Spectrum of Aortic Stenosis: 
Etiology and Echo Quantification

Martin G. Keane, MD, FASE
Professor of Medicine
Lewis Katz School of Medicine
at Temple University
Review Question #1

What can lead to underestimation of the aortic valve gradient on echo as compared with invasive hemodynamics at cath:

A. Pressure Recovery
B. Equating peak instantaneous gradient to “peak-to-peak” gradient
C. A large incident angle to the aortic outflow
D. Failure to account for high subvalvular flow
E. Low stroke volume
Reflect upon the image below:

Transesophageal (TEE):
Review Question #2

Which of the following statements best describes this aortic valve:

A. Unicuspid - Single Commissure
B. Bicuspid - Fusion of left & right cor. cusps
C. Bicuspid - Fusion of left & noncoronary cusps
D. Functionally Bicuspid Aortic Valve (trileaflet)
E. Cannot be determined
Review Question #3

A patient presents with the following echo findings:

- **LVOT diameter** = 2.0 cm
- **LVOT velocity** = 130 cm/s
- **Aortic velocity** = 4.1 m/s

2D: Moderately calcified AV, Normal LVEF (70%)
The aortic valve area is most likely:

A. Normal
B. Mildly reduced
C. Moderately reduced
D. Severely reduced
E. Cannot be calculated (incongruent units)
Basic root structure

Parasternal Long Axis View

- Fibrous Annulus
- Sinotubular junction
- Leaflets
- Sinuses of Valsalva
Normal AV
parasternal color Doppler
Normal AV M-Mode
coaptation in center of aortic root
Normal AV orientation and opening

Diastole

Systole
Normal AV

Apical views

Apical 5-Chamber

Apical Long Axis
Spectral Doppler of the AV
Apical Five Chamber

AS jet

AR jet
Bicuspid Aortic Valve

- Most common congenital anomaly (1-2%)

- **Commissure may be horizontal or vertical**
  - Horizontal: Anterior and Posterior leaflets
  - Vertical: Right and Left (coronary) leaflets

- Accel. calcification & premature stenosis

- Proximal aortopathy (even in normals)

- Associated aortic abnormalities
Bicuspid Aortic Valve
PLAX View – Doming

Diastole

Systole
Bicuspid Aortic Valve
PSAX view morphology

Diastole

Systole

Systolic ellipsoidal orifice identifies as...
Aortic Valve: Other Anomalies associated with AS

Unicuspid AoV

Quadracuspid AoV
Aortic Stenosis

Etiology

- Senile/Degenerative Calcific
  - Calcification resembles ectopic bone
  - Risk factors similar to those for atherosclerosis
  - Renal dysfunction may accelerate

- Premature Calcific Bicuspid / Congenital

- Rheumatic
  - Less common in the United States

- Less common
  - Type 2 Hyperlipidemia, SLE, Irradiation, Paget’s Dz
Calcific Aortic Stenosis: Reduction in leaflet motion
Rheumatic Aortic Stenosis: 
Commissural fusion
Aortic Stenosis: Physiologic Sequelae

- Chronic LV pressure overload
  - Myocardial Hypertrophy - Progressive
  - LA dilatation

- END STAGE: Limited Cardiac Output
  - Systolic Dysfunction
  - Diastolic Dysfunction

- SYMPTOMS:
  - Dyspnea and Fatigue (often subtle)
  - Typical and Atypical Chest Pressure
  - Syncope
  - Congestive Heart Failure
Evaluation of AS: *Echo Essentials*

- **Valve Anatomy** - establish etiology
  - Exclude other forms of LVOT obstruction

- **Severity of stenosis**

- **Physiologic sequelae**
  - LV hypertrophy, diastolic fxn, systolic fxn
  - LA dilatation, Pulmonary hypertension

- **Evaluate concurrent disease**
  - Proximal aorta and arch
  - Aortic Valve Regurgitation, Mitral Disease
Aortic Stenosis: Assessing Severity

- Peak AV Jet Velocity
- Mean AV Gradient
- Valve Area by continuity equation
- Velocity Ratio ("Dynamic Index")
- Planimetry

ASE / EAE Recommend

Aortic Stenosis: 
Prognosis of Velocity

- Variable Rate of Progression  
  - Avg \( \sim 0.3 \) m/sec/year

- High rate of events, even for “asymptomatic” AS

- Baseline AoV Peak Jet Velocity, rate of change of velocity and functional status predict clinical outcome

Aortic Stenosis: 
Peak Velocity

- Continuous Wave (CW) Doppler in Apical 5 Chamber View

- Must be parallel to the ejection jet

- Confirm – Right Parasternal
  - Suprasternal also possible

- Use highest velocity
  - Avoid feathery signals at tip
  - Piedoff – “non-imaging” probe
  - Decrease gains & adjust baseline
Aortic stenosis
Assessment by Peak Velocity

- Mild stenosis: 2.0 – 2.9 m/s
- Moderate stenosis: 3.0 – 3.9 m/s
- Severe stenosis: > 4.0 m/s
- “Very Severe” or “Critical” stenosis: > 5.0 m/s
Aortic Stenosis: 

**Peak Gradient**

- **Peak Gradient** = 4 \((V_{AV})^2\)
  - Peak Instantaneous Gradient
Instantaneous Gradient vs. Peak-to-Peak

- Echo a more “physiologic” measurement
- Doppler peak gradient always higher
- Mean gradient and AVA should correlate
- Gradients are flow dependent
Aortic Stenosis:
Mean Gradient

- Mean Gradient
  - Integration of velocity over time
  - Estimate \( - 0.7 \times \text{Peak Grad.} \)
  - Correlates with cath Peak-to-Peak gradient
Aortic stenosis
Assessment by Mean Gradient

- Mild stenosis: $< 20$ mmHg
- Moderate stenosis: $20 - 39$ mmHg
- Severe stenosis: $\geq 40$ mmHg
Velocity and Gradient pitfall: Influence of Cardiac Output

- **High CO = High gradient**
  - Aortic regurgitation
  - Hyperdynamic function

- **Low CO = Low gradient**
  - Reduced ejection fraction
  - Small ventricular cavity/LVH
  - High systemic vascular resistance/impedance
  - Significant mitral regurgitation
Aortic stenosis
Assessment of Valve Area

- Normal valve area: $= 3 - 4 \text{ cm}^2$
- Mild stenosis: $> 1.5 \text{ cm}^2$
- Moderate stenosis: $1.0 - 1.5 \text{ cm}^2$
- Severe stenosis: $< 1.0 \text{ cm}^2$
- “Critical” stenosis: $< 0.7 \text{ cm}^2$
Calculation of AV Area: *Continuity Equation*

- Based on conservation of mass

**Flow within LVOT = Flow across AV**

- LVOT area \( \times VTI_{LVOT} = AVA \times VTI_{AV} \)

- \( [\pi \times (LVOT_{rad})^2] \times VTI_{LVOT} = AVA \times VTI_{AV} \)

- \( [\pi \times (LVOT_{radius})^2] \times VTI_{LVOT} = AVA \)
  \( \frac{VTI_{AV}}{VTI_{AV}} \)
LVOT diameter

2.1 cm
Flow through LVOT

**Pulse Wave Doppler**

- **Spectral Envelope**
  - With sample volume in LVOT

- **Velocity Time Integral (VTI)**
  - Flow through a single point

VTI = 19 cm
Flow Across the Aortic Valve: Continuous Wave Doppler

VTI = 85 cm
Calculating Aortic Valve Area

\[
AVA = \frac{(Diameter_{LVOT} / 2)^2 \times \pi \times VTI_{LVOT}}{VTI_{AV}}
\]

\[
AVA = \frac{(2.1 \text{ cm} / 2)^2 \times 3.14 \times 19 \text{ cm}}{85 \text{ cm}}
\]

\[
AVA = 0.7 \text{ cm}^2
\]
Pitfalls of the Continuity Equation

- **LVOT measurement**
  - Diameter is squared - can propagate large error

- **LVOT velocity**

- **AV velocity**
  - Missing the Peak: use multiple sites / Piedoff
  - Use highest velocity obtained
  - Beware MR
Doppler Velocity Index

- Eliminates errors of LVOT measurement
  - \[ \text{DVI} = \frac{\text{VTI}_{\text{LVOT}}}{\text{VTI}_{\text{AV}}} \]

- Criteria for Severe AS:
  - \[ \text{DVI} < 0.25 \]
Planimetry of the Aortic Valve

AVA = 1.1 cm$^2$
Planimetry

- Correlates with invasively obtained areas

- Flow dependent
  - Difficult to distinguish decreased opening due to LV failure

- TEE superior - use of color flow area

- Dense calcification reduces accuracy
## Summary

### Table 3: Recommendations for classification of AS severity

<table>
<thead>
<tr>
<th>Aortic jet velocity (m/s)</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 2.5 m/s</td>
<td>2.6–2.9</td>
<td>3.0–4.0</td>
<td>&gt; 4.0</td>
</tr>
<tr>
<td>Mean gradient (mmHg)</td>
<td>&lt; 20 (&lt;30⁰)</td>
<td>20–40b (30–50⁰)</td>
<td>&gt; 40b (&gt;50⁰)</td>
</tr>
<tr>
<td>Aortic valve area (cm²)</td>
<td>&gt; 1.5</td>
<td>1.0–1.5</td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>Indexed AVA (cm²/m²)</td>
<td>&gt; 0.85</td>
<td>0.60–0.85</td>
<td>&lt; 0.6</td>
</tr>
<tr>
<td>Velocity ratio</td>
<td>&gt; 0.50</td>
<td>0.25–0.50</td>
<td>&lt; 0.25</td>
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</table>

ESC Guidelines.
AHA/ACC Guidelines.

So...

My patient has severe aortic stenosis! What do I do? Who do I talk to?

WHEN SHOULD I OPERATE?
The Good Old Days: The Symptomatic “Cliff”

Time for an Update: *The Asymptomatic “Slide”*

Why??

- Progression of Stenosis
- Worsening LV Hypertrophy
  - Subclinical Diastolic Dysfunction
  - Subclinical Systolic Dysfunction
- LA Pressure Overload and Congestion
  - Pulmonary Hypertension
- Patients in denial
- Doctors in denial
"Stages" of Disease

- **Stage A:**
  - At risk for disease

- **Stage B:**
  - Progressive disease

- **Stage C:**
  - Severe disease (asymptomatic)

- **Stage D:**
  - Severe disease (symptomatic)

More accurate definition of severity
More precise decisions on when to intervene
“Stage C” can be subdivided:

- **Stage A:**
  - At risk for disease

- **Stage B:**
  - Progressive disease

- **Stage C1:**
  - Severe (asymptomatic) – Compensated LV

- **Stage C2:**
  - Severe (asymptomatic) – Decompensated LV

- **Stage D:**
  - Severe disease (symptomatic)
Guidelines Assist in Decision-Making

Calcified/Thickened leaflets
Reduced Systolic Opening

“Asymptomatic”

Vmax ≥5 m/s + low AVR risk

Vmax ≥4 m/s

EF <50%

EF ≥50%

Undergoing other CV Surgery

ETT
BP / ↓ex capacity

Rapid progression + low AVR risk

AVR (IIa)

AVR (I)

AVR (I)

AVR (IIa)

AVR (IIb)
Decreased LV Function: “Low Gradient” Aortic Stenosis
Low Output – Low Gradient AS

- Why does a low EF pt have an AVA of 0.5 cm², but a mean gradient of 15mmHg?
  - Because low SV (low flow) leads to low gradients

- "Real AS"
  - 1° Prob: Severe obstruction to flow
  - 2° Prob: Depressed LVEF

- "Pseudo-AS"
  - 1° Prob: Depressed LVEF
  - 2° Prob: Mild/Mod obstruction is made to look severe by ↓SV

Improves with AVR
Low Output – Low Gradient AS

- **Dobutamine Stress Testing**
  - Increase LV contractility -> Increase Stroke Volume

- **Increase Stroke Volume by 20% ->**
  - **Real AS**
    - Peak vel/mean gradient significantly↑↑
    - AVA stays unchanged or ↓slightly
  - **Pseudo AS**
    - Peak vel/mean gradient minimal↑
    - AVA↑

- **What if LV contractility / SV don’t increase?**
Low Gradient - Normal EF

- **EF ≥ 50%, AVA < 1 cm², mean grad < 40mmHg**
  - Whah???

- **Still a stroke volume problem!!**
  - **SV\text{index} ≥ 35 ml/m²** despite EF

- "Typical" patient:
  - Older, h/o hypertension, women
  - Concentric LVH, small cavity, impaired filling
  - Markedly increased vascular impedance

Guidelines Assist in Decision-Making

Suspected “Low Flow” AS

Symptoms

$V_{\text{max}} \geq 4 \text{ m/s}$

- EF $< 50\%$
  - DSE
    - MG $\geq 40\text{ mmHg}$ or
    - Pk Vel $\geq 4 \text{ m/s}$
  - AVR (I)

$V_{\text{max}} < 4 \text{ m/s}$

- EF $\geq 50\%$
  - AVR (IIa)

No Symptoms

$V_{\text{max}} < 4 \text{ m/s}$

- EF $\geq 50\%$
  - AVR (IIa)
  - $\text{AVA}_{\text{index}} \leq 0.6 \text{ cm}^2/\text{m}^2$
    - and
    - $\text{SV}_{\text{index}} < 35 \text{ ml/m}^2$
  - Rule Out other causes for Sx!!

$V_{\text{max}} \geq 4 \text{ m/s}$

- No Symptoms
  - AVR NOT Indicated

EF $< 50\%$

- AVR (IIa)
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Short Axis TEE view - AoV
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DI = \(\frac{130}{410}\)

DI = 0.32
Thank You!