Aortic Stenosis

Hemodynamic Severity: Area Gradient Mismatch

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mayo

DISCLOSURE

Relevant Financial Relationship(s)

None

Off Label Usage

None

Aortic Stenosis
Hemodynamic Severity

	Aortic V_{max} (m/s)	Mean Gradient (mmHg)	Valve Area (cm^2)	Valve Area Index (cm^2/m^2)
Mild	2.0-2.9	<20	>1.5	>0.8
Moderate	3.0-3.9	20-39	1.1-1.5	0.7-0.8
Severe	≥4.0	>40	≤1.0	≤0.6

Nishimura, et al, 2014

Expected Mean Gradient When The Valve Area is 1.0cm²

- Flow = Area x Velocity x Cc
- Velocity = Cv $\sqrt{2g\,\Delta P}$

$$Flow^2 = Area^2 \times \Delta P$$

$$\Delta P = \frac{Flow^2}{Area^2} = \frac{5^2}{1^2} = 25$$

Cc=coefficient of orifice contraction
Cv = coefficient of velocity *Note $\sqrt{2g} = 44.3$

Relation of The Aortic Valve Area To The Mean Gradient

Aortic Valve Area (cm^2)	Mean Gradient (mmHg)
3.0	2.6
2.0	6.6
1.0	26
0.9	32
0.8	41
0.7	53
0.6	73

Carabello BA. NEJM 2002;346:677-682

Aortic Stenosis

Area Gradient Mismatch

	Mean Gradient (mmHg)	Valve Area (cm^2)	Valve area index (cm^2/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, 2014

Area Gradient Mismatch?

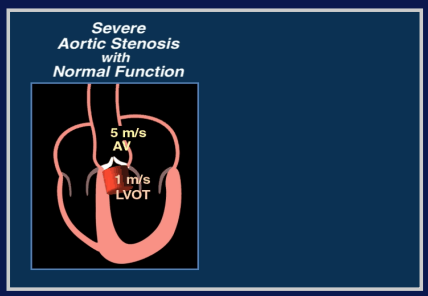
1.

KEEP CALM & FOLLOW THE RULES

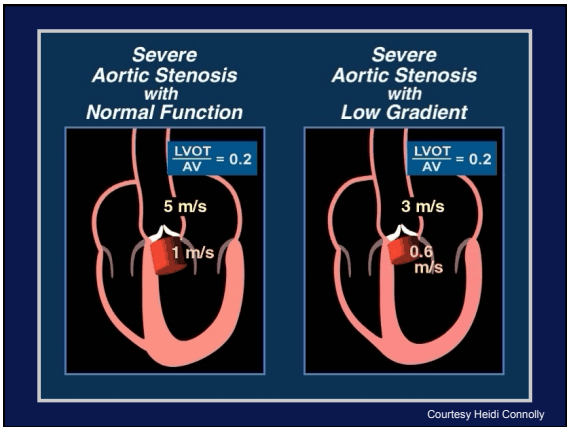
2. Discrepancy?

Velocity Ratio

Doppler Velocity Index



Courtesy Heidi Connolly



Courtesy Heidi Connolly

Aortic Stenosis
Area Gradient Mismatch

Low flow (normal or reduced LVEF)
Vmax < 4 m/sec or Mean Gradient <40mmHg
AVA ≤1.0cm²

- True, Severe AS
- Mild-Mod AS Low Flow (pseudo AS)

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
Vmax >4.0 m/sec, Normalize CO,↓ BP, VT, HR>120, symptoms, 20 mcg/kg/min

Dobutamine Echocardiography

Baseline Doppler hemodynamics

↓

Dobutamine stress

↙ Vmax ≥ 4.0m/sec
AVA ≤ 1.0cm²

↓

True Severe AS
(D2) IIa

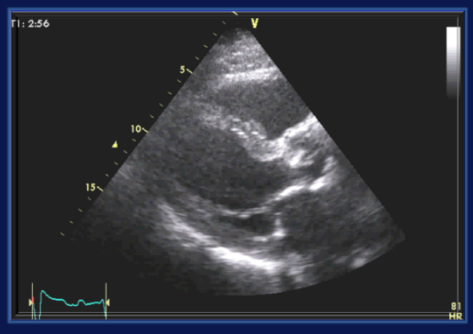
↘ ↑ Mean gradient
↑ AV Area

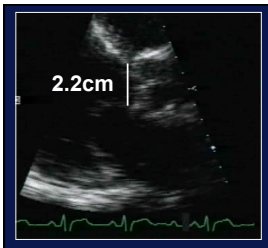
↓

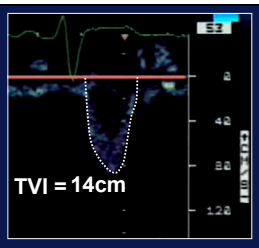
Pseudo Severe AS

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 x

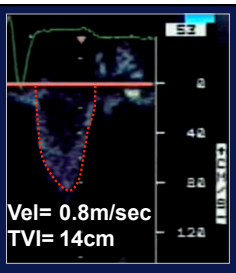
= 53cm^3

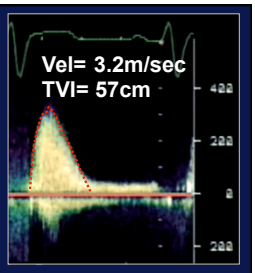
Low Flow

LVSVI = 53cm^3 / 2.3 m^2 = 23 cm^3/ m^2

(< 35ml/m^2)

CI = 23cm^3/ m^2 x 68bpm = 1.6 L/min/m^2

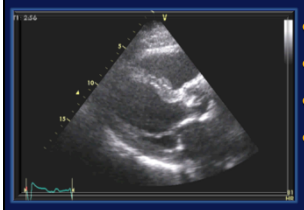




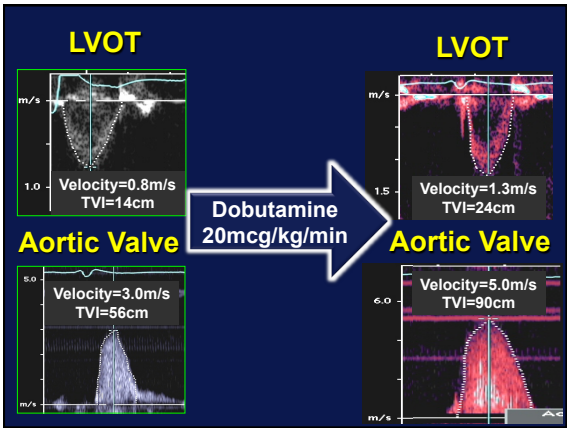
$$\text{Area}_{AV} = \frac{0.785\ (2.2\text{cm})^2 \times (\quad)}{}$$

= 0.9 cm^2 ; MG 24mmHg

Low EF Area Gradient Mismatch



- LVEF 30% (<50%)
- LVSVI 23ml/m²
- AVA 0.9cm²
- Mean Gradient 24mmHg



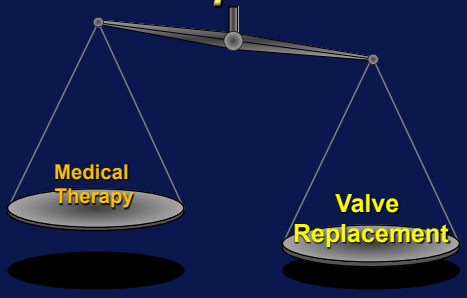
Dobutamine Stress

LV Stroke Volume Index
26ml/m² – 40ml/m²

Mean AV Gradient
24 – 52mmHg

Valve Area
0.9cm² – 1.0cm²

Medical Therapy vs *Valve Replacement*



- Surgery: 23 mm SJ AVR; no additional CABG needed
- Dismissed home 6 days post-op
- Follow-up 6 mos later:

  No recurrent heart failure; NYHA class II DOE only

  Echo: Normal AVR
  LVEF 39%

What If?

LV Stroke Volume Index

Rest

$0.785(2.2cm)^2 \times 14cm$ = cm^3/m^2

No Contractile Reserve

Exercise

$0.785(2.2cm)^2 \times 15cm$ = 57 cm^3 = 28 cm^3/m^2

Contractile Reserve

136 patients: Mean AV gradient 29±6 mmHg, AV area 0.7±0.1 cm², LVEF 30±5%

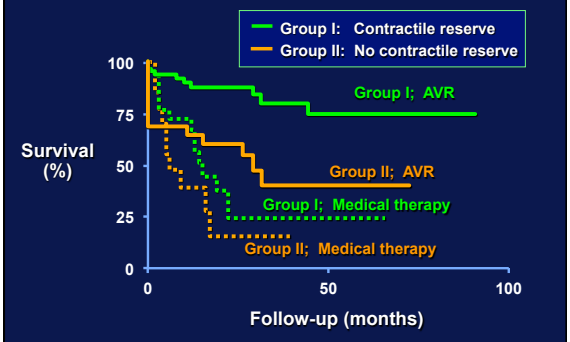
Contractile Reserve on DSE (≥ 20% ↑ in stroke volume)

Yes → Operative Mortality 5%

No → Operative Mortality 32%

Monin JL et al: Circulation 108:319, 2003

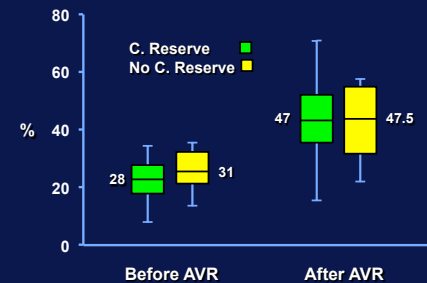
Contractile Reserve



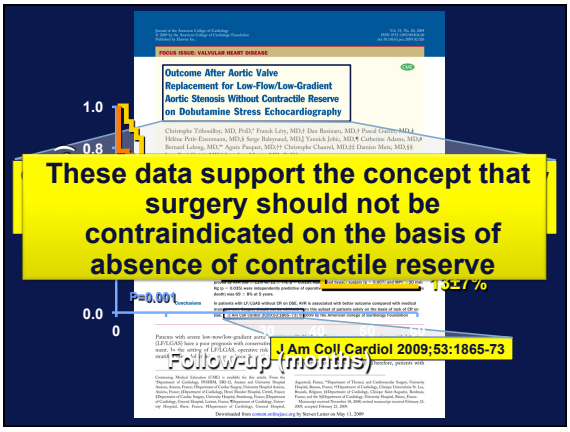
Monin JL et al: Circulation 108:319, 2003

Change in LVEF after AVR

Severe AS with Low EF Area Gradient Mismatch

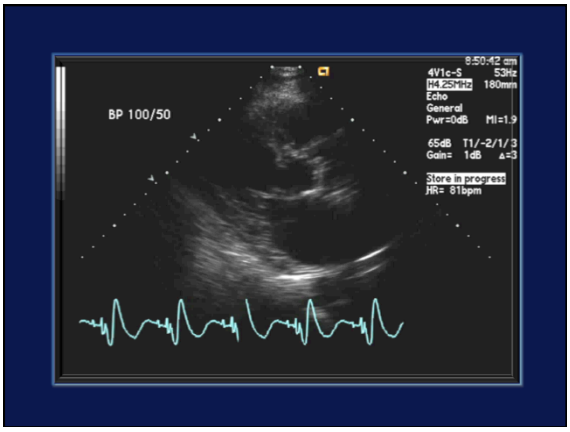


Quere et al. Circulation 2006; 113:1738-1744



Case

- 75 year old male
- Presents with dyspnea and syncope
- HTN (treated BP 135/75)
- Grade III/VI mid peaking systolic murmur LSB



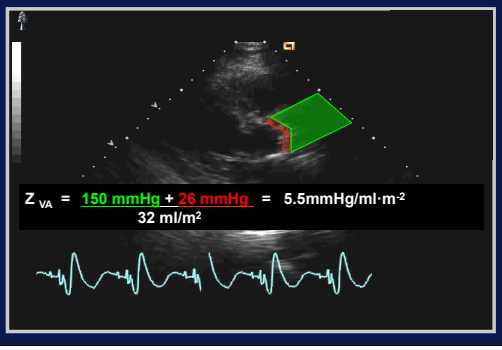
Echocardiography
Normal EF Area Gradient Mismatch

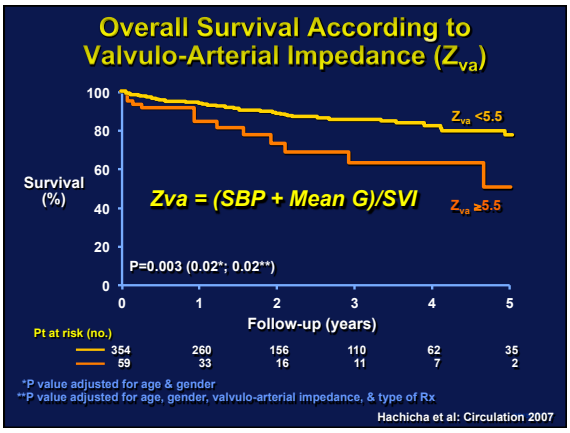
- LVEF 55%
- SVi (low flow) 32 ml/m^2
- AV Mean G 26mmHg
- AVA 0.8cm^2
- AVA index 0.45cm^2/m^2
- LVEDV 88ml

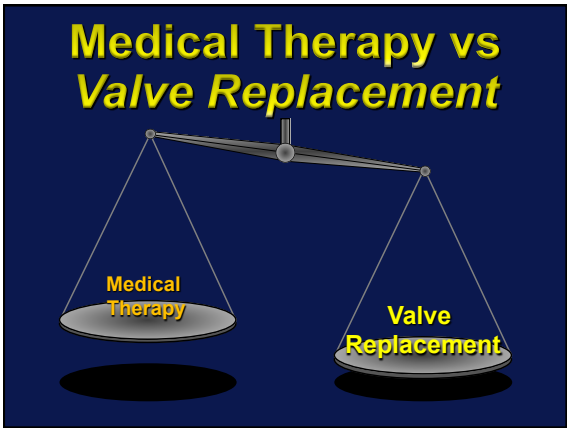
Aortic Stenosis Severity?

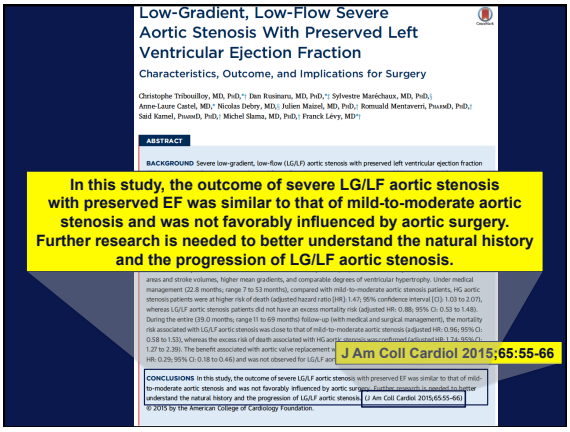
1. Mild
2. Moderate
3. Severe
4. Can't tell

Paradoxical LFLG Severe AS
Global Left Ventricular Afterload




Overall Survival According to Valvulo-Arterial Impedance (Z_{va})
100
80
60
40
20
0
Survival (%)
Z_{va} <5.5
Zva = (SBP + Mean G)/SVI
Z_{va} ≥5.5
P=0.003 (0.02*; 0.02**)
0 1 2 3 4 5
Follow-up (years)
Pt at risk (no.)
354 260 156 110 62 35
59 33 16 11 7 2
*P value adjusted for age & gender
**P value adjusted for age, gender, valvulo-arterial impedance, & type of Rx
Hachicha et al: Circulation 2007


Medical Therapy vs Valve Replacement
Medical Therapy
Valve Replacement


Low-Gradient, Low-Flow Severe Aortic Stenosis With Preserved Left Ventricular Ejection Fraction
Characteristics, Outcome, and Implications for Surgery
ABSTRACT
In this study, the outcome of severe LG/LF aortic stenosis with preserved EF was similar to that of mild-to-moderate aortic stenosis and was not favorably influenced by aortic surgery. Further research is needed to better understand the natural history and the progression of LG/LF aortic stenosis.
J Am Coll Cardiol 2015;65:55-66

Progression of Low-Gradient, Low-Flow, Severe Aortic Stenosis With Preserved Left Ventricular Ejection Fraction

Christophe Tribouilloy, MD, PhD[a,b,*], Dan Rusinaru, MD, PhD[b,c], Vincent Charles, MD[a], Jamila Boulif, MS[d], Frédéric Maes, MD[d], Franck Lévy, MD[a], Agnès Pasquet, MD, PhD[d], Sylvestre Maréchaux, MD, PhD[b,e], and Jean-Louis Vanoverschelde, MD, PhD[d]

Low-gradient (LG), low-flow (LF), severe aortic stenosis (AS) with preserved ejection

- Over 2 yrs 41% progressed to classic high gradient AS and showed a decline in LVEF.
- "This result suggests that LG/LF AS with PEF is an intermediate stage between moderate AS and HG AS rather than an advanced form of the disease."

(55% to 69%) to 58% (51% to 65%), p = 0.001. At follow-up, MDG increase was observed in 51 patients (86%), and 24 patients (41%) acquired the features of classical high-gradient (HG) severe AS (MDG ≥40 mm Hg and peak aortic jet velocity ≥400 cm/s). There were no differences as regard to baseline hemodynamic parameters between patients who displayed ≥5 mm Hg MDG increase and those in whom such increase was not observed. In univariate analysis, most patients with LG/LF AS with PEF exhibit over time Am J Cardiol 2015 decrease in AVA with slight EF impairment. This result suggests that LG/LF AS with PEF is an intermediate stage between moderate AS and HG AS rather than an advanced form of the disease. (Am J Cardiol 2015;■:■–■)

2014 AHA/ACC Guideline for the Management of Patients with Valvular Heart Disease

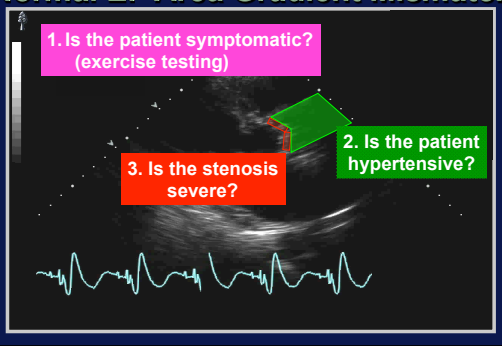
A Report of the American College of Cardiology/American Heart Association Task

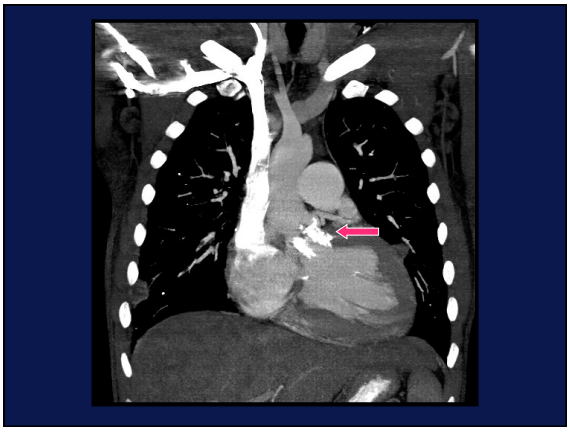
AVA ≤1cm², LVEF ≥ 50% and normotensive (stage D3)

AS likely cause of symptoms

AVR (IIa)

Approach to Patients with Normal EF Area Gradient Mismatch





Sex Differences in Aortic Valve Calcification Measured by Multidetector Computed Tomography in Aortic Stenosis

Shivani R. Aggarwal, MBBS*; Marie-Annick Clavel, DVM, PhD*; David Messika-Zeitoun, MD, PhD; Caroline Cueff, MD; Joseph Malouf, MD; Philip A. Araoz, MD; Rekha Mankad, MD; Hector Michelena, MD; Alec Vahanian, MD; Maurice Enriquez-Sarano, MD

1. **Despite a similar degree of AS severity women have lower AVC loads then men, even after indexing for their smaller body size.**
2. **For AS severity diagnostic purposes, interpretation of AVC load should be different in men and in women.**

Conclusions—In this large AS population, women incurred similar AS severity than men for lower AVC loads, even after indexing for their smaller body size. Hence, the relationship between valvular calcification process and AS severity differs in women and men, warranting further pathophysiological inquiry. For AS severity diagnostic purposes, interpretation of AVC load should be different in men and in women. (*Circ Cardiovasc Imaging*. 2013;6:40-47.)

Impact of Aortic Valve Calcification, as Measured by MDCT, on Survival in Patients with Aortic Stenosis

Results of an International Registry Study

Marie-Annick Clavel, DVM, PhD,* Philippe Pibarot, DVM, PhD,† David Messika-Zeitoun, MD, PhD,‡§ Romain Capoulade, PhD,† Joseph Malouf, MD,* Shivani Aggarwal, MBBS,* Philip A. Araoz, MD,* Hector I. Michelena, MD,* Caroline Cueff, MD,‖ Eric Larose, MD, MSc,† Jordan D. Miller, PhD,* Alec Vahanian, MD,‡§ Maurice Enriquez-Sarano, MD*

ABSTRACT

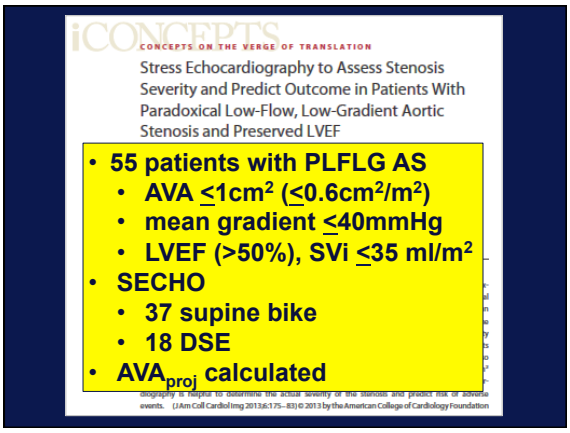
Aortic Valve Calcium Burden

1. **1200 AU (women), 2000 AU (Men)**
2. **300 AU/cm² (women), 500 AU/cm² (men)**

RESULTS During follow-up, there were 440 aortic valve implantations (AVIs) and 194 deaths (115 under medical treatment). Univariate analysis showed strong association of absolute AVC and $AVC_{Density}$ with survival (both, $p < 0.0001$) with a spline curve analysis pattern of threshold and plateau of risk. After adjustment for age, sex, coronary artery disease, diabetes, symptoms, AS severity on hemodynamic assessment, and LV ejection fraction, severe absolute AVC (adjusted hazard ratio [HR]: 1.75, 95% confidence interval [CI]: 1.04 to 2.92; $p = 0.03$) or severe $AVC_{Density}$ (adjusted HR: 2.44; 95% CI: 1.37 to 4.37; $p = 0.002$) independently predicted [illegible] predictive value (all, $p \leq 0.04$) and a net reclassification index [illegible] 1.7); 95% CI: 1.12 to 2.62; $p = 0.01$) and severe $AVC_{Density}$ [illegible] independently predicted overall mortality, even with adjustment for time-dependent AVI.

CONCLUSIONS This large-scale, multicenter outcomes study of quantitative Doppler echocardiographic and MDCT assessment of AS shows that measuring AVC load provides incremental prognostic value for survival beyond clinical and Doppler echocardiographic assessment. Severe AVC independently predicts excess mortality after AS diagnosis, which is greatly alleviated by AVI. Thus, measurement of AVC by MDCT should be considered for not only diagnostic but also risk-stratification purposes in patients with AS. (J Am Coll Cardiol 2014;64:1202-13)

J Am Coll Cardiol 2014;64:1202-13



Projected Aortic Valve Area

$$AVA_{proj} = AVA_{rest} + VC \times (250 - Q_{rest})$$

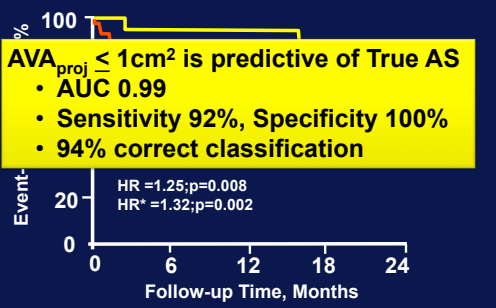
$$\text{Valve Compliance (VC)} = \frac{AVA_{peak} - AVA_{rest}}{Q_{peak} - Q_{rest}}$$

$$Q_{mean} = \frac{\text{Stroke Volume}}{\text{LV ejection time}}$$

Is This Too Complicated?

1. LVOT diameter (use the same rest / stress)
2. $LVOT_{TVI}$ (rest / stress)
3. AoV_{TVI} (rest / stress)
4. Measure the ejection time

Event Free Survival According to AVA_{proj}

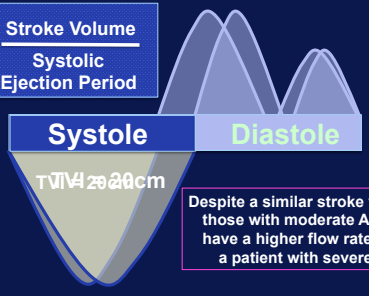


$AVA_{proj} \leq 1cm^2$ is predictive of True AS
- AUC 0.99
- Sensitivity 92%, Specificity 100%
- 94% correct classification

Clavel et al. J Am Coll Cardiol Img 2013;6:175-83

Defining Low Flow?
Stroke Volume Index vs Flow Rate

$$\text{Flow Rate} = \frac{\text{Stroke Volume}}{\text{Systolic Ejection Period}}$$



Despite a similar stroke volume those with moderate AS will have a higher flow rate than a patient with severe AS

Resting Aortic Valve Area at Normal Transaortic Flow Rate Reflects True Valve Area in Suspected Low Gradient Severe Aortic Stenosis

Navtej S. Chahal, MBBS,*† Maria Drakopoulou, MD,* Ana M. Gonzalez-Gonzalez, MD,* Ramasamy Manivarmane, MBBS,* Rajdeep Khattar, MBBS,*† Roxy Senior, MD*†‡

ABSTRACT

- 67 patients with area gradient mismatch and suspected severe AS ($AVA < 1cm^2$, MG < 40mmHg and either EF < 50% or $SVi < 35ml/m^2$)
- Stress Echo (exercise or dobutamine) and if AVA remained $< 1cm^2$ and stress MG ≥ 40mmHg were classified as true severe AS.

METHODS Sixty-seven patients with suspected low-flow, low-gradient aortic stenosis who underwent SE were retrospectively studied. Following stratification by rest LVEF, SVi, and flow rate–using cutoffs of 50%, 35 ml/m², and 200 ml/s, respectively–we tested for significant changes in AVA during SE.

RESULTS Mean age was 77 ± 9 years and 60% of patients were male. Mean values for rest variables were as follow: AVA: 0.77 ± 0.12 cm², mean gradient: 27 ± 7 mm Hg, flow rate: 182 ± 37 ml/s, SVi: 32 ± 8 ml/m², and LVEF: 45 ± 15%. During SE, significant increases in AVA were observed regardless of resting LVEF and SVi state. In patients with rest flow rate ≥200 ml/s, AVA did not increase significantly during stress (rest AVA: 0.9[illegible] positive predictive value for confirming underlying true severe aortic stenosis [illegible] was the only parameter associated with severe AS (odds ratio: 1.05, 95% [illegible]

CONCLUSIONS Rest AVA measured under normal flow rate conditions is likely to reflect the true severity of AS and unlikely to change significantly with SE. Flow normalization may only be required in patients with AVA <1 cm² and mean gradient <40 mm Hg when the rest flow rate is <200 ml/s. (J Am Coll Cardiol Img 2015;■:■–■)

J Am Coll Cardiol Img 2015

Resting Aortic Valve Area at Normal Transaortic Flow Rate Reflects True Valve Area in Suspected Low Gradient Severe Aortic Stenosis

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	n	Rest AVA, cm^2	Stress AVA, cm^2	p value
Q < 200 ml/s	48	0.74±0.12	0.89±0.25	<0.001
Q ≥ 200 ml/s	19	0.85±0.09	0.89±0.12	0.19

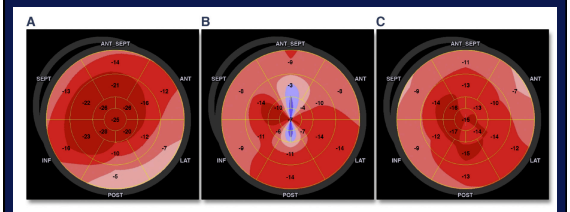
Interpretation: If normal resting flow rate, the corresponding AVA is likely to be represent the true hemodynamic severity of the stenosis and further "flow correction" with SECHO is not likely required.

LV Mechanics in Mitral and Aortic Valve Diseases

Value of Functional Assessment Beyond Ejection Fraction

J Am Coll Cardiol Img 2014;7:1151-66

Elena Galli, MD, PhD,* Patrizio Lancellotti, MD, PhD,† Partho P. Sengupta, MD, DM,‡ Erwan Donal, MD, PhD*



A	B	C
MG = 60 mm Hg	MG = 17 mm Hg	MG = 34 mm Hg
SVi 46 ml/m^2	SVi 26 ml/m^2	SVi 27 ml/m^2
LVEF 69%	LVEF 60%	LVEF 35 %
SGL -17%	SGL -12%	SGL -12%

Summary

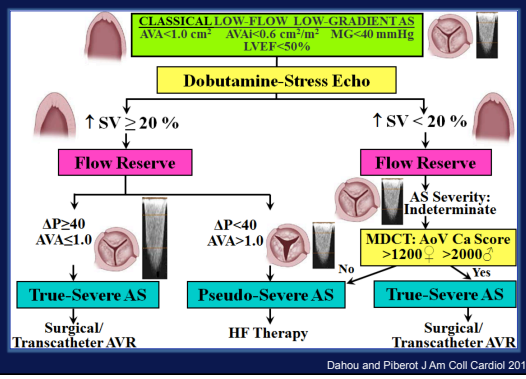
Aortic Stenosis With Low Flow

- Is a true clinical entity
- Stress echocardiography is the best way to distinguish True from Pseudo Severe AS and to evaluate for Contractile Reserve when LVEF is depressed.
- Low flow and low gradient severe AS can also happen with normal LVEF, especially in the elderly with HTN.

Summary
Aortic Stenosis With Low Flow

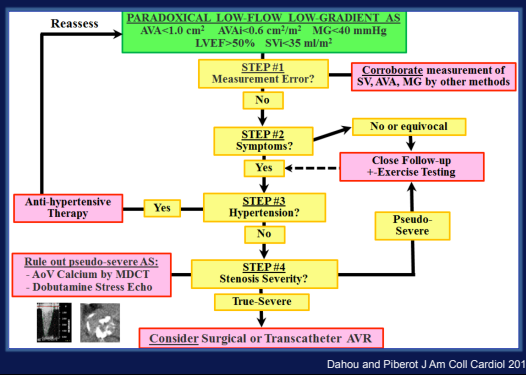
- In addition to standard hemodynamic parameters of stenosis severity (gradients, area, projected area), stroke volume, ejection flow and blood pressure considerations help in correct interpretation of AS severity.
- AVR appears to be the best option is truly severe AS.

Low EF Area-Gradient Mismatch



Dahou and Piberot J Am Coll Cardiol 2015

Normal EF Area-Gradient Mismatch



Dahou and Piberot J Am Coll Cardiol 2015

Aortic Stenosis

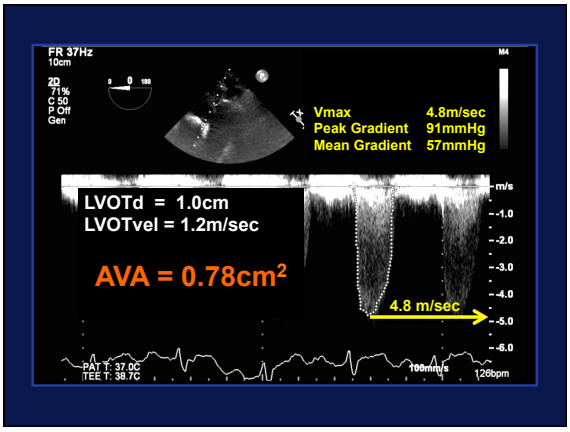
Reverse Area Gradient Mismatch

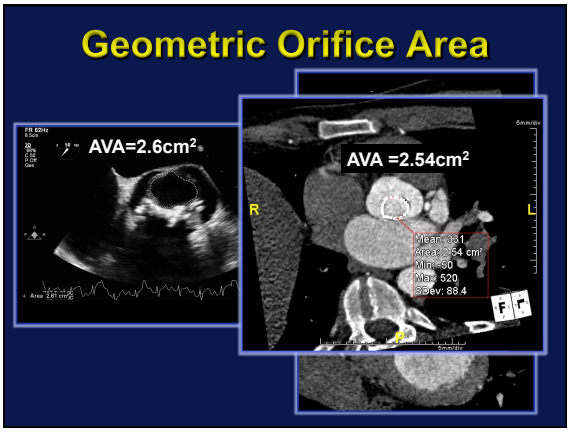
	Mean Gradient (mmHg)	Valve Area (cm^2)	Valve area index (cm^2/BSA)
Mild	<25	>1.5	>0.8
Moderate	25- 40	1.0-1.5	0.6-0.8
Severe	>40	<1.0	<0.6

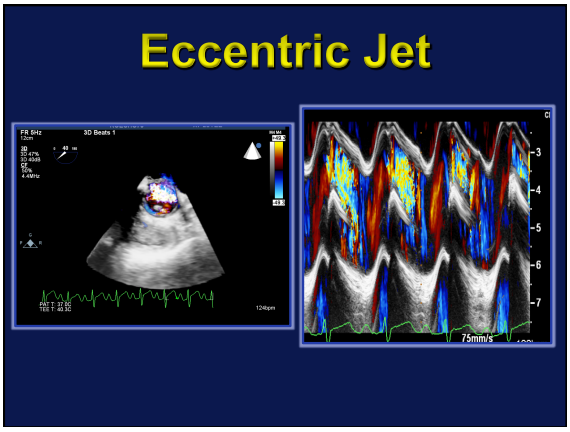
Bonow RO, et al. Circulation, 2008

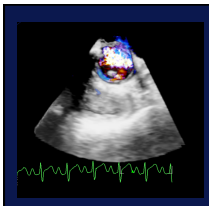
Case

- 29 y/o male
- Carries a diagnosis of Asymptomatic severe AS
- Quit Law School


Vmax 4.8m/sec
Peak Gradient 91mmHg
Mean Gradient 57mmHg
LVOTd = 1.0cm
LVOTvel = 1.2m/sec
AVA = 0.78cm²
4.8 m/sec


Geometric Orifice Area
AVA=2.6cm²
AVA =2.54cm²

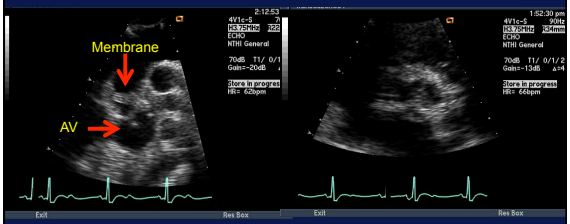

Eccentric Jet



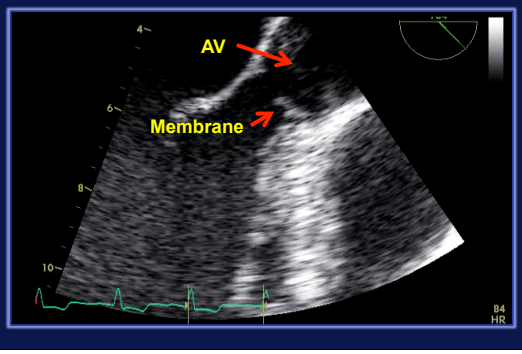
Jet Eccentricity

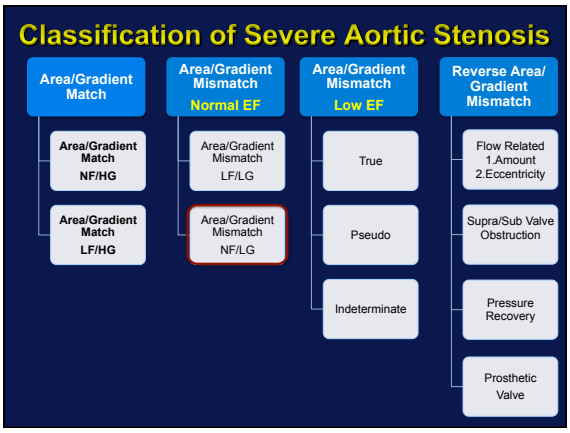
- Jet collides with wall, more energy loss due to heat, flow separation and vortex formation.
- Elevated gradient and reduced pressure recovery
- Valve area calculations are based on measures of gradient results in larger coefficient of orifice contraction

Supra-Aortic Membrane

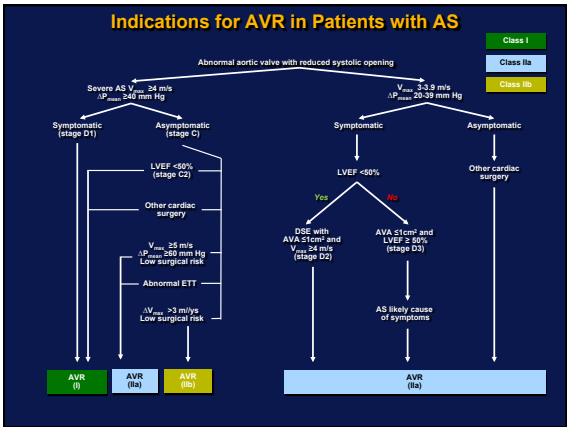


Sub-Aortic Membrane




Classification of Severe Aortic Stenosis
Area/Gradient Match
Area/Gradient Match NF/HG
Area/Gradient Match LF/HG
Area/Gradient Mismatch Normal EF
Area/Gradient Mismatch LF/LG
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


mayo


Indications for AVR in Patients with AS
Class I
Class IIa
Class IIb
Abnormal aortic valve with reduced systolic opening
Symptomatic (stage D1)
Asymptomatic (stage C)
Symptomatic
Asymptomatic
LVEF <50% (stage C2)
Other cardiac surgery
Abnormal ETT
LVEF <50%
Other cardiac surgery
Yes
No
DSE with AVA ≤1cm² and (stage D2)
AVA ≤1cm² and LVEF ≥ 50% (stage D3)
AS likely cause of symptoms
AVR (I)
AVR (IIa)
AVR (IIb)
AVR (IIa)