Mitral Stenosis: Pathophysiology

- MVA <1.5 cm² before development of symptoms
- MVA >1.5 cm² will not typically produce symptoms at rest
  - Increase in transmural flow or decrease in diastolic filling period (ie: tachycardia) may increase LAP
  - Dyspnea may occur with exercise, emotional stress, infection, pregnancy, AFib with rapid ventricular rate
  - Pulmonary vascular disease
  - Increased pulmonary arterial resistance
  - Reversible pulmonary venous obstruction

The definition of "severe" MS is based on the severity at which symptoms occur as well as the severity at which intervention will improve symptoms. Thus, a mitral valve area ≤1.5 cm² is considered severe. Nishimura, RA et al, Circulation March 3, 2014

Stages of Mitral Stenosis

<table>
<thead>
<tr>
<th>Stage</th>
<th>Indication</th>
<th>Valve Anatomy</th>
<th>Valve Hemodynamics</th>
<th>Valve Operative</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>All forms of MS</td>
<td>Mild valve disease during diastole</td>
<td>Normal transmitral flow pressures</td>
<td>Planimetryed MVA &gt;1.5 cm²</td>
<td>None</td>
</tr>
<tr>
<td>B</td>
<td>Progressive MS</td>
<td>Mitral valve changes with commissural fusion and diastolic opening of the mitral valve leaflets</td>
<td>Increased forward flow due to left atrial hypertension</td>
<td>Planimetryed MVA ≤1.5 cm²</td>
<td>None</td>
</tr>
<tr>
<td>C</td>
<td>Absent severe MS</td>
<td>Mitral valve changes with commissural fusion and diastolic opening of the mitral valve leaflets</td>
<td>Increased left atrial pressure due to mitral valve obstruction</td>
<td>Planimetryed MVA ≤1.5 cm²</td>
<td>None</td>
</tr>
<tr>
<td>D</td>
<td>Symptomatic severe MS</td>
<td>Mitral valve changes with commissural fusion and diastolic opening of the mitral valve leaflets</td>
<td>Increased left atrial pressure due to mitral valve obstruction</td>
<td>Planimetryed MVA ≤1.5 cm²</td>
<td>None</td>
</tr>
</tbody>
</table>

Note: Very Severe MS is defined as MVA ≤1.0 cm² or PHT ≥220 ms

Nishimura, RA et al JAmCollCardiol 2014, Jun 10;63(22):2438-88

Rhahn Mitral Stenosis
**Rheumatic (commissural fusion)**

- Degenerative (mitral annular and leaflet calcification)

**Guidelines and Standards**

Echocardiographic Assessment of Valve Stenosis: EAE/ASE Recommendations for Clinical Practice

- Heart Rate
- Mitral Stenosis
- Mitral valve repair
- Mitral valve replacement

**Mitral Valve Score**

- Grade 1: Highly mobile valve with only leaflet tips restricted
- Grade 2: Minimal thickening just below the mitral leaflets
- Grade 3: Leaflets near normal in thickness (4–5 mm)
- Grade 4: Considerable thickening of all leaflet tissue (> 8–10 mm)

**Echo Score Index for Mitral Stenosis**

- Grade 1: Highly mobile valve with only leaflet tips restricted
- Grade 2: Minimal thickening just below the mitral leaflets
- Grade 3: Leaflets near normal in thickness (4–5 mm)
- Grade 4: Considerable thickening of all leaflet tissue (> 8–10 mm)

**ASE: Severity of Mitral Stenosis**

- Normal
- Mild
- Moderate
- Severe

**Data Element**

- **Recording**
  - 2D parasternal SAX
  - Apical windows
  - CW Doppler
  - Parasternal SAX

- **Measurement**
  - Contour of the inner mitral orifice
  - Valve thickness
  - Maximum velocity of TR
  - Commissural fusion

**Imaging Views**

- **Parasternal SAX**
  - Position of measurement can be oriented by 3D
  - Lowest gain to visualize whole orifice

- **Scan valve for smallest orifice**
  - Position of measurement can be oriented by 3D

- **Lowest gain to visualize whole orifice**
  - Position of measurement can be oriented by 3D

- **Contour of the inner mitral orifice**
  - Position of measurement can be oriented by 3D

- **Average measurements in atrial fibrillation**
  - Position of measurement can be oriented by 3D

**ASE: Diastolic PHT**

- Relevant not only on the degree of mitral obstruction but also the compliance of the left ventricle and the LA and other measures of mitral valve area, such as the continuity equation or the proximal isovelocity surface area, may be used if discrepancies exist.

**Echocardiogram**

- Reverse flow in the proximal isovelocity surface area
  - Diameter
  - Mitral orifice area
  - Effective orifice area

**New Value Definitions**

- Severe
  - PK/MN = 17/11 mmHg
  - MVOA = 1.0 cm²

**ASE: Mitral Valve Score**

- Grade 1: Highly mobile valve with only leaflet tips restricted
- Grade 2: Minimal thickening just below the mitral leaflets
- Grade 3: Leaflets near normal in thickness (4–5 mm)
- Grade 4: Considerable thickening of all leaflet tissue (> 8–10 mm)

**ASE: Diastolic PHT**

- Relevant not only on the degree of mitral obstruction but also the compliance of the left ventricle and the LA and other measures of mitral valve area, such as the continuity equation or the proximal isovelocity surface area, may be used if discrepancies exist.

**ASE: Mitral Valve Score**

- Grade 1: Highly mobile valve with only leaflet tips restricted
- Grade 2: Minimal thickening just below the mitral leaflets
- Grade 3: Leaflets near normal in thickness (4–5 mm)
- Grade 4: Considerable thickening of all leaflet tissue (> 8–10 mm)

**ASE: Diastolic PHT**

- Relevant not only on the degree of mitral obstruction but also the compliance of the left ventricle and the LA and other measures of mitral valve area, such as the continuity equation or the proximal isovelocity surface area, may be used if discrepancies exist.
Echocardiographic Score: Mitral Valve Regurgitation

<table>
<thead>
<tr>
<th>Grade</th>
<th>Subvalvular thickening</th>
<th>Leaflet thickening (score each leaflet separately)</th>
<th>Calcification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minimal thickening just below the mitral leaflets</td>
<td>Leaflets near normal in thickness (4–5 mm)</td>
<td>Fibrosis and/or calcium in only one commissure</td>
</tr>
<tr>
<td>2</td>
<td>Thickening of chordal structures extending up to 1/3 of the chordal length</td>
<td>Leaflets fibrotic and/or calcified evenly; no thin areas</td>
<td>Both commissures mildly affected</td>
</tr>
<tr>
<td>3</td>
<td>Thickening extending to the distal 1/3 of the chord</td>
<td>Leaflets fibrotic and/or calcified with uneven segments are mildly thickened (5-8 mm)</td>
<td>Calcium in both commissures, one markedly affected</td>
</tr>
<tr>
<td>4</td>
<td>Extensive thickening and shortening of all chordal structures extending down the papillary muscles</td>
<td>Leaflets fibrotic and/or calcified with uneven distribution; thinner segments are near normal (4-5 mm)</td>
<td>Calcium in both commissures, both markedly affected</td>
</tr>
</tbody>
</table>

Padia et al, JACC, 1996

The Echo Score Revisited
Impact of Incorporating Commissural Morphology and Leaflet Displacement to the Prediction of Outcome for Patients Undergoing Percutaneous Mitral Valvuloplasty

Maria Camo P. Nunes, MD, PhD; Timothy C. Tan, MD, PhD; Sunny Elmirah, MD, MPH; Rodrigo de Lago, MD; Ronan M. Mong, MD; Ignacio Cruz-Gonzalez, MD; Hui Zheng, PhD; Mark D. Handschumacher, BS; Ignacio Ingellis, MD; Igor F. Palacios, MD; Anthony E. Weyman, MD; Judy Hung, MD

- Novel quantitative parameters including
  - Ratio between the commissural areas
  - Maximal excursion of the leaflets from the annulus in diastole


Commissural Morphology

Echocardiographic parasternal short-axis view showing 2 traced areas to calculate the commissural area ratio.

Ratio of Commissural Areas: Asymmetry of commissural thickening was quantified by the ratio between the largest to the smallest area.

Note: Because the ratio between the areas was used and not absolute value, variation in receiver gain settings should have limited influence on the ratio.


Leaflet Displacement

- Apical displacement of the leaflets was measured in the apical 4-chamber view as the distance from the mitral annulus to the mid-portion of the leaflets at their point of maximal displacement from the annulus (doming height) in diastole


Prediction of PBMV Outcome

<table>
<thead>
<tr>
<th>Table 3. Score for Immediate Outcome Prediction*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>LV area c/1cm²</td>
</tr>
<tr>
<td>Maximum L/D c/2 mm</td>
</tr>
<tr>
<td>LA syst. L/D c/15</td>
</tr>
<tr>
<td>Subvalvular involvement</td>
</tr>
</tbody>
</table>

Three risk groups were defined:
- low (score of 0-3)
- intermediate (score of 4-5)
- high (score of 6-11)

Observed suboptimal PBMV results of 16.9%, 56.3%, and 73.8%.

Long-term outcome was predicted by age and post-procedural variables, including mitral regurgitation, mean gradient, and pulmonary pressure.


Level of recommendations: (1) appropriate in all patients (yellow); (2) reasonable in selected patients (green); and (3) not recommended (blue).

---

**Mitral Stenosis: Planimetry**

- **2D:** Planimetry of area in parasternal short-axis view
- **Feasible in 95% of patients**
- **Accuracy:**
  - **Underestimates** compared to surgical valve area (Henry et al, Circ 1975;51:827)
  - **Overestimates** compared to hemodynamic valve area (Weyman et al, AJC 1979;43:386)
- **Best correlation with direct anatomic measurement** (Faletra F et al. J Am Coll Cardiol 1996;28:1190-7)

- **Advantage:** relatively hemodynamic-independent assessment MVOA
- **Limitation:**
  - Difficulty measuring the smallest area of a funnel-shaped orifice
  - Align the LAX view with orifice perpendicular to the incision beam to assure alignment in SAX view
  - Simultaneous biplane imaging may be very helpful and can redirect the angle of the SAX view

**Tips to Accurate Planimetry**

- From the long-axis view measure the maximum dimension of anterior/posterior leaflet separation
- This measurement should be the same in the short-axis view and confirms you are not in the region of leaflet doming

**Use of Three-D Echo**

Planimetered MVA = 1.05 cm²


Median MVA of 3 classic measures: 2D planimetry, PHT and PISA
Pressure Half-time Calculation

- Pressure half-time reflects the rate at which left atrial and ventricular pressures move toward equilibrium in diastole.
- PHT (or \(Pt_{1/2}\)) is the time interval for the peak pressure gradient to reach half its value or for the velocity to reach \(1/\sqrt{2}\) of it value

\[
Pt_{1/2} = \frac{1}{2} \frac{P_{\text{max}}}{4 \times (V_{t1/2})^2} = \frac{1}{2} \left[ \frac{4 \times V_{\max}}{v} \right]
\]

\[
(V_{t1/2})^2 = \frac{1}{2} (V_{\max})^2
\]

\[V_{t1/2} = \frac{V_{\max}}{\sqrt{2}} = \frac{1}{\sqrt{2}} \times V_{\max} \times 0.71
\]

\[PHT = 0.293 \times \text{Deceleration Time}
\]

Hatle et al (Br Heart J 1978;40:131) related the PHT to mitral area using an empiric equation:

Mitral Valve Area = \(\frac{220}{\text{PHT}} = 750/\text{DT}\)

Note: constant of 220 msec is proportional to net compliance (of LV and LA) and the square root of maximum transmitral gradient and does NOT take into account active relaxation of the LV

Nonlinear Decay Slope

- PHT is dependent upon the initial (peak) velocity (or pressure gradient):
- Nonlinear decay may underestimates PHT (overestimates valve area) if the peak velocity is used

Correct PHT:
1. Use dominant (longer) slope
2. Extrapolate back to initial flow profile

Gonzalez MA, et al. Am J Cardiol 1987;60:327-32

Pitfalls of PHT Calculation

- Pressure half-time reflects the rate at which left atrial and ventricular pressures move toward equilibrium in diastole.
- PHT will be shortened if:
  - Left ventricular diastolic pressure rises faster than expected based on valve area alone
  - Aortic regurgitation
  - Noncompliant ventricle
  - Left atrial pressures fall faster than expected
  - ASD (i.e. post-valvulotomy)
  - Noncompliant left atrium (chronic atrial fibrillation)
- PHT will be lengthened if:
  - Left ventricular diastolic pressure rises slower than expected based on valve area alone
  - Abnormal LV relaxation (note: peak velocities usually low)

PHT Pitfalls: AR and ASD

LV diastolic pressures rise faster due to filling across both the mitral and aortic valves.
Pressure halftime shorter

LA pressures fall faster due to emptying across both the mitral valve and ASD.
Pressure halftime shorter
**Pitfalls of PHT Calculation**

- **PHT (and planimetered MVA) may not be “flow-independent”**

- **PHT is also dependent upon**
  - Initial LA pressure (MV opening pressure)
  - Higher with MR
  - Higher with prosthetic valves
  - Higher with worsening diastolic function

**Reported Limitations of PHT in Literature**

- **Severe MR**

- **Aortic regurgitation**

- **Nonlinear Doppler velocity curves**
  - Gonzalez MA, et al Am J Cardiol 1987;60:327-32

- **Pregnancy**

**Pitfalls of Peak and Mean Gradients**

- **High gradient with large MVA**
  - High forward output
    - Hyperdynamic LV with high output: anemia, exercise
    - Significant mitral regurgitation
    - Tachycardia: shortened diastolic filling period
    - Subvalvular obstruction (chordal calcification)
  - Low gradient with small MVA
    - Low forward output (Low stroke volume index < 35 cc/m²)
    - Reduced LV function with low cardiac output
    - Increased LV diastolic pressures (dysfunction, AR)
    - Low LA pressure (ie: with bradycardia)

**Conservation of Mass: Continuity Equation**

\[ \text{Mitral Valve Area} = \frac{\text{LVOT} \times \text{LVOT VTI}}{\text{LV} \times \text{MVOA}} \]

**Peak and Mean Gradients**

- **Peak and mean gradients correlate well with cath pressures in each chamber**
  - LV diastolic pressures
    - High LVDP will lower gradient
  - Left atrial filling pressures
    - Low LAP lowers gradients
  - High LAP raises gradients
  - Pressure gradient depends on heart rate and cardiac output
    - Shorter diastolic filling period, higher LA filling pressures
      - Tachycardia: increased stroke volume may increase gradient

**Atrial fibrillation:**
- Average multiple beats, avoid short diastoles

**Post-PBMV**
- Atrial fibrillation:
  - Tachycardia

**Peak and Mean Gradients**

- Peak and mean gradients correlate well with cath pressures in each chamber
  - LV diastolic pressures
    - High LVDP will lower gradient
  - Left atrial filling pressures
    - Low LAP lowers gradients
  - High LAP raises gradients
  - Pressure gradient depends on heart rate and cardiac output
    - Shorter diastolic filling period, higher LA filling pressures
      - Tachycardia: increased stroke volume may increase gradient

**Tachycardia**

Always report HEART RATE when assessing mitral valve stenosis
Case Study

- 80 year old woman, S/P open mitral commissurotomy 39 years ago, now presents with progressive DOE with mild exertion
  - BP = 124/56 mmHg
  - HR = 80-90 bpm (atrial fibrillation)
  - BSA = 1.65 cm²

Case: Assess LA, LV, MV

- Peak/mean gradient = 16/6 mmHg
- MV VTI = 41.5 cm
- Pressure Halftime = 133 msec

Case: 2D Mitral Assessment

- Look at orientation of opening
- Will you get a good SAX view from this window (Use 3D!)
- Measure the maximum tip separation
- Match to parasternal dimension in mid-diastole

Case: Multiplanar Reconstruction

- MVOA = 1.03 cm²

Case: LV Stroke Volume

- LVOT Diam = 18.5 cm
- LVOT VTI = 17.5 cm
- LVOT Stroke Volume = 47 cc
Case: RVOT Stroke Volume

- RVOT = 2.3 cm
- RVOT = 2.1 cm
- RVOT area = 3.79 cm²
- RVOT SV = 47 cc

Conservation of Mass: Continuity Equation

\[ \text{LVOT Diam} = 1.85 \text{ cm} \]
\[ \text{LVOT VTI} = 17.5 \text{ cm} \]
\[ \text{X} = \text{Mitral Valve Area} \]
\[ \text{X} = \text{Mitral Valve Stroke Volume} \]

Case: Tricuspid Regurgitation

- PASP = 44 mmHg
- Mean PAP = 30 mmHg

Case Hemodynamic Summary

- **Gradients**
  - Peak = 16 mmHg
  - Mean = 5 mmHg

- **PHT**
  - PHT = 133 msec
  - MVOA = 1.65 cm²

- **Planimetry**
  - 2D = 0.98 cm²
  - 3D = 1.0-1.06 cm²

- **Continuity equation**
  - LVOT stroke volume = 47 cc (mild AR)
  - RVOT stroke volume = 46.6 cc (trace PR)
  - MV CW VTI = 42.5 cm
  - MVOA = 1.1 cm²

- **Mitral Valve Area**

<table>
<thead>
<tr>
<th>Case</th>
<th>Severity MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient</td>
<td>14/6 mmHg</td>
</tr>
<tr>
<td>PHT</td>
<td>1.65 cm²</td>
</tr>
<tr>
<td>Planimetry 2D</td>
<td>1.0 cm²</td>
</tr>
<tr>
<td>Planimetry 3D</td>
<td>1.0 cm³</td>
</tr>
<tr>
<td>Cont. Eq.</td>
<td>1.1 cm³</td>
</tr>
</tbody>
</table>

- **Why did Gradients Fail?**
- **Why did PHT Fail?**

Pitfalls of PHT Calculation

- Pressure half-time reflects the rate at which left atrial and ventricular pressures move toward equilibrium in diastole.
  - **PHT will be shortened if**
    - Left ventricular diastolic pressure rises faster than expected based on valve area alone
    - Aortic regurgitation
    - Noncompliant ventricle
    - ASD (post-valvulotomy)
    - Noncompliant left atrium (chronic atrial fibrillation)
  - **PHT will be lengthened if**
    - Left ventricular diastolic pressure rises slower than expected based on valve area alone
    - Abnormal LV relaxation (note: peak velocities usually low)
**Low Stroke Volume**

- LVOT stroke volume = 47 cc (mild AR)
- RVOT stroke volume = 46.6 cc (trace PR)

**LOW STROKE VOLUME:**
- SV index = 47cc/1.65 m² = 28.5 cc/m²

**Right Ventricular Systolic Pressure**

- Tricuspid Regurgitation
  - RVSP = [(VelocityTR)² x 4] + RA pressure

**Pulmonary Artery Diastolic Pressure**

- Pulmonic Regurgitation
  - PADP = [(VelocityPte)² x 4] + RAP
  - Mean PAP = [(VelocityPp)² x 4] + RAP

**Proximal Isovelocity Surface Area: Another Continuity Equation**

\[ MVOA = \frac{2\pi r^2 \times \text{Alias Velocity}}{\text{MV Peak Velocity} \times \frac{9}{180°}} \]

**Mitral Stenosis: PISA**

- Transthoracic Echo: Aliasing Vel = 0.56 m/s
- Transesophageal Echo: Aliasing Vel = 0.41 m/s

CAVEAT: Angle correction may not be required if higher aliasing velocities makes the PISA small enough not to be restricted by the leaflets.

**PISA during TEE**

MOVA by PHT = 1.88 cm² with mean gradient = 20 mmHg (heart rate 96 bpm)

MVOA by PISA = 0.51 cm²
**Case: Mitral Valve Area by PISA**

\[
MVOA = \frac{2\pi r^2 \times \text{velocity}}{\text{Peak MV Velocity}} \times \frac{\alpha}{180°} \\
= \frac{6.282 \times (1.25)^2 \times 43 \text{ cm/s}}{195 \text{ cm/s}} \times \frac{90°}{180°} \\
= 1.08 \text{ cm}^2
\]

Angle correction essential if PISA appears restricted by the leaflets.

**PISA for MVA in Mitral Stenosis**

<table>
<thead>
<tr>
<th>Method</th>
<th>Total population</th>
<th>AF</th>
<th>ATR</th>
<th>Willius score &gt;8</th>
<th>Associated MR</th>
<th>No MR</th>
<th>Associated AR</th>
<th>No AR</th>
<th>Commissural calcification</th>
<th>Without commissural calcification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planimetry</td>
<td>108</td>
<td>0.03</td>
<td>0.97</td>
<td>0.04</td>
<td>0.21</td>
<td>0.19</td>
<td>1.23</td>
<td>0.19</td>
<td>0.28</td>
<td>0.28</td>
</tr>
<tr>
<td>PHT</td>
<td>64</td>
<td>0.03</td>
<td>0.97</td>
<td>0.03</td>
<td>0.11</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>CE</td>
<td>64</td>
<td>0.03</td>
<td>0.97</td>
<td>0.03</td>
<td>0.11</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
</tbody>
</table>

*Technically challenging and not recommended for routine use*


**In MS, the high temporal resolution of color M-mode PISA allows accurate MVA measurements.**

- MVA remained unchanged throughout diastole underscoring the lack of flow-related valvular reserve in MS.
- A trend towards underestimation of MVA by 2D-PISA was observed (1.23–0.42 cm²).

*PISA for MVA in mitral stenosis is valid in multiple clinical settings including the presence of AR and MR*

**Additional Information: Vena Contracta**

- Vena contracta in the 4Ch view of < 1.0 cm
  - sensitivity of 88% and a specificity of 77% for severe MS (compared to planimetry, PHT, and CE).

**Echo Score Index for Mitral Stenosis**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Mobility</th>
<th>Subvalvular Thickening</th>
<th>Leaflet Thickening</th>
<th>Calcification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Highly mobile valve with only leaflet tips restricted</td>
<td>Minimal thickening just below the mitral leaflets</td>
<td>Leaflets near normal in thickness (4 – 5 mm)</td>
<td>A single area of echo brightness</td>
</tr>
<tr>
<td>2</td>
<td>Leaflet mid and base portions have normal mobility</td>
<td>Thicking of chordal structures extending up to 1/3 of the chordal length</td>
<td>Mid-leaflet normal, considerable thickening of margins (5 – 8 mm)</td>
<td>Scattered areas of brightness confined to leaflet margins</td>
</tr>
<tr>
<td>3</td>
<td>Valve continues to move forward in diastole, mainly from the base</td>
<td>Thicking extending to the distal 1/3 of the chords</td>
<td>Thicking extending the entire length of the leaflet (5-8 mm)</td>
<td>Brightness extending into the midportion of the leaflets</td>
</tr>
<tr>
<td>4</td>
<td>No or minimal forward movement of the leaflets in diastole</td>
<td>Extensive thickening and shortening of all chordal structures extending down the papillary muscles</td>
<td>Considerable thickening of all leaflet tissue (6 – 10 mm)</td>
<td>Extensive brightness throughout much of the leaflet tissue</td>
</tr>
</tbody>
</table>

Abascal VM et al, JACC 1988;12:606-615

**Echocardiographic Score: Mitral Valve Regurgitation**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Subvalvular Thickening</th>
<th>Leaflet Thickening</th>
<th>Calcification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minimal thickening just below the mitral leaflets</td>
<td>Leaflets near normal in thickness (4 – 5 mm)</td>
<td>Fibrosis and/or calcium in only one commissure</td>
</tr>
<tr>
<td>2</td>
<td>Thickening of chordal structures extending up to 1/3 of the chordal length</td>
<td>Leaflets fibrotic and/or calcified, no thin areas</td>
<td>Both commissures mildly affected</td>
</tr>
<tr>
<td>3</td>
<td>Thickening extending to the distal 1/3 of the chords</td>
<td>Leaflets fibrotic and/or calcified with uneven distribution; thinner segments are mildly thickened (5.5 mm)</td>
<td>Calcium in both commissures, one markedly affected</td>
</tr>
<tr>
<td>4</td>
<td>Extensive thickening and shortening of all chordal structures extending down the papillary muscles</td>
<td>Leaflets fibrotic and/or calcified with uneven distribution; thinner segments are near normal (4.5 mm)</td>
<td>Calcium in both commissures, both markedly affected</td>
</tr>
</tbody>
</table>

Padia et al, JACC, 1996

**What would you recommend?**

A. Surgery (STS score ~8)
B. Balloon Mitral Valvuloplasty
C. Medical therapy since this is mild MS
D. Stress Echo to further assess severity of valvular disease

**Stress Testing in Mitral Stenosis**

Stress Testing for Valvular Heart Disease

- Symptom response
- PA pressures
- Clinical Decision-making
- BP and EKG response
- Ventricular response
- Valvular Hemodynamics
Exercise Testing: Recommendation

- **CLASS IIa**
  - Exercise testing is reasonable in selected patients with asymptomatic severe VHD to:
    1. confirm the absence of symptoms, or
    2. assess the hemodynamic response to exercise, or
    3. determine prognosis.

    *(Level of Evidence: B)*

Nishimura, RA et al. J Am Coll Cardiol. 2014 Jun 10;63(22):2438-88

Diagnosis Testing MS

- **CLASS I**
  - 1. TTE is indicated in patients with signs or symptoms of MS to establish the diagnosis, quantify hemodynamic severity (mean pressure gradient, mitral valve area, and pulmonary artery pressure), assess concomitant valvular lesions, and demonstrate valve morphology (to determine suitability for mitral commissurotomy) (8, 143, 288-295). *(Level of Evidence: B)*
  - 2. TEE should be performed in patients considered for percutaneous mitral balloon commissurotomy to assess the presence or absence of left atrial thrombus and to further evaluate the severity of MR (289, 296-298). *(Level of Evidence: B)*
  - Exercise testing with Doppler or invasive hemodynamic assessment is recommended to evaluate the response of the mean mitral gradient and pulmonary artery pressure in patients with MS when there is a discrepancy between resting Doppler echocardiographic findings and clinical symptoms or signs. *(Level of Evidence: C)*

Nishimura, RA et al. J Am Coll Cardiol. 2014 Jun 10;63(22):2438-88

Valve Stress Echocardiography

A Practical Guide for Referral, Procedure, Reporting, and Clinical Implementation of Results From the HAVEC Group

Garbi, M et al. J Am Coll Cardiol Img. 2015;8:724–36

Symptomatic Patients with Non-severe Valve Disease

- **Non-severe regurgitation (MR and AR)**
  - Assess increase in regurgitation, ≥SPAP ↑>50 mmHg, EF ↑<4%

- **Non-severe MS**
  - ↑Mean grad ≥15 mmHg (ex) or >18 mmHg (DSE), ≥SPAP ↑>60 mmHg
  - Assess peak/mean gradient increase and change in valve area

- **Non-severe AS or paradoxical low-flow AS**
  - Assess gradient and valve area change

- **Equivocal PPM (AVR or MVR)**

Asymptomatic Patients with Severe Valve Disease

- **Severe MR**
  - Assess symptoms and ex-tolerance, ≥SPAP ↑>50 mmHg, EF ↑<4%, ≥GLS ↑<2%

- **Severe MS**
  - Assess symptoms and ex-tolerance, ≥Mean grad ≥15 mmHg, ≥SPAP ↑>60 mmHg

- **Severe AR**
  - Assess symptoms and ex-tolerance and contractile reserve

- **Severe AS**
  - Assess symptoms and ex-tolerance, ≥SBP ↓<20 mmHg, ST depression, RVMA, contractile reserve, GLS, SPAP ↑>60 mmHg, ↑mean gradient ≥18-20 mmHg

- **Low Flow AS (low EF)**
  - Flow reserve, gradient, valve area
**Choice of Stress**

- **Treadmill stress**
  - Higher maximum heart rate
  - Functional aerobic capacity well-defined
- **Bicycle stress**
  - Higher blood pressure
  - Allows continuous imaging and Doppler assessment, including peak stress
- **Pharmacologic Stress**
  - Dobutamine better than vasodilators for wall motion assessment with good HR response (but lower BP)
  - Allows continuous imaging throughout stress
  - Numerous relative contraindications
    - Never use in setting of hypertrophic obstructive cardiomyopathy

**Considerations: Exercise Stress Testing in MS**

- Guidelines do not include indexed valve areas
  - “Moderate MS” may be hemodynamically severe in larger patients
- Gradient thresholds for severe MS have been established as
  - $>15$ mm Hg on exertion or $>18$ mm Hg during dobutamine infusion
  - $\text{SPAP} > 60$ mm Hg on exertion

---

**Case 2**

- 50 year old woman with history of asthma and rheumatic fever who presents with exertional dyspnea (Class III NYHA)
- **MOVA by PHT = 4.6 cm$^2$**
- Mean gradient = 10 mmHg
- TR = 2.5 m/s

**Case**

- Mean gradient = 25 mmHg
- TR = 3.8 m/s
- Gradient = 58 mmHg (assumed RAP = 20 mmHg)
Calculation of mitral valve area by Doppler methods is controversial
- Reliability of PHT calculation questionable
- Mean transmitial gradients and peak tricuspid regurgitant velocities are reliable
- Patient's symptoms reliable

Exercise-induced pulmonary hypertension (>60-70 mmHg) warrants close follow-up

Nishimura, RA et al. J Am Coll Cardiol 2014 Jun 10;63(22):2438-88

Which of the following parameters for assessing the severity of mitral stenosis is appropriate in all patients and correlates best with anatomic valve area?
1. Continuity equation
2. Planimetry
3. Proximal isovelocity surface area
4. Mean transmitial gradient with exercise

Approaches to Evaluating MS

Planimetry using 2D echocardiography of the mitral orifice has the advantage of being a direct measurement of mitral valve area and, unlike other methods, does not involve any hypothesis regarding flow conditions, cardiac chamber compliance, or associated valvular lesions.

Planimetry has been shown to have the best correlation with anatomic valve area as assessed on explanted valves. For these reasons, planimetry is considered as the reference measurement of mitral valve area.

Baumgartner H et al. JASE 2009;22(1):1-23

Mitral valve area calculations

Mitrval Annulus Calcification

- Mitral annulus calcification (MAC) is a chronic, degenerative process in the fibrous base of the mitral valve
- Mechanisms, such as atherosclerosis and abnormal calcium-phosphorus metabolism, also contribute to the development of MAC
- MAC is associated with an increased incidence of cardiovascular disease, mitral valve disease, arrhythmias, and mortality.


Commissural Fusion

Degenerative (mitral annular and leaflet calcification)
Echocardiographic Grading of MAC

- **Long-Axis Grading**
  - Maximal MAC thickness measured from the anterior to the posterior edge at its greatest width
  - >4 mm defining severe MAC
- **Short-axis Grading**
  - Mild (focal, limited increase in echodensity of the mitral annulus)
  - Moderate (marked echodensity involving one-third to one-half of the ring circumference)
  - Severe (marked echodensity involving more than one-half of the circumference of the ring or with intrusion into the LV inflow tract)

Cardiac CT

- Cardiac CT is a useful tool to predict the extent and location of MAC and to quantify MAC objectively in order to assess the severity and associations of this entity.

Association of MAC with MR and MS

<table>
<thead>
<tr>
<th>MAC and MR</th>
<th>MAC and MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC is more coming in patients with MR (11.7%) versus without MR (4.3%)</td>
<td></td>
</tr>
<tr>
<td>Mechanisms: calcium infiltration of the base of the posterior leaflet reduces leaflet mobility, increases traction on the chordae, and elevates the leaflets, failure of the calcified annulus to contract</td>
<td></td>
</tr>
<tr>
<td>Severe MAC could produce a significant resting gradient across the mitral valve, thus causing mitral stenosis</td>
<td></td>
</tr>
<tr>
<td>This process was seen in approximately 0.3% of unselected outpatient echocardiograms</td>
<td></td>
</tr>
<tr>
<td>Linked to restriction of anterior mitral leaflet motion, such that the leaflet's hinge becomes displaced toward its free margin</td>
<td></td>
</tr>
</tbody>
</table>

Risk of MV Surgery with MAC

<table>
<thead>
<tr>
<th>MAC and MR</th>
<th>MAC and MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is a contributing factor in cardiac rupture at the atrioventricular junction, in rupture of the LV free wall, and in injury to the circumflex artery when debridement of MAC is performed</td>
<td></td>
</tr>
<tr>
<td>Surgical Techniques:</td>
<td></td>
</tr>
<tr>
<td>Mitral valve replacement without annular calcium debridement, securing the prosthetic valve inside the calcified annulus</td>
<td></td>
</tr>
<tr>
<td>Mitral valve edge-to-edge repair without annulus reconstruction</td>
<td></td>
</tr>
<tr>
<td>Complete decalcification and reconstruction of the mitral annulus using methods that have evolved from the treatment of annular abscesses</td>
<td></td>
</tr>
</tbody>
</table>

Peak gradient = 64 mmHg
Mean gradient = 40 mmHg
LV Stroke volume = 45 cc
**Rhahn Mitral Stenosis**

**Case 1**
- LV Stroke volume = 45 cc
- Peak / Mean gradient = 12/6 mmHg
- MVOA = 1.3 cm²

Answer: there is BOTH severe AS and severe MS

**Could the small valve area be the consequence of a low stroke volume?**

**Options for Treatment**
- Percutaneous Balloon Mitral Valvuloplasty
- Open MVR
- Transcatheter MVR

**Percutaneous Balloon Valvuloplasty**
- Independent predictors of event free survival (events defined as all cause mortality, repeat balloon commissurotomy of mitral valve replacement)
  - Older age
  - Higher calcium grade
  - Greater severity of MS
  - Calcium grade predicted less favorable results (higher residual LA pressure, smaller MVOA) and recurrent stenosis

 Patients with calcified mitral valve and high echo score ≥ 10 who had suboptimal commissurotomy results, had an event rate of 75% at 2.5 years.

**Case**
- 50 y/o Female
- PMH:
  - HTN, HL, Hypothyroidism, bio AVR #21 2009 in the setting of Severe Aortic Stenosis, Hx of multiple PNEAs, Retinal artery occlusion 2009 on Coumadin, childhood Ovarian cancer s/p oophorectomy, chemotherapy and radiation (including mediastinum) in remission, Porcelain Ao, Lung disease secondary to Bleomycin and Radiotherapy s/p recent multiple pneumonias.
  - Symptoms: DOE NYHA III
  - Ht= 160 cm  Wt= 68.8 Kg  BMI= 26.8
  - BNP= 1021 pg/ml  Cr= 1
  - STS score: 3.27% for mitral replacement

**Case 2**

<table>
<thead>
<tr>
<th>Echo Variable (TTE)</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak MVG (mmHg)</td>
<td>20.3</td>
</tr>
<tr>
<td>Mean MVG (mmHg)</td>
<td>10.5</td>
</tr>
<tr>
<td>Severity of MR</td>
<td>Mod</td>
</tr>
<tr>
<td>Severity of AR</td>
<td>Trace</td>
</tr>
<tr>
<td>Ejection Fraction</td>
<td>70-75</td>
</tr>
<tr>
<td>PASP (mmHg)</td>
<td>52.7</td>
</tr>
<tr>
<td>Severity of TR</td>
<td>Moderate-Severe</td>
</tr>
</tbody>
</table>

**TEE Variable | Measure |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak MVG (mmHg)</td>
<td>25.2</td>
</tr>
<tr>
<td>Mean MVG (mmHg)</td>
<td>11.4</td>
</tr>
<tr>
<td>MVA by continuity (cm²)</td>
<td>0.92</td>
</tr>
<tr>
<td>Severity of MR</td>
<td>Moderate</td>
</tr>
<tr>
<td>Annulus Max diameter (mm)</td>
<td>ND</td>
</tr>
<tr>
<td>Annulus Min diameter (mm)</td>
<td>ND</td>
</tr>
<tr>
<td>TEE annulus area (mm²)</td>
<td>ND</td>
</tr>
<tr>
<td>LAA thrombus (Yes/No)</td>
<td>No</td>
</tr>
</tbody>
</table>

**MVOA by Planimetry = 1.1 cm²**
A recent small case series suggested that percutaneous mitral repair with the MitraClip in the setting of severe MAC is feasible, safe, and acceptably effective.

Multiple reports of successful transcatheter valve (SAPIEN XT) implant in a native mitral valve via a surgical transapical approach.

Mean gradient across the mitral prosthesis was 7 mm Hg.

64 patients from 32 centers in 11 countries (Sept 2012-July 2015)
Mean follow-up 5 months (1 to 34 months)
Procedural Outcomes

<table>
<thead>
<tr>
<th>Outcome</th>
<th>by MVARC criteria</th>
<th>Technical success</th>
<th>Need for second valve</th>
<th>LVOT obstruction with hemodynamic compromise</th>
<th>Valve embolization</th>
<th>Conversion to open surgery (embolization=2, LV perforation=1, LVOTO=1)</th>
<th>Pulmonary vein perforation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>47 (73.4%)</td>
<td>10 (15.6%)</td>
<td>5 (7.8%)</td>
<td>4 (6.25%)</td>
<td>4 (6.25%)</td>
<td>1 (1.56%)</td>
</tr>
</tbody>
</table>

Guerrero M et al, TCT 2015

30 Day/Procedural Mortality

<table>
<thead>
<tr>
<th>Outcome</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiovascular</td>
<td>8/64 (12.5%)</td>
</tr>
<tr>
<td>LVOT Obstruction</td>
<td>2 (3.2%)</td>
</tr>
<tr>
<td>LV Perforation</td>
<td>2 (3.2%)</td>
</tr>
<tr>
<td>Complete AV block</td>
<td>1 (1.56%)</td>
</tr>
<tr>
<td>MI due to air emboli / Pulmonary vein perforation</td>
<td>1 (1.56%)</td>
</tr>
<tr>
<td>Stroke</td>
<td>2 (3.1%)</td>
</tr>
<tr>
<td>Non-Cardiac</td>
<td>11/64 (17.2%)</td>
</tr>
<tr>
<td>Multi-organ failure</td>
<td>5 (7.8%)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>3 (4.6%)</td>
</tr>
<tr>
<td>Thoracentesis related bleeding complication</td>
<td>1 (1.56%)</td>
</tr>
<tr>
<td>Infection</td>
<td>2 (3.1%)</td>
</tr>
</tbody>
</table>

Guerrero M et al, TCT 2015

Clinical Outcomes relative to experience

<table>
<thead>
<tr>
<th>Outcome</th>
<th>First Half (n=32) n (%)</th>
<th>Second Half (n=32) n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical success *</td>
<td>20 (62.5%)</td>
<td>27 (84.4%)</td>
</tr>
<tr>
<td>30 Day Mortality</td>
<td>12 (37.5%)</td>
<td>7 (21.9%)</td>
</tr>
<tr>
<td>Complications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valve Embolization</td>
<td>3 (9.3%)</td>
<td>1 (3.1%)</td>
</tr>
<tr>
<td>LVOTO</td>
<td>4 (12.5%)</td>
<td>2 (6.2%)</td>
</tr>
<tr>
<td>Need for a second valve</td>
<td>7 (21.9%)</td>
<td>3 (9.3%)</td>
</tr>
<tr>
<td>Cardiac Perforation</td>
<td>2 (6.25%)</td>
<td>0</td>
</tr>
<tr>
<td>Conversion to open surgery</td>
<td>4 (12.5%)</td>
<td>0</td>
</tr>
</tbody>
</table>

Guerrero M et al, TCT 2015

Mean Mitral Valve Gradients

NYHA Class

Guerrero M et al, TCT 2015

Case 2

Annulus by CT (Date)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Diameter (mm)</td>
<td>18.6</td>
</tr>
<tr>
<td>Max Diameter (mm)</td>
<td>33.6</td>
</tr>
<tr>
<td>Annular Area (mm²)</td>
<td>571.7</td>
</tr>
</tbody>
</table>

Comment:

LVOT Analysis

<table>
<thead>
<tr>
<th>Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aorto-Mitral Angle</td>
<td>213</td>
</tr>
<tr>
<td>% Obstruction at 60°40</td>
<td>64%</td>
</tr>
</tbody>
</table>

Anything above 60% is high risk for LVOT obstruction

Case 2: Open Transcatheter Valve in MAC

High Risk LVOT Obstruction

Peak/mean Gradient 20/10 mmHg
PHT = 300 msec
Peak/Mean Gradients = 10 and 4 mmHg
No LVOT Obstruction

Caveats
- The severity of MS should not be defined by a single value but rather be assessed by a multi-parametric approach
  - Mitral valve area by planimetry and PHT (CE and PISA in some cases)
  - Mean Doppler gradients
  - Pulmonary pressures
  - Stress testing in select cases

Caveats
- The timing and choice of interventions is in evolution with transcatheter solutions
  - Percutaneous balloon mitral valvuloplasty in rheumatic disease
  - Transcatheter mitral valve replacement for degenerative disease
  - Aortic THVs in Mitral Annular Calcium
  - Transcatheter Mitral Valve Replacement

THANK YOU!