Aortic Stenosis:
Spectrum of Disease, Low Flow/Low Gradient and Variants

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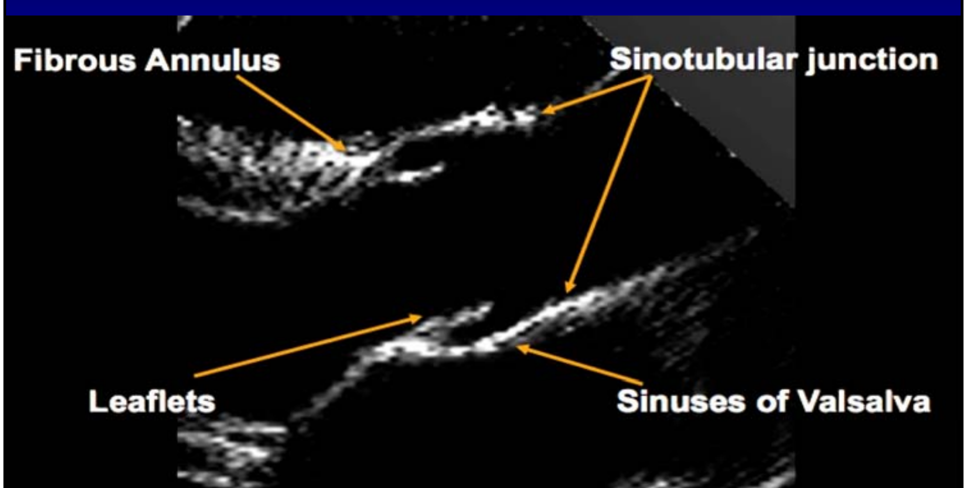
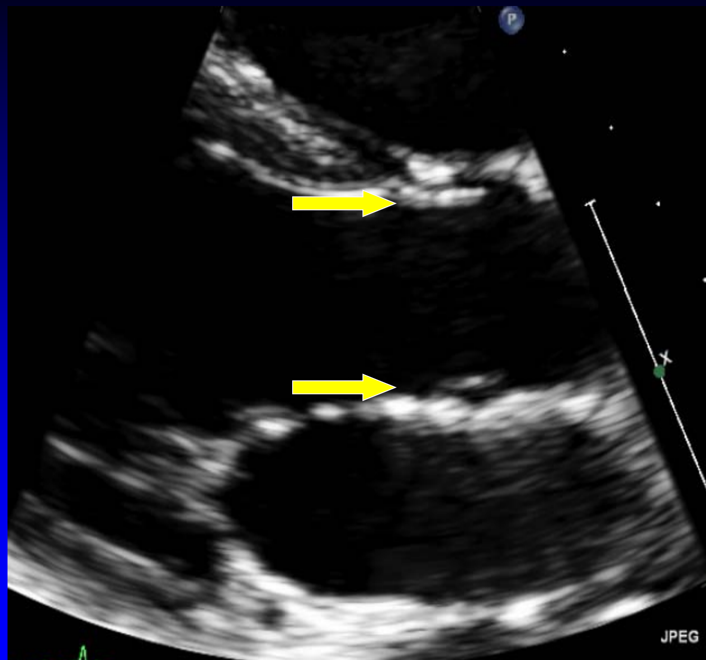
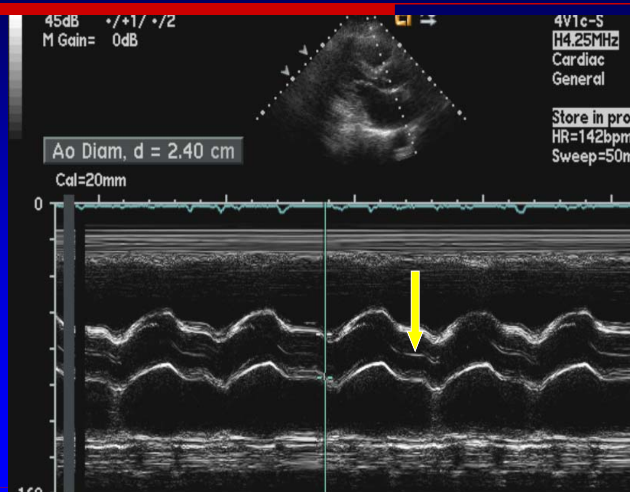
Basic root structure
Parasternal Long Axis View





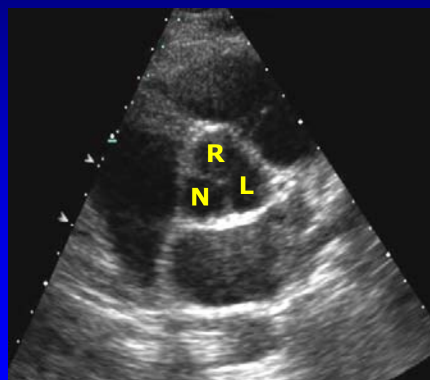
Normal AV M-Mode

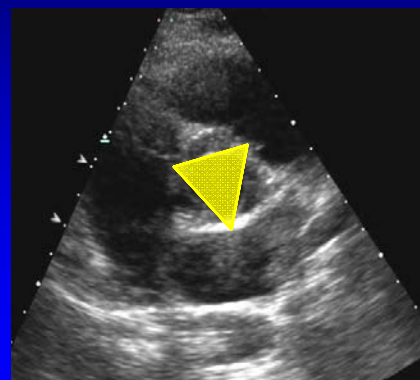
coaptation in center of aortic root



Normal AV
orientation and opening

Diastole **Systole**

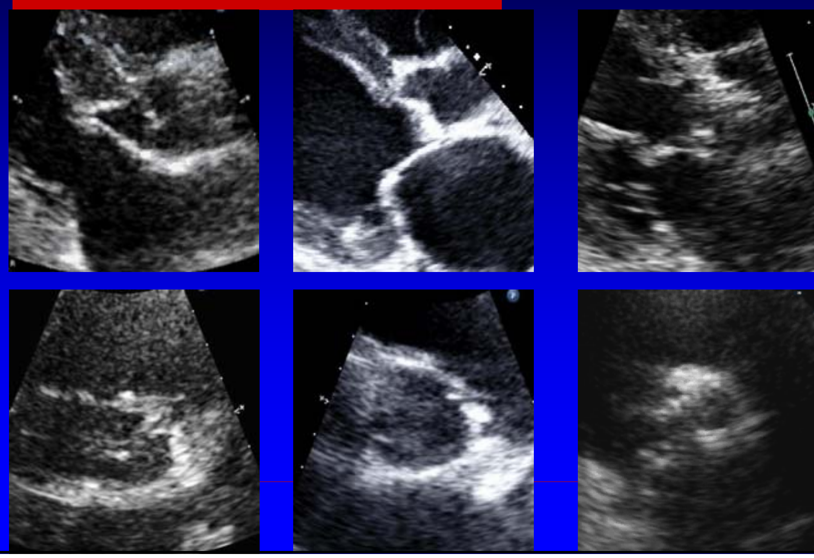




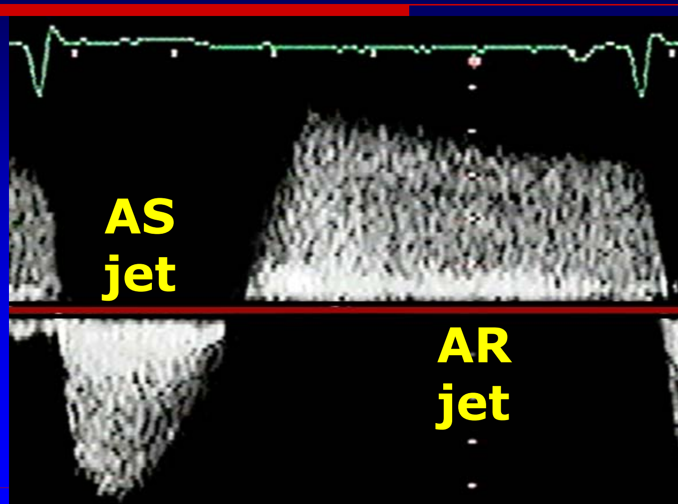
Aortic Stenosis
Etiology

- 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:
Progressive reduction in leaflet motion



Spectral Doppler of the AV
Apical Five Chamber



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 abnormalities - coarctation

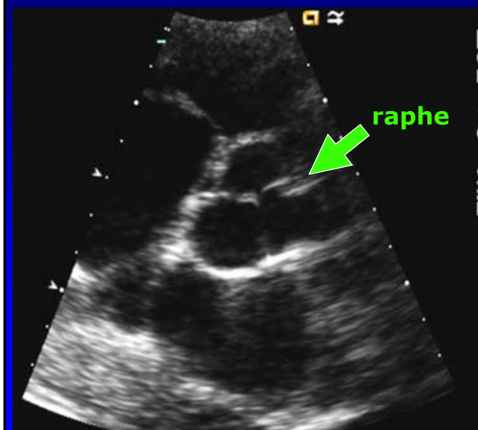
Bicuspid Aortic Valve
PLAX View – Doming

Diastole

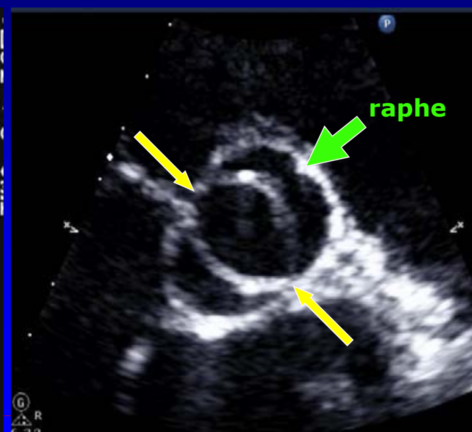
Systole

Bicuspid Aortic Valve
PSAX view morphology

Diastole

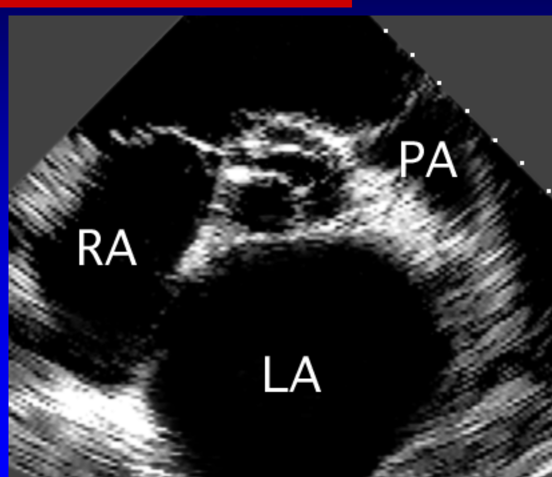


Systole



Systolic ellipsoid orifice identifies as

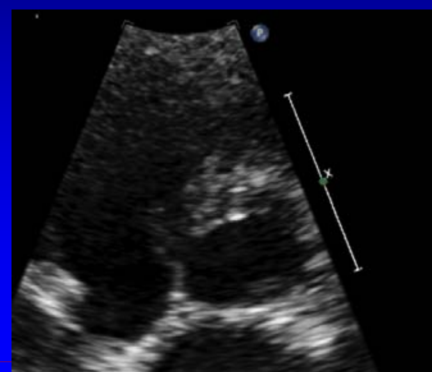
Rheumatic Aortic Stenosis:
Less calcification, More commissural fusion



Aortic Valve:
Other Anomalies associated with AS

Unicuspid AoV

Quadracuspid AoV



Aortic Stenosis:
Physiologic Sequelae

- **Chronic LV pressure overload**
  - Myocardial Hypertrophy – Progressive, Concentric
  - LA dilatation
- **Progressive diastolic & systolic dysfunction**
  - END STAGE: Limited Cardiac Output
- **After long latency… SYMPTOMS:**
  - Early: Dyspnea and Fatigue (often subtle)
  - Late: “Cardinal Symptoms”
    - 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

} ASE / EAE Recommend

- Velocity Ratio ("Dynamic Index", "Dimensionless Index"…)
- Planimetry

AS: Assessing Severity - 2017

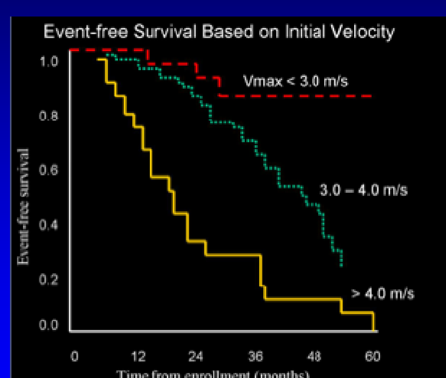
Table 2 Measures of AS severity obtained by Doppler-echocardiography

	Units	Formula/method	Cut-off for severe	Concept	Advantages	Limitations
AS jet velocity[12-15]	m/s	Direct measurement	4.0	Velocity increases as stenosis severity increases	Direct measurement of velocity. Strongest predictor of clinical outcome	• Correct measurement requires parallel alignment of ultrasound beam • Flow dependent.
Mean gradient[12-14]	mmHg	$\Delta P = \sum 4v^2/N$	40	Pressure gradient calculated from velocity using the Bernouli equation	• Mean gradient is obtained by tracing the velocity curve • Units comparable to invasive measurements	• Accurate pressure gradients depend on accurate velocity data • Flow dependent
Continuity equation valve area[16-18]	cm^2	$AVA = (CSA_{LVOT} \times VTI_{LVOT})/VTI_{AV}$	1.0	Volume flow proximal to and in the stenotic orifice is equal	• Measures effective orifice area • Feasible in nearly all patients • Relatively flow independent	Requires LVOT diameter and flow velocity data, along with aortic velocity. Measurement error more likely
Simplified continuity equation[18,19]	cm^2	$AVA = (CSA_{LVOT} \times V_{LVOT})/V_{AV}$	1.0	The ratio of LVOT to aortic velocity is similar to the ratio of VTIs with native aortic valve stenosis	Uses more easily measured velocities instead of VTIs	Less accurate if shape of velocity curves is atypical
Velocity ratio[19,20]	None	$VR = \frac{V_{LVOT}}{V_{AV}}$	0.25	Effective AVA expressed as a proportion of the LVOT area	Doppler-only method. No need to measure LVOT size, less variability than continuity equation	Limited longitudinal data. Ignores LVOT size variability beyond patient size dependence
Planimetry of anatomic valve area[21,22]	cm^2	TTE, TEE, 3D-echo	1.0	Anatomic (geometric) CSA of the aortic valve orifice as measured by 2D or 3D echo	Useful if Doppler measurements are unavailable	Contraction coefficient (anatomic/effective valve area) may be variable. Difficult with severe valve calcification

Baumgartner H, et al. ***JASE*** (2017) 30:372-392

Aortic Stenosis:
Prognosis of Velocity

- Variable Rate of Progression
  - Avg ~0.3 m/sec/year
- High rate of events, even for "asymptomatic" AS
- Peak Jet Velocity, Rate of velocity change, Functional status: predict clinical outcome



Otto C, et al. Circulation (1997) 95:2262

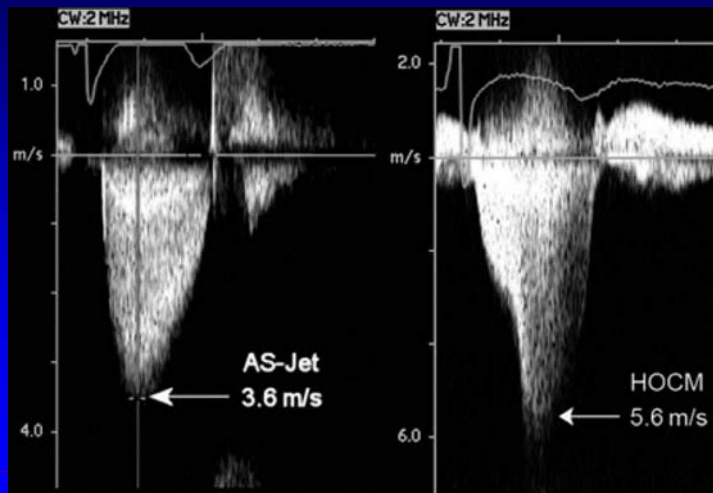
Aortic Stenosis:
Peak Velocity – Continuous Wave (CW) Doppler

- Generally in A5C View, also Apical LAX (A3C)
- **Parallel to the ejection jet!**
- Confirm – Right Parasternal
  - Suprasternal also possible
- Use highest velocity
  - Avoid feathery signals at tip
  - Piedoff –
    - "non-imaging" probe
    - "Dual Crystal CWD Transducer"

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

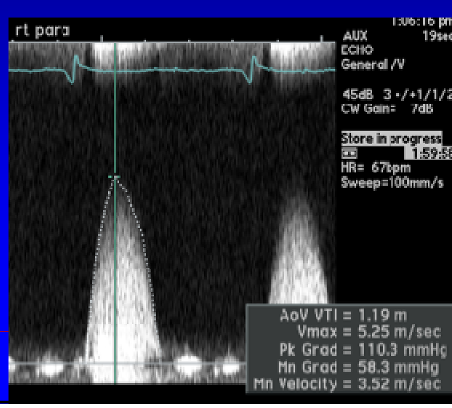
Beware the Dynamic Gradient!!



Baumgartner H, et al. ***JASE*** (2017) 30:372-392

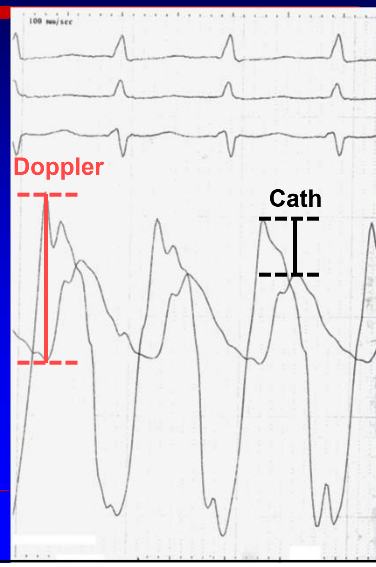
Aortic Stenosis:
Peak Gradient

- **Peak Gradient = 4 (V_{AV})^2**
  - Peak Instantaneous Gradient



Instantaneous 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 * 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: ≥ 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

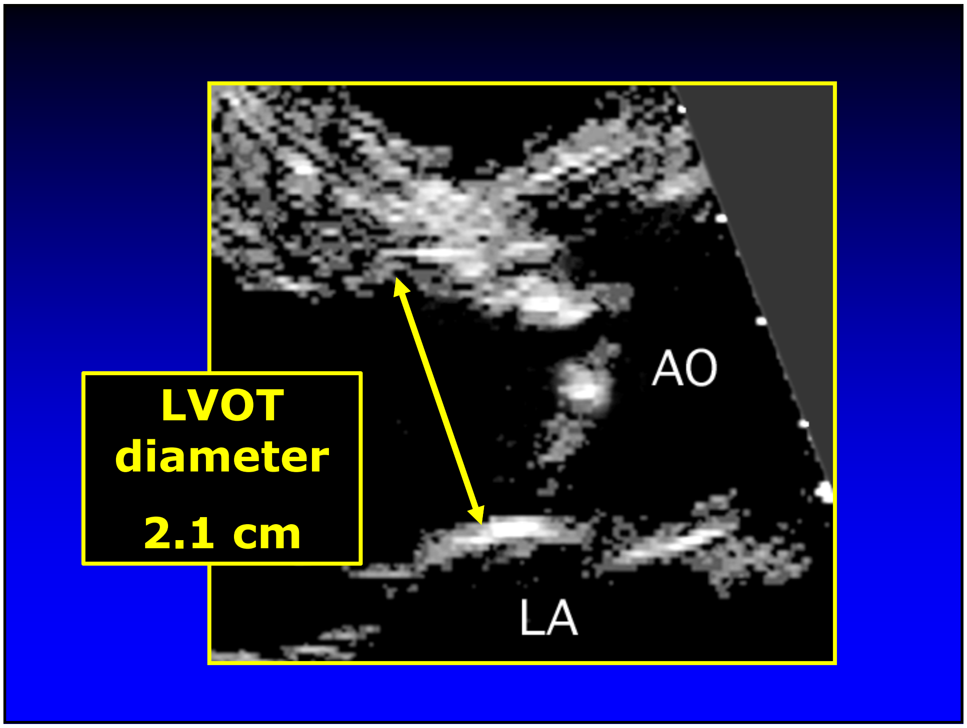
- Normal valve area: $= 3 - 4\ cm^2$
- Mild stenosis: $> 1.5\ cm^2$
- Moderate stenosis: $1.0 – 1.5\ cm^2$
- Severe stenosis: $< 1.0\ cm^2$
- "Critical" stenosis: $< 0.7\ cm^2$

Calculation of AV Area:
Continuity Equation

- Based on conservation of mass

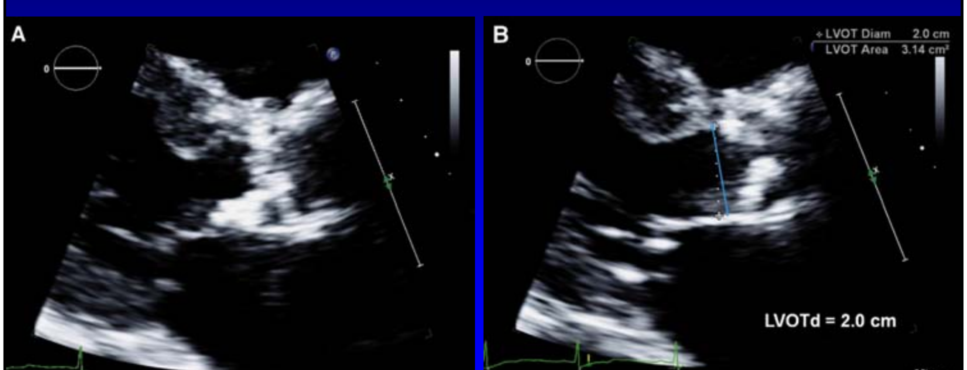
Flow within LVOT = Flow across AV

- $\text{LVOT area} * VTI_{LVOT} = AVA * VTI_{AV}$
- $[\pi * (LVOT_{radius})^2] * VTI_{LVOT} = AVA * VTI_{AV}$
- $\dfrac{[\pi * (LVOT_{radius})^2] * VTI_{LVOT}}{VTI_{AV}} = AVA$



The LVOT is never easy...

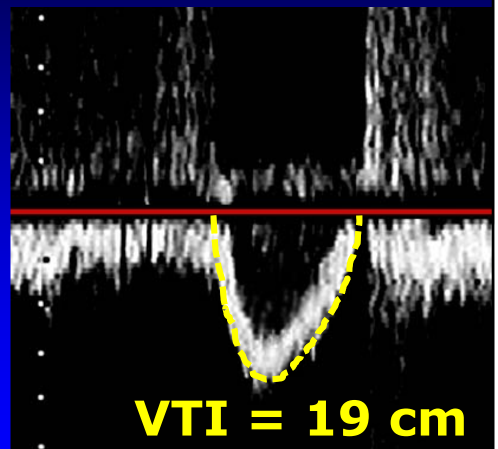
??? | Go slightly off-axis



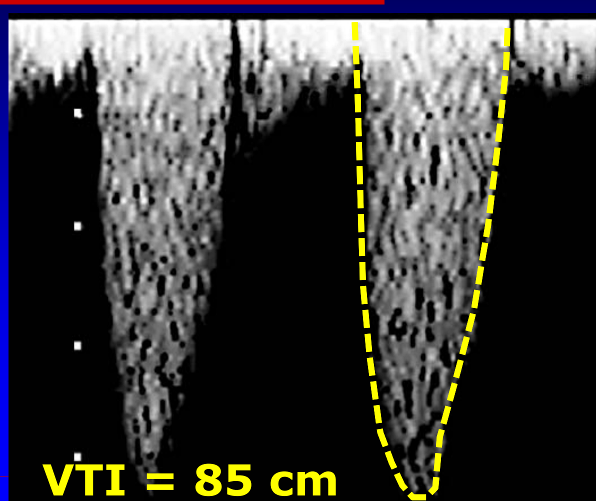
Baumgartner H, et al. ***JASE*** (2017) 30:372-392

Flow through LVOT
Pulse Wave Doppler

- Spectral Envelope
  - With sample volume in LVOT
- **Velocity Time Integral (VTI)**
  - flow through a single point



Flow Across the Aortic Valve:
Continuous Wave Doppler



Calculating Aortic Valve Area

- AVA = $\dfrac{(\text{Diameter}_{LVOT} / 2)^2 \times \pi \times VTI_{LVOT}}{VTI_{AV}}$
- AVA = $\dfrac{(2.1\ \text{cm} / 2)^2 \times 3.14 \times 19\ \text{cm}}{85\ \text{cm}}$
- **AVA = 0.7 cm^2**

Continuity Equation: *Pitfalls*

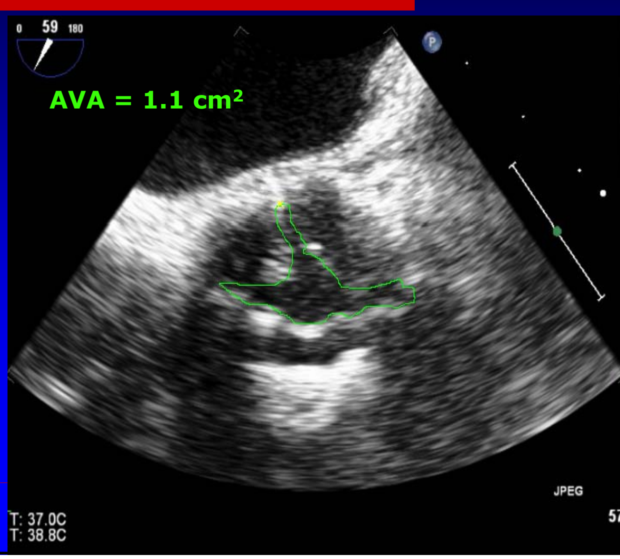
- **LVOT measurement**
  - **Diameter^2** - Can propagate large error
  - LVOT often elliptical – CSA best from 3D TEE or CT
- LVOT velocity
- AV velocity
  - Missing the Peak:
    - Use multiple sites / Piedoff / highest velocity
  - Beware MR!

Doppler Velocity Index

- Eliminates errors of LVOT measurement
  - **DVI = VTI_{LVOT} / VTI_{AV}**
- Criteria for Severe AS:
  - **DVI < 0.25**

Relatively flow-independent measure of stenosis

Planimetry of the Aortic Valve



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 grading of AS severity

	Aortic sclerosis	Mild	Moderate	Severe
Peak velocity (m/s)	≤2.5 m/s	2.6–2.9	3.0–4.0	≥4.0
Mean gradient (mmHg)	–	<20	20–40	≥40
AVA (cm^2)	–	> 1.5	1.0–1.5	<1.0
Indexed AVA (cm^2/m^2)	–	>0.85	0.60–0.85	<0.6
Velocity ratio	–	> 0.50	0.25–0.50	<0.25

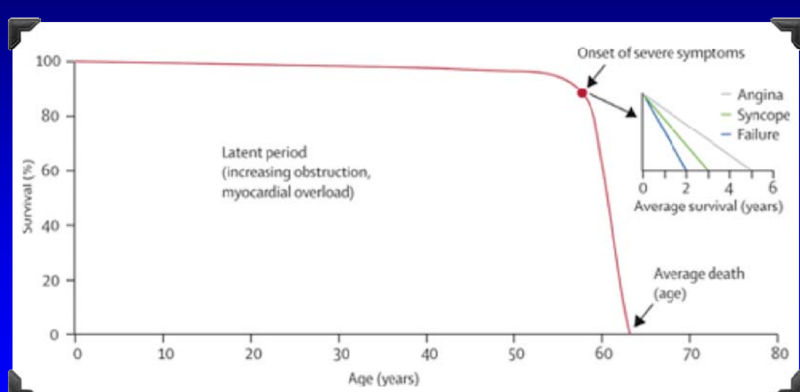
Baumgartner H, et al. ***JASE*** (2017) 30:372-392

So…

My patient has severe aortic stenosis! What do I do? Does echo help me?

WHEN SHOULD I OPERATE?

The Good Old Days: *The Symptomatic "Cliff"*



Braunwald E, et al. *Circulation* (1968) 38:61-67

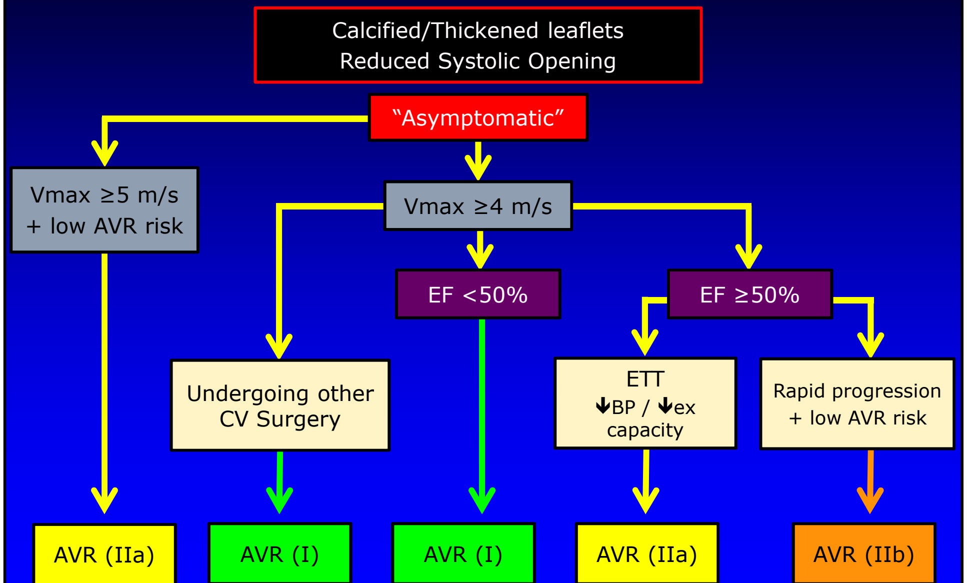
"Stages" of Disease

- **Stage A:**
  - At risk for disease
- **Stage B:**
  - Progressive disease
- **Stage C:**
  - Severe disease (asymptomatic)
- **Stage D:**
  - Severe disease (symptomatic)

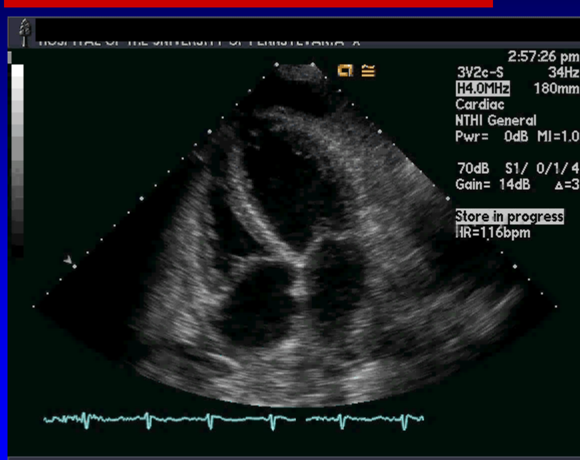
"Stage C" can be subdivided:

- **Stage A:** — Observe
  - At risk for disease
- **Stage B:** — Observe
  - Progressive disease
- **Stage C1:** — ???
  - Severe (asymptomatic) – Compensated LV
- **Stage C2:** — Intervene
  - Severe (asymptomatic) – Decompensated LV
- **Stage D:** — Intervene
  - Severe disease (symptomatic)

Guidelines Assist in Decision-Making



"Low Gradient" Aortic Stenosis



Peak Velocity
2.74 m/sec

Mean Gradient
15 mmHg

Calculated AVA
0.5 cm²

Low Output – Low Gradient AS
Low Ejection Fraction

- AVA of 0.5 cm^2, but MG of 15mmHg? WHY?
  - Because low SV (low flow) leads to low gradients
- **"Real AS"**
  - 1^o Prob: Severe obstruction to flow
  - 2^o Prob: Depressed LVEF
- **"Pseudo-AS"**
  - 1^o Prob: Depressed LVEF
  - 2^o Prob: Mild/Mod obstruction is made to look severe by ↓SV

Improves with AVR

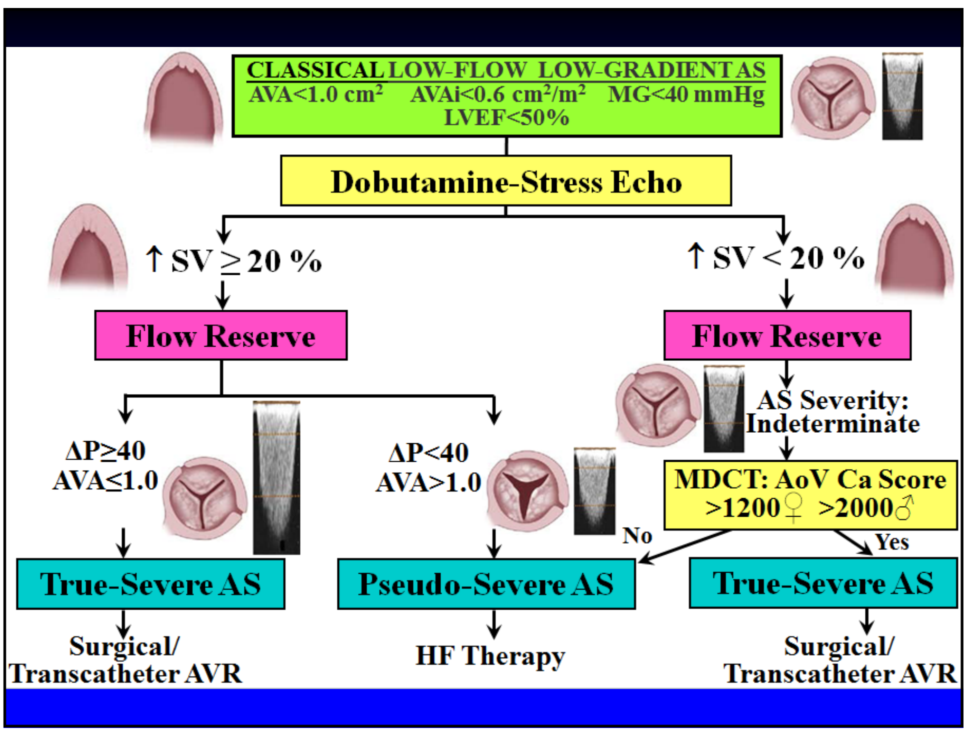
Low Output – Low Gradient AS

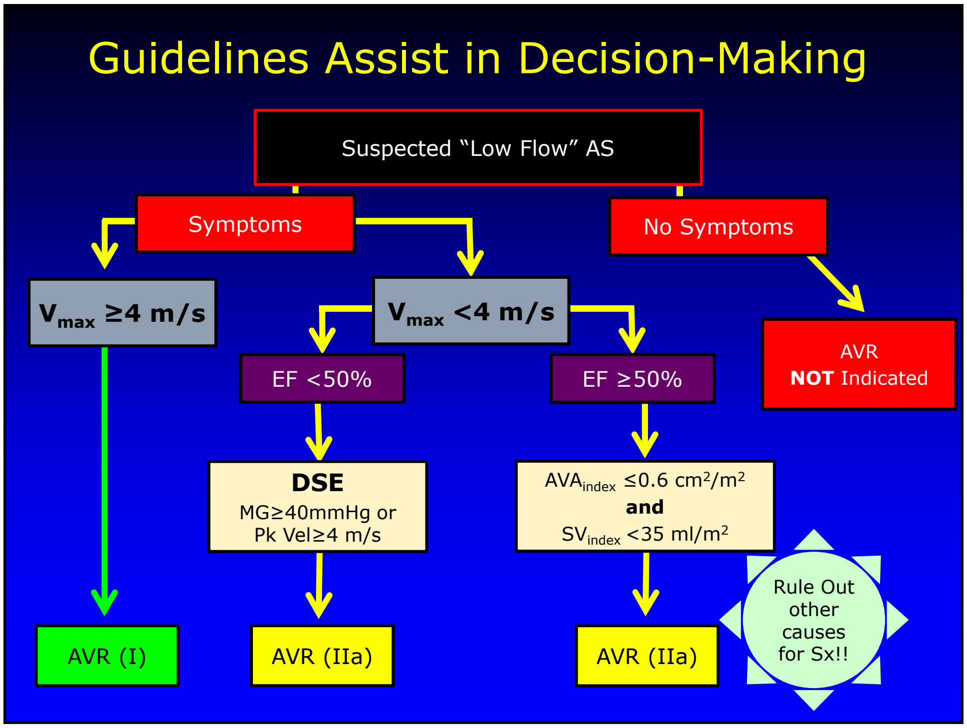
- Dobutamine Stress Testing
  - Increase LV contractility -> Increase Stroke Volume
- Increase Stroke Volume by 20% ->
  - **Real AS** Peak vel/mean gradient significantly↑↑ AVA stays unchanged or ↓slightly
  - **Pseudo AS** Peak vel/mean gradient minimal↑ AVA↑
- What if LV contractility / SV don't increase?

Low Gradient - Normal EF

- EF ≥50%, AVA <1 cm^2, mean grad <40mmHg
  - Whah???...
- **Still a stroke volume problem!!**
  - **SV_{index} ≤35 ml/m^2 despite EF**
- “Typical” patient:
  - Older, h/o hypertension, women
  - Concentric LVH, small cavity, impaired filling
  - Markedly increased vascular impedance

Pibarot P, Dumesnil JG. **Heart** (2010) 96:1431-33




Guidelines Assist in Decision-Making
Suspected "Low Flow" AS
Symptoms
No Symptoms
V_{max} ≥4 m/s
V_{max} <4 m/s
EF <50%
EF ≥50%
AVR
NOT Indicated
DSE
MG≥40mmHg or
Pk Vel≥4 m/s
AVA_{index} ≤0.6 cm²/m²
and
SV_{index} <35 ml/m²
Rule Out other causes for Sx!!
AVR (I)
AVR (IIa)
AVR (IIa)

Thank You!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