QUANTIFICATION OF MITRAL REGURGITATION
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- Spatial Area Mapping
- Vena Contracta
- Proximal Isovelocity Surface Area (PISA) Radius
- Spectral Doppler
- Regurgitant Volume and Fraction
- Effective Regurgitant Orifice Area

Assessment of Mitral Regurgitation Severity
Grading severity of MR into mild, moderate or severe integrates multiple 2D + Doppler parameters. These parameters are influenced by hemodynamic and technical factors. For instance changes in systolic BP or the Nyquist limit can dramatically influence the presentation of color Doppler flow which must be taken into careful consideration. Single frame measurements (vena contracta or PISA) may overestimate MR severity when MR is brief in duration.
- Specific methods have a high positive predictive value of regurgitation severity
- Supportive signs, though less specific, suggest lesion severity
- Quantitative techniques should be used to differentiate MR severity when more than mild MR is present

### Spatial Area Mapping
Regurgitant jet area is traced as the mosaic colour flow within the LA, both as an absolute and a relative ratio of MR jet / LA area. This is a practical method to screen for MR, but it is no longer used to assess severity. There are many technical and hemodynamic factors that influence jet size: pressure gradient (LA + LV), LA size and compliance (LAP), instrument settings (Nyquist), and jet direction.

In acute severe MR, the large regurgitant orifice creates less turbulent flow, making CFD unreliable for assessing MR. With an eccentric MR jet, jet energy is lost (Coanda effect) and the qualitative severity should be upgraded by one level (e.g. moderate to severe).

### Vena Contracta (VC)
VC is the smallest, highest velocity region of jet flow located at or just downstream from the regurgitant orifice. It is a one-dimensional measure of an often non-circular orifice, the regurgitant orifice area (ROA), an independent measure of MR severity. It is evaluated perpendicular to the line of leaflet coaptation which is often in the ME AV LAX and 4C views. It is the diameter measured above the flow acceleration region at a Nyquist 50-60cm/s. VC > 0.6mm distinguishes mild/ moderate from moderate/severe MR. It is useful for eccentric but not multiple jets. VC size is relatively independent of flow rate and driving pressure for a fixed orifice and is less sensitive to hemodynamic variations, instrument settings, orifice geometry, and inter-individual interpretation.

### Proximal Isovelocity Surface Area (PISA) Radius
PISA method is derived from the hydrodynamic principle describing flow through a narrowed orifice (see below). The velocity of rbcs increase as they approach the smaller orifice, so that those with similar velocity form concentric hemispheric shells. The smaller shell has a higher isovelocity. The radius (r) is measured from the edge of the hemispheric shell where the color scale changes to the base of the shell at the plane of the leaflets. The color scale is adjusted (25-40cm/s) or the baseline shifted in the direction of the MR jet to create a nice hemispheric shell. Severe MR is present if the PISA radius > 10mm (Nyquist 40cm/s).

The PISA method can be used to calculate the EROA and the regurgitant volume as described below.
The PISA radius changes during systole depending on the underlying pathology: (A) Rheumatic has a constant radius, (B) MVP late systolic enhancement, and (C) Functional MR early and late peaks and mid-systolic decreases.

**Spectral Doppler**

CWD thru the MV leaflets in the ME views shows high velocity flow towards the transducer. The peak velocity occurs in early systole but does not indicate MR severity. CWD trace intensity is proportional to the MR amount; a denser spectral trace indicates greater MR severity.

Significant MR increases antegrade velocity from greater transmural volume flow. PW Doppler mitral inflow velocity of > 1.5m/s (↑ E wave, ↓ A wave) may indicate moderate to severe MR in the absence of mitral stenosis.

PW Doppler mitral to aortic VTI ratio is a strong additional easily measured parameter to quantify isolated pure organic MR. Mitral inflow Doppler tracings are obtained at the mitral leaflet tips and aortic flow at the annulus level. A VTI ratio 1.4 strongly suggests severe MR, whereas a VTI ratio 1 is in favor of mild MR.

**Pulmonary Venous Doppler (PVD)**

Finding a normal pattern (peak S to D wave ratio ≥ 1) accurately predicts mild MR, whereas a reversed pattern (peak S to D wave ratio < 0) is highly specific of severe MR. The blunted pattern (peak S to D wave ratio < 1) has low predictive value for moderate MR. Pulmonary venous waveform patterns are influenced by multiple factors including LV dysfunction, LA physiology, and direction of the MR jet. All pulmonary veins should be sampled as an eccentric jet may affect only specific right or left veins.

**Regurgitant Volume (RegVol) and Fraction (Reg F)**

Quantification of RegVol and RegF directly assesses MR severity. Both volumetric and EROA techniques can be used to determine the RegVol. The volumetric technique is time consuming as it requires calculation of stroke volume through the regurgitant and non-regurgitant valves. It is invalid in the presence of significant intra-cardiac shunts and more then mild regurgitation in the reference valve. This method has advantages over single frame measurements (PISA, VC) of being valid with eccentric or multiple jets and better assesses MR severity that occurs for the entire duration of systole.

<table>
<thead>
<tr>
<th>Mitral Regurgitant Volume (RegV)</th>
<th>Mitral Regurgitant Fraction (RegF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of blood that regurgitates thru an incompetent valve</td>
<td>Fraction of total stroke volume (SV) that regurgitates thru an incompetent valve</td>
</tr>
<tr>
<td>RegV (cc) = SV MV - SV AV (cc)</td>
<td>RegF (%) = ( \frac{SV_{MV} - SV_{AV}}{SV_{MV}} )</td>
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<tr>
<td>Normal</td>
<td>&lt; 30</td>
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<tr>
<td>Mild</td>
<td>30 - 45</td>
</tr>
<tr>
<td>Moderate</td>
<td>45 - 60</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt; 60</td>
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<tr>
<td>Pitfalls:</td>
<td></td>
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<tr>
<td>PW sample location: MV annulus/ LVOT</td>
<td></td>
</tr>
<tr>
<td>Diameter measurements: location, timing, error is squared</td>
<td></td>
</tr>
<tr>
<td>Arrhythmias: average 10 beats</td>
<td></td>
</tr>
<tr>
<td>SV MV</td>
<td>≥ 0.4cm²</td>
</tr>
<tr>
<td>SV AV</td>
<td>≥ 0.4cm²</td>
</tr>
<tr>
<td>CWD MR signal</td>
<td></td>
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</tbody>
</table>

**Effective Regurgitant Orifice Area (EROA)**

EROA is the gap in leaflet coaptation through which the regurgitant volume flows. EROA in MR is often dynamic varying in size during the cardiac cycle and changes significantly with load conditions. It is calculated using the continuity or PISA method. PISA uses the instantaneous peak flow rate and provides the maximal EROA which may be larger then EROA calculated by other methods. Size corresponds to MR severity: **EROA ≥ 0.4cm²** is severe MR.

**EROA (cm²) = RV (cc)/VTI MR signal (cm)**

- Calculate regurgitant volume: RegV = SV MV - SV AV
- Calculate peak regurgitant velocity (Vmr) of CWD jet
- CW MR signal
- Trace VTI regurgitant volume signal

**PIE Method**

EROApeak (cm²) = Flow mr (cc/s)/Vmr (cm/s)

- Optimize 2D image of MV orifice + zoom CFD of convergence region
- Shift color flow baseline upward to:
  - hemispheric shell
  - alias velocity (Va) 20-40cm/s
- Measure "r" from aliased region to orifice (cm)
- Measure peak regurgitant velocity (Vmr) of CW jet
- Calculate flow mr: Flow MR (cm³/sec) = 6.28r² x Va (cm/s) x a/180
- Calculate EROApeak: EROApeak (cm²) = Flow mr (cm³/sec) / Vmr (cm/s)
- Reg Vol = EROApeak (cm²) x VTI (cm)

**PIA for pinheads**

Flow = 2πr² x V x a/180

- 2πr² × V = EROA × peak Vmr
- EROA = 2πr² × V / peak Vmr

**PISA Limitations**

- Small error in measuring may lead to large error calculating ROA
- PISA is not always a hemisphere
  - flatter → overestimate
  - peaked → underestimate
- Less accurate in eccentric jets, not valid in multiple jets
- Flail leaflets have a funnel shaped convergence (<180°), overestimates ROA

**ROA**

- Orifice of regurgitant flow
- Variable shape:
  - circular (1°), ellipse (2°)
- Quantify MR
- Larger ROA, more Reg Vol
- Estimate ROA from PISA, continuity
- Severe MR ≥ 0.4cm²
### Summary

<table>
<thead>
<tr>
<th>MV Assessment</th>
<th>Method</th>
<th>Central</th>
<th>Eccentric</th>
<th>Multiple</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanism</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Jet Area Mapping (cm²)</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Jet Area (JA) / Left Atrial (LA) Area (%)</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>Vena Contracta (mm)</td>
<td>✓</td>
<td>±</td>
<td>x</td>
<td></td>
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<tr>
<td>PISA Radius (mm)</td>
<td>±</td>
<td>±</td>
<td>±</td>
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<tr>
<td><strong>Etiology</strong></td>
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<tr>
<td><strong>Severity</strong></td>
<td></td>
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<tr>
<td>1. Jet area (50-60cm/s)</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
<td></td>
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<tr>
<td>2. Vena Contracta (50-60cm/s)</td>
<td>✓</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>3. PISA radius (40cm/s)</td>
<td>✓</td>
<td>±</td>
<td>±</td>
<td></td>
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<tr>
<td>4. MR Spectral Doppler</td>
<td>±</td>
<td>±</td>
<td>±</td>
<td></td>
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<tr>
<td>5. MV inflow, AV outflow</td>
<td>±</td>
<td>±</td>
<td>±</td>
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<tr>
<td>6. Pulmonary vein Doppler</td>
<td>±</td>
<td>±</td>
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<tr>
<td>7. ROA</td>
<td>±</td>
<td>±</td>
<td>±</td>
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<tr>
<td>8. Regurgitant Volume</td>
<td>±</td>
<td>±</td>
<td>±</td>
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</tbody>
</table>

**Algorithm Approach to Diagnose Severe MR (from Ref 5)**

VCW, vena contracta width; MV, VCA, vena contracta area; 3D, 3-dimensional; EROA, effective regurgitant orifice area; PISA, proximal isovelocity surface area; RV, regurgitant volume; RF, regurgitant fraction; VC, vena contracta; CW, continuous-wave Doppler; LA, left atrium

**Suggested Readings**