Aortic Stenosis
Severe by Gradient not Valve Area

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DISCLOSURE

Relevant Financial Relationship(s)  None

Off Label Usage  None
Pre Questions (1)

- The Difference between Doppler MIG and catheterization PPG
  
  A. Is due to pressure recovery
  
  B. Is due to different measurement timing of the LV and aortic pressures
  
  C. Occurs only in patients with small aortas
  
  D. Is used to calculate aortic valve area
Pre Questions (2)

• Catheter-Doppler Discordance maybe due to
  A. Pressure recovery
  B. Eccentric jet
  C. High flow states
  D. Very severe aortic stenosis
## Severe Aortic Stenosis Area Gradient Match

<table>
<thead>
<tr>
<th></th>
<th>Mean Gradient (mmHg)</th>
<th>Valve Area (cm²)</th>
<th>Valve area index (cm²/BSA)</th>
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<tr>
<td><strong>Mild</strong></td>
<td>&lt;25</td>
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<tr>
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iAVA < 0.6 cm/m²  

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### Severe Aortic Stenosis

**Mean Gradient (mmHg)** | **Valve Area (cm²)** | **Valve area index (cm²/BSA)**
---|---|---
Mild | <25 | >1.5 | >0.8
Moderate | 25-40 | 1.0-1.5 | 0.6-0.8
Severe | >40 | <1.0 | <0.6

*Nishimura, et al., J Am Coll Cardiol 2014*
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Nishimura, et al., Circulation 2014
Aortic Stenosis
Determining the “True” Severity

Measurement Errors Must be Excluded
Discordance of Area and Gradient Severity

REVIEW ARTICLE

Aortic Valve Stenosis: To the Gradient and Beyond—The Mismatch Between Area and Gradient Severity

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From the ¹Department of Cardiology, William Beaumont Hospital, Royal Oak, Michigan; and ²Department of Internal Medicine, Division of Cardiovascular Diseases, Mayo Clinic, Scottsdale, Arizona

The clinical severity of aortic stenosis (AS) is based largely on symptoms. However, AS severity is primarily determined by estimating the aortic valve area (AVA) and pressure gradients (ΔP). Conditions may arise in which there is a mismatch in severity between AVA and ΔP determinations secondary to errors in measurement and/or assumption, alterations of flow, or variations in the magnitude of pressure recovery. The cause of discrepancy between area and gradient determinations must be deciphered so as to best counsel patients on the most ideal treatment strategy. (J Interven Cardiol 2012;00:1–12)
Topics of Discussions

- GOA Vs. EOA
- Doppler Vs. Catheter
- Factors affecting Gradient
- Area/Gradient Mismatch
- Reverse Area Gradient Mismatch
GOA Versus EOA

GOA: Planimetry
EOA: Continuity Equation
Coefficient of Contraction: EOA/GOA
Doppler versus Catheter Area and Gradient Assessment

EOA
Doppler Catheter
GOA
Catheter Gradient
Doppler Gradient
• **Continuity Equation**
  
  \[ A_1 \times V_1 = A_2 \times V_2 \]

  \[ A_2 (AV) = \frac{A_1 \times V_1}{V_2} \]

• Also, \( A_2/A_1 = V_1/V_2 \)

• The ratio of velocities is the inverse of the ratio of areas

• Dimensionless index = \( V_1/V_2 < 0.25 \)
Doppler Aortic Valve Area Assessment

LVOT Diameter = 2 cm
LVOT Area = 0.785 x (2)^2
LVOT Area = 3.14 cm^2

- LVOT diameter
- Measure in systole
- At Leaflet insertion
- Error squared!!

LVOT assumed as a circle = \( \Pi r^2 \)
LVOT Area = \( \Pi (\text{LVOT radius})^2 \)
LVOT Area = 3.14 \times (\text{LVOT diameter}/2)^2
LVOT Area = 0.785 \times (\text{LVOT diameter})^2
Doppler Aortic Valve Area Assessment

- **PW: LVOT**
- Use proper cursor alignment parallel to blood flow to obtain optimum signal

LVOT Velocity = 1 m/sec
LVOT TVI = 25 cm
Doppler Aortic Valve Area Assessment

AV velocity = 4 m/sec
AV TVI = 98 cm

- CW: AV
- Multiple windows
- Use proper cursor alignment parallel to blood flow to obtain optimum signal.
LVOT diam 2.0 cm
LVOT TVI 25 cm

Area 1 x TVI_1 = Area 2 x TVI_2

\[0.785 \times (\text{LVOT diam})^2 \times \text{AV TVI} = \text{AVA} \times \text{AV TVI}
\]

AVA = \[
\frac{78.8}{98}
\]

AVA = 0.8cm^2
Doppler Aortic Valve Gradient Assessment

- Doppler
  - \( \text{MIG} = 4V_2^2 - 4V_1^2 \)
  - \( \text{MIG} = 4V_2^2 \)
  - Use \( \text{MIG} = 4V_2^2 - 4V_1^2 \)
    - \( V_1 > 1.5 \text{ m/second} \)
    - \( V_2 < 3 \text{ m/second} \)
Doppler versus Catheter Gradient Assessment

- Catheterization
  - Peak to Peak
  - $P_{mean\ Catheter}$
- Doppler
  - MIG ($4V_2^2 - 4V_1^2$)
  - $P_{mean\ Doppler}$
  - MIG always > PPG
  - $P_{mean\ Doppler} - P_{mean\ Catheter} = P_{rec}$

![Diagram showing Doppler and catheter gradients](image)
Pressure Recovery

- LV Pressure: Mean 180 mmHg
- Aortic Pressure: Mean 140 mmHg
- Catheterization Gradient = Mean 40 mmHg
- Doppler Mean Gradient = 50 mmHg
- Pressure Recovery = 10 mmHg
Not Pressure Recovery

- LV Pressure: Peak 200 mmHg
- Aortic Pressure: Peak 150 mmHg
- Cath Peak to Peak: 50 mmHg
- Doppler Velocity: 4.5 m/second
- Doppler Maximum Instantaneous Gradient: Peak: 81
- Doppler-Cath difference: 31 mmHg
Inherent technique difference (timing) and not pressure recovery
Pressure Recovery

- Increase in pressure in the aorta distal to the valve and the vena contracta
- Decrease in pressure gradient between LV and aorta
- Increase in EOA distal to the valve and vena contracta
- Catheter measures distal to the vena contracta
Factors Affecting Gradient

- **Area**: The lower the area, the higher the gradient
- \[ \Delta P = \frac{Q^2}{K \times EOA^2} \]
Factors Affecting Gradient

- **Flow**: The lower the flow, the lower the gradient
  - Low Flow: SVI < 35 ml/m²
  - High Flow: SVI > 58 ml/m²

![Graph showing transvalvular gradient vs. aortic valve flow](image)
Gradient: 40 mmHg
Gradient: 24 mmHg
Factors Affecting Gradient

- **Jet Eccentricity**
- More eccentricity, more pressure loss, higher gradient, the less pressure recovery
- No further increase beyond 30°
Factors Affecting Gradient

• **Jet Eccentricity**
• Increase in velocity by 0.7 m/sec, gradient 23 mmHg, and decrease in EOA 0.2 cm$^2$

Color Jet occupies the entire aorta indicating a central jet emanating across the AV

Color Jet occupies only $\frac{1}{2}$ of the aorta indicating an eccentric jet emanating across the AV
Aortic root diameter

- The larger the aortic root, the more the energy loss, the less the pressure recovery, the higher the catheter gradient. This effect plateaus at a diameter of 30 mm (area 7 cm$^2$)
- The smaller the root, the more pressure recovery.

**ELCo = AVA x AAa**

\[ \frac{AAa - AVA}{AVA} \]
Factors Affecting Gradient

- Doppler/Catheter Discordance
  Small Aortic Root

- Doppler/Catheter Concordance
  Eccentric Jet
Normal Ejection Fraction
Normal Cardiac Output
Area/Gradient Match
AVA $< 1 \text{cm}^2$
$\Delta P_{\text{mean}} > 40 \text{mmHg}$
Aortic Stenosis
Area/Gradient Mismatch
Aortic Stenosis
Area Gradient Mismatch

- Low flow (normal or reduced LVEF)
- Mean Gradient <30-40mmHg
- AVA <1.0cm²

- True, Severe AS
- Mild-Mod AS Low Flow (pseudo AS)
Severe Aortic Stenosis with Normal Function

- Area/Gradient Match
  - AVA < 1 cm²
  - $\Delta P_{\text{mean}} > 40$ mmHg
  - MIG: 100 mmHg

Severe Aortic Stenosis with Low Gradient

- Area/Gradient Mismatch
  - AVA < 1 cm²
  - $\Delta P_{\text{mean}} < 40$ mmHg
  - MIG: 36 mmHg
Low EF Area Gradient Mismatch

Risk Stratify
Dobutamine Stress
Dobutamine Stress

Resting Hemodynamics
HR, BP, gradient, CO, AVA

Dobutamine
2.5-5.0 mcg/kg/min

Repeat Hemodynamics
Increase by 5 mcg/kg/min

Endpoints
↓ BP, VT, HR>120, symptoms
Normalize CO, 20 mcg/kg/min
Dobutamine Echocardiography

Baseline Doppler hemodynamics

Dobutamine stress

↑↑ Mean gradient
↔ AV Area

↑ Mean gradient
↑ AV Area

True Severe AS

Pseudo Severe AS
Low Gradient Aortic Stenosis

\[
\frac{LVOT}{AV} = 0.2
\]

3 m/s

0.6 m/s

Courtesy Heidi Connolly
Dobutamine

**Truly Stenotic**
- LVOT/AV = 0.2
- 5 m/s
- 1 m/s

**Functionally Stenotic**
- LVOT/AV = 0.3
- 3 m/s
- 1 m/s
Case

- 62 y/o male
- STEMI and subsequent CABG five years ago
- Recurrent heart failure x 3 months
Stroke Volume = CSA x TVI

= 0.785 (2.2cm)^2 x

= 53cm^3
Low Flow

\[
\text{LVSVI} = \frac{53 \text{ cm}^3}{2.3 \text{ m}^2} = 23 \text{ cm}^3/\text{ m}^2 \quad (< 35 \text{ ml/m}^2)
\]

\[
\text{CI} = 23 \text{ cm}^3/\text{ m}^2 \times 68 \text{ bpm} = 1.6 \text{ L/min/m}^2
\]
$$\text{Area}_{AV} = \frac{0.785 \times (2.2\text{ cm})^2 \times (\text{ })}{\text{ }}$$

$$= 0.9 \text{ cm}^2, \text{ MG 24 mmHg}$$
Low EF Area Gradient Mismatch

- LVEF 30% (<45%)
- LVSVI 23ml/m²
- AVA 0.9cm²
- Mean Gradient 24mmHg
LVOT
Velocity = 0.8 m/s
TVI = 14 cm

Aortic Valve
Dobutamine 20 mcg/kg/min
Velocity = 3.0 m/s
TVI = 56 cm

SVI: 26 ml/m^2
P_{mean}: 24 mmHg

LVOT
Velocity = 1.3 m/s
TVI = 24 cm

Aortic Valve
Velocity = 5.0 m/s
TVI = 90 cm

SVI: 40 ml/m^2
P_{mean}: 52 mmHg
Dobutamine Stress

LV Stroke Volume Index
26ml/m^2 – 40ml/m^2

Mean AV Gradient
24 – 52mmHg

Valve Area
0.9cm^2 – 1.0cm^2
Case

- 75 year old male
- Presents with dyspnea and syncope
- HTN (treated BP 150/75)
- Grade III/VI mid peaking systolic murmur LSB
Echocardiography

Normal EF Area Gradient Mismatch

- LVEF: 55%
- AV Mean G: 26mmHg
- AVA: 0.8 cm$^2$
- AVA index: 0.45 cm$^2$/m$^2$
- LVEDV: 88 ml
- SVi: 32 ml/m$^2$
Aortic Stenosis Severity?

1. Mild
2. Moderate
3. Severe
4. Can’t tell
Flow Versus EF

A: EDV = 115, ESV = 45, SV = 115-45 = 70 ml
EF = 70/115 = 60%
BSA = 1.79
SVI = 39 ml/m²

B: EDV = 85, ESV = 35, SV = 85-35 = 50 ml
EF = 50/85 = 60%
BSA = 1.79
SVI = 28 ml/m²
Paradoxical LFLG Severe AS
Global Left Ventricular Afterload

Normal EF Area Gradient Mismatch

\[ Z_{VA} = \frac{150 \text{ mmHg} + 26 \text{ mmHg}}{32 \text{ ml/m}^2} = 5.5 \text{ mmHg/ml·m}^{-2} \]
Global Left Ventricular Afterload

Moderate AS and low compliance = Severe AS and normal compliance
Overall Survival According to Valvulo-Arterial Impedance ($Z_{va}$)

$Z_{va} = (SBP + Mean G)/SVI$

Survival (%) vs. Follow-up (years)

- $Z_{va} < 5.5$
- $Z_{va} \geq 5.5$

**P value adjusted for age, gender, valvulo-arterial impedance, & type of Rx**

*P value adjusted for age & gender

Hachicha et al: Circulation 2007

<table>
<thead>
<tr>
<th>Follow-up (years)</th>
<th>Pt at risk (no.)</th>
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<tbody>
<tr>
<td>0</td>
<td>354</td>
</tr>
<tr>
<td>1</td>
<td>260</td>
</tr>
<tr>
<td>2</td>
<td>156</td>
</tr>
<tr>
<td>3</td>
<td>110</td>
</tr>
<tr>
<td>4</td>
<td>62</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
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- Orange line: $Z_{va} \geq 5.5$
- Yellow line: $Z_{va} < 5.5$
Aortic Stenosis
Reverse Area/Gradient Mismatch
Elevated Gradient Despite non-critical AS

Reverse Area/Gradient Mismatch
AVA > 1 cm²
\( \Delta P_{\text{mean}} > 40 \text{mmHg} \)
Causes of Reverse A/G Mismatch

- Errors of Measurement
- High Flow
- Pressure recovery
- Eccentric Jet
- Para-valvular Obstruction
- Prosthetic-Specific
  - Mechanical Valve Central Orifice Pressure Drop
  - Patient-prosthesis mismatch
Mitral Regurgitant Jet Versus Aortic Stenosis Jet

- Mitral regurgitation occupies IVC and IVR
Errors of Measurements

LVOT Measurement

- Measure in systole
- At leaflet insertion
- Error squared!!
- Echo underestimates LVOT by 17%
High Flow

- Aortic regurgitation
- Hyperdynamic states (dialysis, anemia)
- Dimensionless Index
Pressure Recovery/High Flow

Doppler
P\text{mean} = 34 \text{ mmHg}
EOA = 0.6 \text{ cm}^2

Catheterization
P\text{mean} = 18 \text{ mmHg}
EOA = 1 \text{ cm}^2

\text{APR} = 34 - 18 = 16 \text{ mmHg}
\text{RPR} = 16/34 = 47\%
Energy Loss Index

- Energy loss Co-efficient
  \[ ELCo = \frac{AVA \times AAa}{AAa-AVA} \]
- \( AVA \) = aortic valve area, \( AAa \) = aortic area
- Energy loss index: \( ELCo/BSA \)
- \( ELI < 0.52-0.76 \text{ cm}^2 \) has poor outcomes and severe AS
- More significant with increase flow and moderate aortic stenosis
Pressure Recovery/High Flow

EOA = 0.6 cm²
AAd = 2.2 cm
AAa = 3.8 cm²
ElCo = 3.8x0.6/3.8-0.6
ElCo = 0.72 cm²
ELI = 0.72/BSA
Eccentric Jet

• Case:
• 29 y/o male
• Carries a diagnosis of Asymptomatic severe AS
• Quit Law School
Cardiac Catheterization $P_{\text{mean}} = 50 \text{ mmHg}$, $AVA = 1 \text{ cm}^2$
Eccentric Jet
Eccentric Jet: Echo

Aortic Diameter = 4.0 cm
Eccentric Jet: MRI

1 Angle: 31 degrees
Aortic Stenosis
Reverse Area Gradient Mismatch

Elevated Gradient/GOA ok
Mean Gradient >40mmHg
AVA >1.0cm²

Bicuspid Aortic Valves
Para-valvular Obstruction

- Sub-Aortic membrane
- Hypertrophic Obstructive Cardiomyopathy
- Supravalvular Obstruction
- Mitral valve Prosthesis
Sub-Aortic Membrane
Sub-Aortic Membrane

Progressive Disease
Other congenital anomalies in 50%
VSD/PDA/Coarctation
Shone’s Complex
Bicuspid AV
leftsided-SVC
Types: Membrane, fibromuscular ridge, Diffuse tunnel narrowing, mitral tissue

May Cause aortic regurgitation
Treatment: Surgery
No symptoms: Catheter LVOT-A peak/Doppler Mean = 50 mmHg
Symptoms: Catheter LVOT-A peak/Doppler Mean = 30-50 mmHg
Adults may use Doppler Peak > 50 mmHg
Resection/Konno procedure

AVmax= 4.1 m/s
MIG = 65 mmHg
PMean= 39 mmHg
Hypertrophic Obstructive Cardiomyopathy

Alcohol Septal Ablation or Surgery
High Risk features
ICD
Non-Familial Sporadic
William syndrome:
- Elfin Facial
- Hypercalcemia
- Behavioral
- Diagnosed by CVS and fetal echo

Familial Sporadic
Coronary anomalies
Types: Hour glass, Membrane, Diffuse narrowing
Surgery
Obstruction by Mitral Valve Prosthesis
Localized Pressure Loss and High Gradient in Central Orifice of Bileaflet Mechanical Valve

$AV_{max} = 3.6 \text{ m/s}$

$MILC = 53 \text{ mmHg}$

$P_{mean} = 30 \text{ mmHg}$
Localized Pressure Loss and High Gradient in Central Orifice of Bileaflet Mechanical Valve

- Fluoroscopy
Patient Prosthesis Mismatch

- Doppler Velocity Index: LVOT /aortic velocity
- Acceleration Time: Jet onset to peak
Patient Prosthesis Mismatch
Patient Prosthesis Mismatch

- \( \Delta P = \frac{Q^2}{(K \times EOA^2)} \)
- To keep gradient low, EOA must accommodate flow
- Under basal conditions, Basal flow depends on BSA, hence small valves = high gradients
- Normal DVI > 0.3, DVI = 28/108 = 0.26, Normal Acceleration time < 100 msec, Acceleration = 60 msec
- iEOA < 0.85 cm/m\(^2\) = PPM
- iEOA < 0.65 cm/m\(^2\) = severe PPM
Elevated Prosthesis Gradient

Peak Prosthetic Aortic Jet Velocity > 3 m/s

- DVI ≥ 0.30
- DVI 0.25 – 0.29
- DVI < 0.25

Jet Contour

- AT (ms)
  - >100
  - <100

Consider PrAV stenosis with
- Sub-valve narrowing
- Underestimated gradient
- Improper LVOT velocity

Normal PrAV

EOA Index

High Flow

Suggests PrAV Stenosis

Consider Improper LVOT velocity

PPM

B
Conclusions
Reverse Area Gradient Mismatch

- **Errors:** Mitral regurgitation jet/LVOT area/angle
- **Increased flow:** systemic or due to severe aortic regurgitation; Doppler & catheter
- **Pressure Recovery:** dependent on aortic area
- **Para-valve Obstruction:** above or below the valve
- **Eccentric jets:** increased pressure loss and an elevated gradient; Doppler & catheter
- **Prosthetic Valve:** Localized pressure drop, PPM
Pre Questions (1)

• The Difference between Doppler MIG and catheterization PPG
  A. Is due to pressure recovery
  B. Is due to different measurement timing of the LV and aortic pressures
  C. Occurs only in patients with small aortas
  D. Is used to calculate aortic valve area
Answer (1)

- B. Is due to different measurement timing of the LV and aortic pressures
• Catheter-Doppler Discordance maybe due to
  A. Pressure recovery
  B. Eccentric jet
  C. High flow states
  D. Very severe aortic stenosis
Pre Questions (2)

- A. Pressure recovery
Conclusions
Reverse Area Gradient Mismatch

- Watch for units to avoid miscalculations
- Realize the difference between MIG and PPG and the mean gradient by both
- EOA is not GOA.

GOA is measured by planimetry
EOA by continuity equation and is the area at the vena contracta
Aortic Stenosis Classification

Area/Gradient Match
  - Area/Gradient Match NF/HG
  - Area/Gradient Match LF/HG

Area/Gradient Mismatch Normal EF
  - Area/Gradient Mismatch NF/LG

Area/Gradient Mismatch Low EF
  - True
  - Pseudo
  - Indeterminate

Reverse Area/Gradient Mismatch
  - Flow Related
    1. Amount
    2. Eccentricity
  - Supra/Sub Valve Obstruction
  - Pressure Recovery
  - Prosthetic Valve

Low EF
  - True
  - Pseudo
  - Indeterminate

Indeterminate
THANK YOU