HOW TO ASSESS AORTIC STENOSIS:
NEW GUIDELINES, BICUSPID AORTIC VALVE, DILATED AORTIC ROOT

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DISCLOSURES

• NO FINANCIAL DISCLOSURES
• NO CONFLICTS OF INTEREST
EACVI/ASE CLINICAL RECOMMENDATIONS

Recommendations on the Echocardiographic Assessment of Aortic Valve Stenosis: A Focused Update from the European Association of Cardiovascular Imaging and the American Society of Echocardiography

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- **As = Most Common Primary Heart Valve Disease**
- **Echo is the Primary Modality for Assessment & Staging**


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ECHO ESSENTIALS FOR EVALUATION OF AS

- **Valve Anatomy for Etiology**
- **Severity of Stenosis**
- **Assisting with Management Decision-Making**
- **Recognize Low Output / Low Gradient States**
BASIC ROOT STRUCTURE
PARASTERNAL LONG AXIS VIEW

- Fibrous Annulus
- Sinotubular junction
- Leaflets
- Sinuses of Valsalva
NORMAL AV M-MODE
COAPTATION IN CENTER OF AORTIC ROOT

NORMAL AV
ORIENTATION AND OPENING

Diastole

Systole
AORTIC STENOSIS – ETIOLOGY

• SENILE / DEGENERATIVE CALCIFIC
  • RESEMBLES ECTOPIC BONE
  • RISK FACTORS ~ ATHEROSCLEROSIS
  • RENAL DYSFUNCTION MAY ACCELERATE

• PREMATURE CALCIFIC BICUSPID STENOSIS

• RHEUMATIC
  • LESS COMMON IN THE US
  • MORE FUSION / LESS CALCIFICATION

• LESS COMMON
  • TYPE 2 HYPERLIPIDEMIA, SLE, IRRADIATION, PAGET’S DISEASE

CALCIFIC AORTIC STENOSIS:
PROGRESSIVE REDUCTION IN LEAFLET MOTION
BICUSPID AORTIC VALVE

- **Most common congenital anomaly (1.3%)**
- **Commissure may be horizontal or vertical**
  - **Horizontal:** Anterior and Posterior leaflets
  - **Vertical:** Right and Left (coronary) leaflets
- **Accelerated calcification → premature stenosis**
- **Proximal aortopathy (even in normals)**
- **Associated abnormalities**
  - **Coarctation — 6% prevalence (vice versa — 50% BAV prev. w/coarct**
  - **Intracranial aneurysms — 10% prevalence, screen w/coarct**

BICUSPID AORTIC VALVE
PLAX VIEW – DOMING

Diastole

Systole
BICUSPID AORTIC VALVE
PSAX VIEW MORPHOLOGY

Diastole

Systole

SYSTOLIC ELLIPSOID ORIFICE IDENTIFIES AS BICUSPID.

BICUSPID AV PHENOTYPES

- Genetic heterogeneity
- Significance controversial
  - Raphe = ↑'ed AS, AR, ultimate AVR
  - Ø reproducible assoc — aneurysm / DISS

**BICUSPID AORTOPATHY**

- **Root & proximal ascending aorta dilated**
  - **Normal**s and **ABNLS** – out of proportion to valve Dz
  - **Risk**: Aneurysm (0.9%) & Dissection (0.03%)

- **What is “abnormal”?**
  - Dilation: Root ≥40 mm, Ascending ≥37 mm
  - Growth rate ~0.4-0.6 mm/yr

- **When to intervene?**
  - **Dissection rate (0.5%)** when aorta ≥45 mm
  - **Isolated aorta** – replace ≥55 mm, or ≥50 mm + “High risk”
  - **Surgical BAV Dz** – replace if ≥45 mm

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*Echo diagnosis, but confirm with CT or MR*

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*If first-time patient, may reimage at 6 months and if no progression then yearly*
RHEUMATIC AORTIC STENOSIS:
LESS CALCIFICATION, MORE COMMISSURAL FUSION

AORTIC VALVE:
OTHER ANOMALIES ASSOCIATED WITH AS

UNICUSPID AoV

QUADRACUSPID AoV
LVOT OBSTRUCTION RULE-OUTS

- Dynamic Sub-Valvular
- Fixed Sub-Valvular
- Supra-Valvular

ECHO ESSENTIALS FOR EVALUATION OF AS

- Valve Anatomy for Etiology
- Severity of Stenosis
- Assisting with Management Decision-Making
- Recognize Low Output / Low Gradient States
MULTIFACTORIAL ASSESSMENT OF SEVERITY

Level 1 Recommendation – Appropriate in all patients

- **Peak AV jet velocity (m/sec)**
- **Mean AV gradient (mmHg)**
- **Valve area by continuity equation (cm²) – VTI**
- **“Simplified” continuity equation – V_max**
- **Velocity ratio (dimensionless)**
- **Planimetry**

### Table 2: Measures of AS severity obtained by Doppler-echocardiography

<table>
<thead>
<tr>
<th>Measure</th>
<th>Units</th>
<th>Formula/Method</th>
<th>Cut-off for severe</th>
<th>Concept</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AS jet velocity</strong></td>
<td>m/s</td>
<td>Direct measurement</td>
<td>4.0</td>
<td>Velocity increases as stenosis severity increases</td>
<td>Direct measurement of velocity. Strongest predictor of clinical outcomes</td>
<td>Correct measurement requires parallel alignment of ultrasound beam</td>
</tr>
<tr>
<td><strong>Mean gradient</strong></td>
<td>mmHg</td>
<td>( \Delta P = \frac{1}{2} \rho v^2 )</td>
<td>40</td>
<td>Pressure gradient calculated from velocity using the Bernoulli equation</td>
<td>Mean gradient is established by tracing the velocity curve</td>
<td>Flow dependent</td>
</tr>
<tr>
<td><strong>Continuity equation valve area</strong></td>
<td>cm²</td>
<td>( AVA = \frac{V_{max} \times VTI_{max}}{VTI_{min}} )</td>
<td>1.0</td>
<td>Volume flow proximal to and in the stenotic orifice is equal</td>
<td>Measures effective orifice area. Feasible in nearly all patients</td>
<td>Requires LVOT diameter and flow velocity data, along with aortic velocity.</td>
</tr>
<tr>
<td><strong>Simplified continuity equation</strong></td>
<td>cm²</td>
<td>( AVA = \frac{V_{max} \times VTI_{max}}{VTI_{min}} )</td>
<td>1.0</td>
<td>The ratio of LVOT to aortic velocity is similar to the ratio of AVA to effective aortic valve area</td>
<td>Uses more easily measured velocities instead of VTI</td>
<td>Less accurate if shape of velocity curves is atypical.</td>
</tr>
<tr>
<td><strong>Velocity ratio</strong></td>
<td>None</td>
<td>( VR = \frac{V_{max}}{V_{aortic}} )</td>
<td>0.25</td>
<td>Effective AVA expressed as a proportion of the LVOT area</td>
<td>Doppler-only method. No need to measure LVOT size. Less variability than continuity equation.</td>
<td>Limited longitudinal data. Ignores LVOT size variability beyond patient size dependence.</td>
</tr>
<tr>
<td><strong>Planimetry of anatomic valve area</strong></td>
<td>cm²</td>
<td>TTE, TEE, 3D-echo</td>
<td>1.0</td>
<td>Anatomic (stenotic) CSA of the aortic valve orifice as measured by 2D or 3D echo</td>
<td>Useful if Doppler measurements are unreliable</td>
<td>Construction coefficients (anatomic/effective) value area may be variable. Difficult with severe valve calcification.</td>
</tr>
</tbody>
</table>
PEAK JET VELOCITY – CONTINUOUS WAVE DOPPLER

• **Multiple acoustic windows**
  • Highest velocity – R parasternal, supra-sternal

• **Parallel to ejection jet**
  • Probe positioning
  • No angle correction

• **Pedof preferred**
  • Signal-to-noise ratio
  • Optimize spectral outline
  • 50–100 mm/s sweep
  • Avoid feathery signals

AORTIC STENOSIS 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
BEWARE THE DYNAMIC GRADIENT!!


PEAK AoV GRADIENT =
“MAXIMUM INSTANTANEOUS GRADIENT”

Can be calculated from the peak jet velocity, using modified Bernoulli:

\[ 4 \times (V_{\text{MAX}})^2 \]

\[ 4 \times (5.25 \text{ m/s})^2 \]

110 mmHg
**INSTANTANEOUS VS. PEAK-TO-PEAK**

- **Doppler peak gradient always higher than Cath**
- **Echo a more “physiologic” measurement**
- **Mean gradient and AVA should correlate**
- **Gradients are flow dependent**

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**MEAN GRADIENT – CONTINUOUS WAVE DOPPLER**

- **Average gradient during entire ejection period**
  - Integration of velocity over time
  - Approximately 70% of Peak Instantaneous Gradient

**STENOSIS SEVERITY BY MEAN GRADIENT**

- **Mild stenosis:** < 20 mmHg
- **Mod stenosis:** 20 – 39 mmHg
- **Severe stenosis:** ≥ 40 mmHg
**PITFALLS OF MEASUREMENT**

- **Misalignment with Aortic Flow**
  - Under-estimation of peak velocity
  - Major under-estimation of mean gradient

- **Recording Eccentric MR Jet**
  - Major over-estimation of velocity & gradient
  - CW spectral morphology differences

- **Pressure Recovery Issues**
  - Magnitude ~ EOA / Aortic-A
  - Over-estimation of PV & MG with small aortas (<30 mm)

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**PITFALLS OF "FLOW STATES"**

- **Higher SV = Higher Gradients**
  - Aortic regurgitation
  - Hyperdynamic function

- **Lower SV = Lower Gradients**
  - Reduced ejection fraction
  - Small ventricular cavity (LVH)
  - High systemic vascular resistance / impedance
  - Significant mitral regurgitation
AORTIC STENOSIS
VALVE AREA ASSESSMENT

- NORMAL VALVE AREA = 3 - 4 cm²
- MILD STENOSIS: > 1.5 cm²
- MODERATE STENOSIS: 1.0 - 1.5 cm²
- SEVERE STENOSIS: < 1.0 cm²
- “CRITICAL” STENOSIS: < 0.7 cm²

CONTINUITY EQUATION

BASED ON CONSERVATION OF MASS

FLOW WITHIN LVOT = FLOW ACROSS AV

- LVOT AREA * VTI_{LVOT} = AVA * VTI_{AV}
- \( \pi \times (LVOT_{\text{radius}})^2 \) * VTI_{LVOT} = AVA * VTI_{AV}

\[
\frac{\pi \times (LVOT_{\text{radius}})^2 \times VTI_{LVOT}}{VTI_{AV}} = AVA
\]
LVOT diameter 2.1 cm

PITFALLS – THE LVOT IS NEVER EASY

???  Go slightly off-axis

FLOW THROUGH LVOT
PULSE WAVE DOPPLER

- PW SPECTRAL ENVELOPE
  - SAMPLE VOLUME IN LVOT
  - LAMINAR ENVELOPE !!
  - APICAL VIEWS

- 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

• \( \text{AVA} = \frac{(\text{Diameter}_{LVOT} / 2)^2 \times \pi \times VTI_{LVOT}}{VTI_{AV}} \)

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

• \( \text{AVA} = 0.7 \text{ cm}^2 \)

PITFALLS FOR THE CONTINUITY EQUATION

• LVOT MEASUREMENT
  • \( \text{RADIUS}^2 \) – PROPAGATE LARGER ERROR
  • LVOT ELLIPTICAL – CSA FROM 3D TEE OR CT

• LVOT VELOCITY
  • TOO CLOSE TO THE AV – OVER-ESTIMATE AVA
  • TOO FAR INTO THE LV – UNDER-ESTIMATE AVA

• AV VELOCITY
  • MISSING TRUE PEAK:
    • USE MULTIPLE SITES / PEDOF / HIGHEST VELOCITY
  • BEWARE MR!
DOPPLER VELOCITY RATIO

• Derived from continuity equation
  • Eliminates some errors — no LVOT factor
  • Relatively “flow independent”

\[ \text{DVR} = \frac{\text{VTI}_{LVOT}}{\text{VTI}_{AV}} \]

• Can use velocity instead of VTI

• Criteria for severe AS – DVR < 0.25

PLANIMETRY OF THE AORTIC VALVE

• Correlates with invasively obtained areas

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

• TEE superior
  • Use color flow area

• Dense calcification reduces accuracy

AVA = 1.1 cm²
**SUMMARY**

**MEMORIZE!!!**

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Recommendations for grading of AS severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic sclerosis</td>
<td>Mild</td>
</tr>
<tr>
<td>Peak velocity (m/s)</td>
<td>≤ 2.5 m/s</td>
</tr>
<tr>
<td>Mean gradient (mmHg)</td>
<td>–</td>
</tr>
<tr>
<td>AVA (cm²)</td>
<td>–</td>
</tr>
<tr>
<td>Indexed AVA (cm²/m²)</td>
<td>–</td>
</tr>
<tr>
<td>Velocity ratio</td>
<td>–</td>
</tr>
</tbody>
</table>

**ECHO ESSENTIALS FOR EVALUATION OF AS**

- **Valve anatomy for etiology**
- **Severity of stenosis**
- **Assisting with management decision-making**
- **Recognize low output / low gradient states**
AORTIC STENOSIS – PHYSIOLOGIC SEQUELAE

• CHRONIC LV PRESSURE OVERLOAD
  • MYOCARDIAL HYPERTROPHY – PROGRESSIVE, CONCENTRIC
  • LA DILATATION

• PROGRESSIVE DYSFUNCTION
  • DIASTOLIC, THEN SYSTOLIC
  • END STAGE – LIMITED CARDIAC OUTPUT

• AFTER LONG LATENCY... SYMPTOMS
  • EARLY – DYSPNEA AND FATIGUE (OFTEN SUBLTE)
  • LATE – "CARDINAL SX" – ANGINA, SYNCOPE, CHF

THE OLD DAYS:
THE “SYMPTOMATIC CLIFF”

[Diagram showing survival rates and onset of severe symptoms with age]

BRAUNWALD E, ET AL. CIRCULATION (1968) 38:61-67
THE NEW ERA (2014) 
“STAGES” OF DISEASE

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

• **Stage B:**
  • Progressive disease (asymptomatic)

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

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

“Stage C” can be subdivided:

• **Stage A:**
  • At risk for disease  
  ![Observe]

• **Stage B:**
  • Progressive disease  
  ![Observe]

• **Stage C1:**
  • Severe (asymptomatic) – Compensated LV  
  ![??]

• **Stage C2:**
  • Severe (asymptomatic) – Decompensated LV  
  ![Intervene]

• **Stage D:**
  • Severe disease (symptomatic)  
  ![Intervene]
ASSIST DECISION-MAKING IN ASYMPTOMATIC PATIENT

CALCIFIED/THICKENED LEAFLETS
REDUCED SYSTOLIC OPENING

“ASYMPTOMATIC”

V\text{max} \geq 5 \text{ m/s} + \text{low AVR risk}

\begin{align*}
\text{V}_{\text{max}} \geq 4 \text{ m/s; MG} \geq 40\text{mmHg} \\
\text{EF} < 50\% \\
\text{ETT} \downarrow \text{BP} \downarrow \text{ex capacity} \\
\text{Rapid progression + low AVR risk}
\end{align*}

\begin{align*}
\text{AVR (IIa)} & \quad \text{AVR (I)} & \quad \text{AVR (I)} & \quad \text{AVR (IIa)} & \quad \text{AVR (IIb)}
\end{align*}

ECHO ESSENTIALS FOR EVALUATION OF AS

• VALVE ANATOMY FOR ETIOLOGY
• SEVERITY OF STENOSIS
• ASSISTING WITH MANAGEMENT DECISION-MAKING
• RECOGNIZE LOW OUTPUT / LOW GRADIENT STATES
LOW GRADIENT" AORTIC STENOSIS

Peak Velocity
2.74 m/sec

Mean Gradient
15 mmHg

Calculated AVA
0.5 cm²

LOW GRADIENT AS
LOW OUTPUT - LOW EJECTION FRACTION

- Low SV (Low Flow) leads to low gradients

- "REAL AS"
  - 1° Problem: Severe obstruction to flow
  - 2° Problem: Depressed EF

- "PSEUDO AS"
  - 1° Problem: Depressed EF
  - 2° Problem: Moderate obstruction to flow
    Made to look severe by SV

Improves with AVR

Does not improve with AVR
LOW GRADIENT AS
DOBUTAMINE STRESS ECHO

- Low dose Dobutamine (<10 mcg/kg/min)
  - ↑ LV contractility  ↑ Stroke Volume
- Increase SV by ≥ 20%
  - Real AS  Peak vel / mean gradient ↑-↑↑
    AVA unchanged or ↓ (≤ 1 cm²)
  - Pseudo AS  Peak vel / mean gradient minimal ↑
    AVA typically ↑ (>1 cm²)

- What if SV doesn’t increase?
  - Lack of contractile reserve – bad situation

LOW GRADIENT AS
LOW OUTPUT - NORMAL EJECTION FRACTION

- EF >50%, AVA ≤1 cm²  ... but MG <40 mmHg?
- Still at stroke volume problem
  - SV INDEX ≤35 mL/m² despite NL EF
- “Typical” patient:
  - Older, h/o hypertension, women
  - Concentric LVH, small cavity, impaired filling
  - Markedly increased vascular impedance
- Low dose DSE may or may not help

SUMMARY - ACE THE EXAM!!
ECHO ESSENTIALS FOR EVALUATION OF AS

- **Valve Anatomy for Etiology**
  - Trileaflet Calcific, BAV, Rheumatic

- **Severity of Stenosis**
  - Know "The Big 3" — Memorize Table 3 from EACVI/ASE

- **Assisting with Management Decision-Making**
  - Physiologic sequelae (LVH/Dysfxn); Concurrent DZ
  - How ECHO Helps in Asymptomatic and Symptomatic AS

- **Recognize Low Output / Low Gradient States**
  - Discern TRUE from PSEUDO Severe AS