HOW TO ASSESS AORTIC STENOSIS:

NEW GUIDELINES, BICUSPID AORTIC VALVE, DILATED AORTIC ROOT

MARTIN G. KEANE, MD, FASE
PROFESSOR OF MEDICINE, LEWIS KATZ SCHOOL OF MEDICINE
DIRECTOR OF ECHOCARDIOGRAPHY, TEMPLE UNIVERSITY HEALTH SYSTEM

ASCeXAM/ReASCE REVIEW COURSE 19th ANNUAL

The most comprehensive review to help you prepare for the NBE certification examinations.

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

Helmut Baumgartner, MD, FESC, (Chair), Judy Hung, MD, FASE, (Co-Chair), Javier Bermejo, MD, PhD, John B. Chambers, MB BChir, FESC, Thor Edvardsen, MD, PhD, FESC, Steven Goldstein, MD, FASE, Patrizio Lancellotti, MD, PhD, FESC, Melissa LeFevre, RDCS, Fletcher Miller Jr., MD, FASE, and Catherine M. Otto, MD, FESC, *Muenster, Germany; Boston, Massachusetts; Madrid, Spain; London, United Kingdom; Oslo, Norway; Washington, District of Columbia; Liège, Belgium; Bari, Italy; Durham, North Carolina; Rochester, Minnesota; and Seattle, Washington*

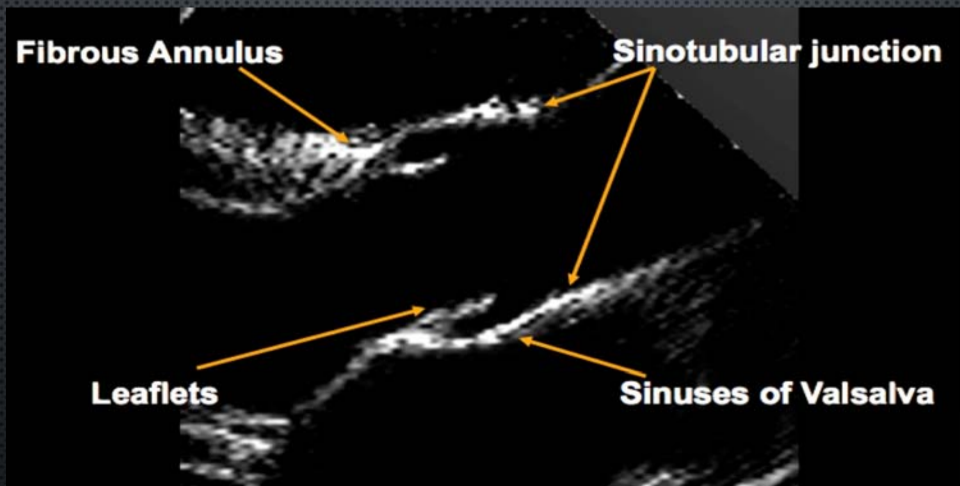
- AS = MOST COMMON PRIMARY HEART VALVE DISEASE
- ECHO IS THE **PRIMARY MODALITY** FOR ASSESSMENT & STAGING

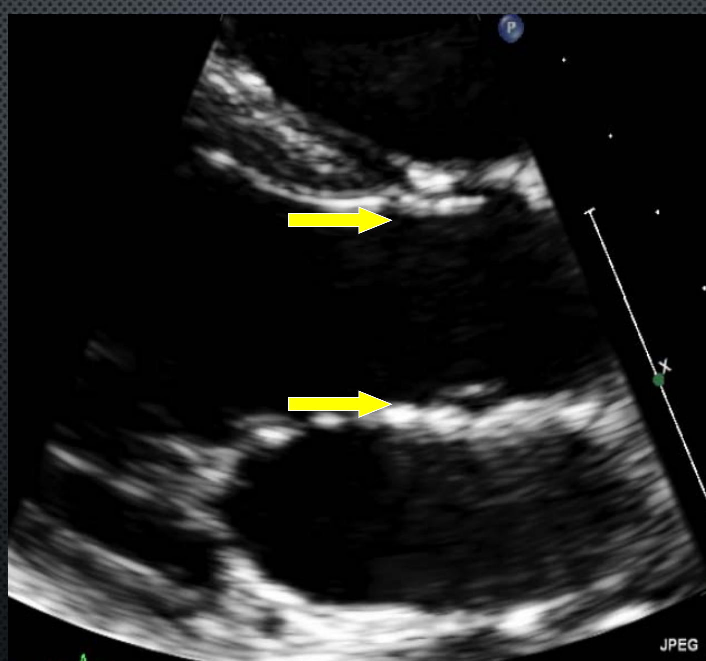
Baumgartner H, et al. **J Am Soc Echocardiogr** (2017) 30:372-392

ECHO ESSENTIALS FOR EVALUATION OF AS

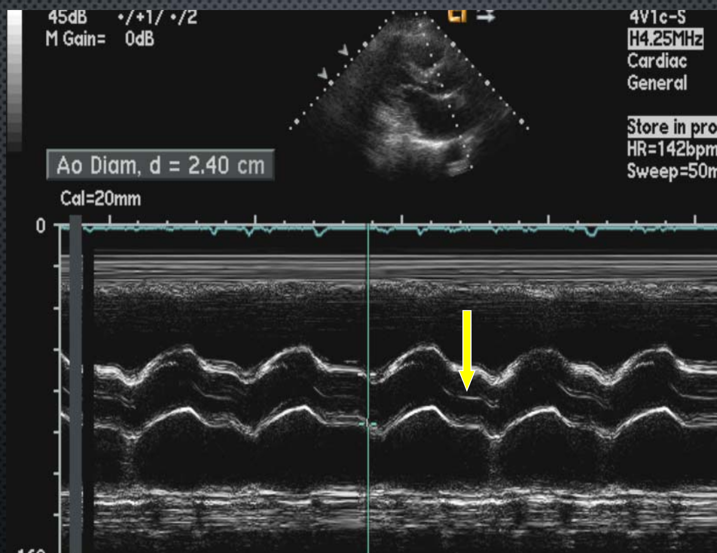
- VALVE ANATOMY FOR ETIOLOGY
- SEVERITY OF STENOSIS
- ASSISTING WITH MANAGEMENT DECISION-MAKING
- RECOGNIZE LOW OUTPUT / LOW GRADIENT STATES

BASIC ROOT STRUCTURE
PARASTERNAL LONG AXIS VIEW



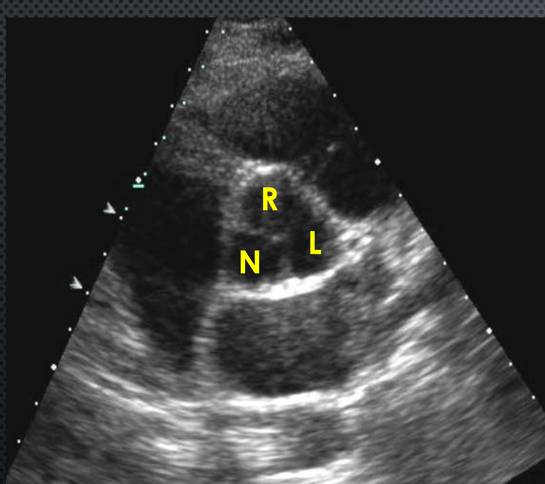


NORMAL AV M-MODE
COAPTATION IN CENTER OF AORTIC ROOT

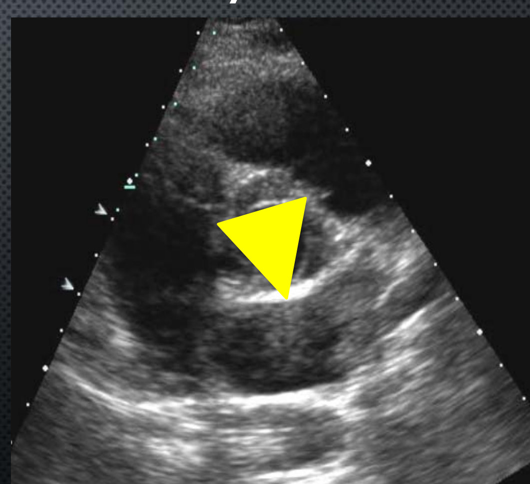


NORMAL AV
ORIENTATION AND OPENING

Diastole



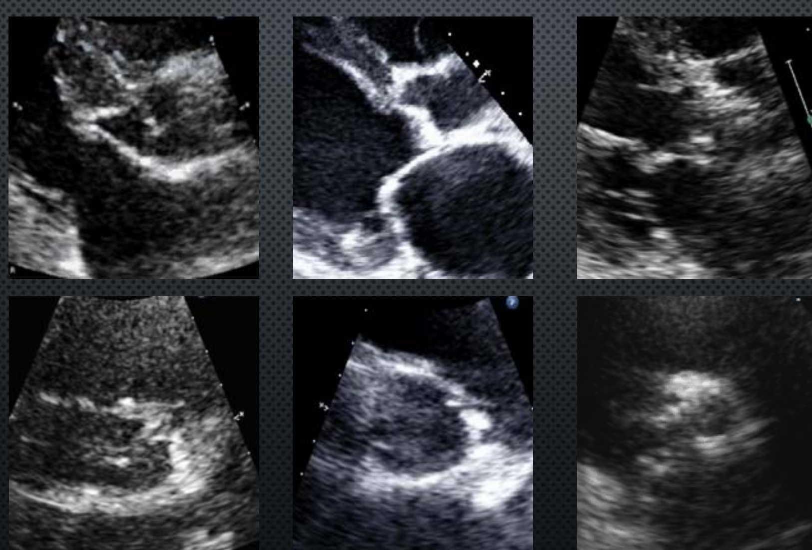
Systole



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

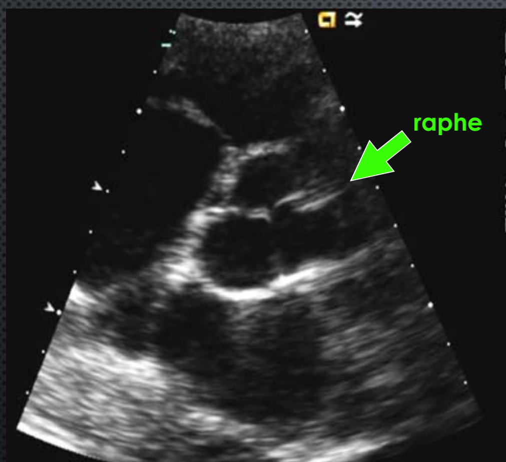
BICUSPID AORTIC VALVE
PLAX VIEW – DOMING

Diastole

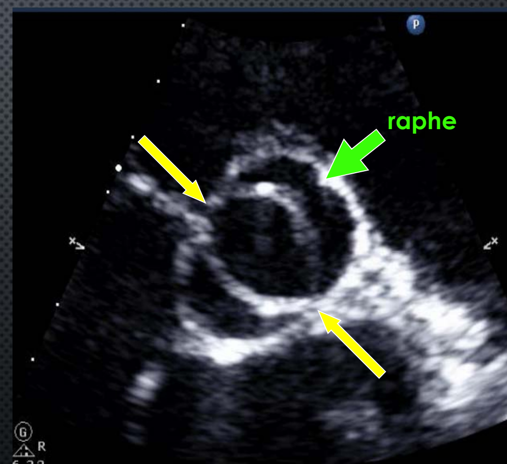
Systole

BICUSPID AORTIC VALVE
PSAX VIEW MORPHOLOGY

Diastole

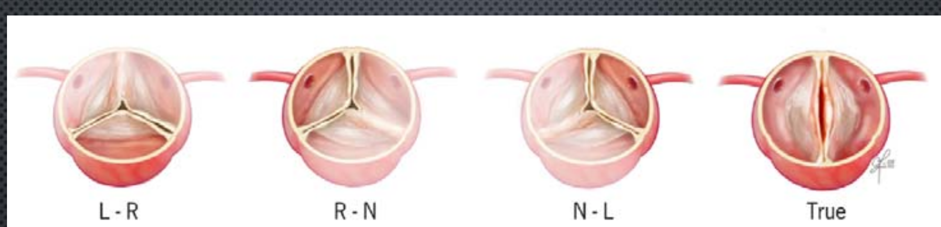


Systole



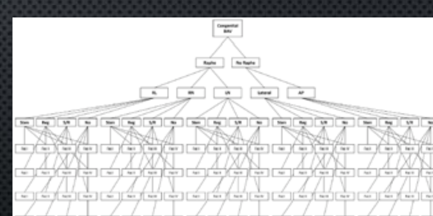
SYSTOLIC ELLIPSOID ORIFICE IDENTIFIES AS BICUSPID.

BICUSPID AV PHENOTYPES



80%

20%



- GENETIC HETEROGENEITY
- SIGNIFICANCE CONTROVERSIAL
  - RAPHE = ↑'ED AS, AR, ULTIMATE AVR
  - Ø REPRODUCIBLE ASSOC – ANEURYSM / DISS

Masri A, et al. **Heart** (2017) 103:1323-1330

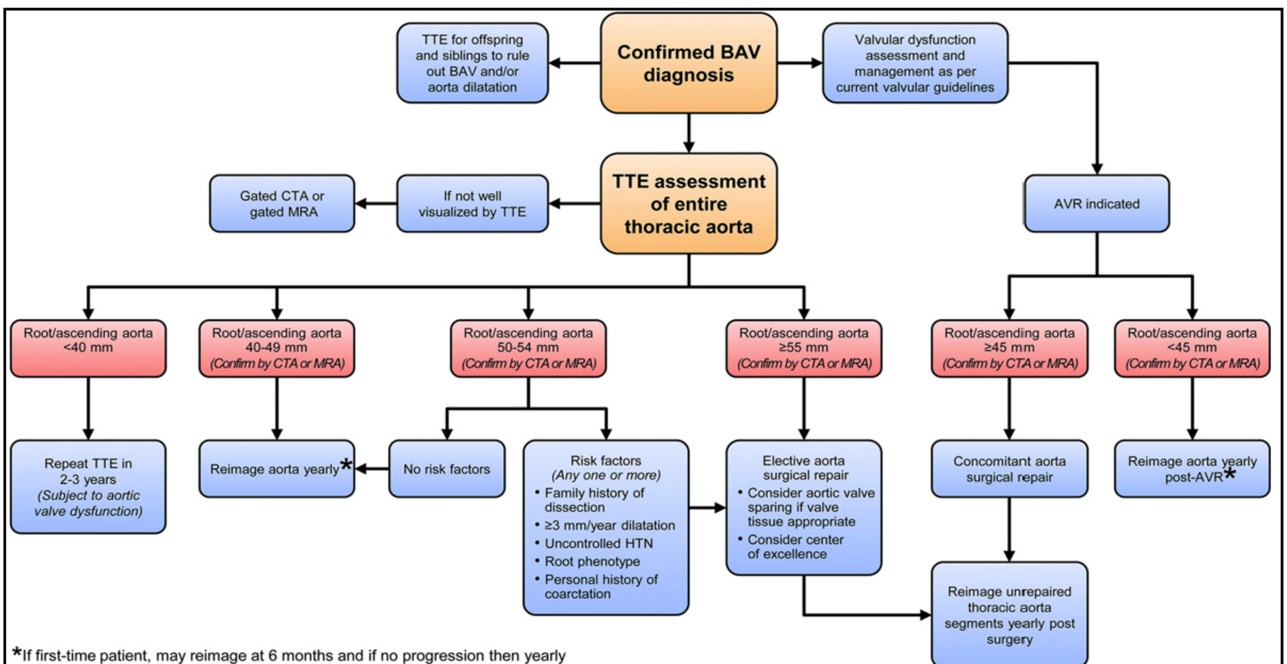
BICUSPID AORTOPATHY

HETEROGENEITY

- Root & proximal ascending aorta dilated
  - **Normals** 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

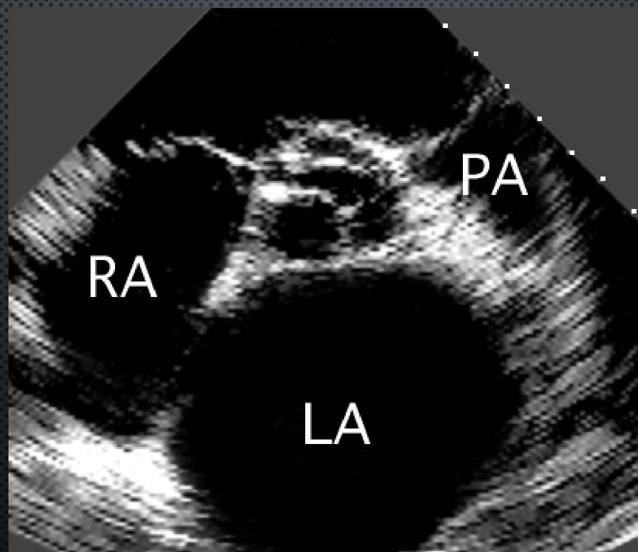
Echo diagnosis, but confirm with CT or MR

Michelina HI, et al. **Int J Cardiol** (2015) 201:400-407



Michelina HI, et al. **Int J Cardiol** (2015) 201:400-407

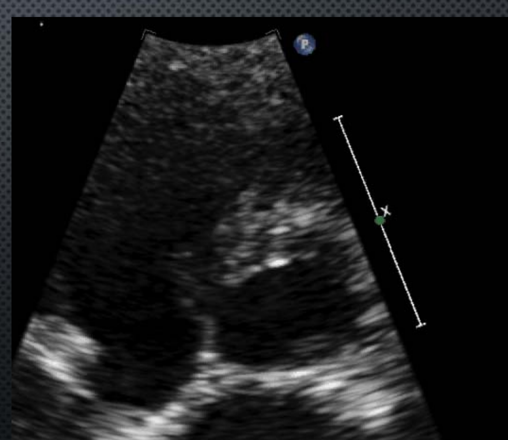
RHEUMATIC AORTIC STENOSIS:
LESS CALCIFICATION, MORE COMMISSURAL FUSION



AORTIC VALVE:
OTHER ANOMALIES ASSOCIATED WITH AS

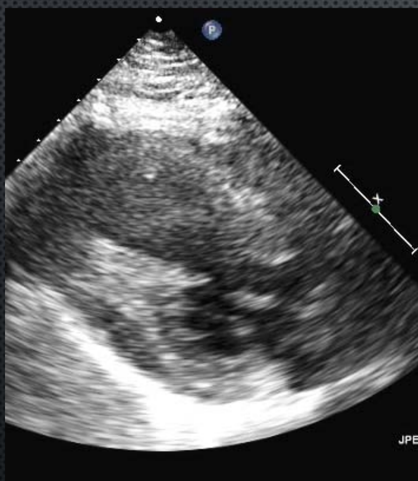
UNICUSPID AOV

QUADRACUSPID AOV

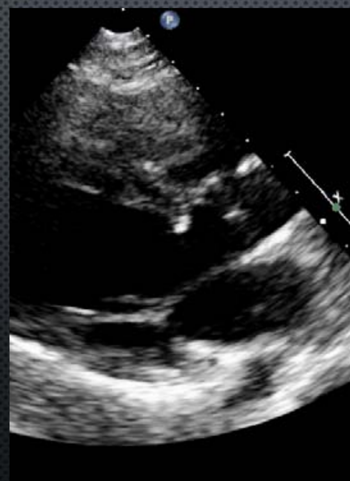


LVOT OBSTRUCTION RULE-OUTS

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 (cm^2) – VTI
- "Simplified" continuity equation – V_{MAX}
- Velocity ratio (dimensionless)
- Planimetry

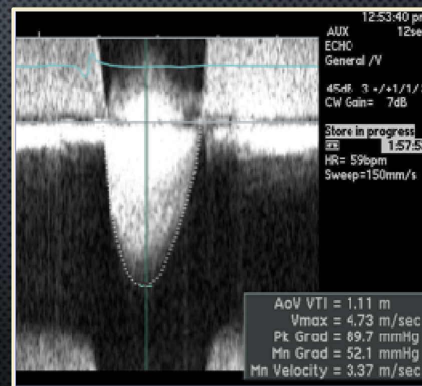
Table 2 Measures of AS severity obtained by Doppler-echocardiography

	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. **J Am Soc Echocardiogr** (2017) 30:372-392

PEAK JET VELOCITY – CONTINUOUS WAVE DOPPLER

- MULTIPLE ACOUSTIC WINDOWS
  - HIGHEST VELOCITY – R PARASTERNAL, SUPRASTERNAL
- 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

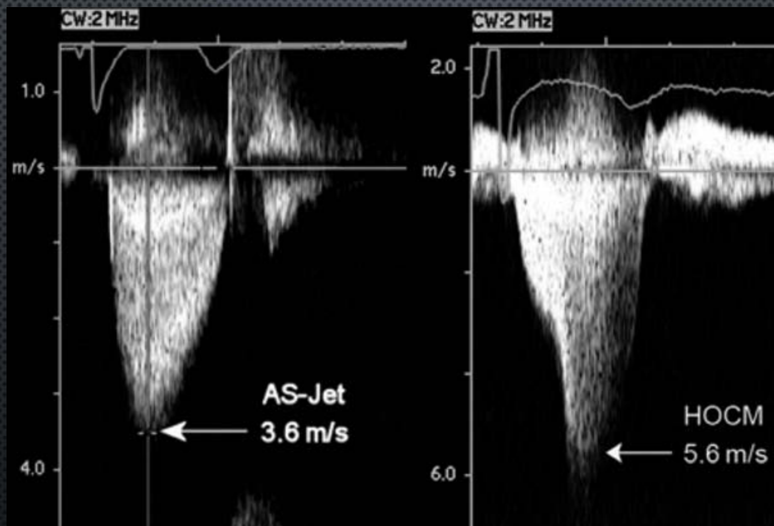


REGULAR RHYTHM – 3 BEAT AVG
IRREGULAR RHYTHM – 5 BEAT AVG

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!!



Baumgartner H, et al. **J Am Soc Echocardiogr** (2017) 30:372-392

PEAK AoV GRADIENT = "MAXIMUM INSTANTANEOUS GRADIENT"

CAN BE CALCULATED FROM THE PEAK JET VELOCITY, USING MODIFIED BERNOULLI

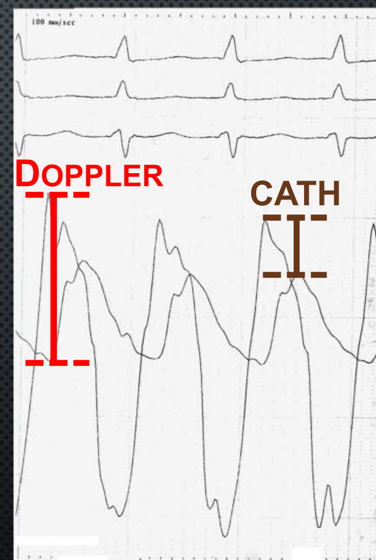
$$4 \times (V_{MAX})^2$$

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

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

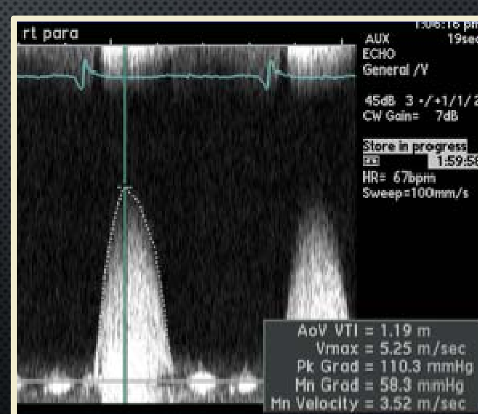


Mean Gradient – Continuous Wave Doppler

- 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)

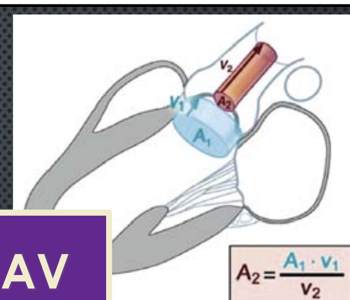
PITFALLS OF "FLOW STATES"

- **HIGHER SV = HIGHER GRADIENTS**
  - AORTIC REGURGITATION
  - HYPERDYNAMIC FUNCTION
- **LOWER SV = LOWER GRADIENTS**
  - REDUCED EJECTION FRACTION
  - SMALL VENTRICULAR CAVITY (LVH)
  - HIGH SYSTEMIT VASCULAR RESISTANCE / IMPEDENCE
  - SIGNIFICANT MITRAL REGURGITATION

AORTIC STENOSIS
VALVE AREA ASSESSMENT

- 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

CONTINUITY EQUATION

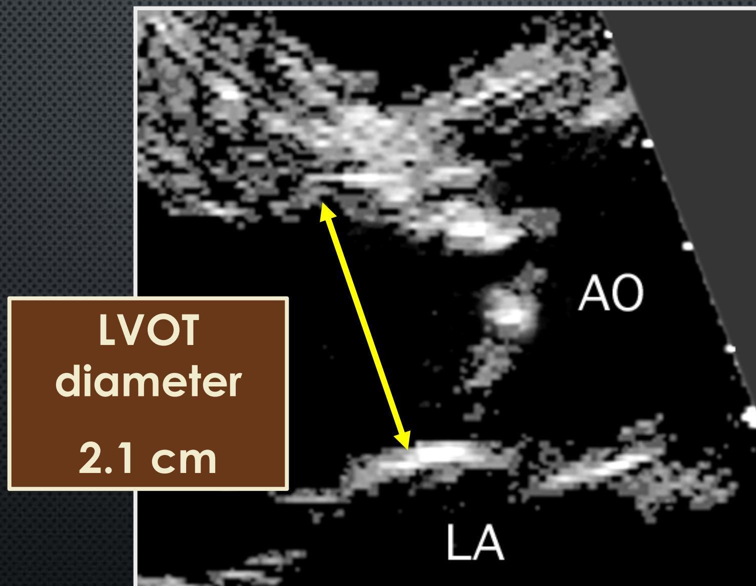


BASED ON CONSERVATION OF MASS

FLOW WITHIN LVOT = FLOW ACROSS AV

- LVOT AREA * VTI_{LVOT} = AVA * VTI_{AV}
- $[\pi * (LVOT_{RADIUS})^2] * VTI_{LVOT} = AVA * VTI_{AV}$

$$\frac{[\pi * (LVOT_{RADIUS})^2] * VTI_{LVOT}}{VTI_{AV}} = \mathbf{AVA}$$



PITFALLS – THE LVOT IS NEVER EASY

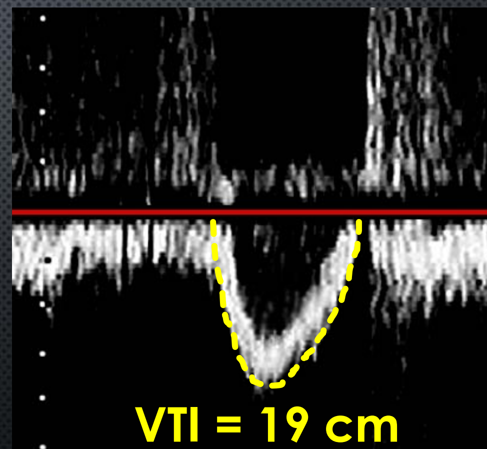
???

GO SLIGHTLY OFF-AXIS

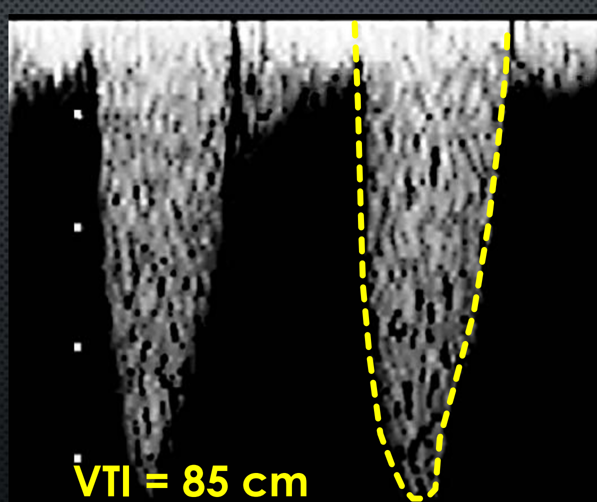
BAUMGARTNER H, ET AL. ***J AM SOC ECHOCARDIOGR*** (2017) 30:372-392

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



FLOW ACROSS THE AORTIC VALVE:
CONTINUOUS WAVE DOPPLER



CALCULATING AORTIC VALVE AREA

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

PITFALLS FOR THE CONTINUITY EQUATION

- LVOT MEASUREMENT
  - **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

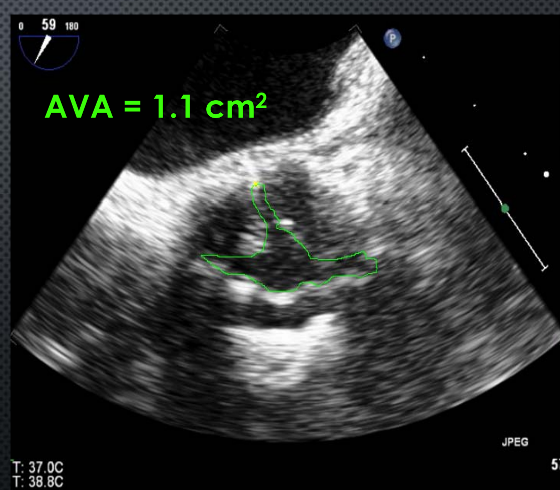
- Derived from continuity equation
  - Eliminates some errors – no LVOT factor
  - Relatively "flow independent"

$$DVR = VTI_{LVOT} / VTI_{AV}$$

  - 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



SUMMARY

MEMORIZE!!!

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. *J Am Soc Echocardiogr* (2017) 30:372-392

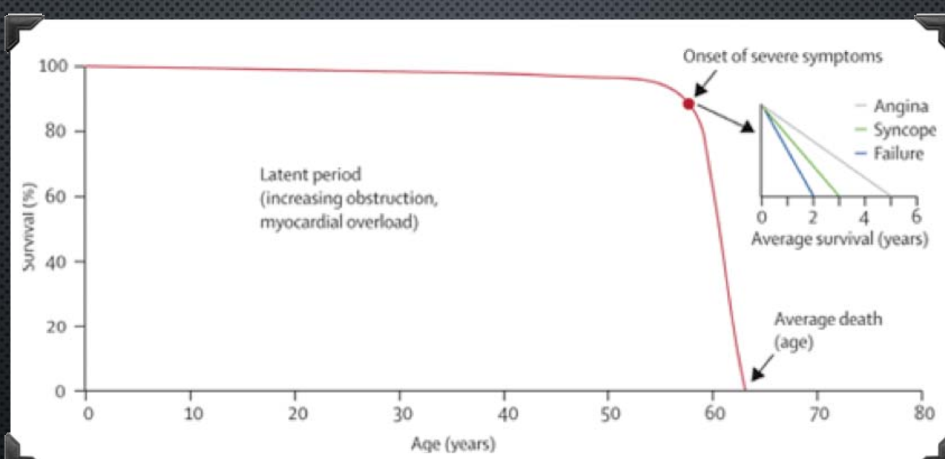
ECHO ESSENTIALS FOR EVALUATION OF AS

- Valve anatomy for etiology
- Severity of Stenosis
- **Assisting with management decision-making**
- Recognize low output / low gradient states

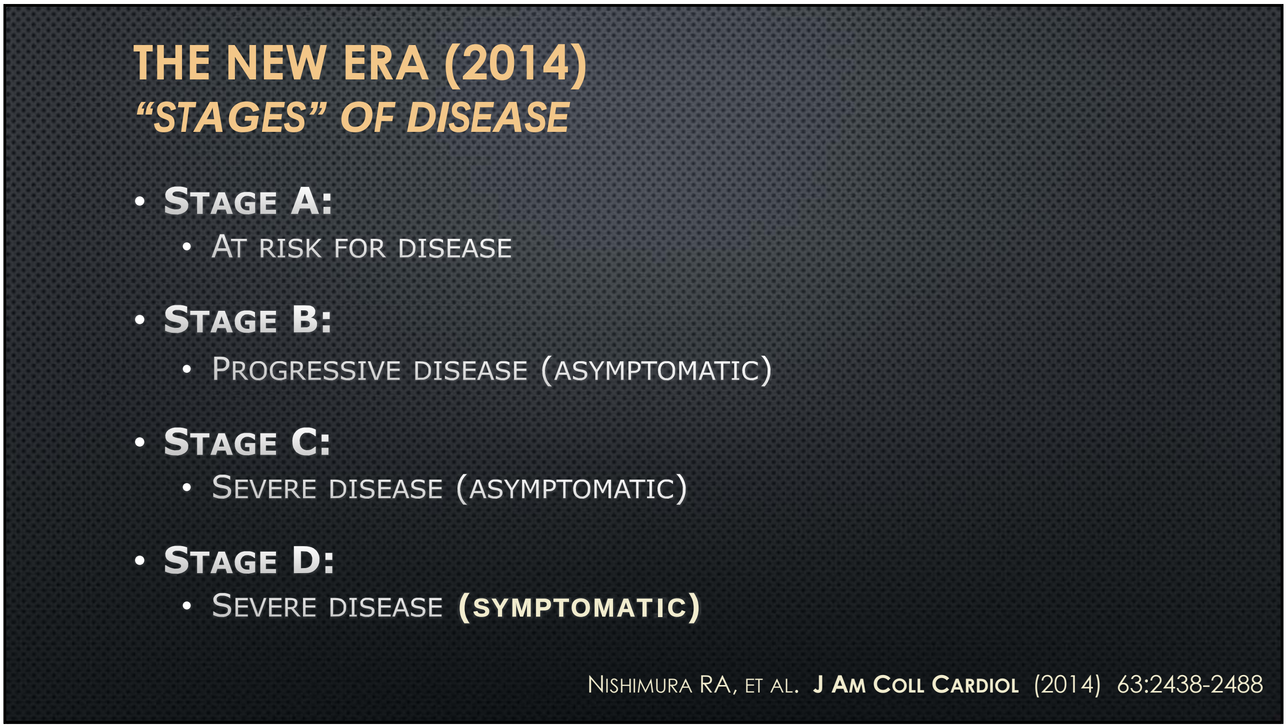
Aortic Stenosis – Physiologic Sequelae

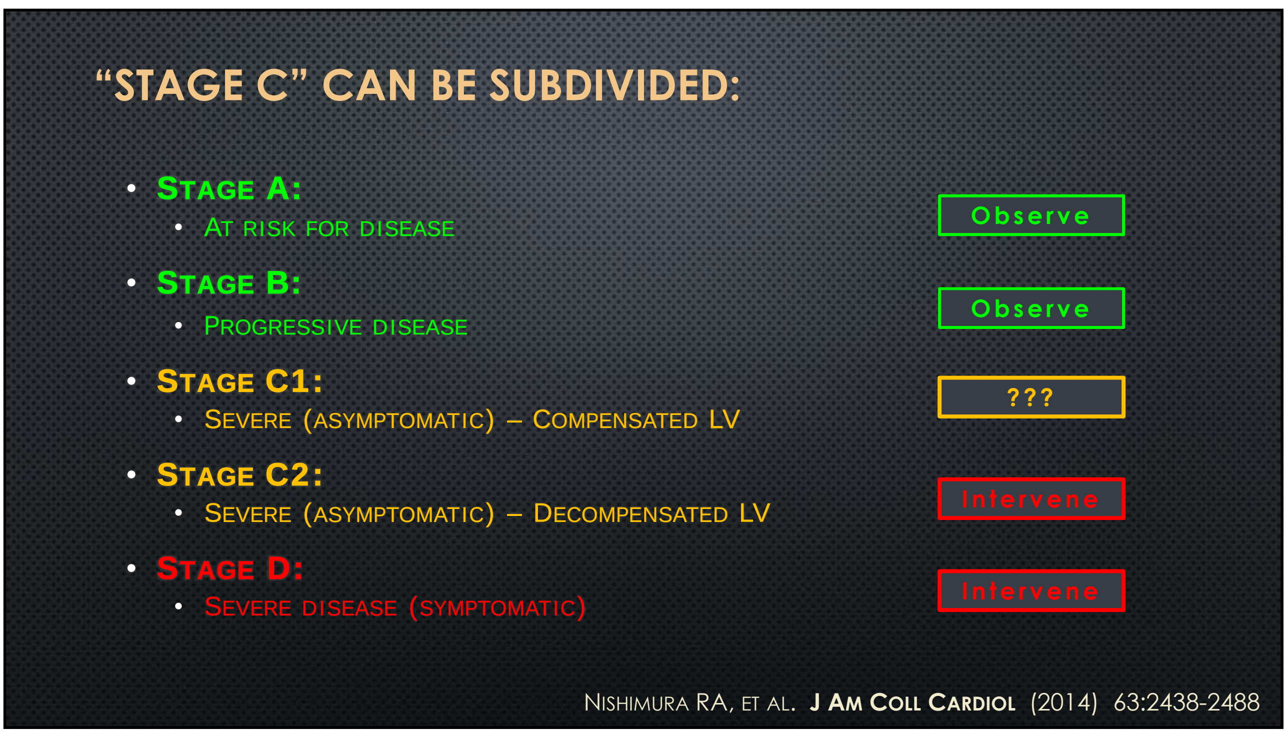
- Chronic LV pressure overload
  - Myocardial hypertrophy – Progressive, Concentric
  - LA dilatation
- Progressive Dysfunction
  - Diastolic, then Systolic
  - END STAGE – limited cardiac output
- After long latency… SYMPTOMS
  - Early – dyspnea and fatigue (often subtle)
  - Late – "Cardinal Sx" – angina, syncope, CHF

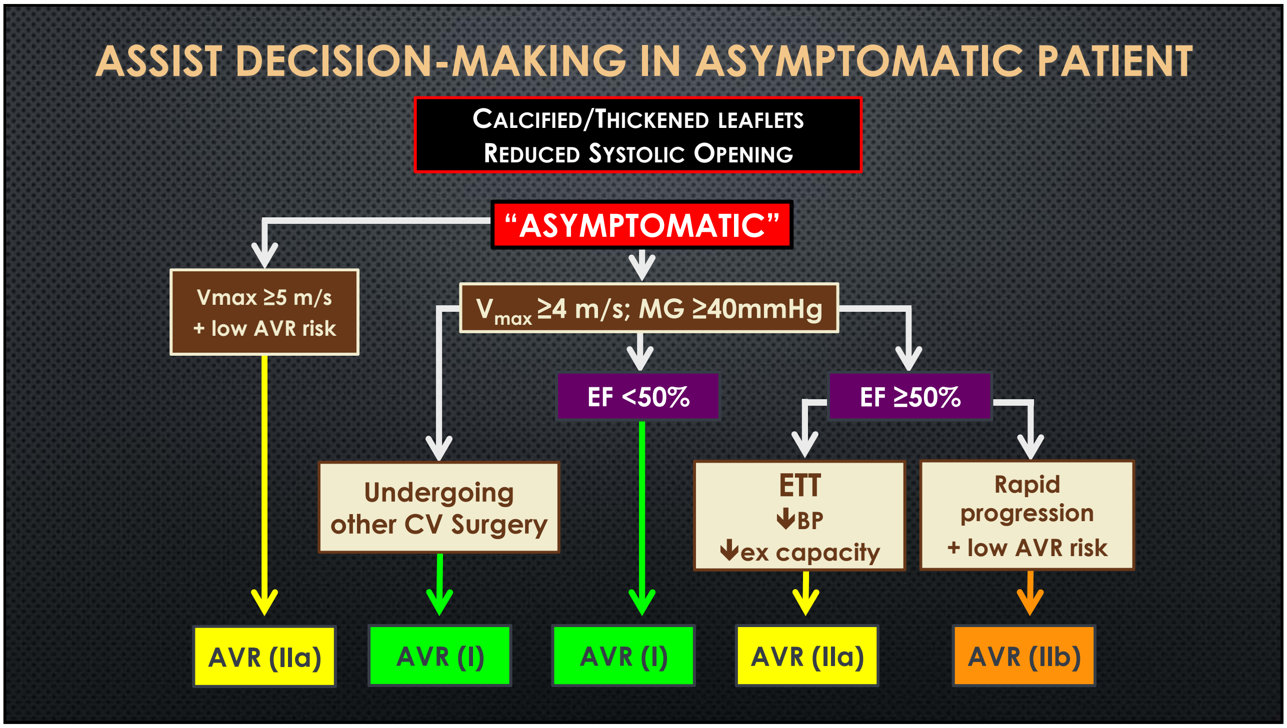
The Old Days:
The "Symptomatic Cliff"



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)
NISHIMURA RA, ET AL. J AM COLL CARDIOL (2014) 63:2438-2488

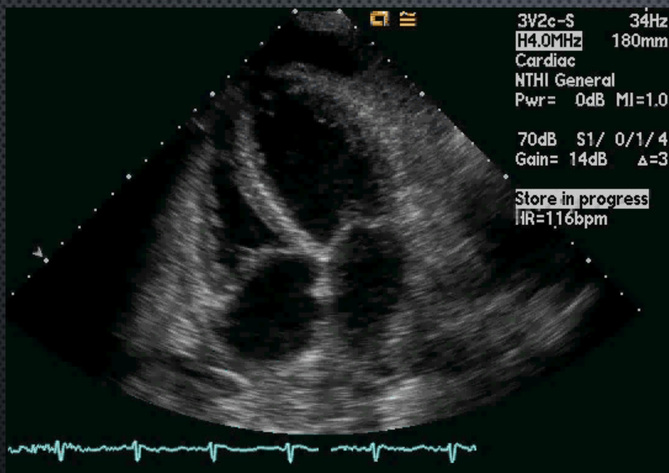

"STAGE C" CAN BE SUBDIVIDED:
• STAGE A:
• AT RISK FOR DISEASE
Observe
• STAGE B:
• PROGRESSIVE DISEASE
Observe
• STAGE C1:
• SEVERE (ASYMPTOMATIC) – COMPENSATED LV
???
• STAGE C2:
• SEVERE (ASYMPTOMATIC) – DECOMPENSATED LV
Intervene
• STAGE D:
• SEVERE DISEASE (SYMPTOMATIC)
Intervene
NISHIMURA RA, ET AL. J AM COLL CARDIOL (2014) 63:2438-2488



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 cm^2

HOW??

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

Improves with AVR

- **"PSEUDO AS"**
  - 1° PROBLEM: DEPRESSED EF
  - 2° PROBLEM: MODERATE OBSTRUCTION TO FLOW MADE TO LOOK SEVERE BY SV

Does **not** improve with AVR

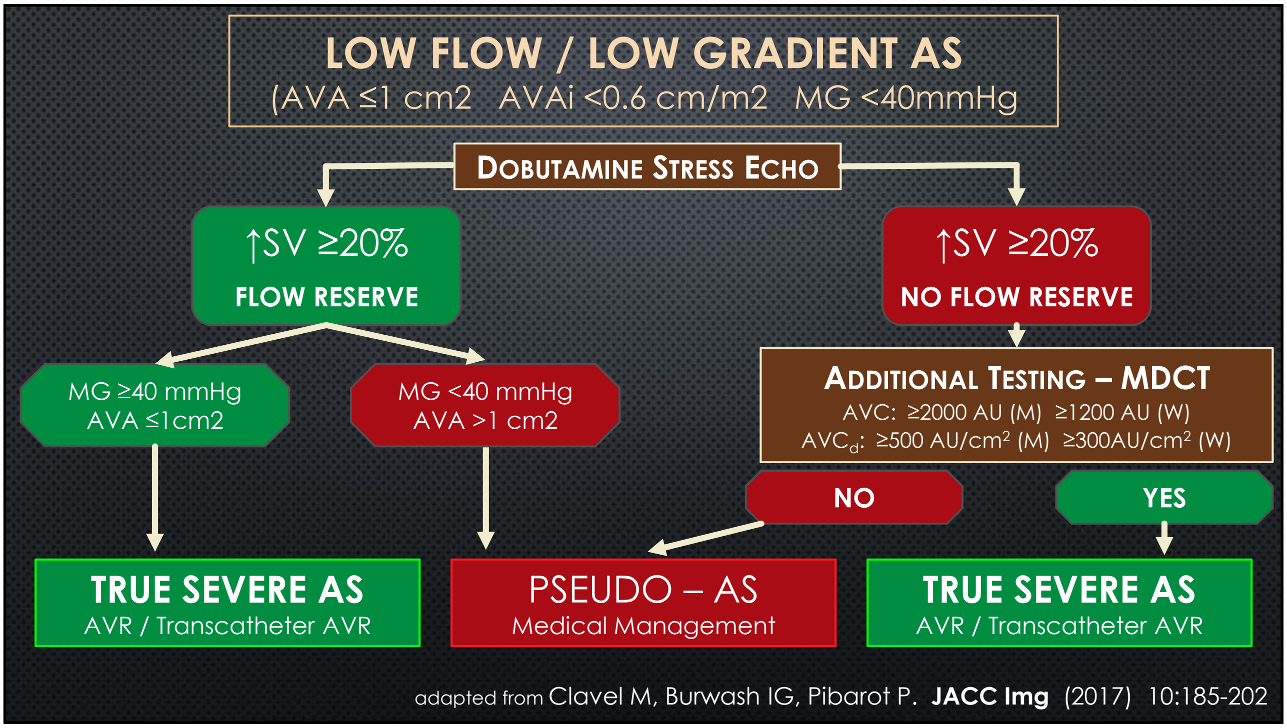
Low Gradient AS
Dobutamine Stress Echo

- 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 ≤1cm² … 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 impedence
- Low dose DSE may or may not help

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



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

Thank You!