Assessment of valvular stenosis severity

- Peak velocity / peak gradient
- Mean gradient
  - (rest / exercise / dobutamine)
- Valve area
  - planimetry (MS, AS)
  - continuity equation (AS)
  - pressure half-time (MS)
- Indirect signs
  - LVH (AS), RVH (PS)
  - PAP (MS), RVP (PS)
Assessment of Valvular Stenosis Severity

CW Doppler: Measurement of transvalvular velocity

Calculation of peak gradient

\[ \Delta P_{\text{peak}} = 4v^2 \]

Calculation of mean gradient

\[ \Delta P_{\text{mean}} = \frac{\sum 4v^2}{N} \]

Sources of Error

(1) Underestimation of Catheter Gradient:

- Inappropriate recording angle
- Poor signal quality
- Recording “wrong vel.” (LVOT)
- Lack of technical expertise or appropriate equipment

Try all approaches!
Right parasternal!
Suprasternal!
Doppler Assessment of Transvalvular Gradient

Sources of Error

(2) Overestimation of Catheter Gradient:

- Failure to account for an increased subvalvular velocity

Gradient Calculation by CW-Doppler

**BERNOULLI EQUATION**

\[
p_1 - p_2 = \frac{1}{2} \rho \left( \frac{v_2^2 - v_1^2}{v_1^2} \right) + \mu \frac{d^2v}{dt^2} + R \left( \mu v \right)
\]

- Convective acceleration
- Flow acceleration
- Viscous friction

\[
\Delta p = \frac{1}{2} \rho \left( \frac{v_2^2 - v_1^2}{v_1^2} \right)
\]

\[
\Delta p = 4 \left( \frac{v_2^2}{v_1} \right) 
\]

\[
\Delta p = 4v_2^2 
\]

Subv. velocity

(V1; subv. velocity (LVOT) = 1m/s)
Doppler Assessment of Transvalvular Gradient

Sources of Error

(2) Overestimation of Catheter Gradient:
- Failure to account for an increased subvalvular velocity
- Inappropriate comparison of different gradients
- Recording the wrong velocity (f.e. mitral regurgitation / aortic stenosis)

Recording the Wrong Signal
(Aortic Stenosis - Mitral Regurgitation)

Different shape and timing!
Doppler Assessment of Transvalvular Gradient

Sources of Error

(2) Overestimation of Catheter Gradient:

- Failure to account for an increased subvalvular velocity
- Inappropriate comparison of different gradients
- Recording the wrong velocity (e.g., mitral regurgitation / aortic stenosis)
- Nonrepresentative selection of velocity recording (arrhythmias - tendency to select highest velocities)
- Pressure recovery

Pressure Recovery

Pressure recovery in aortic stenosis

\[ p_3 - p_2 = \frac{1}{2} \rho v^2 \cdot 2AVA/AoA \cdot (1 - AVA/AoA) \]

Aortic Stenosis: Doppler and Corrected Doppler Gradients vs. Catheter Gradients

[Baumgartner H et al (Circulation 1994;90:I-276)]
Pressure recovery in aortic stenosis
Impact of the size of the ascending aorta

Assessment of Stenosis Severity
PLANIMETRY OF VALVE AREA (AS)

Baumgartner H et al (Circulation 1994;90:I-276)

Flow Dependence of Transvalvular Gradient

Assumptions:
Ht = 88 b/min
SEP = 0.32 sec

Grossman W. Cardiac Catheterization and Angiography
Aortic Valve Area Calculation

CONTINUITY EQUATION

\[ A_2 = \frac{A_1 \cdot V_1}{V_2} \]
Approaches to evaluation of mitral stenosis

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Units</th>
<th>Invasive</th>
<th>Noninvasive</th>
<th>Concept</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimation of mitral orifice area</td>
<td>m²</td>
<td>Yes</td>
<td>No</td>
<td>Estimated using Doppler echocardiography</td>
<td>Simple, non-invasive method</td>
<td>Requires accurate measurement of valve area</td>
</tr>
<tr>
<td>Leaflet thickness</td>
<td>mm</td>
<td>Yes</td>
<td>No</td>
<td>Measured using echocardiography</td>
<td>High accuracy</td>
<td>Requires specialized equipment</td>
</tr>
<tr>
<td>Relative valve area</td>
<td>m²</td>
<td>Yes</td>
<td>No</td>
<td>Calculated using the Gorlin formula</td>
<td>Simple, non-invasive method</td>
<td>Requires accurate measurement of valve area</td>
</tr>
<tr>
<td>Effective orifice area</td>
<td>m²</td>
<td>Yes</td>
<td>No</td>
<td>Measured using the Gorlin formula</td>
<td>Simple, non-invasive method</td>
<td>Requires accurate measurement of valve area</td>
</tr>
<tr>
<td>Flow contraction coefficient</td>
<td>-</td>
<td>Yes</td>
<td>No</td>
<td>Calculated using the Gorlin formula</td>
<td>Simple, non-invasive method</td>
<td>Requires accurate measurement of valve area</td>
</tr>
<tr>
<td>Vena contracta</td>
<td>mm</td>
<td>Yes</td>
<td>No</td>
<td>Measured using Doppler echocardiography</td>
<td>Simple, non-invasive method</td>
<td>Requires accurate measurement of valve area</td>
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</table>
Findings indicative for hemodynamically significant tricuspid stenosis

**Specific Findings**
- Mean pressure gradient
- Inflow jet velocity integral
- Ts
- Valve area by continuity equation

**Supportive Findings**
- Enlarged right atrium or moderate/tricuspid valve annulus

<table>
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<tr>
<th>Pulmonic Stenosis</th>
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<tbody>
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<td>Mean Gradient</td>
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<td>Right ventricular pressure (TR velocity)</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
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<tbody>
<tr>
<td>Peak velocity (m/s)</td>
<td>&lt; 3</td>
<td>3-4</td>
</tr>
<tr>
<td>Peak gradient (mm Hg)</td>
<td>&lt; 36</td>
<td>36 to 60</td>
</tr>
</tbody>
</table>

Assessment of valvular regurgitation severity

- **Qualitative**
  - Valve morphology (flail, coaptation)
  - Color flow jet (size)
  - CW signal of regurgitant jet

- **Semi-quantitative**
  - VC width
  - Flow convergence zone size
  - PW flow pattern: PV (MR), desc. Ao (AR), PA (PR), HV (TR)
  - CW signal shape (PHT in AR...)

- **Quantitative**
  - EROA, R Vol (PISA, volumetric)
  - Secondary signs: LV/RV volume load, atria, PAP

**Quantitative assessment of regurgitation:**

**Volumetric approach**
Color Doppler assessment of regurgitation severity

Proximal Jet Width
"Vena contracta"
QUANTIFICATION OF REGURGITATION
Prox. jet width / vena contracta (VC)

Average VC Diameter (cm)

Grading the severity of aortic regurgitation

Proximal jet width
< 3mm   > 6mm

COLOR DOPPLER REGURGITANT JET

Proximal Jet Width
"Vena contracta"
Flow Convergence
Proximal Isovelocity Surface Area
Flow convergence zone

Continuity Principle: \(A \times V = \text{constant}\)

Proximal Flow Convergence

PISA method for quantification of regurgitant flow and effective regurgitant orifice area (EROA), regurgitant volume (R vol)

Hemispheric surface = \(2 \times r^2 \times \pi\)

Regurgitant flow \(Q = (2 \times r^2 \times \pi) \times \text{alias velocity}\)

\((2 \times r^2 \times \pi) \times \text{alias velocity} = \text{EROA} \times \text{MR velocity}\)

\[
\text{EROA} = \frac{2 \times r^2 \times \pi \times \text{alias velocity}}{\text{MR velocity}}
\]

Regurgitant volume = \(\text{EROA} \times \text{VTI}_{\text{MR}}\)
Limitations of the PISA method:

1) Position for PISA estimation

Vandervoort et al., JACC 1993

Limitations of PISA method:

2) Accurate radius measurement

- low nyquist limit
- high resolution imaging
- zoom magnification

Where is the orifice?

Limitations of PISA method:

3) Dynamic changes of the anatomic regurgitant orifice area

- decrease in dilated cardiomyopathy
- increase in mitral valve prolaps
- constant in rheumatic mitral regurgitation

Schwammenthal et al., Circulation 1994
Limitations of PISA method:

4) Effect of orifice geometry (multiple orifices!) and inlet angle of the valve cusps

Surface can in general not be assumed to be flat (particularly in MV prolapse/flail) This angle is normally ignored!!!

Limitations of PISA method

5) Movement of the regurgitant orifice

Doppler measures the velocity relative to the transducer

Regurgitant orifice may be moving away from or towards the transducer
Mitral regurgitation
Pulmonary venous flow

Grading the severity of aortic regurgitation
CW-Doppler in AR

Pressure Half-Time

Angiography (Grade)

msec

0 200 400 600 800
Quantification of Valvular Regurgitation

Grading the severity of aortic regurgitation

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<tr>
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<th>Mild</th>
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<th>Severe</th>
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<tr>
<td>Colour flow jet direction</td>
<td>Lateral (or posterolateral)</td>
<td>posteromedial (or anteromedial)</td>
<td>posterolateral (or anteromedial)</td>
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<td>&lt; 1 cm</td>
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EAE recommendations 2010

Grading the severity of mitral regurgitation

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EAE recommendations 2010
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