Low Gradient Aortic Stenosis

William A. Zoghbi MD, MACC

*Elkins Family Distinguished Chair in Cardiac Health*

*Professor and Chairmen, Department of Cardiology*

*Houston Methodist DeBakey Heart & Vascular Center*

*Houston, Texas*
Aortic Stenosis

Echocardiographic Imaging

- Evaluate Aortic valve structure (Ca, # Cusps, ? Rheumatic)
- LV size, hypertrophy
- LV function (systolic & Diastolic)
- Other etiologies of Murmurs (Subaortic membrane, HCM, Supravalvular AS)
Doppler Echocardiography

Worsening AS: Higher velocity, later Peak velocity, longer Ejection time…
Pressure Gradient from Doppler

Modified Bernoulli Equation

\[ \Delta P \approx 4 \left( V_2^2 - V_1^2 \right) \]
Aortic Valve Area with the Continuity Equation

Less Flow dependent

\[
AVA = \frac{CSA_{lvo} \times TVI_{lvo}}{TVI_{jet}}
\]

\[
= \frac{SV}{TVI_{jet}}
\]

Aortic Stenosis

Echo-Doppler Assessment

- Valve structure
- Maximal velocity/gradient
- Mean gradient
- Valve area (continuity equation)
- Contour of the AS jet
Natural History of Aortic Stenosis Treated Medically

Ross J & Braunwald E, Circ Sup V: 61, 1968
# Aortic Stenosis

## AHA & ACC Guidelines

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet velocity</td>
<td>&lt; 3.0 m/s</td>
<td>3.0 – 4.0</td>
<td>&gt; 4.0 m/s</td>
</tr>
<tr>
<td>Mean gradient</td>
<td>&lt; 25 mmHg</td>
<td>25 – 40</td>
<td>&gt; 40 mmHg</td>
</tr>
<tr>
<td>Valve area</td>
<td>&gt; 1.5 cm²</td>
<td>1.0 – 1.5</td>
<td>&lt; 1.0 cm²</td>
</tr>
</tbody>
</table>

Nishimura R. et al. JACC 2014
Gradient cut-off of > 40 mmHg is specific for severe AS
Valve Area < 1 cm² is more sensitive; 0.8 cm² is more appropriate.

Minners J et al European Ht J 2008: 29, 1043
Low Gradient
Severe Aortic Stenosis

Mean Gr < 40 mmHg (or Pk Vel < 4 m/s), and AVA < 1 cm²

- Error of calculation (diameter of LVO, Pulsed or CW Doppler mal-position)
- Low Stroke Volume (Small LV with Normal EF)
- Low Stroke Volume (Depressed EF)
- Problems with definition of Severe AS (valve area 0.9-1 cm²).
$SV = 70 \text{ ml}$

$\text{Mean Gradient} = 23 \text{ mmHg}$

$AVA = 0.95 \text{ cm}^2$
PW

2-2006

2-2007

3-2008

3-2009

CW

3 m/s

3.5 m/s

4 m/s

4.5 m/s

SV = 70 ml

77 ml

74

80 ml

MG = 23 mmHg

32 mmHg

44 mmHg

52 mmHg

AVA = 0.95 cm²

0.8 cm²

0.7 cm²

0.67 cm²
75M with AS & NYHA Class III Heart Failure

SV = 40 ml
Mn Gr = 46 mmHg
AVA = 0.40 cm²

VTI = 12.8 cm
VTI = 100 cm – 4 m/s
62 yr old man with NYHA class III heart failure and a systolic ejection murmur in the “aortic” position. The aortic valve appeared thickened/calcified and the LV was dilated and diffusely hypokinetic. EF was 24%.
Mean gradient = 23mmHg
SV = 39 ml
AVA = 39/56 = 0.70cm²
Dobutamine Echo in AS with Depressed LVEF & Low Gradient

3 types of responses seen

- $\uparrow$ SV and EF, $\uparrow$ gradient, minimal change in AVA

- $\uparrow$ SV and EF, minimal change in gradient, $\uparrow$ AVA

- No change in EF, SV, gradient or AVA (*poor contractile reserve*)

*deFilippi CR, et al: Am J Cardiol 1995;75:191-194*
Dobutamine Infusion
Rest

Dobutamine 20mcg/kg/min

TVI=10.3cm

TVI=20cm
**Rest**

- Peak velocity = 3m/s
- Mean gradient = 23mmHg
- Stroke volume = 39ml
- AVA = 0.70cm$^2$

**Dobutamine 20mcg/kg/min**

- Peak velocity = 4.5m/s
- Mean gradient = 49mmHg
- Stroke volume = 79ml
- AVA = 0.85cm$^2$
What is “Paradoxical Low Flow, Low Gradient” Aortic Stenosis?

Low flow and gradient in the presence of “preserved” LVEF.
Pronounced Concentric Remodeling

Small LV (intrinsic)

Atrial Fibrillation

Impaired Diastolic Filling

Reduced Forward Stroke Volume

Reduced Transvalvular flow rate

Low-Flow, Low gradient AS with Preserved LVEF

Mitral Regurgitation

RV Failure

Mitral Stenosis

Tricuspid Regurgitation

Modified from Pibarot and Dumesnil., Circulation. 2013;128:1729
Paradoxical Low Flow, Low Gradient Severe AS

$SV = 38 \text{ ml}$

$Mean \text{ Gradient} = 35 \text{ mmHg}$

$AVA = 0.5 \text{ cm}^2$

$2D \text{ SV} = EDV - ESV$

$= 65 - 25$

$= 40 \text{ ml}$
Earlier Studies on Low flow, Low Gradient Severe AS with Normal LVEF

- 2 Retrospective Studies
- Several Co-morbidities
- Presence of heart failure/Hypertrophy
- 30-50% of pts had mean gradient < 30mmHg

Hachicha Z et al. 115: 2856, 2007
Prognosis of AS patients in Partners A & B According to Flow & LVEF

Herrmann et al., Circulation. 2013;127:2316-2326
Prognosis of Asymptomatic Aortic Stenosis With Normal LVEF

Jander et al

Otto et al.

Zoghbi  Circulation 123: 838, 2011
Paradoxical Low Flow, Low Gradient Severe Aortic Stenosis

Mean Gr < 40 mmHg, SVi < 35ml/m² and AVA < 0.4-0.6 cm²/m²

- The entity exists and has multiple etiologies, leading to a small ventricle with preserved LVEF
- Carries poor prognosis, likely exacerbated by the underlying/concomitant cardiac conditions
- Patients can be asymptomatic & along with low co-morbidities have prognosis similar to moderate AS
- Need to be vigilant in deriving valve area (error in diameter of LVO, Pulsed or CW Doppler mal-position)
- Low Stroke Volume by Doppler needs to be corroborated by LV volume (small) and function.
Low-Gradient Severe Aortic Stenosis With Preserved Ventricular Function

Trust But Verify*

William A. Zoghbi, MD

Aortic Stenosis

- Echo/Doppler is the first line and frequently the sole modality for diagnosis & management.
- Evaluate valve structure and cardiac adaptation to the pressure load.
- Beware of errors in calculations of AVA; look at flow, gradient and valve area.
- In patients with Depressed LV function and severe AS, Dobutamine Doppler is indicated for further classification and management.
- Paradoxical low flow, low gradient AS: low Stroke Volume by Doppler needs to be corroborated by LV volume (small) and function.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>SAME STUDY (ob₁-ob₂)</th>
<th>DAY 1 - (same ob)</th>
<th>DAY 2 (ob₁-ob₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>dlvo (%)</td>
<td>5 ± 5</td>
<td>4 ± 5</td>
<td>3 ± 4</td>
</tr>
<tr>
<td>CSAIvo (%)</td>
<td>11 ± 10</td>
<td>8 ± 10</td>
<td>6 ± 9</td>
</tr>
<tr>
<td>PkVlvo (%)</td>
<td>8 ± 9</td>
<td>12 ± 12</td>
<td>13 ± 10</td>
</tr>
<tr>
<td>PkVjet (%)</td>
<td>5 ± 5</td>
<td>6 ± 5</td>
<td>7 ± 7</td>
</tr>
</tbody>
</table>
Progression of Aortic Stenosis

Significant progression of aortic stenosis was observed in 20 patients, or 40% of the population (open circles).
Aortic Stenosis

Echo-Doppler Assessment of Progression

• Valve area depends on 3 measurements
• Review measurements.
• Did ventricular function change?
• Most reproducible: Velocity of the jet/Gradient (provided no change in flow)
The peak AV velocity is the lowest velocity where there is NO aliasing Increments & no continuum in velocity

Lopez-Mattei. Methodist DeBakey Cardiovasc J. 2013 Jul-Sep;9(3):142-8
Prognosis of AS patients according to Flow & Gradient

Adjusted incidence of cardiac events, %

$p = 0.009$

Follow-up, months

J.G. Dumesnil et al. Curr Opin Cardiol 2013, 28:524–530
Potential Pitfalls of Phase Contrast CMR

Underestimation of Velocities:

- Imaging plane NOT perpendicular to flow
- Partial volume averaging
- Signal loss in turbulent jets
- Phase shift errors due to fast acceleration
- Lower temporal resolution

Role of CT in AS...limited...pre-TAVR
CoreValve® Device and Patient Selection Measurements Per MSCT

<table>
<thead>
<tr>
<th>Valve Size</th>
<th>Aortic Annulus Measurements</th>
<th>Sinus of Valsalva Diameter</th>
<th>Native Leaflet to Sinutubular Junction Length</th>
<th>Ascending Aorta Diameter*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diameter</td>
<td>Perimeter</td>
<td>Area Range</td>
<td>≥ 25 mm</td>
</tr>
<tr>
<td>23</td>
<td>18-20 mm</td>
<td>56.5-62.8 mm</td>
<td>254.5-314.2 mm</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>20-23 mm</td>
<td>62.8-72.3 mm</td>
<td>314.2-415.5 mm</td>
<td>≥ 27 mm</td>
</tr>
<tr>
<td>29</td>
<td>23-26 mm</td>
<td>72.3-84.8 mm</td>
<td>415.5-572.6 mm</td>
<td>≥ 29 mm</td>
</tr>
<tr>
<td>31</td>
<td>26-29 mm</td>
<td>81.6-91.1 mm</td>
<td>530.9-660.5 mm</td>
<td>≥ 29 mm</td>
</tr>
</tbody>
</table>

*Ascending Aorta measurements are taken at 80 mm from the aortic annulus for the 23 mm device and at 40 mm from the aortic annulus for the 26, 29, and 31 mm devices.
Velocity Across the Aortic Valve vs. Prognosis

Role of CT

STJ

Sinotubular Junction Diameter
Min. Ø: 25.6 mm
Max. Ø: 26.4 mm

Compass: 64...
Distance: 248...

AORTIC VALVE CALCIFICATION

LAO: 93°
Caudal: 55°

RC
NC
LC

SINUS HEIGHT

LCC

RCC

NCC

20.7 mm
16.5 mm
21.4 mm
19.0 mm
23.6 mm
Role of CT

ANNULUS
- Annulus Diameter
  - Min. Ø: 24.5 mm
  - Max. Ø: 26.9 mm
- Area: 528.2 mm²
- Perimeter: 82.7 mm

SOV DIAMETER
- Sinus of Valsalva Width - RCC
  - Ø: 33.7 mm
- Sinus of Valsalva Width - NCC
  - Ø: 33.0 mm
- Sinus of Valsalva Width - ICC
  - Ø: 32.5 mm

LVOT
- LVOT Diameter
  - Min. Ø: 19.1 mm
  - Max. Ø: 27.7 mm

ASCENDING AORTA
- Ascending Aorta Diameter
  - Min. Ø: 30.9 mm
  - Max. Ø: 33.1 mm
Prognosis of AS patients in Partner A & B according to Flow and Type of intervention
Prognosis of AS patients according to Flow & Gradient

Mohty et al., Circulation. 2013;128[suppl 1]:S235-S242
NORMAL-LVEF
NORMAL-FLOW, HIGH-GRADIENT

NORMAL-LVEF
“PARADOXICAL” LOW-FLOW, LOW-GRADIENT

LOW-LVEF
“CLASSICAL” LOW-FLOW, LOW-GRADIENT AS

DIASTOLE

SYSTOLE

Pibarot and Dumesnil, J Am Coll Cardiol 2012;60:1845–53)
Hemodynamic Scenarios of Severe Aortic Stenosis

\((EOAi < 0.6, \text{ preferably } < 0.4 \text{ cm}^2/\text{m}^2)\)

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<thead>
<tr>
<th>Normal Flow</th>
<th>High Gradient</th>
<th>Low Gradient</th>
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<tr>
<td>(\text{SVi} \geq 35\text{ml/m}^2) \n(\text{Mean Gradient} \geq 40 \text{ mmHg})</td>
<td>\text{“Normal flow, high gradient”}</td>
<td>\text{“Normal flow, low gradient”}</td>
</tr>
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<table>
<thead>
<tr>
<th>Low Flow</th>
<th>High Gradient</th>
<th>Low Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{SVi} &lt; 35\text{ml/m}^2) \n(\text{Mean Gradient} \geq 40 \text{ mmHg})</td>
<td>\text{“Low flow, high gradient”}</td>
<td>\text{“Low flow, low gradient”}</td>
</tr>
</tbody>
</table>

\(\text{Usualy AS is not too severe}\)

| Normal or Depressed LVEF |
**Paradoxical Low Flow, Low Gradient Severe AS**

- \( SV = 55 \text{ ml} \)
- Mean Gradient = 23 mmHg
- \( AVA = 0.7 \text{ cm}^2 \)
- \( 2D \ SV = EDV - ESV \)
  - = 95 - 45
  - = 50 ml
Stages of Valvular Aortic Stenosis

A
At risk

B
Progressive

C
Asymptomatic
Severe
C1 (nl EF)
C2 (EF<50%)

D
Symptomatic
Severe
D1 (high Gr)
D2,3 (low flow, low Gr)

ACC/AHA Valve Guidelines Nishimura R. et al. JACC 2014