Echocardiography Assessment of Aortic Stenosis

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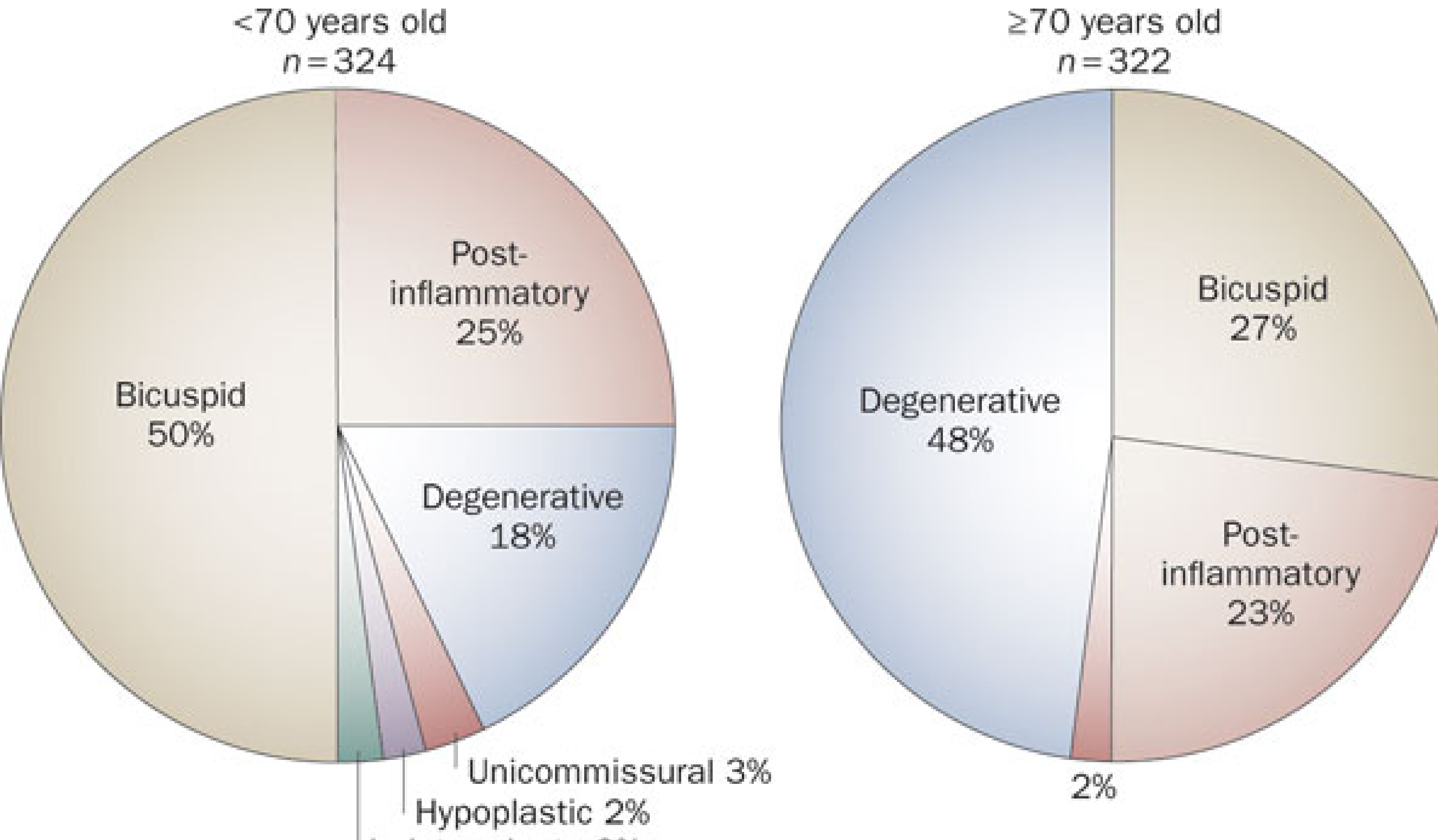
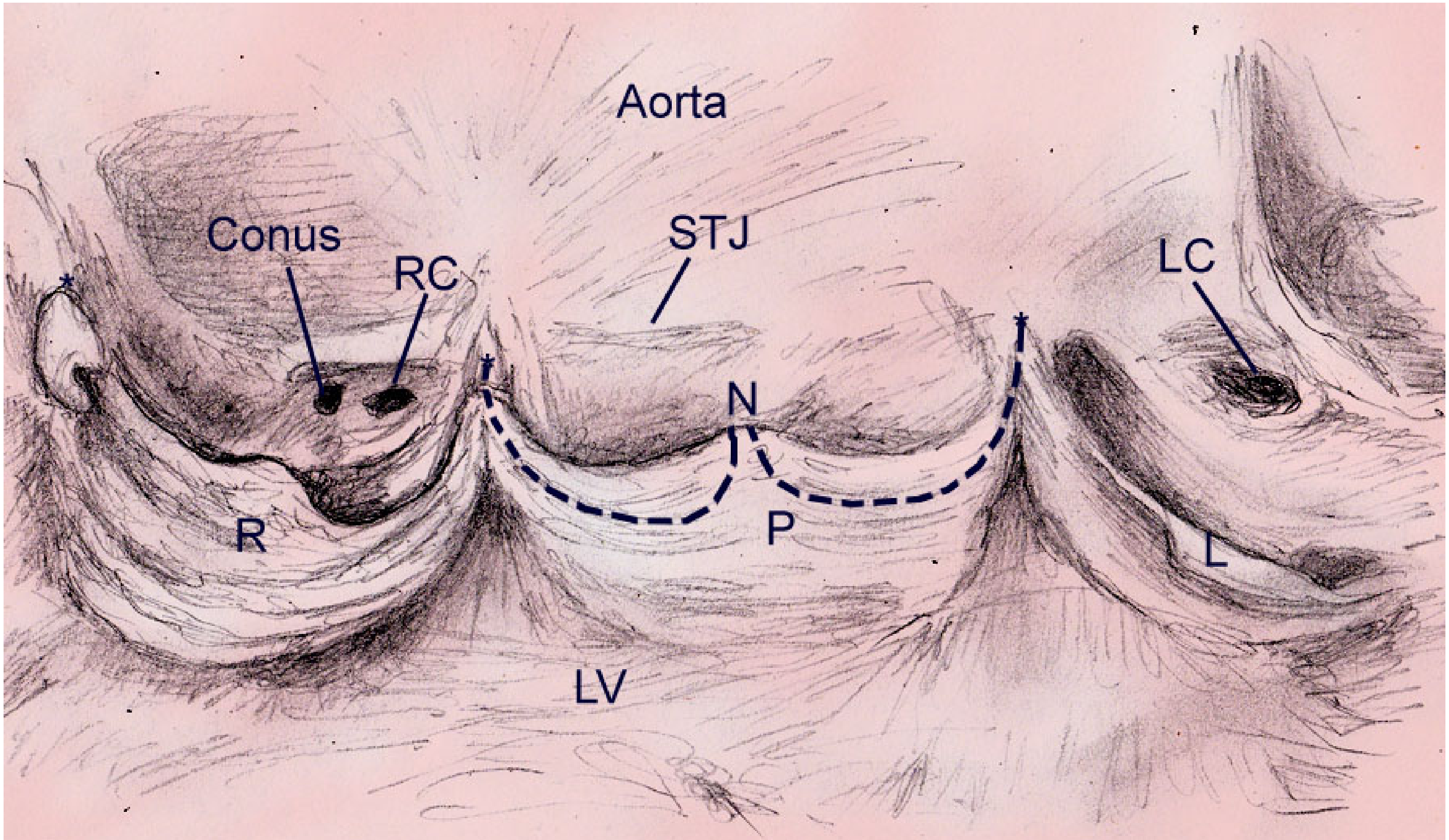
Etiology of Aortic Stenosis



Anatomy of Aortic Valve



Valvular Stenosis

- Aortic Stenosis
  - Supravavular
  - Subvalvular
  - Valvular

Aortic Stenosis Severity

- Morphology
  - Trileaflet
  - Biscupid
  - Quadriscuspid
  - Unicuspid

- Hemodynamic Assessment
  - Velocity, Gradient, Area
  - Changes with Excerise

Supravalvular Aortic Stenosis

- Level of obstruction: Aorta
  - Single discrete narrowing
  - Long tubular hypoplasia
- Physical Exam
  - Thrill in suprasternal notch or R carotid
  - Loud A2
- Associated with elfin facies, high Ca, PS-Elastin gene

Supravalvular Aortic Stenosis

- Need Picture

Supravalvular Aortic Stenosis

- Diagnosis
  - 2D and Doppler: Outflow gradient with narrowing aorta
  - MRA or CT needed to define

  - Surgical intervention
  - May need conduit

Supravalvular Aortic Stenosis

- Seen in 10% of pt with AS
  - Discrete ridge
  - Tunnel stenosis
- Frequent accompanied by AR
  - Due to jet on aortic valve

Subvalvular

- Need picture

Subvalvular

- Diagnosis
  - Suspected when there is a high Doppler gradient and normal AV
  - May need repeat TTE or TEE
- Operate for complete “cure”
  - Prevent progressive AR
  - Thus resection indicated in most pts, especially if severe or symptomatic

Valvular

Grading of Severity

	Aortic sclerosis	Mild	Moderate	Severe
Aortic jet velocity (m/s)	≤2.5 m/s	2.6-2.9	3.0-4.0	>4.0
Mean gradient (mmHg)	–	<20 (<30[a])	20-40[b] (30-50[a])	>40[b] (>50[a])
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

Severe Aortic Stenosis

- Aortic Valve Area: $<1.0\ cm^2$
- Indexed AVA:$<\ 0.6\ cm^2/m^2$ for BSA

- Aortic Jet Velocity: 4 m/s

- Mean Transvalvular Pressure Gradient: >40mmHg

- Velocity Ratio/Dimensionless Index: <0.25
- (VTI of LVOT)/(VTI of AV)

Basic Echo Review

- Bernoulli Equation
- Change in Pressure = $4V^2$
- Assumption Flow is Parallel, Cosine of the angle 0 or 180
- Aortic Valve Assessment

Aortic Valve Area Calculations

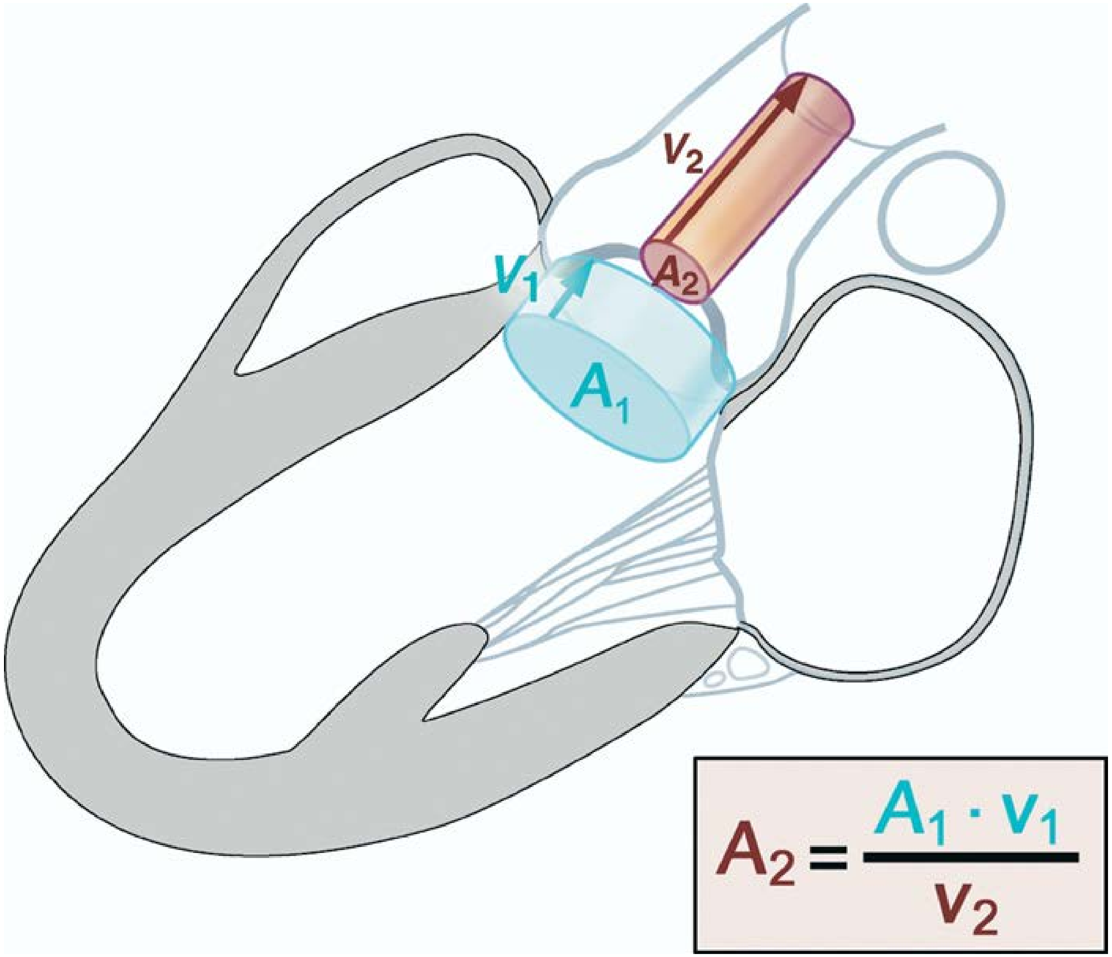
- Echo:
  - Continuity Equation:

$$\frac{(\text{CSA of LVOT}) \times (\text{VTI of LVOT})}{(\text{VTI of AV})}$$

Measure the physiologic or effective orifice area (EOA) of the stenotic valve known as vena contracta, the narrowest portion of the flow stream

Continuity Equation:

$$AVA = \frac{0.785(D_{LVOT})^2\ VTI_{LVOT}}{VTI_{AV}}$$



$$A_2 = \frac{A_1 \cdot v_1}{v_2}$$

Derivation of CSA of LVOT

- $SV_{AV} = SV_{LVOT}$

- $AVA \times VTI_{AV} = CSA_{LVOT} \times VTI_{LVOT}$

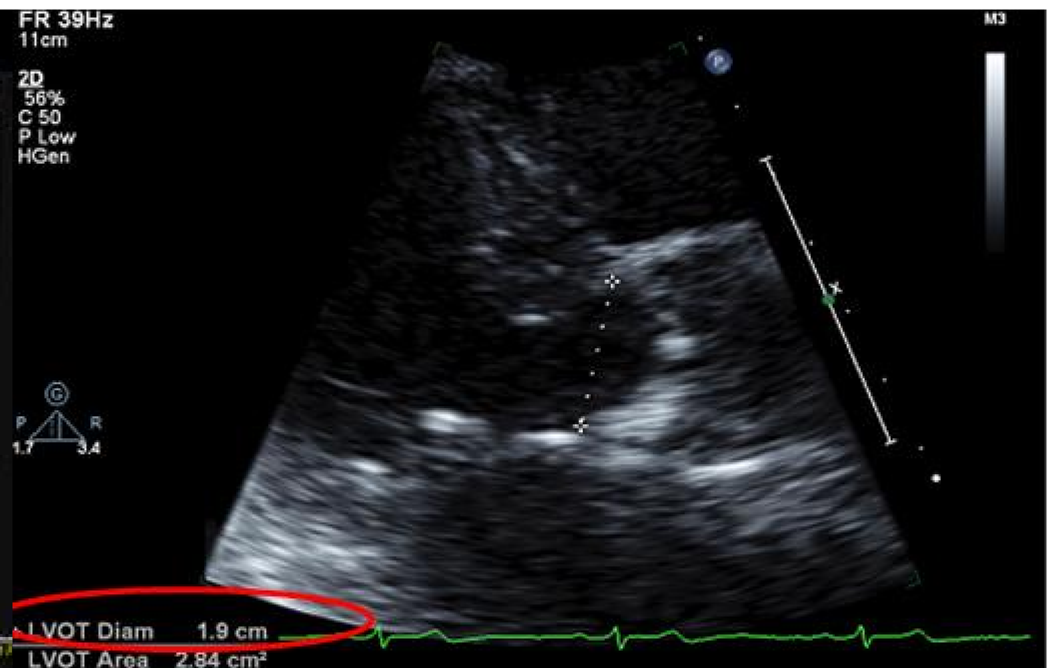
- $AVA = \dfrac{CSA_{LVOT} \times VTI_{LVOT}}{VTI_{AV}}$

- $CSA_{LVOT} = \pi(D/2)^2$

- $CSA_{LVOT} = 0.785 \times D^2$

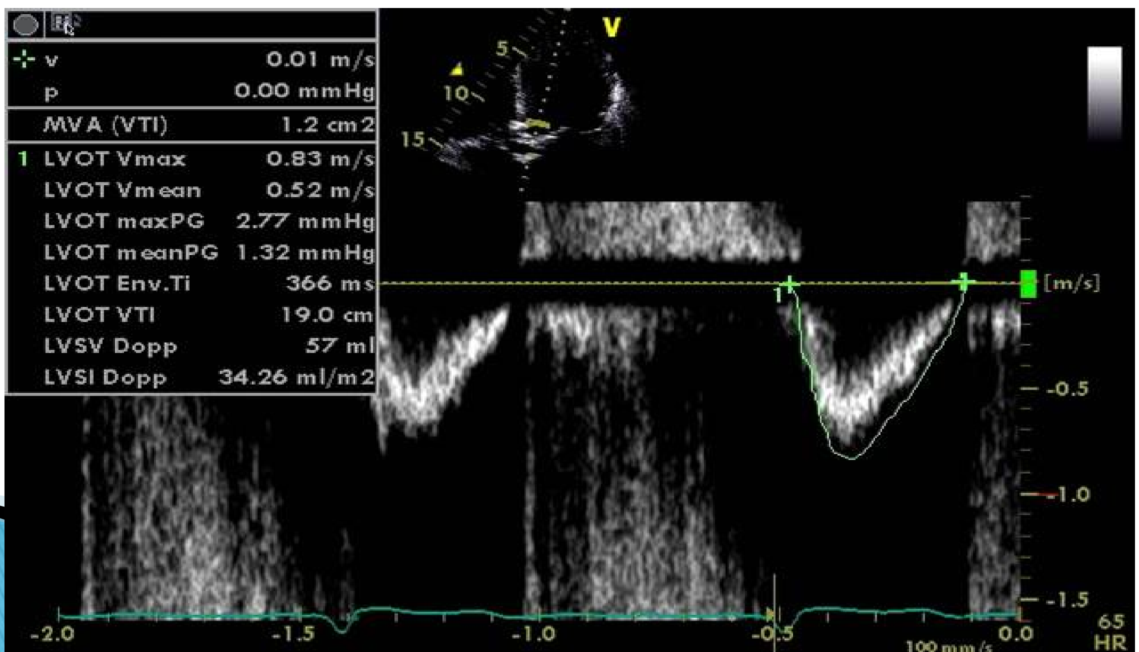
LVOT Diameter

- Parasternal Long Axis
- Zoom in on LVOT
- Measure the diameter on cusps insertion, one or two frames after maximal systolic leaflet separation



Time Velocity Integral–LVOT

- The distance a red blood cells travels with each heart beat
- Apical 5 Chamber
- PW Doppler of LVOT
- Trace Envelope of LVOT



Time Velocity Integral– AV

- The distance a red blood cells travels with each heart beat
- Apical 5 Chamber
- CW Doppler of Aortic Valve
- Trace Envelope of Aortic Valve

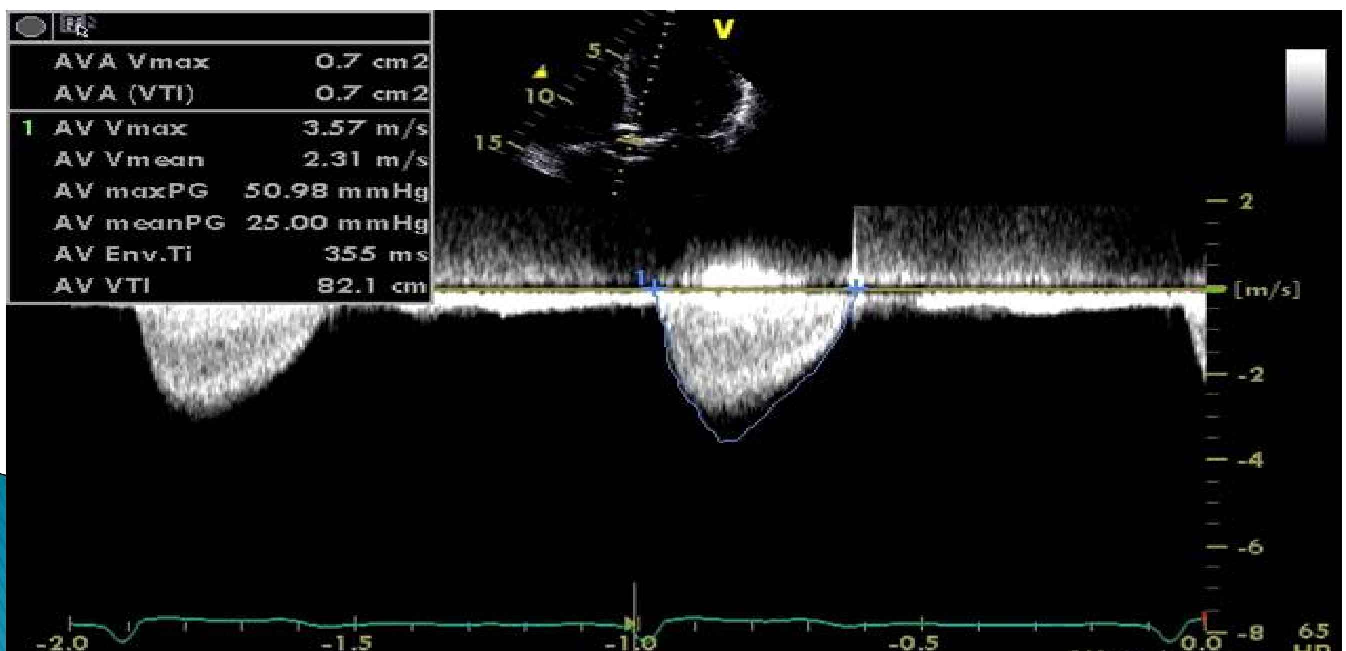
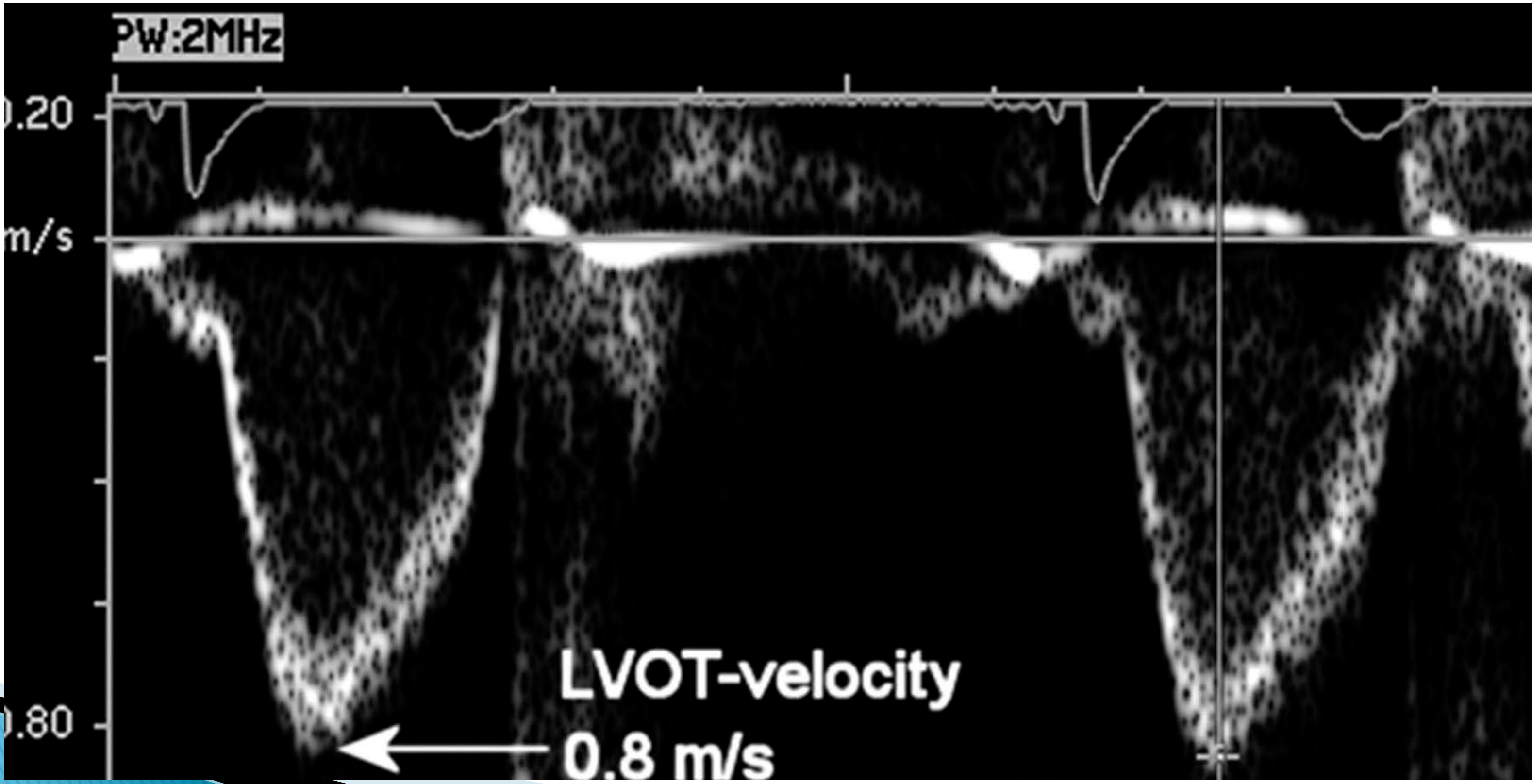


Table 1 Recommendations for data recording and measurement for AS quantitation

Data element	Recording	Measurement
LVOT diameter	• 2D parasternal long-axis view • Zoom mode • Adjust gain to optimize the blood tissue interface	• Inner edge to inner edge • Mid-systole • Parallel and adjacent to the aortic valve or at the site velocity measurement (see text) • Diameter is used to calculate a circular CSA
LVOT velocity	• Pulsed-wave Doppler • Apical long axis or five-chamber view • Sample volume positioned just on LV side of valve and moved carefully into the LVOT if required to obtain laminar flow curve • Velocity baseline and scale adjusted to maximize size of velocity curve • Time axis (sweep speed) 100 mm/s • Low wall filter setting • Smooth velocity curve with a well-defined peak and a narrow velocity range at peak velocity	• Maximum velocity from peak of dense velocity curve • VTI traced from modal velocity
AS jet velocity	• CW Doppler (dedicated transducer) • Multiple acoustic windows (e.g. apical, suprasternal, right parasternal, etc) • Decrease gains, increase wall filter, adjust baseline, and scale to optimize signal • Gray scale spectral display with expanded time scale • Velocity range and baseline adjusted so velocity signal fits but fills the vertical scale	• Maximum velocity at peak of dense velocity curve • Avoid noise and fine linear signals • VTI traced from outer edge of dense signal curve • Mean gradient calculated from traced velocity curve • Report window where maximum velocity obtained
Valve anatomy	• Parasternal long- and short-axis views • Zoom mode	• Identify number of cusps in systole, raphe if present • Assess cusp mobility and commisural fusion • Assess valve calcification

Continuity Equation

$$\frac{\text{CSA of LVOT} \times \text{Velocity of LVOT}}{\text{Velocity of AV}}$$



Gorlin Formula

- AVA = Valve Flow (ml/sec)
- 44.3 x √Mean Valvular Gradient

$$AVA = \frac{\text{Valve Flow (ml/sec)}}{44.3 \times \sqrt{\text{Mean Valvular Gradient}}}$$

- Valve flow= Cardiac Output (ml/min)
- Systolic Ejection Period(sec/beat) x HR

$$\text{Valve flow} = \frac{\text{Cardiac Output (ml/min)}}{\text{Systolic Ejection Period(sec/beat)} \times HR}$$

- Measures the anatomic orifice area

(area between the valve cusps)

- LIMITATIONS: Reduced C.O <2.5L, overestimates the severity of aortic valve stenosis, AI

Hakki Formula

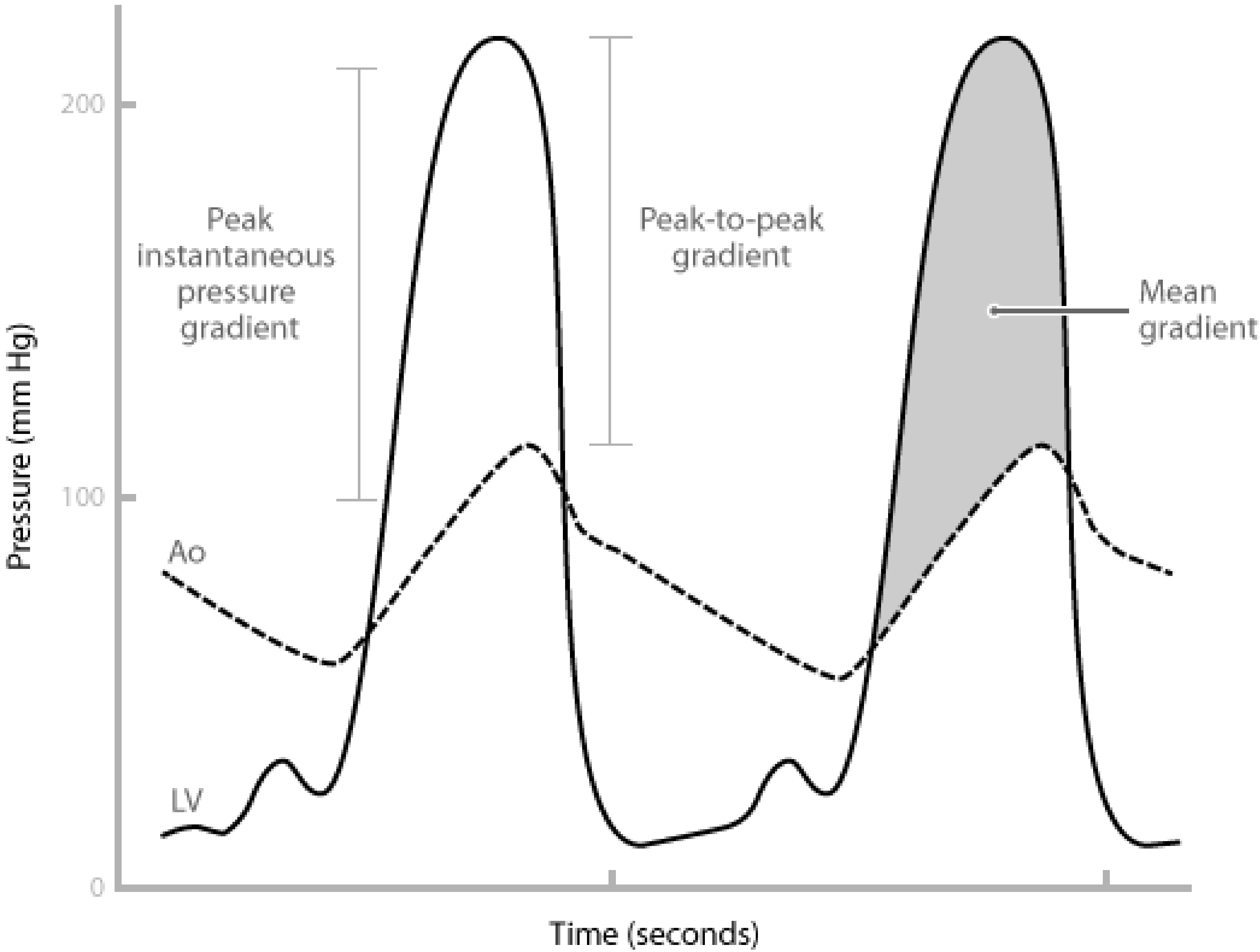
- Aortic Valve Area= $\dfrac{\text{Cardiac Output}}{\sqrt{\text{Peak-to-Peak Gradient}}}$

Mean Valvular Gradient calculated by the superimposing the aortic and left ventricular pressure tracings

Peak to peak gradients- difference between the highest systolic pressure measured in the left ventricle and the highest systolic pressure gradient measured in the aorta

Mean Valvular Gradient correlates with Peak to peak gradient in Severe Aortic Stenosis

Peak to Peak cath gradient is always lower than echo gradient but mean gradient should be equivalent. MG=.70(PG)



200
100
0
Pressure (mm Hg)
Time (seconds)
Peak
instantaneous
pressure
gradient
Peak-to-peak
gradient
Mean
gradient
Ao
LV

Caveats

- Cath–echo gradient discordance
  - Small aortic root/ascending aorta
  - Increased pressure recovery with ascending aorta< 3.0 cm
    - Overestimate
  - Angle of Incidence COS Theta
    - Large incident angel to the aortic ….underestimate
  - Equate peak instaneous gradient with Peak to Peak gradient

Pitfalls of the Continuity Equation

- Accuracy of the LVOT Diameter
  - Error is squared
- LVOT Velocity
  - Angle Theta, laminar flow before stenosis
- CW Aortic Velocity Inaccuracy
  - Measure signal at multiple windows
  - Distinguishing AS from MR
- Non simultaneous measurement of LVOT and peak velocities

Table 4 Resolution of apparent discrepancies in measures of AS severity

AS velocity >4 m/s and AVA >1.0 cm^2

1. Check LVOT diameter measurement and compare with previous studies[a]
2. Check LVOT velocity signal for flow acceleration
3. Calculate indexed AVA when
   a. Height is <135 cm (5′5″)
   b. BSA <1.5 m^2
   c. BMI <22 (equivalent to 55 kg or 120 lb at this height).
4. Evaluate AR severity
5. Evaluate for high cardiac output
   a. LVOT stroke volume
   b. 2D LV EF and stroke volume

Likely causes: high output state, moderate–severe AR, large body size

AS velocity ≤4 m/s and AVA ≤1.0 cm^2

1. Check LVOT diameter measurement and compare with previous studies[a]
2. Check LVOT velocity signal for distance from valve
3. Calculate indexed AVA when
   a. Height is <135 cm (5′5″)
   b. BSA <1.5 m^2
   c. BMI <22 (equivalent to 55 kg or 120 lb at this height)
4. Evaluate for low transaortic flow volume
   a. LVOT stroke volume
   b. 2D LV EF and stroke volume
   c. MR severity
   d. Mitral stenosis
5. When EF <55%
   a. Assess degree of valve calcification
   b. Consider dobutamine stress echocardiography

Likely causes: low cardiac output, small body size, severe MR

Aortic Stenosis

- Doppler Echocardiography
  - Mean Aortic Valve Gradient
    - Can underestimate gradient
      - Not parallel to jet
    - Cannot overestimate gradient
      - Unless Hb<8 or subvalvuar stenosis
      - Gradient >40=severe

Aortic Stenosis

- Pitfalls: Doppler Echocardiography
  - Aortic Valve Area
    - Gradient if flow dependent
    - Use if gradient$<$40mmHg
  - Continuity equation
    - Highly operator dependent
      - Measurement of LVOT

Table 2 Measures of AS severity obtained by Doppler echocardiography

	Units	Formula / Method	Cutoff for Severe	Concept	Advantages	Limitations
AS jet velocity [8-10, 12]	m/s	Direct measurement	4.0	Velocity increases as stenosis severity increase.	Direct measurement of velocity. Strongest predictor of clinical outcome.	Correct measurement requires parallel alignment of ultrasound beam. Flow dependent.
Mean gradient [8-10]	mm Hg	$\Delta P = \sum 4v^2 / N$	40 or 50	Pressure gradient calculated from velocity using the Bernoulli equation	Mean gradient is averaged from the velocity curve. Units comparable to invasive measurements.	Accurate pressure gradients depend on accurate velocity data. Flow dependent
Continuity equation valve area [16, 17, 23]	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 [18,23]	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 [15,18]	none	$VR = \frac{V_{LVOT}}{V_{AV}}$	0.25	Effective aortic valve area 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 [26, 34]	cm^2	TTE, TEE, 3D-echo	1.0	Anatomic (geometric) cross-sectional area 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.

Aortic Measurements

- Surgery is indicated if the diameter of the aortic root or ascending aorta
  - Trileaflet is >5.5 cm or if the rate of increase in diameter is >0.5cm per year or more
  - Bicuspid valve: >4.5 cm
  - Marfan's Syndrome: >4.5cm

Indications for AVR

- Operate at onset of ANY symptoms
  - Irrespective of LV function
  - Other indications
    - Undergoing other cardiac surgery
    - Moderate and Severe AS

Indications for AVR

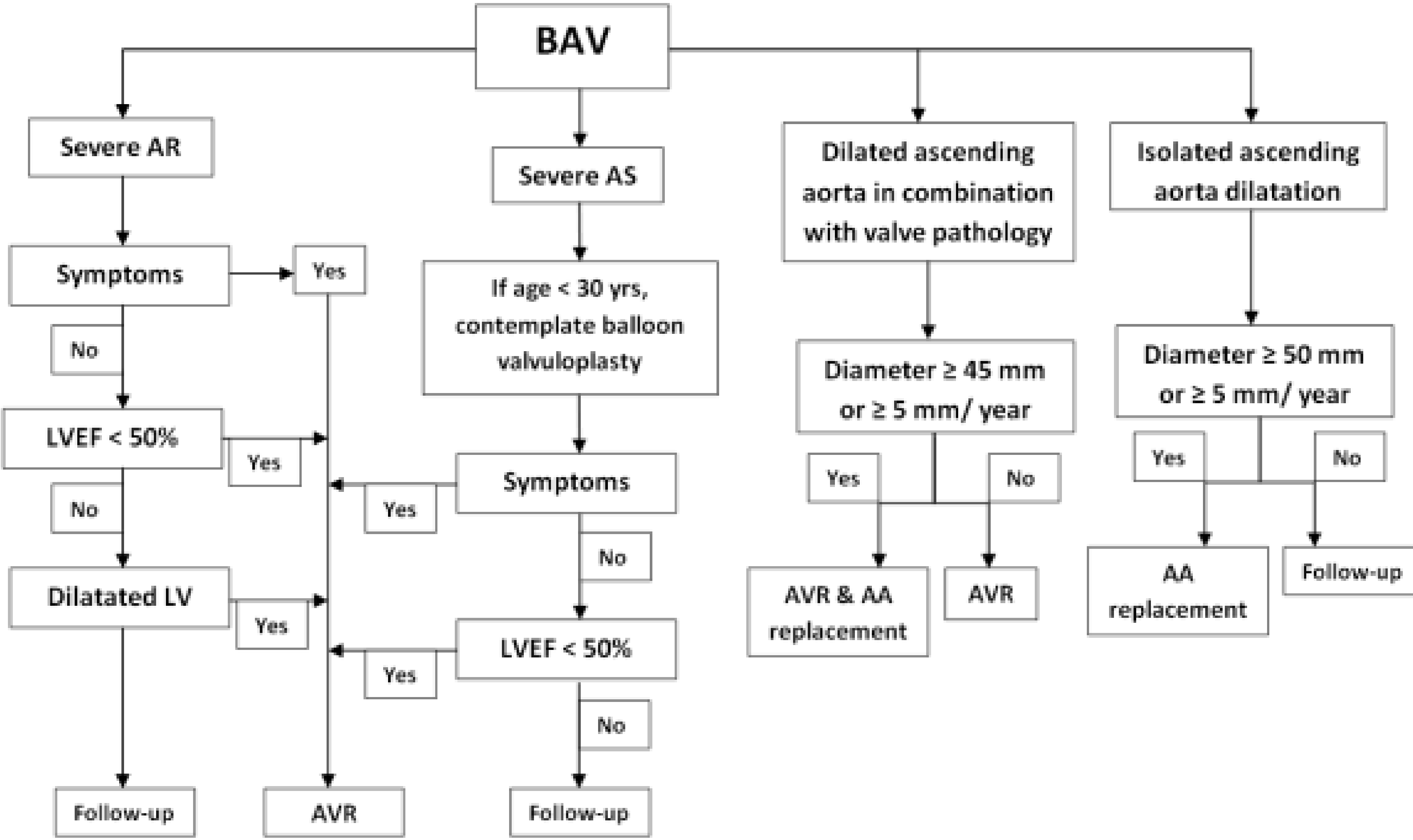
- Asymptomatic Severe AS
  - Operate when EF falls
    - Afterload overwhelms the Left ventricle
    - EF<50% with LVH
    - Prevent sudden death with AVR
    - Ensure truly asymptomatic via exercise treadmill test

Partner Trial

- Transcatheter Aortic Valve Replacement
  - TAVR in high risk patients
    - Comparable mortality vs AVR
    - Higher rate of stroke
    - More vascular complications
    - Aortic regurgitation–a problem
  - "Game changer" for inoperable or high risk patients

AVR in Severe Aortic Stenosis

- Symptomatic patients with severe AS…Class I
- Patients with severe AS having CABG…Class I
- Patients with Severe AS undergoing surgery on aorta or other valves…Class I
- Severe AS & LV systolic dysfunction…Class I
- Moderate AS undergoing CABG or surgery on aorta or other valves…Class II


BAV
Severe AR
Symptoms
Yes
No
LVEF < 50%
Yes
No
Dilatated LV
Yes
Follow-up
AVR
Severe AS
If age < 30 yrs, contemplate balloon valvuloplasty
Symptoms
Yes
No
LVEF < 50%
Yes
No
Follow-up
Dilated ascending aorta in combination with valve pathology
Diameter ≥ 45 mm or ≥ 5 mm/ year
Yes
No
AVR & AA replacement
AVR
Isolated ascending aorta dilatation
Diameter ≥ 50 mm or ≥ 5 mm/ year
Yes
No
AA replacement
Follow-up

Assessment of Aortic Valve

Is cardiac catherization is an appropriate tool to determine the severity of aortic stenosis when TTE has confirmed severe aortic stenosis?

- Is TEE an appropriate first modality to assess the aortic valve?
- In patients with HOCM?
- Subvalvular stenosis?

Appropriate Use Criteria

	Native Valvular Stenosis With TTE	
38.	• Routine surveillance (<3 y) of mild valvular stenosis without a change in clinical status or cardiac exam	I (3)
39.	• Routine surveillance (≥3 y) of mild valvular stenosis without a change in clinical status or cardiac exam	A (7)
40.	• Routine surveillance (<1 y) of moderate or severe valvular stenosis without a change in clinical status or cardiac exam	I (3)
41.	• Routine surveillance (≥1 y) of moderate or severe valvular stenosis without a change in clinical status or cardiac exam	A (8)
	TEE as Initial or Supplemental Test—Valvular Disease	
106.	• Evaluation of valvular structure and function to assess suitability for, and assist in planning of, an intervention	A (9)
107.	• To diagnose infective endocarditis with a low pretest probability (e.g., transient fever, known alternative source of infection, or negative blood cultures/atypical pathogen for endocarditis)	I (3)
108.	• To diagnose infective endocarditis with a moderate or high pretest probability (e.g., staph bacteremia, fungemia, prosthetic heart valve, or intracardiac device)	A (9)
	Chronic Valvular Disease—Asymptomatic With Stress Echocardiography	
192.	• Severe aortic stenosis	I (1)
193.	• Evaluation of equivocal aortic stenosis • Evidence of low cardiac output or LV systolic dysfunction ("low gradient aortic stenosis") • Use of dobutamine only	A (8)
	Chronic Valvular Disease—Symptomatic With Stress Echocardiography	
	Stress Echocardiography for Hemodynamics (Includes Doppler During Stress) Chronic Valvular Disease—Symptomatic	
180.	• Mild aortic stenosis	I (3)
181.	• Moderate aortic stenosis	U (6)
182.	• Severe aortic stenosis	U (5)

Case Presentation

- 79 y/o female with systolic murmur and angina for more than one year
- 2D Echocardiogram
  - Normal LVEF: EF>55%
  - Aortic Peak Velocity: 2 m/s
  - AV MG: 8 mmHg
  - LVOT Diameter: 2.0 cm
  - LVOT VTI: 13.2 cm
  - AV VTI: 45 cm
  - 0.785x(2.0)x 13.2/45=41.448/45
- AVA = 0.9 cm^2

What do you recommend?

Clinical Spectrum of Severe Aortic Stenosis

- NORMAL FLOW, HIGH GRADIENT

  - Does not present any particular challenge with regard to the grading of AS and therapeutic management because all Doppler echocardiographic parameters are met ($\leq$ 1.0 cm^2, $\geq$ 40 mmHg, $\geq$ 4 m/sec)
  - LV concentric hypertrophy in response to pressure overload
  - Cavity size generally normal or mildly reduced
  - LVEF normal or supranormal

Clinical Spectrum of Severe Aortic Stenosis

- <u>LOW FLOW</u>, <u>LOW GRADIENT</u>, **<u>LOW LVEF</u>**
  - Approximately 5-10% of AS patients
  - Dilated LV cavity size
  - <u>Markedly depressed systolic function</u>
  - Poor prognosis if treated medically, but high operative mortality if treated surgically
  - Low dose dobutamine echo useful
    - Assess for flow reserve
    - Differentiate Pseudo-severe Vs. True-severe AS

True Severe Pseudo-severe AS

True Severe

- Valve Disease
- With DSE:
- Little/No increase in EOA
- Increase in gradient

Pressure gradient>40
EOA<1.0–1.2
CT Ca>1650

Pseudo-severe AS

- LV Dysfunction
- With DSE:
- Increase in EOA
- Little/No increase in gradient

Pressure Gradient <40
EOA>1.0–1.2
CT Ca< 1650

Dobutamine Stress Echo

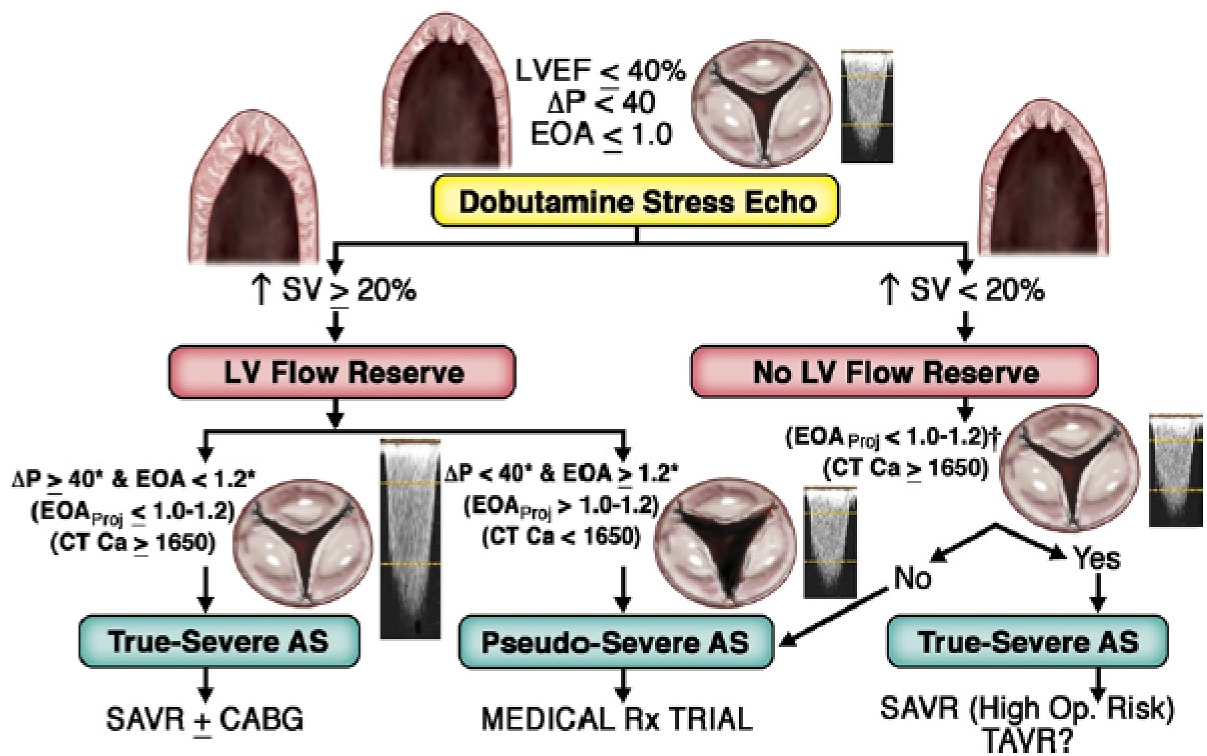
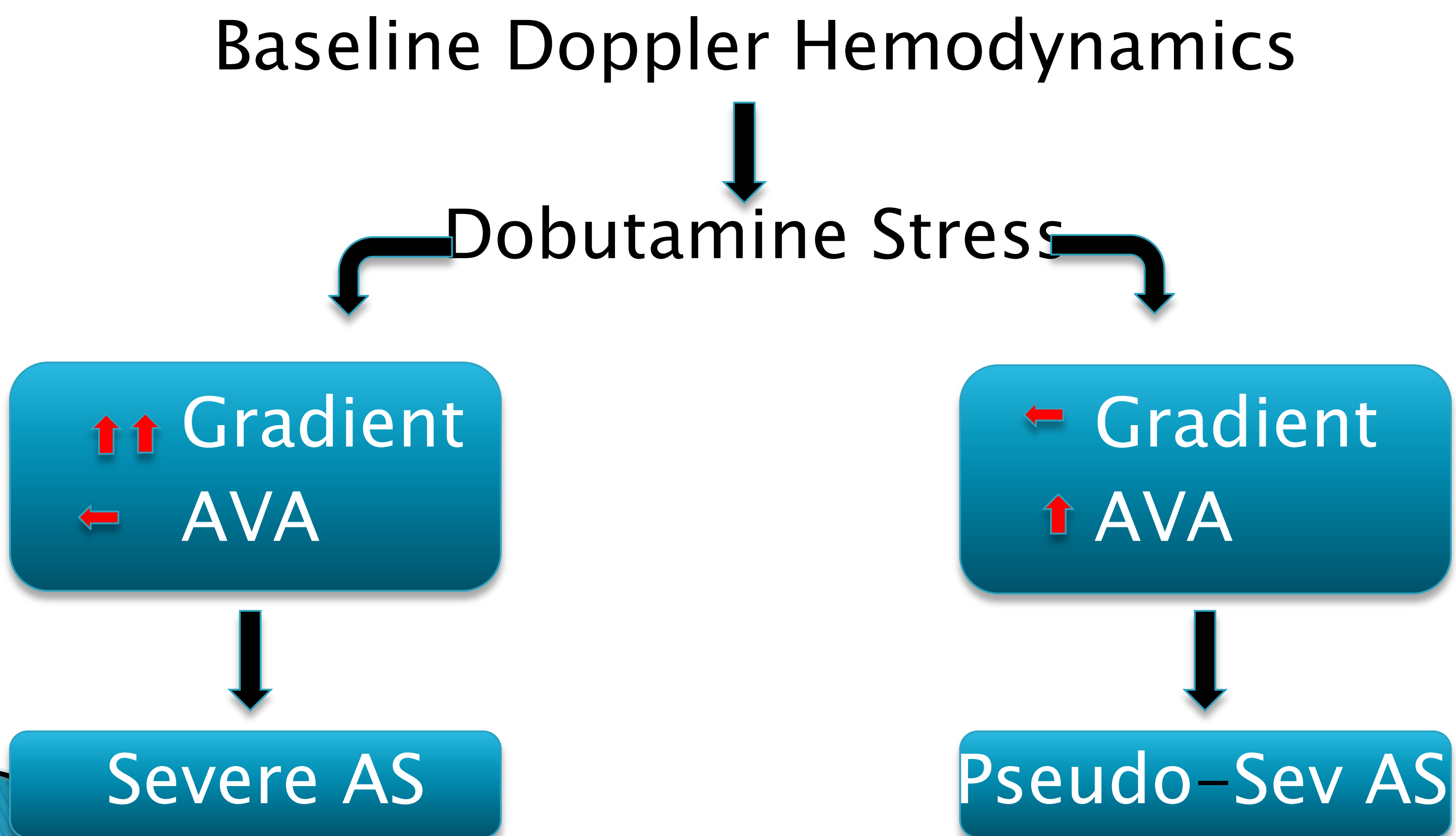


Figure 2 **Clinical Decision Making Process in Low LVEF, LF-LG Severe AS**

Dobutamine stress echocardiography (DSE) is useful to assess LV flow reserve and to distinguish between the true severe and pseudosevere AS. Quantification of valve calcification by multislice computed tomography (CT) may also be used to corroborate stenosis severity. Text between parentheses represents new emerging parameters that need to be further validated. EOA = effective orifice area. (in square centimeters); EOA_{Proj} = projected EOA at normal flow rate (in square centimeters); ΔP = mean transvalvular gradient (in mm Hg); Ca = calcium score (in Agatston Unit); SV = stroke volume; Op.= operative; SAVR = surgical aortic valve replacement; TAVR = trans-catheter aortic valve replacement; other abbreviations as in Figure 1. *Cutoffpoints may vary depending on studies. † See text for explanation and references. Figure illustration by Craig Skaggs.

Dobutamine Stress



Physiological Explanation

- Why does DSE not lead to an increase in Stroke Volume?
  - 1. Afterload mismatch due to imbalance between the severity of the stenosis and myocardial reserve
  - 2. Inadequate increase of myocardial blood flow due to associated CAD
  - 3. Irreversible myocardial damage due to MI/Scar

  - Importance: Patients with no LV flow reserved defined by SV increase <20% during DSE or cath have **Higher Mortality (22-33% vs. 5-8%)**

Management

- No ACC/AHA guidelines on the specific recommendations for treatment of patients with low LVEF, LF-LG AS

- ESC/EACTS guidelines support the use of AVR (Class IIa; Level of Evidence C)

- ESC/EACTS Guidelines for use of AVR in patients with low LVEF, LF-LG AS and no flow reserve (Class IIb; Level of Evidence C)

Transcatheter aortic valve Replacement(TAVR) ?

Clinical Spectrum of Severe Aortic Stenosis

- LOW FLOW, LOW GRADIENT, **PRESERVED LVEF**
  - Presents us with a diagnostic dilemma
  - Normally, when we think of low flow, low gradient AS, we think of it in the context of **LOW EF** (i.e. impaired systolic function)

LF-LG AS with Normal LVEF

- Preserved LVEF, thus labeled "paradoxical LF-LG AS"
- Increases with older age, female gender, htn
- Restrictive physiology, so LV function and SV reduced but PRESERVED LVEF
  - 1. more pronounced LV concentric remodeling and myocardial fibrosis both contributing to reduce the size, compliance, and filling of LV
  - 2. marked reduction in intrinsic LV systolic function but not apparent by LVEF, but may require more sensitive parameters (LV mid-wall or longitudinal shortening)

Management

- No ACC/AHA guidelines on the specific recommendations for treatment of patients with LF-LG AS Normal LVEF
- ESC/EACTS guidelines support the use of AVR in paradoxical LF-LG AS (Class IIa; Level of Evidence C)
- Perplexing since Class I indication for AVR when patient symptomatic vs. conservative therapy for LG AS with normal LVEF (mod AS)

Case Presentation

- 79 y/o female with systolic murmur and angina for more than one year

- 2D Echocardiogram
  - Normal LVEF: EF>55%
  - Aortic Peak Velocity: 2 m/s
  - AV MG: 8 mmHg
  - LVOT Diameter: 2.0 cm
  - LVOT VTI: 13.2 cm
  - AV VTI: 45 cm

- AVA = 0.9 cm^2

- Pt sent for surgery – heavily calcified stenotic aortic valve found, AVR performed, no recurrence of symptoms