| **Regurgitant orifice area (cm2)** | < 0.2 | **0.2** - 0.4 (AR **0.1** - 0.3) | **> 0.4** (>0.2 for secondary MR) |
| **Regurgitant volume (mL)** ***MR/AR*** | < 30 | **30** - 60 (MR/AR) | **> 60** |
| **Regurgitant fraction (%)** ***MR/AR*** | < 30 | **30** - 50 (MR/AR) | > 50 |
| **Jet area / LA ratio (%)** | < 20 | **20 – 40** (AR/LVOT **25** - 65) | > 40 |
| **CW Doppler trace density** | Faint (low density) | | Dense |

1. **Colour Doppler flow mapping**- is widely used to screen for the presence of mitral regurgitation. In fact, a colour flow jet is an image of the spatial distribution of velocities within the imaging plane and **Jet area** is often inaccurate in assessment of severity of MR due to dependence on technical and haemodynamic variables. Nevertheless, colour flow mapping does offer several potential ways to assess MR severity, such as width of the base of the regurgitant jet (Broad-based jet indicates severe MR) and calculating the MR jet area to LA ratio. Notice that inappropriate setting of the colour gain may give inaccurate impression about the severity of the MR. It is, therefore, advisable to set the colour gain by turning it up until noise is encountered and then backing off until the noise just clears from the image. The colour Doppler velocity scale should also be set to a high level in order to accurately depict and qualitatively assess all the velocities' spectrum. **Remember:** systemic arterial pressure is always a significant factor that influences the severity of MR

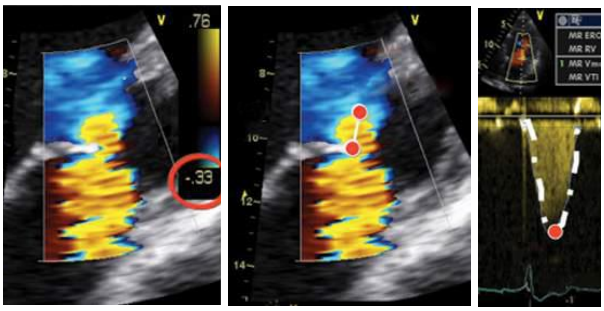
2. **Vena contracta (VC)** – is the narrowest diameter of the regurgitant jet (colour flow) at or just downstream from the orifice of the mitral valve. It is characterized by high velocity, laminar flow and is slightly smaller than the anatomic regurgitant orifice due to boundary effects. Thus, the cross-sectional area of the vena contracta represents a measure of the effective regurgitant orifice area, but not anatomical orifice area. VC width is measured in the PLAX or apical 4C or 3C (EACVI recommends the apical 4C).

   For measurement of jet area and VC width, a Nyquist limit setting of 50–60 cm/s is usually appropriate to avoid under/overestimating severity.

   If the regurgitant orifice is circular, vena contracta width should be an excellent marker of the ROA. Unfortunately, the regurgitant orifice in MR is often elongated along the mitral coaptation line, like a ''smiley face''. The apical 2C, which is oriented parallel to the line of leaflet coaptation, may show a wide vena contracta even in mild MR, so it should not be used to measure vena contracta width
   VC helps gauge severity even if the jet is eccentric, but it cannot be used to assess the severity of multiple regurgitant jets.
   Vena contracta sizes are mainly determined by the orifice area, and are therefore independent of LV function and flow rate.

3. **PISA or flow convergence method for calculation of EROA and Regurgitant volume**
   **The concept behind the PISA method:** the regurgitation flow rate is the same proximal and distal to the valve →
   Proximal regurgitation flow rate = distal regurgitation flow rate →
   Proximal area x proximal velocity = distal area x distal velocity →
   By calculating the proximal flow rate (=PISArea x aliasing velocity), we can calculate:
   EROA = Proximal area x proximal velocity ÷ distal velocity
   Regurgitant volume =EROA x VTI
   Regurgitant fraction = regurgitant volume ÷ forward SV x100
   PISA (Proximal Isovelocity Surface Area) is the surface area of one of the **hemispheric** shells ($2\pi r^2$) of the converging blood flow proximal to the valve (blood flowing towards a circular orifice converges to form a series of hemispheric shells, each of which gets smaller and faster as it approaches the orifice). The chosen hemispheric shell is the one at which aliasing occurs (at the blue-red interface) since the blood velocity at this shell equal the selected aliasing velocity, and this can be used to calculate the flow rate at this shell as follows:

**Stepwise measurement of PISA**



1) Apical 4C view
2) Colour flow display
3) Zoom of the selected zone
4) Downward shift of zero baseline progressively to obtain hemispheric PISA
5) With the cine mode select the best PISA
6) Measure of the PISA radius (the distance between the base of the hemispheric PISA and the first aliasing) in systole.
7) PIS**Area = 2 x 3.14 x (PISA radius)$^2$**
8) CW Doppler of MR jet allows calculating the **EROA** as follows:

- **Flow rate =** PIS**Area X** Aliasing **Velocity**
- **Flow rate = 2 x 3.14 x (PISA radius)$^2$ x Aliasing velocity**
- According to the continuity equation, this flow rate (proximal to the valve) is equal to the flow rate distal to the valve (the regurgitant flow) and can be used in calculation of the regurgitant orifice area as follows:
- **EROA = Flow rate ÷ MR peak velocity**
- **EROA = (PISA X aliasing velocity) ÷ MR** peak **velocity**
- Alternative method to measure mitral valve area directly from apical 4C : $Area_{MV}$ = 0.785 x (mitral annulus diameter)$^2$

9) CW Doppler of LV inflow allows calculating the regurgitant **volume** as follows:

- **Regurgitant volume = EROA x $VTI_{MV}$** (similar to SV equation)

10) PW Doppler of LVOT and measuring LVOT diameter allows calculating the regurgitant **fraction** as follows:

- **Regurgitant fraction = Regurgitant volume ÷ forward SV x100 = EROA x $VTI_{MV}$ ÷ ($Area_{LVOT}$ x $VTI_{LVOT}$) x100**

**Notice:**

- Area of circle = **$\pi r^2$** while Area of hemisphere = **$2\pi r^2$**
- **The PISA technique should not be used if** a clear symmetrical hemisphere cannot be obtained or if the jet is eccentric, but vena contracta can be used with eccentric jet. In nature, the shape of the ERO is not usually perfectly round and the PISA is also not thoroughly hemispherical, generating an error in the final assessment of the severity of regurgitation. However, this method can assess mixed valve pathologies (stenotic and regurgitant) and is equally accurate both in primary and secondary forms of valve disease although in functional MR, the PISA might look like an ellipsoidal shape and the PISA method may underestimate the severity of MR.
- **Regurgitant volume should not be calculated when** there is coexistent aortic regurgitation.
- **PISA and vena contracta methods** are typically **single frame** measurements that can **overestimate** MR severity (particularly in MVP with only late systolic MR) compared to 3D measurements
- **In functional MR**, the PISA might look like an ellipsoidal shape and two separate MR jets originating from the medial and lateral sides of the coaptation line can be observed on 2D echo. When the shape of the flow convergence zone is not a hemisphere, the PISA method may underestimate the degree of functional MR. While, In primary MR, the shape of the PISA is often rounder, which minimizes the risk of EROA underestimation. These findings could explain why the threshold used to define a severe functional MR is inferior to that used for organic MR.
- **In the presence of functional MR**, there is a dynamic variation of the regurgitant orifice area with early and late systolic peaks and a mid-systolic decrease. These changes reflect the phasic variation in transmitral pressure that acts to close the mitral leaflets more effectively when pressure reaches its peak in mid-systole. PISA shape is affected by these systolic changes in regurgitant flow. Therefor, the colour M-mode is important to assess the variation of MR flow and the related PISA during systole.

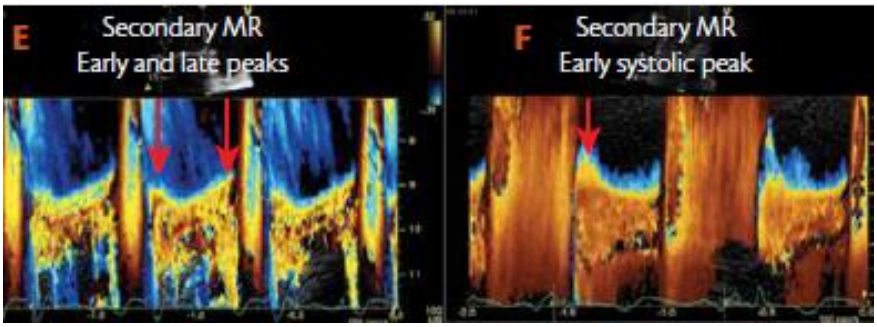



Fig. PISA method limitation: changes in regurgitant flow convergence zone during systole in secondary MR

4. **PW mitral to aortic VTI ratio** is also used as an easily measured index for the quantification of isolated pure organic MR. Mitral inflow Doppler tracings are obtained at the mitral leaflet tips and aortic flow at the annulus level in the apical 4C. A VTI ratio >1.4 strongly suggests severe MR, whereas a TVI ratio <1 is in favour of mild MR.

5. **Prominent E wave** may be seen with MR due to increased LA pressure → increased early diastolic pressure gradient. A peak E velocity >1.5 m/s (in the absence of MS) suggests severe MR in case of primary MR (the cut off is not well defined for secondary MR, but value > 1 m/s is in favour of severe regurgitation). Conversely, a dominant A-wave (atrial contraction) basically excludes severe MR

6. **3D echo** has shown superiority in assessing the mechanism of mitral regurgitation and in precise identification of flail leaflets. Careful consideration of the 3D geometry of VC/PISA may be of interest in evaluating the severity of MR. The best 3D echo method to quantitate MR severity is still not defined

7. **Echo morphological parameters that are measured in ischaemic MR**.

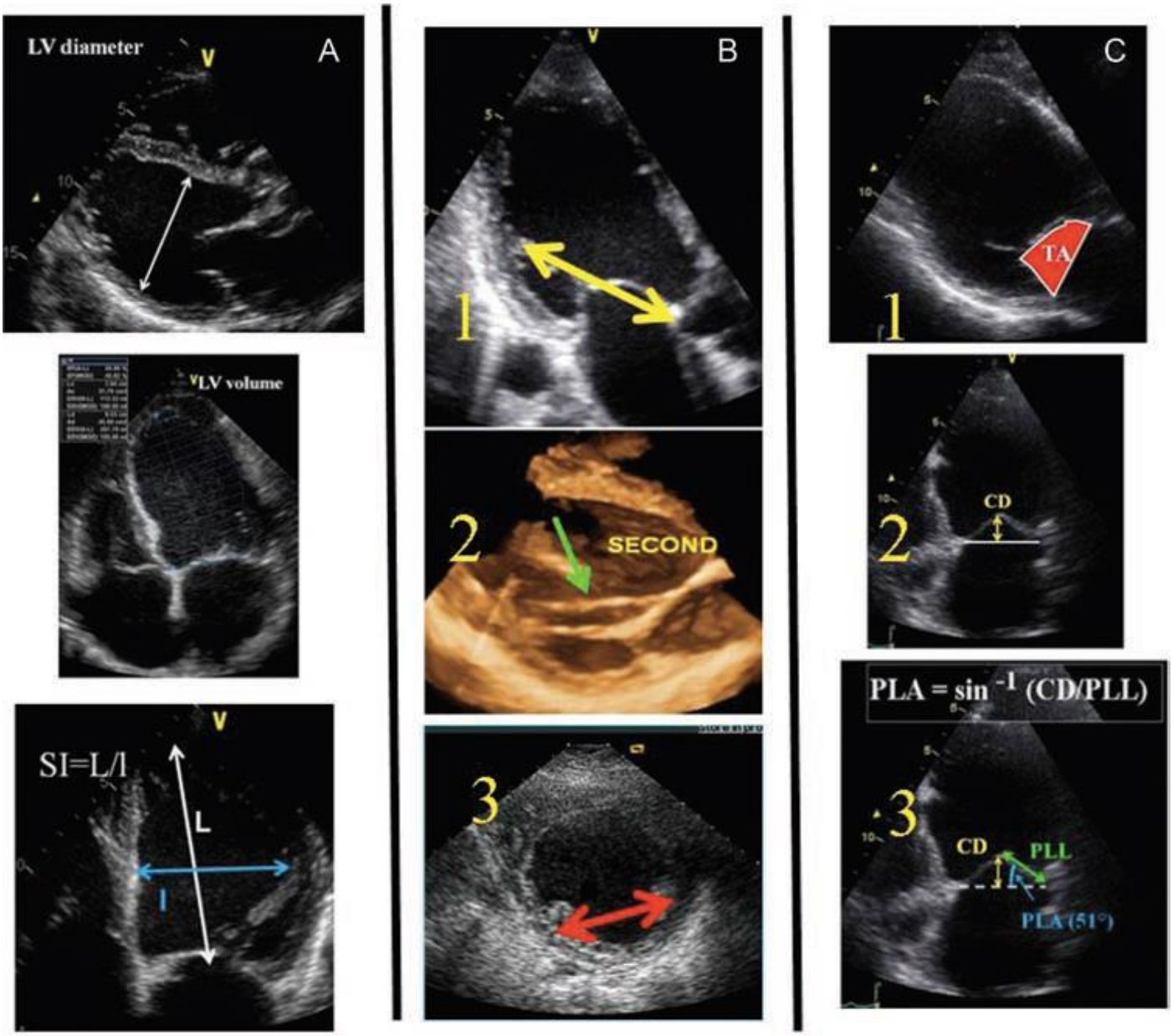
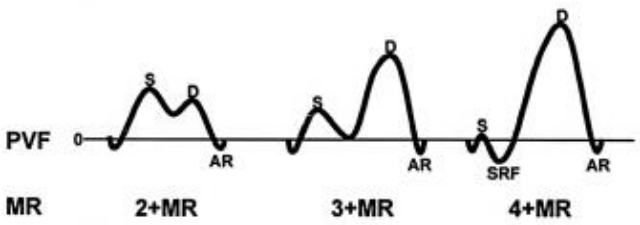



**Fig.** Echo morphological parameters that are measured in ischaemic MR.
**A) Global LV remodelling** [diameter, LV volumes, sphericity index (SI ¼ L/l; L, major axis; l, minor axis)]
**B) Local LV remodelling** (1: apical displacement of the posteromedial papillary muscle; 2: second order chordate; 3: interpapillary muscle distance)
**C) Mitral valve deformation** [1: systolic tenting area (TA); 2: coaptation distance (CD) ; 3: postero-lateral angle (PLA)].

**ASSOCIATED FEATURES & CONSEQUENCES OF SEVERE MR**:

- **Mitral annulus dilatation**: using the PLAX, annular dilatation is identified when the ratio annulus/anterior leaflet is >1.3 (in diastole) or when the annulus diameter is >35 mm.
- **LV dilatation/dysfunction**.
  - In chronic MR, The LV will develop eccentric LVH due to volume overload.
  - MR → LV volumes are ejected into the LA in addition to the aorta → EF will increase (without correlated increase in LV function) → underestimate LV function estimated by LVEEF.
  - In severe, asymptomatic MR, the indications for surgery under current ESC guidance are LV dilatation (*LVESD* **> 45 mm**), LV dysfunction (EF**<60%**), AF or pulmonary hypertension (>50mmHg). The American (ACC/AHA) guidelines differ slightly in that surgery is considered when the end-systolic dimensions reach 40 mm. Patients with LV EF < 60% also displayed an excess mortality as compared to those with ejection fraction ≥ 60%. **Remember:** *LVESD >50 mm or LVEDD >70 mm is an indication for surgery in severe AR.*
- **LA dilatation**- in acute MR, the LA is not compliant with the rapid onset of additional volume, which causes the LA pressure to increase. In chronic MR, the LA, in order to compensate for the regurgitant volume overload, becomes enlarged. This allows normalization of the filling pressures. A normal sized LA is inconsistent with severe MR unless it is acute. Significant enlargement is indicated by LA volume index > 40 mL/m$^2$
- **Specificities in secondary MR**: (1) LV and LA dilatation are in excess to the degree of MR, (2) LA pressure is often elevated despite lower regurgitant volume than in primary MR.
- **PSAP** (significant increase: PSAP > 50 mmHg at rest)
- **Tricuspid annular dilatation** (significant: ≥ 40 mm or > 21 mm/m2 is class IIa indication of TV repair when MV is operated upon)
- **Pulmonary vein systolic flow reversal**. It is usually possible to locate one or other of the right pulmonary veins in the corner of the LA, adjacent to the interatrial septum, in the apical 4C. Place the PW Doppler sample volume 1 cm into the pulmonary vein and obtain a recording. Normally the systolic (S) wave is larger than the diastolic (D) wave: if the D wave is larger, then there is blunting of forward flow in the pulmonary vein, and if the S wave is inverted, there is systolic flow reversal (indicative of severe mitral regurgitation). However, with chronic MR, the LA may become much dilated, when even severe MR may not reach the pulmonary veins.




- **A slow rise to peak velocity** suggests impaired LV function, which may also be a consequence of severe MR and is an indication for valve surgery, as is the development of pulmonary hypertension.
- **AF** is frequently seen in severe MR, which leads to the absence of the A wave. Notice that In AF, several readings (5-10) should be average to minimize the errors of measurements.
- An increase in regurgitant volume >15ml or increase in EROA > 10 mm$^2$ during exercise is associated with a poorer prognosis
- MR → LV volumes are ejected into the LA in addition to the aorta → EF will increase (without correlated increase in LV function) → underestimate LV function estimated by LVEEF

**PITFALLS IN THE ECHO ASSESSMENT OF MR**

- **Preferred method:** PISA derived EROA and vena contracta are preferred methods for assessment of MR (over jet planimetry and calculation of regurgitant volume) in case of associated AS, AR or status post AVR as they are less loading conditions dependant. However, PISA and vena contracta methods are typically single frame measurements and, therefore, may overestimate **MR** severity (particularly in MVP with only late systolic MR) compared to 3D measurements. PISA method may also underestimates the severity of functional MR due to its ellipsoidal shape in functional MR. However,
- The MR Doppler flow should be differentiated from AV Doppler flow in the apical 5C view (see above)
- The apical 2C view images primarily the anterior leaflet and abnormalities of the posterior leaflet will therefore not be readily evident
- **Aliasing velocity** (Nyquist limit) of 50–60 cm/s is usually appropriate for measurement of jet area and VC width. While for image Acquisition for PISA, adjust the aliasing velocity until you see a clear hemisphere of converging blood flow on the ventricular side of the valve, usually at a setting of 20–40 cm/s.
- Peak velocity of the regurgitant jet is not a marker of severity per se.

- Associated AS increases the intraventricular pressure leading to increased mitral regurgitant volume and increased mitral colour flow jet planimetry, while mitral EROA is less affected by presence of associated AS. Therefore, EROA (and/or vena contracta) are the **preferred methods** for MR assessment in presence of associated AS.
- **Doppler volumetric method** (using Doppler mitral inflow and LVOT stroke volume) is inapplicable in the presence of associated AR
- **MR echo findings are not significantly affected by presence of associated MS**
- **Functional MR associated with AV disease is likely to regress after AVR**, predominantly the ones with a tenting area < 2.5 $cm^2$.
- TR associated with MV disease is usually functional. Measurement of tricuspid annulus is essential in such a case as **tricuspid annuloplasty** should be considered, with any plan for MV surgery, when tricuspid annulus is dilated (> 40 mm or > 21 $mm/m^2$ as measured from the middle of the septal annulus to the middle of the anterior annulus in the four-chamber view).
- **Remember**: if mitral regurgitation is present, take the opportunity to assess the LV systolic function by measuring dP/dt

**MITRAL VALVE REPAIR:**

- **In primary MR**, some predictors of unsuccessful repair have been reported: the presence of a large central regurgitant jet, severe annular dilatation (>50 mm), involvement of ≥3 scallops especially if the anterior leaflet is involved, and extensive valve calcification. Moreover, the lack of valve tissue is also an important predictor of unsuccessful repair both in rheumatic valve disease and in patients who have had infective endocarditis with large valve perforation. A thickened, redundant mitral valve can often be repaired rather than replaced, with lower operative mortality and excellent short- and long-term results
- **Unfavourable TTE characteristics for mitral valve repair in secondary MR**:
  1) Mitral valve deformation
     - Coaptation distance ≥1 cm
     - Tenting area >2.5 $cm^2$ (>1.7 cm2 for TR repair)
     - A central regurgitant jet (indicating a severe restriction of both leaflets in patients with severe functional ischaemic MR)
     - Complex jets originating centrally and posteromedially
     - Postero-lateral angle >45° (high posterior leaflet tethering)
  2) Local LV remodelling
     - Interpapillary muscle distance >20 mm
     - Posterior papillary-fibrosa distance >40 mm
     - Lateral wall motion abnormality
  3) Global LV remodelling
     - EDD >65 mm, ESD >51 mm (ESV >140 mL) (low likelihood of reverse LV remodelling after repair and poor long-term outcome)
     - Systolic sphericity index >0.7
- **Factors affecting the possibility of repair of MVP**: prolapse location, valvular/annular calcifications and severity of annulus dilatation
- A coaptation distance >1 cm and systolic tenting area >2.5 $cm^2$ are preoperative indicators of failure of functional MR repair (tenting area > 1.7 for TV repair).
- **Annulus calcium scoring** used in assessment of suitability of MR repair (0-5: P1,P2,P3,AMVL, Commissures)

**In modern practice**, the only contraindication to repair of a MV with organic disease is extensive calcification of the annulus and/or leaflets. In the setting of ischaemic/functional regurgitation, the limiting factor is severe LV dysfunction with inadequate viable myocardium.

**MitraClip® therapy for mitral valve repair**

| Optimal valve morphology | Possibly suitable valve morphology | Unsuitable valve morphology |
|---|---|---|
| Mitral regurgitation originating from segment 2 | Pathology in segments 1 or 3 | Perforated mitral valve leaflet or cleft, with lack of primary and secondary chordal support |
| Lack of calcification in grasping area | Mild calcification outside of the grip-zone of the clip system, ring calcification; post annuloplasty | Severe calcification in the grasping area |
| Mitral valve area (MVA) > 4 $cm^2$ | MVA > 3 $cm^2$ | Haemodynamically significant mitral stenosis (MVA < 3 $cm^2$ or mitral mean gradient < 5 mmHg) |
| Mobile length of posterior leaflet ≥ 10 mm | Mobile length of posterior leaflet 7–10 mm | Mobile length of posterior leaflet < 7 mm |
| Normal leaflet strength and mobility | Leaflet restriction in systole (Carpentier IIIb) | Rheumatic leaflet thickening and restriction in both systole and diastole (Carpentier IIIa) or endocarditis valve disease |
| Flail width < 15 mm and flail gap < 10 mm | | Multiple segment flail leaflets<br>Gap between leaflets < 2 mm |

**ECHO SURVEILLANCE**

- Asymptomatic patients with moderate MR or mild-moderate AR (and normal LV function) should be seen annually and have an echo every 2 years.
- Asymptomatic patients with severe MR (and normal LV function) should be seen every 6 months and have an echo every year (asymptomatic patients with severe AR and normal LV function should be reviewed every 6 months, or annually if stable and not close to needing surgery)
- ACC: annual echo for moderate-severe valvular stenosis/regurgitation and every three years for mild valvular stenosis/regurgitation