Aortic Stenosis

Severe by Gradient not Valve Area

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DISCLOSURE

Relevant Financial Relationship(s)

None

Off Label Usage

None

Pre Questions (1)

- The Difference between Doppler MIG and catheterization PPG
  A. Is due to pressure recovery
  B. Is due to different measurement timing of the LV and aortic pressures
  C. Occurs only in patients with small aortas
  D. Is used to calculate aortic valve area

Pre Questions (2)

- Catheter-Doppler Discordance maybe due to
  - A. Pressure recovery
  - B. Eccentric jet
  - C. High flow states
  - D. Very severe aortic stenosis

Severe Aortic Stenosis

Area Gradient Match

	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

Severe Aortic Stenosis

Severity of Aortic Stenosis

Area Gradient Match

	Mean Gradient (mmHg)	Valve Area (cm^2)	Valve Velocity (cm/sec)
Mild	<20		2 - 2.9
Moderate	20- 40		3 - 3.9
Severe	>40	<1.0	> 4.0

iAVA < 0.6 cm/m^2

Nishimura, et al. Circulation, 2014

Severe Aortic Stenosis

Severity of 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

Bonow RO, et al. Circulation, 2008

Severe Aortic Stenosis

Severity of Aortic Stenosis

Area Gradient Mismatch

	Mean Gradient (mmHg)	Valve Area (cm^2)	Valve Velocity (cm/sec)
Mild	<20		2 - 2.9
Moderate	20- 39		3 - 3.9
Severe	>40	<1.0	> 4.0

Nishimura, et al. Circulation, 2014

Severe Aortic Stenosis

Severity of 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

Nishimura, et al., J Am Coll Cardiol 2014

Severe Aortic Stenosis

Severity of Aortic Stenosis

Reverse Area Gradient Mismatch

	Mean Gradient (mmHg)	Valve Area (cm^2)	Valve Velocity (cm/sec)
Mild	<20		2 – 2.9
Moderate	20-39		3 – 3.9
Severe	>40		> 4.0

Nishimura, et al., Circulation 2014

Aortic Stenosis

Determining the “True” Severity

Measurement Errors Must be Excluded

Discordance of Area and Gradient Severity

REVIEW ARTICLE

Aortic Valve Stenosis: To the Gradient and Beyond—The Mismatch Between Area and Gradient Severity

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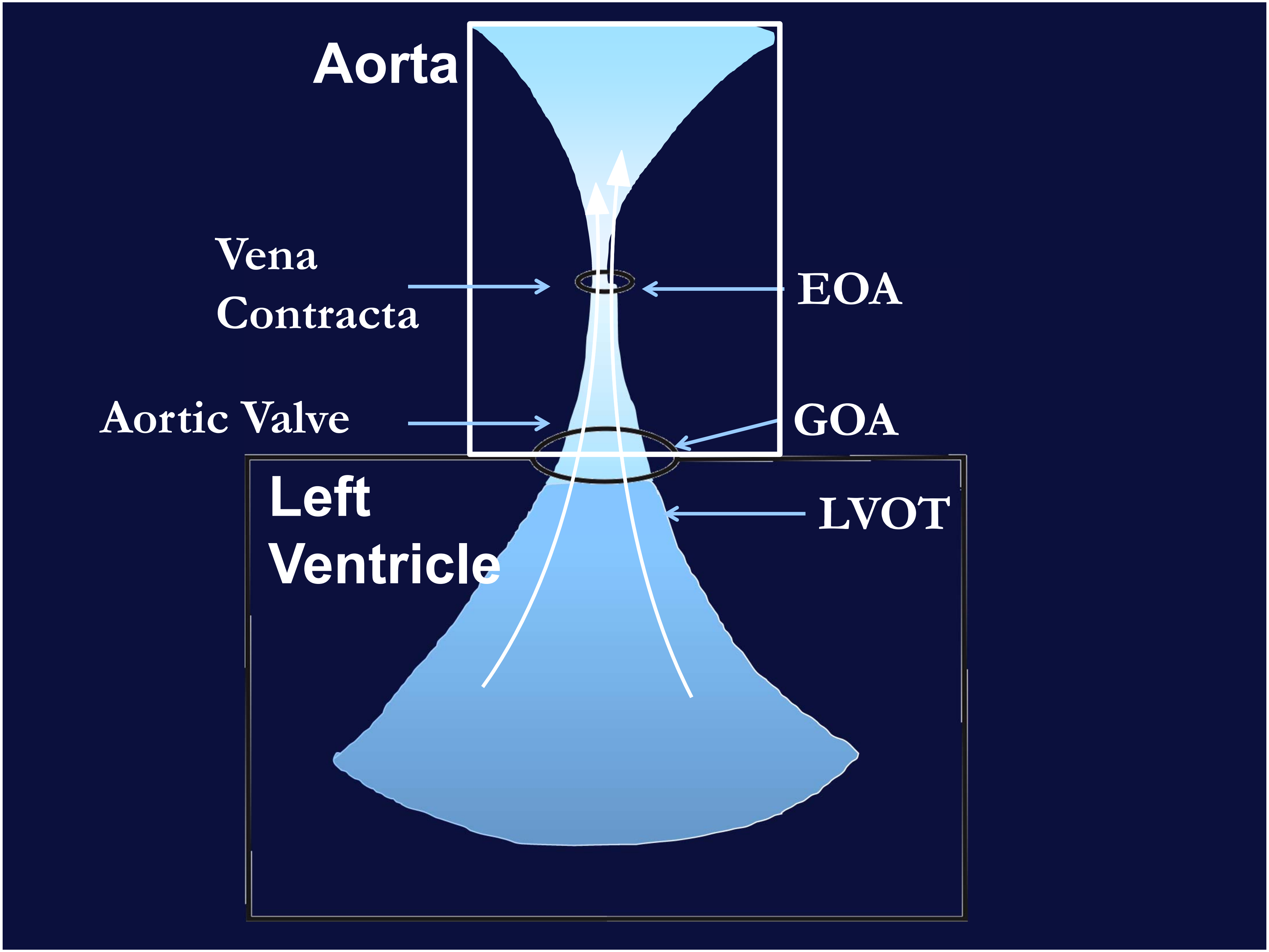
The clinical severity of aortic stenosis (AS) is based largely on symptoms. However, AS severity is primarily determined by estimating the aortic valve area (AVA) and pressure gradients (ΔP). Conditions may arise in which there is a mismatch in severity between AVA and ΔP determinations secondary to errors in measurement and/or assumption, alterations of flow, or variations in the magnitude of pressure recovery. The cause of discrepancy between area and gradient determinations must be deciphered so as to best counsel patients on the most ideal treatment strategy. (J Interven Cardiol 2012;00:1–12)

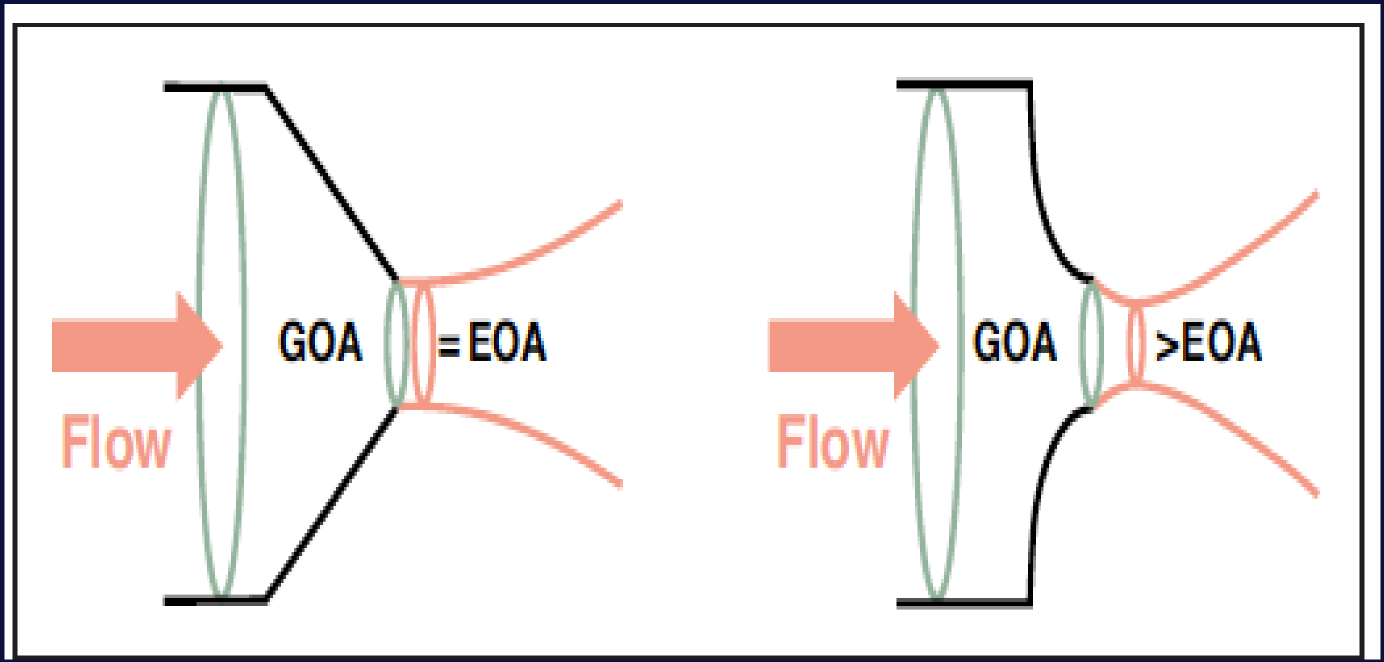
Topics of Discussions

- GOA Vs. EOA
- Doppler Vs. Catheter
- Factors affecting Gradient
- Area/Gradient Mismatch
- Reverse Area Gradient Mismatch



Aorta
Vena
Contracta
EOA
Aortic Valve
GOA
Left
Ventricle
LVOT

GOA Versus EOA



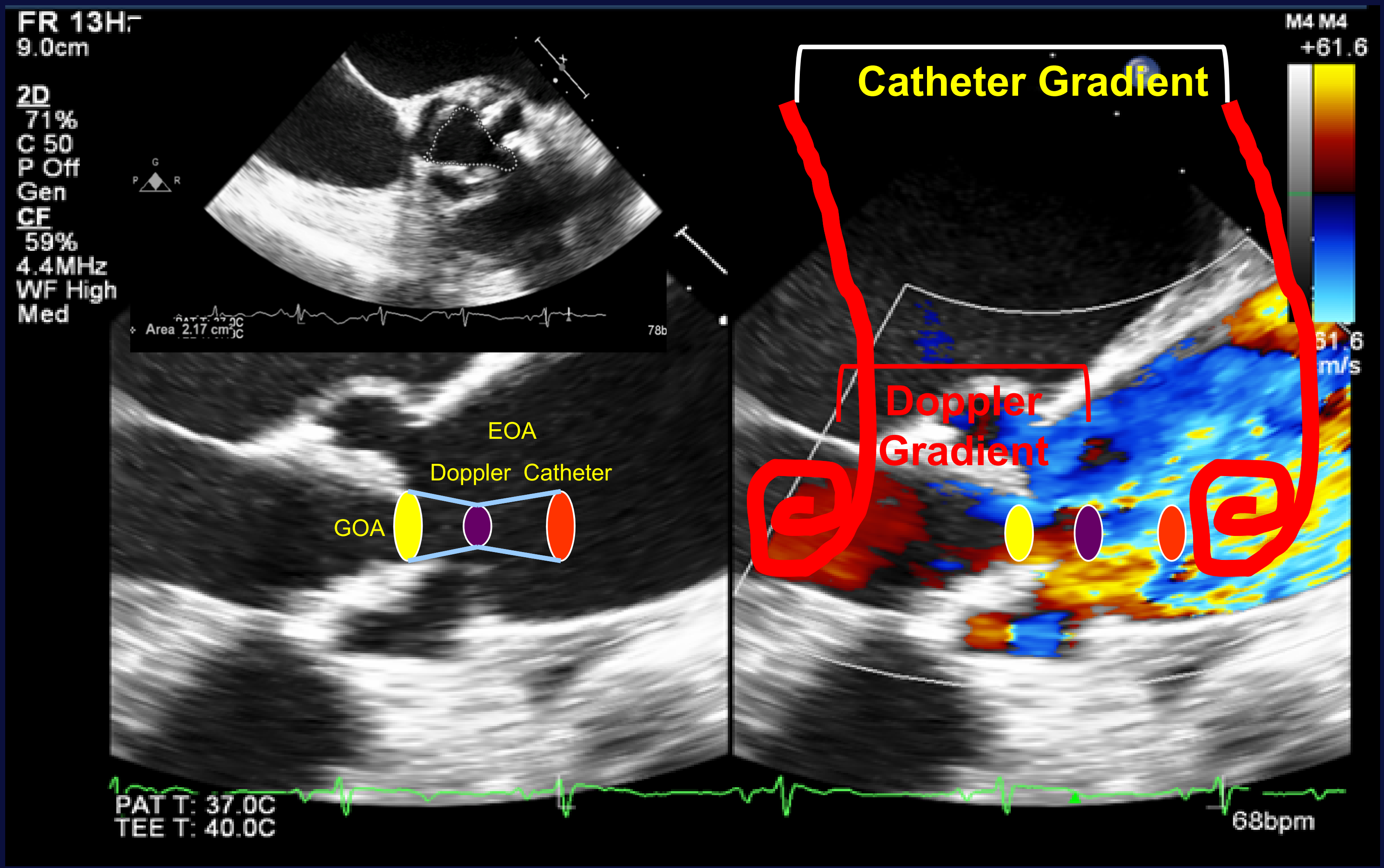
B

GOA: Planimetry

EOA: Continuity Equation

Coefficient of Contraction: EOA/GOA

Doppler versus Catheter Area and Gradient Assessment

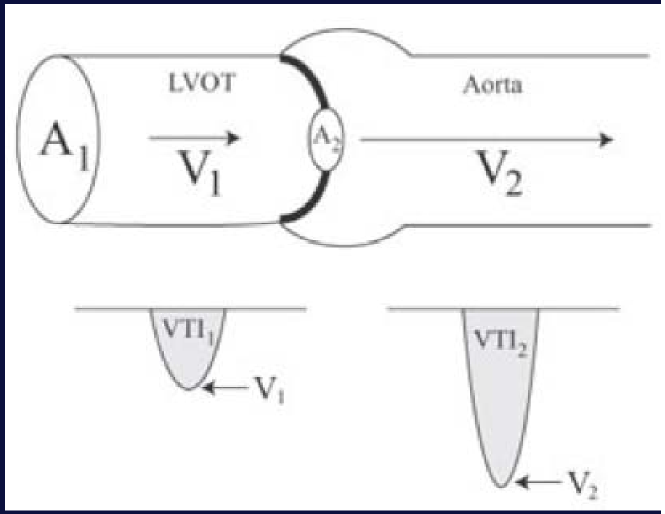


Doppler Aortic Valve Area Assessment

- Continuity Equation
- A1 x V1 = A2 x V2

$$A_2\,(AV) = \frac{A_1 \times V_1}{V_2}$$

B



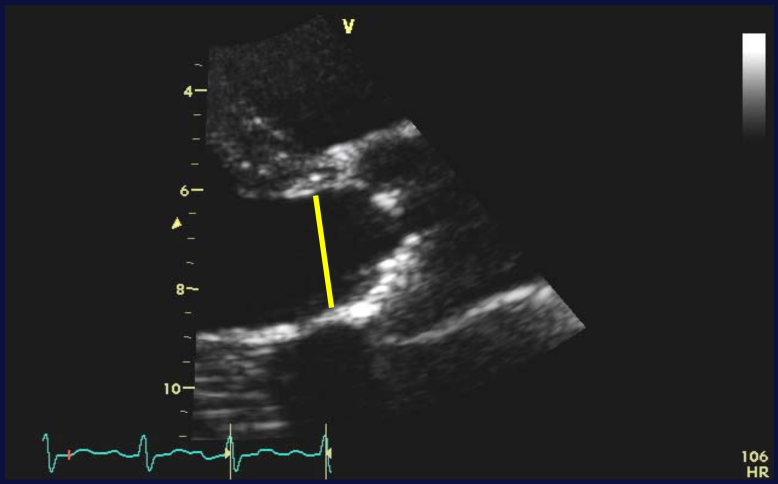
- Also, $A_2/A_1 = V_1/V_2$

B

- The ratio of velocities is the inverse of the ratio of areas
- Dimensionless index = $V_1/V_2 < 0.25$

Doppler Aortic Valve Area Assessment

LVOT Diameter = 2 cm
LVOT Area = $0.785 \times (2)^2$
LVOT Area = 3.14 cm^2



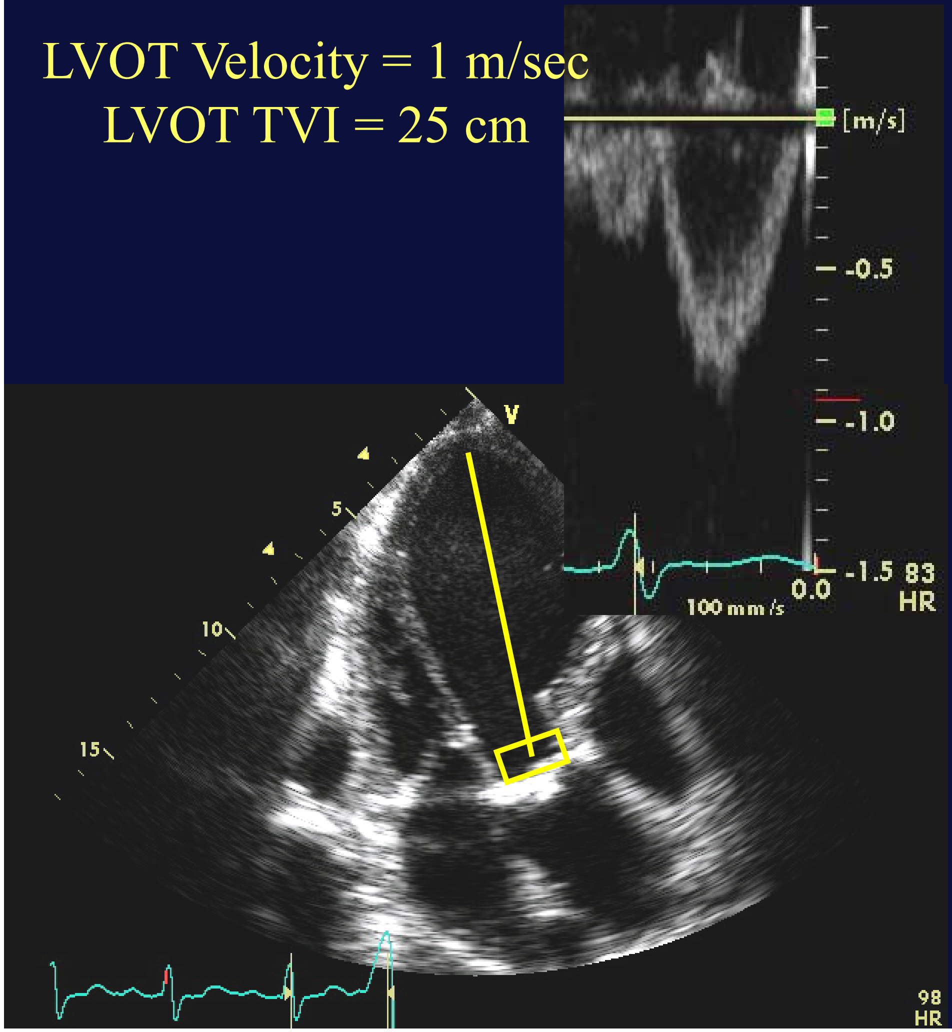
- LVOT diameter
- Measure in systole
- At Leaflet insertion
- Error squared!!

LVOT assumed as a circle = Πr^2
LVOT Area = Π (LVOT radius) ^{2}
LVOT Area = $3.14 \times (\text{LVOT diameter}/2)^2$
LVOT Area = $0.785 \times (\text{LVOT diameter})^2$

B

Doppler Aortic Valve Area Assessment

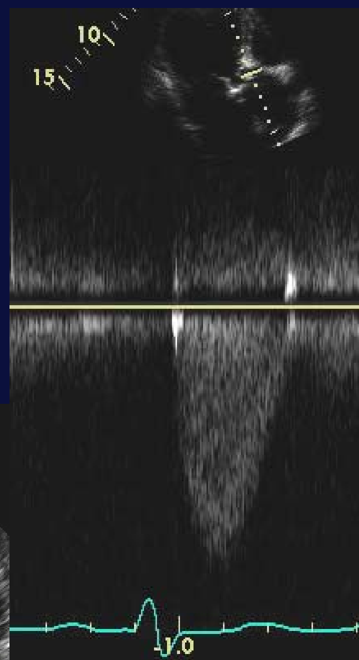
LVOT Velocity = 1 m/sec
LVOT TVI = 25 cm

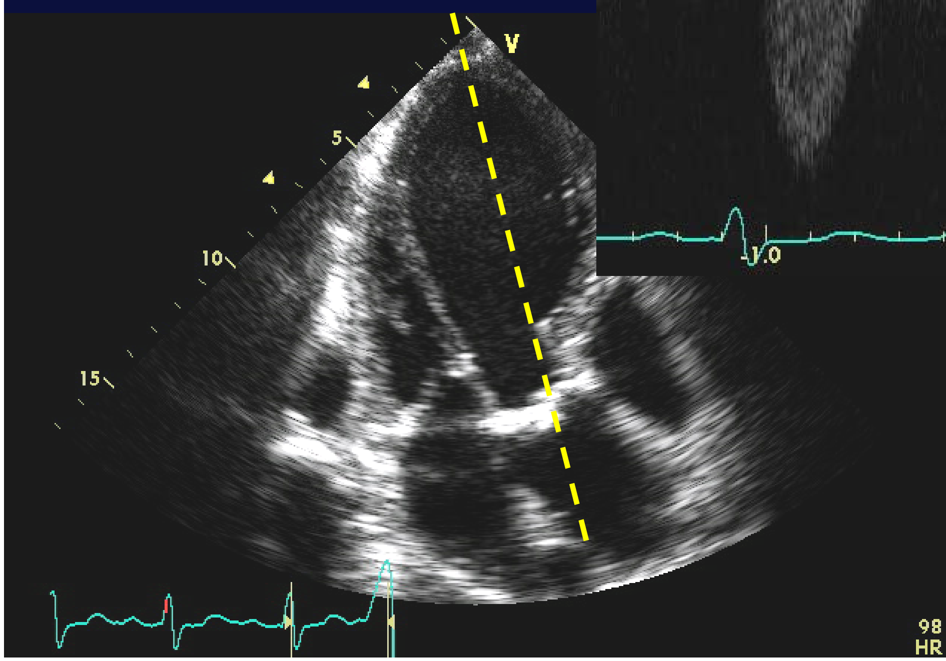


- PW: LVOT
- Use proper cursor alignment parallel to blood flow to obtain optimum signal

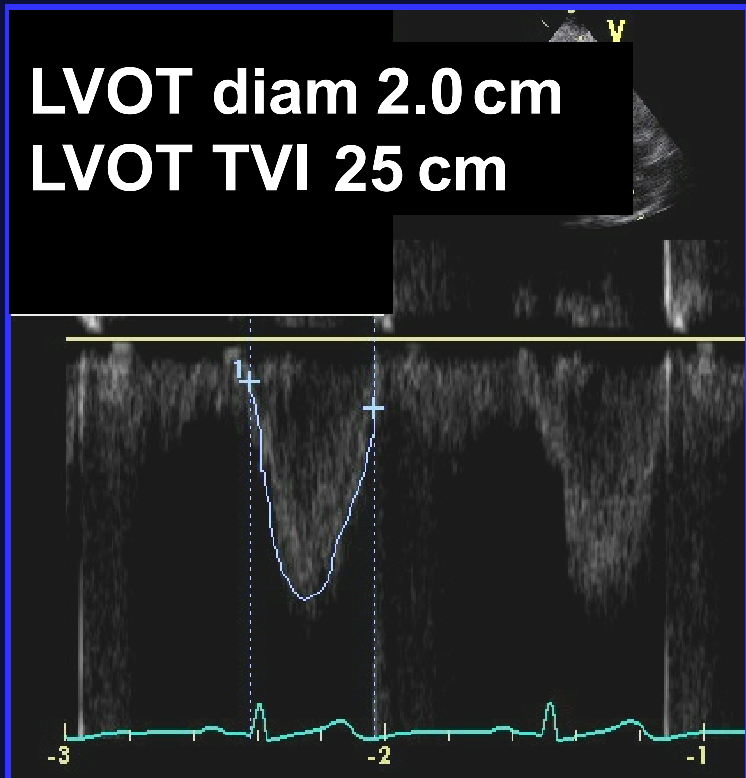
Doppler Aortic Valve Area Assessment

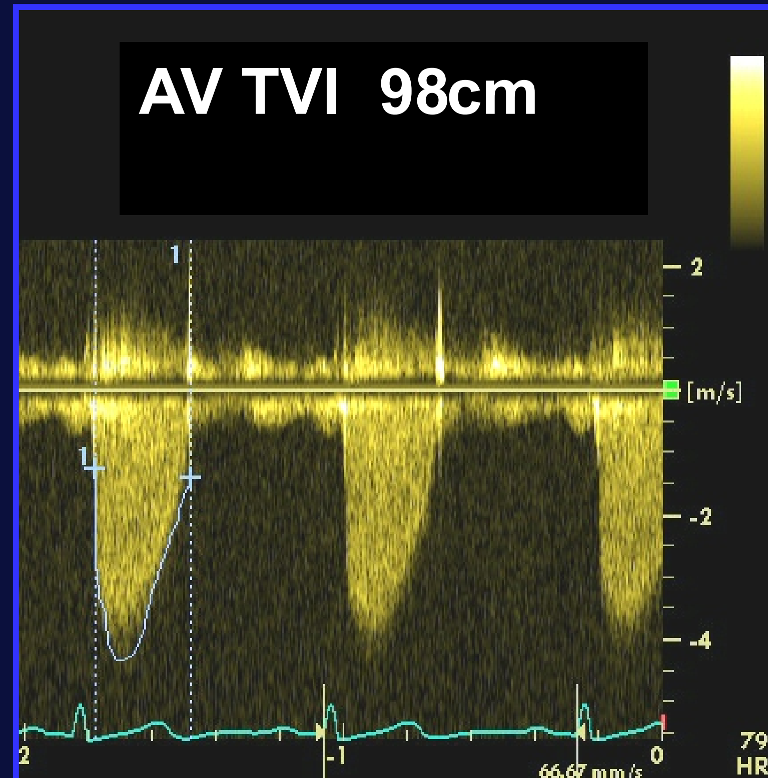
AV velocity = 4 m/sec
AV TVI = 98 cm





- CW: AV
- Multiple windows
- Use proper cursor alignment parallel to blood flow to obtain optimum





$$\text{Area 1} \times TVI_1 = \text{Area 2} \times TVI_2$$

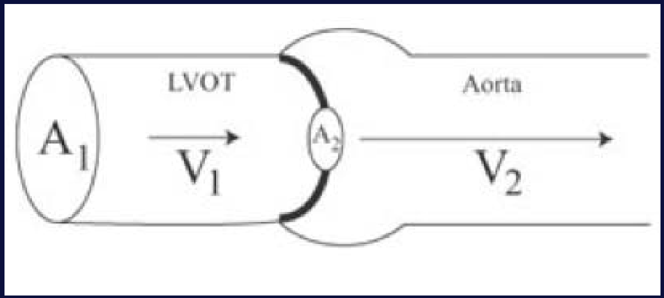
$$.785 \; (\quad)^2 \times \quad = AVA \times$$

$$AVA = 78.8 / 98$$

$$= 0.8 cm^2$$

Doppler Aortic Valve Gradient Assessment

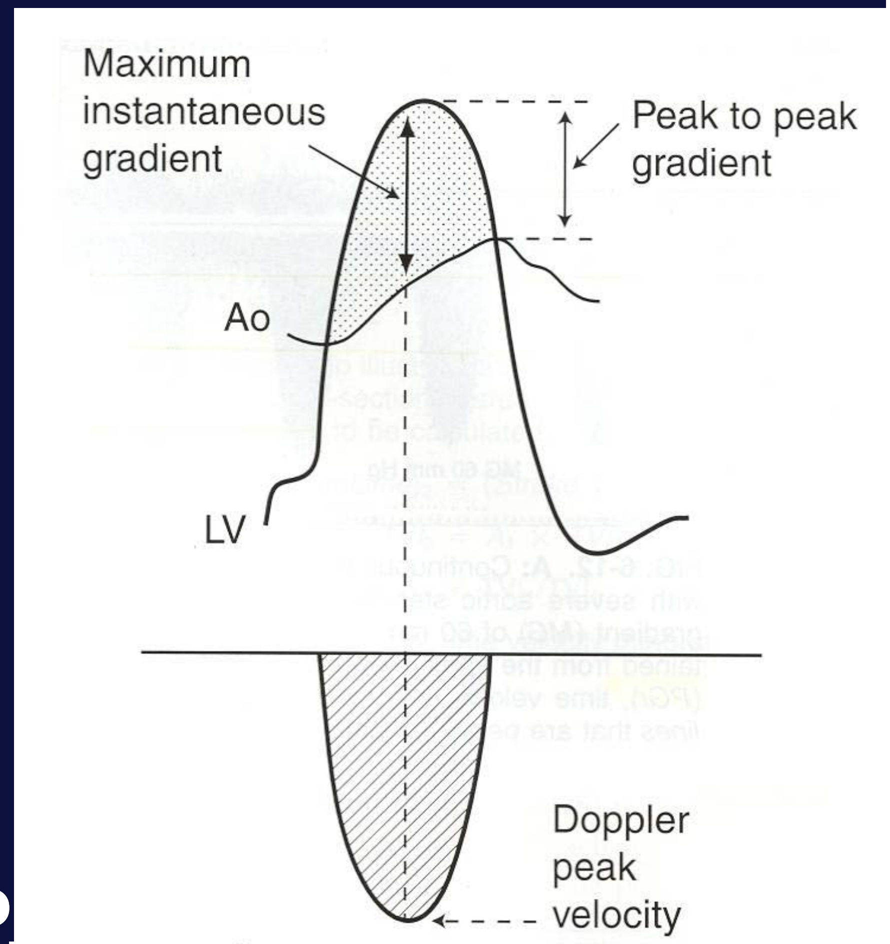
- Doppler
  - MIG = $4V_2^2 - 4V_1^2$
  - MIG = $4V_2^2$
- Use MIG = $4V_2^2 - 4V_1^2$
  - $V_1 > 1.5$ m/second
  - $V_2 < 3$ m/second



B

Doppler versus Catheter Gradient Assessment

- Catheterization
  - Peak to Peak
  - $P_{mean\ Catheter}$
- Doppler
  - MIG ($4V_2^2 - 4V_1^2$)
  - $P_{mean\ Doppler}$
- MIG always > PPG
- $P_{mean\ Doppler} - P_{mean\ Catheter} = P_{rec}$



B

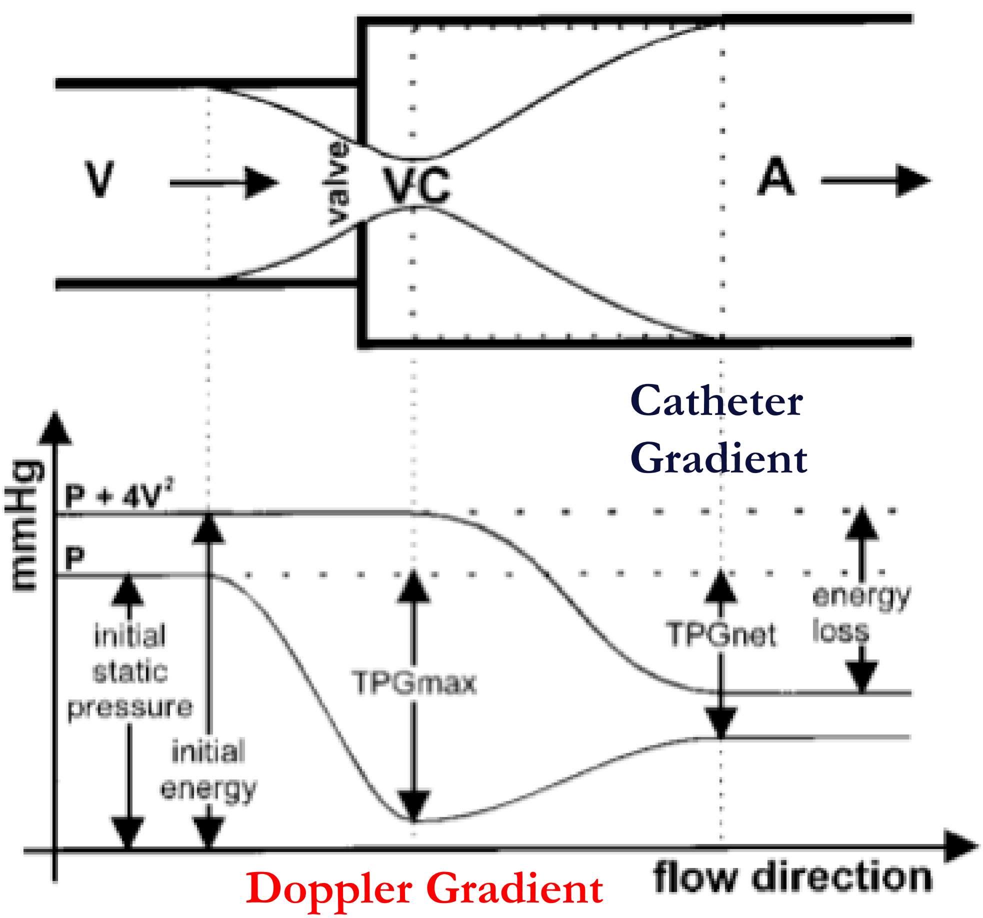
Pressure Recovery

- LV Pressure: Mean 180 mmHg
- Aortic Pressure: Mean 140 mmHg
- Catheterization Gradient = Mean 40 mmHg
- Doppler Mean Gradient = 50 mmHg
- Pressure Recovery = 10 mmHg

Not Pressure Recovery

- LV Pressure: Peak 200 mmHg
- Aortic Pressure: Peak 150 mmHg
- Cath Peak to Peak: 50 mmHg
- Doppler Velocity: 4.5 m/second
- Doppler Maximum Instantaneous Gradient: Peak: 81
- Doppler-Cath difference: 31 mmHg Inherent technique difference (timing) and not pressure recovery

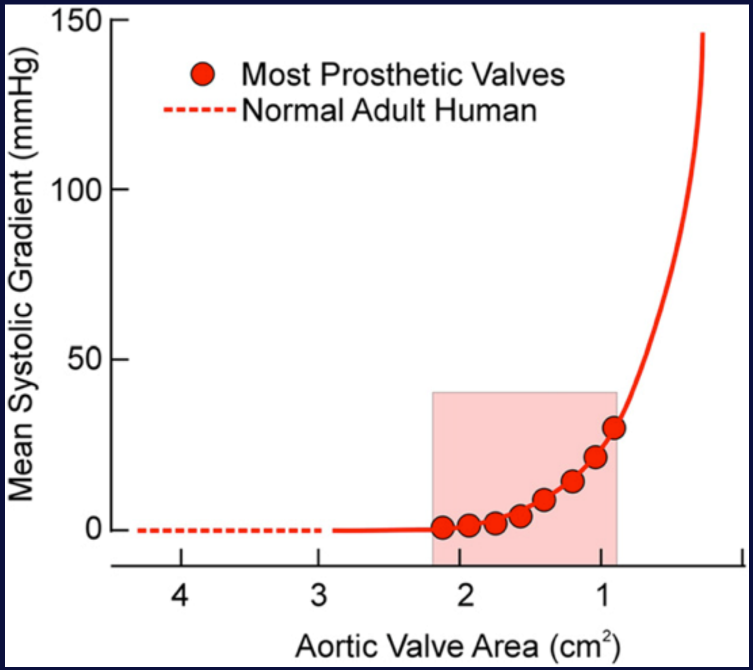
Pressure Recovery



- Increase in pressure in the aorta distal to the valve and the vena contracta
- Decrease in pressure gradient between LV and aorta
- Increase in EOA distal to the valve and vena contracta
- Catheter measures distal to the vena contracta

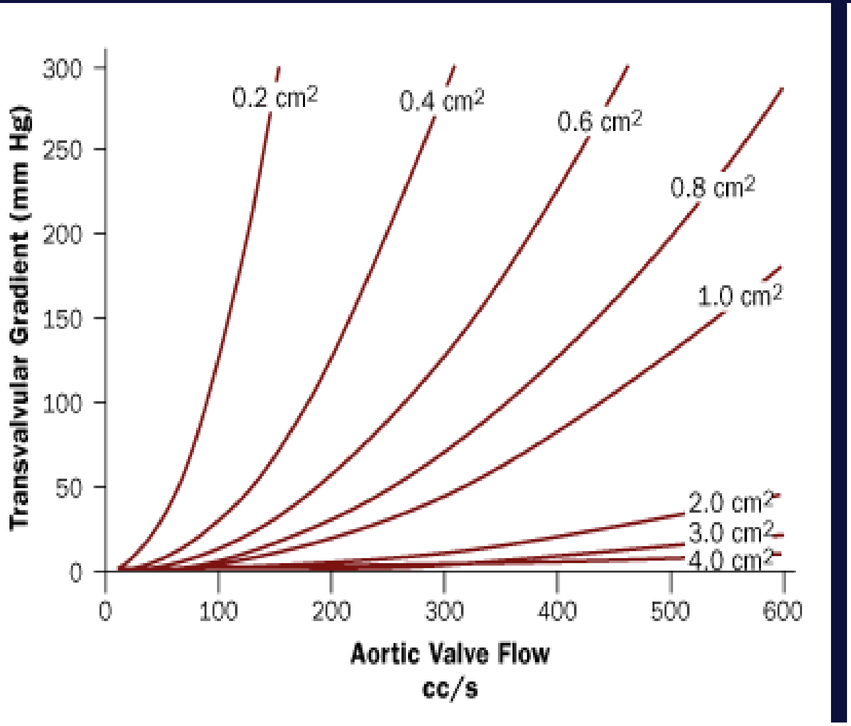
Factors Affecting Gradient

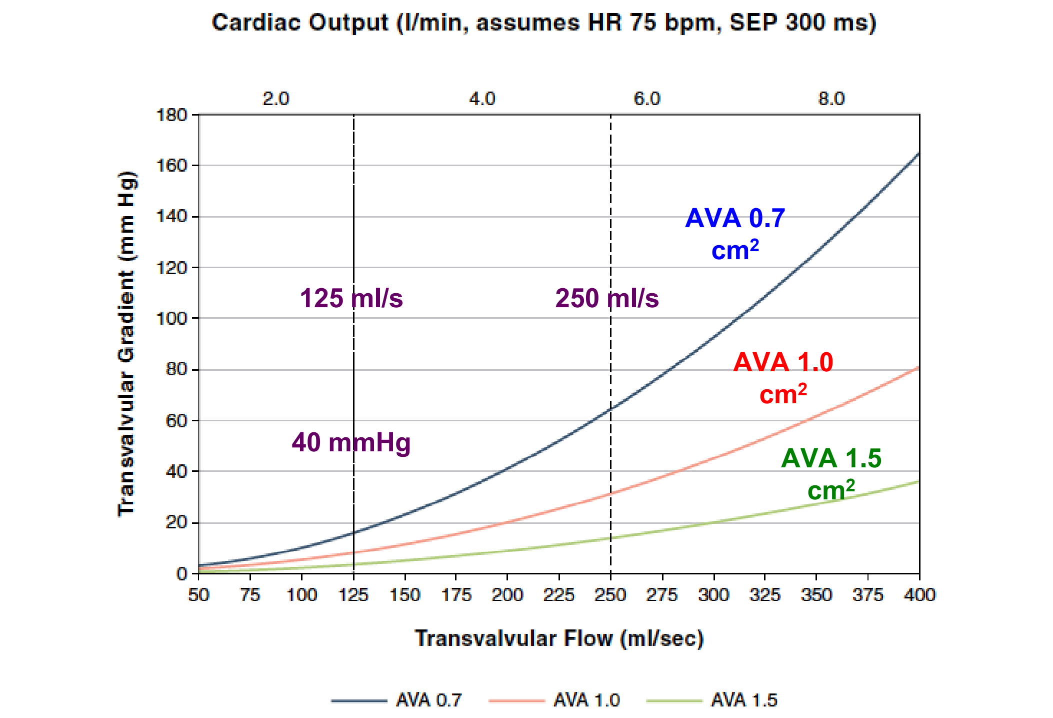
- **Area:** **The lower the area, the higher the gradient**
- **$\Delta P = Q^2/(K \times EOA^2)$**

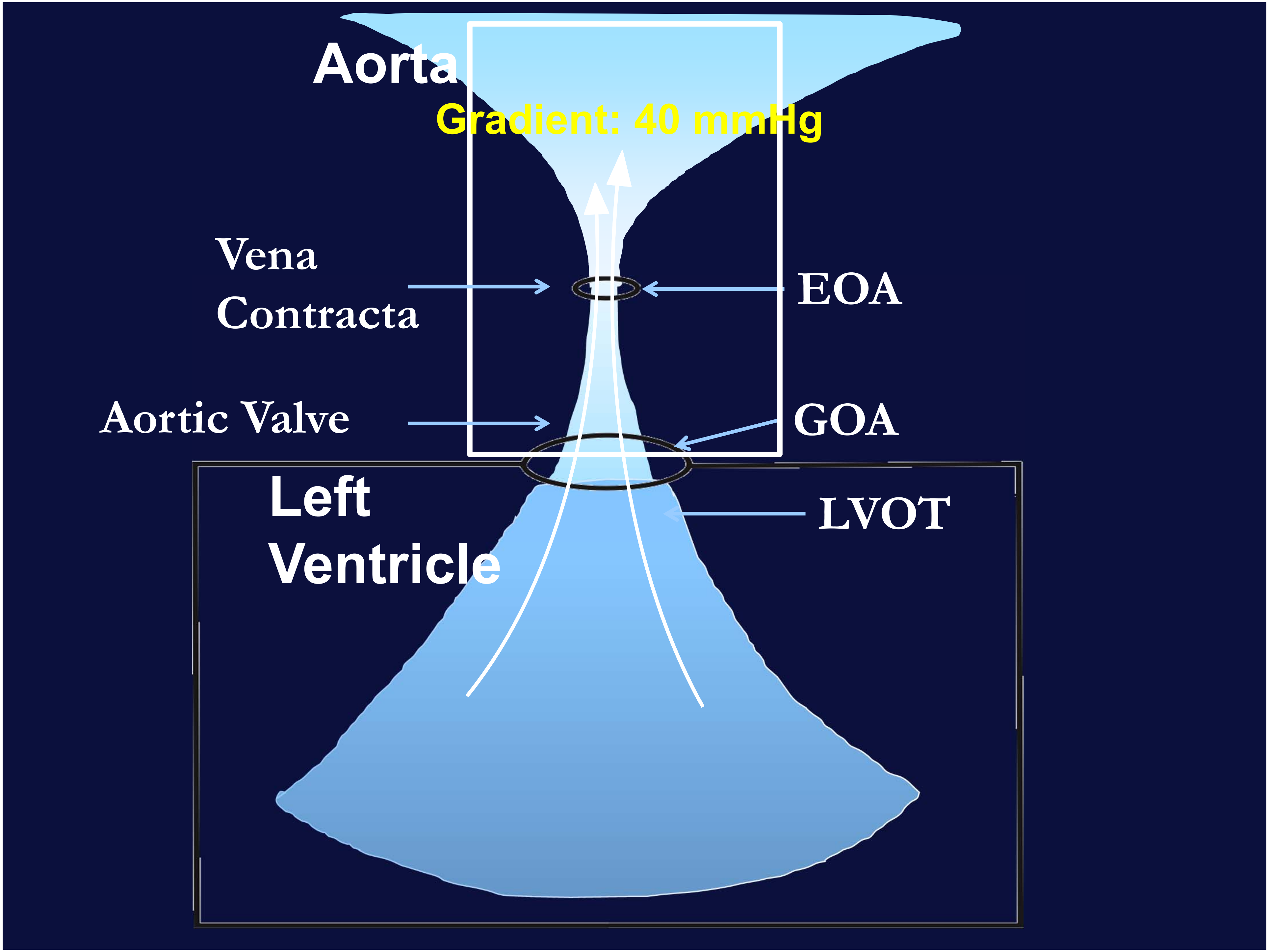


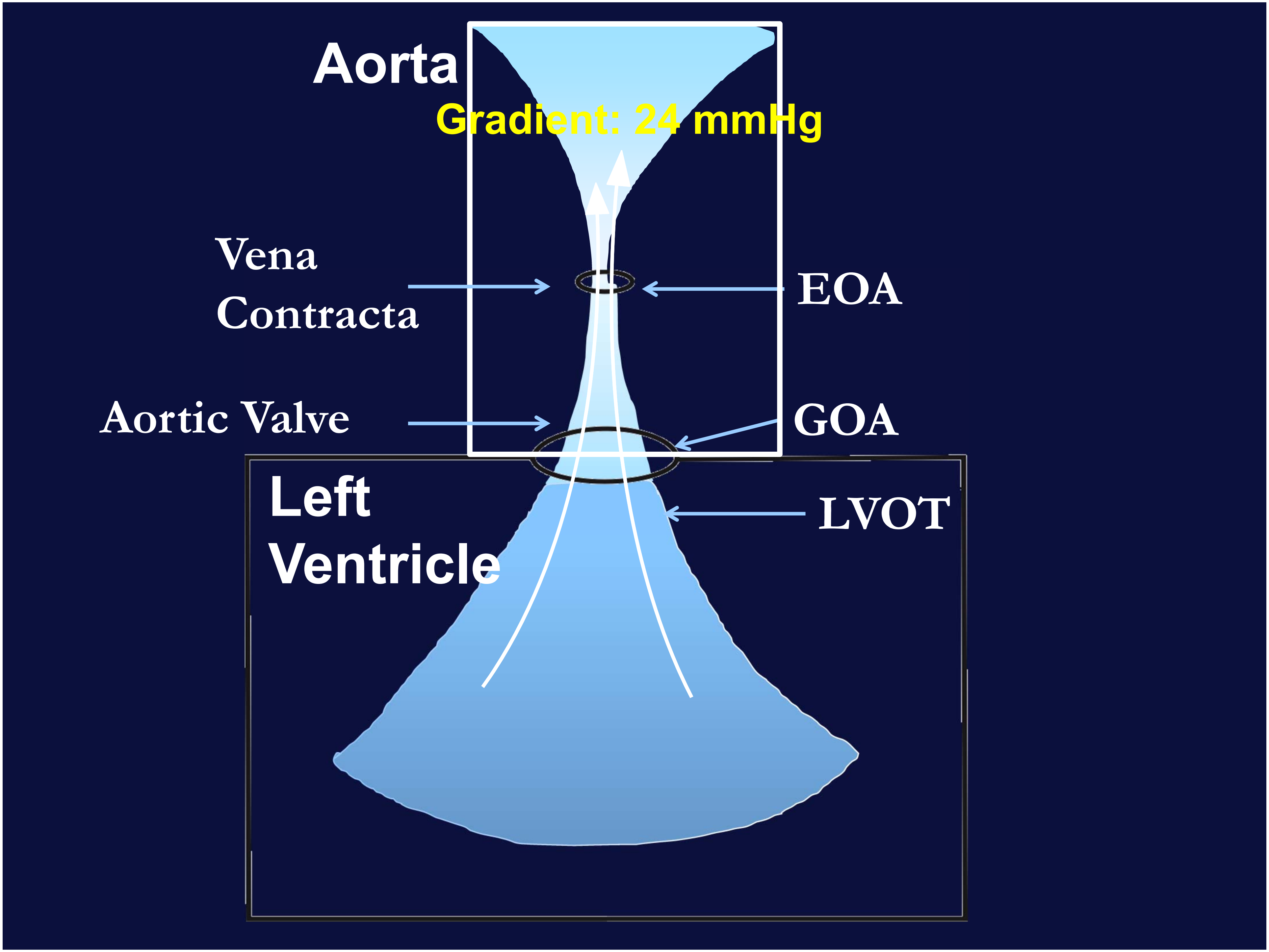
Factors Affecting Gradient

- **Flow:** The lower the flow, the lower the gradient
  - Low Flow: SVI < 35ml/m^2
  - High Flow: SVI > 58 ml/m^2





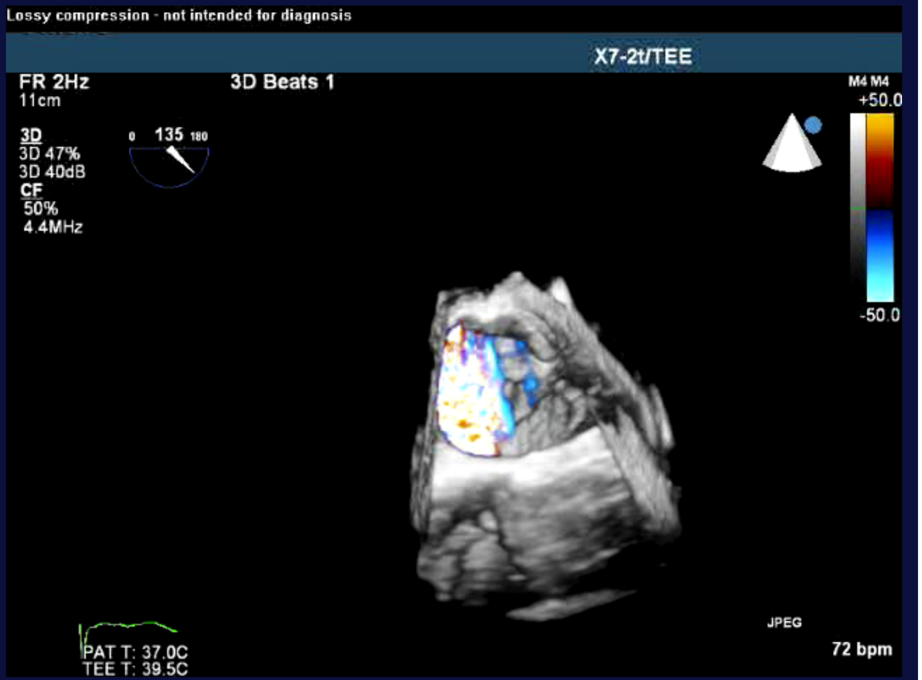

Aorta
Gradient: 40 mmHg
Vena Contracta
EOA
Aortic Valve
GOA
Left Ventricle
LVOT



Aorta
Gradient: 24 mmHg
Vena
Contracta
EOA
Aortic Valve
GOA
Left
Ventricle
LVOT

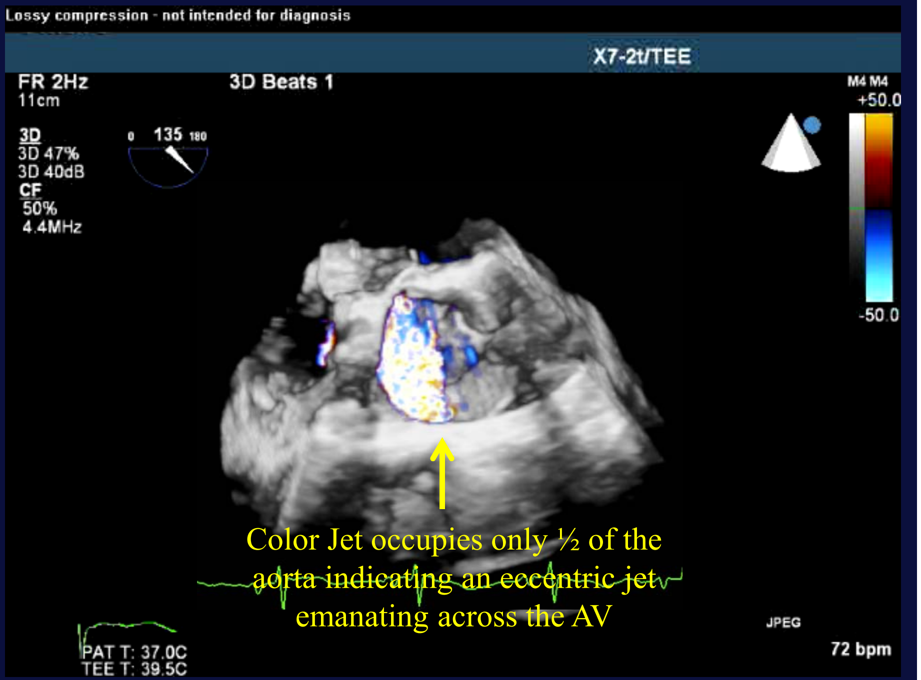
Factors Affecting Gradient

- Jet Eccentricity
- More eccentricity, more pressure loss, higher gradient, the less pressure recovery
- No further increase beyond 30°



Factors Affecting Gradient

- Jet Eccentricity
- Increase in velocity by 0.7 m/sec, gradient 23 mmHg, and decrease in EOA 0.2 cm^2

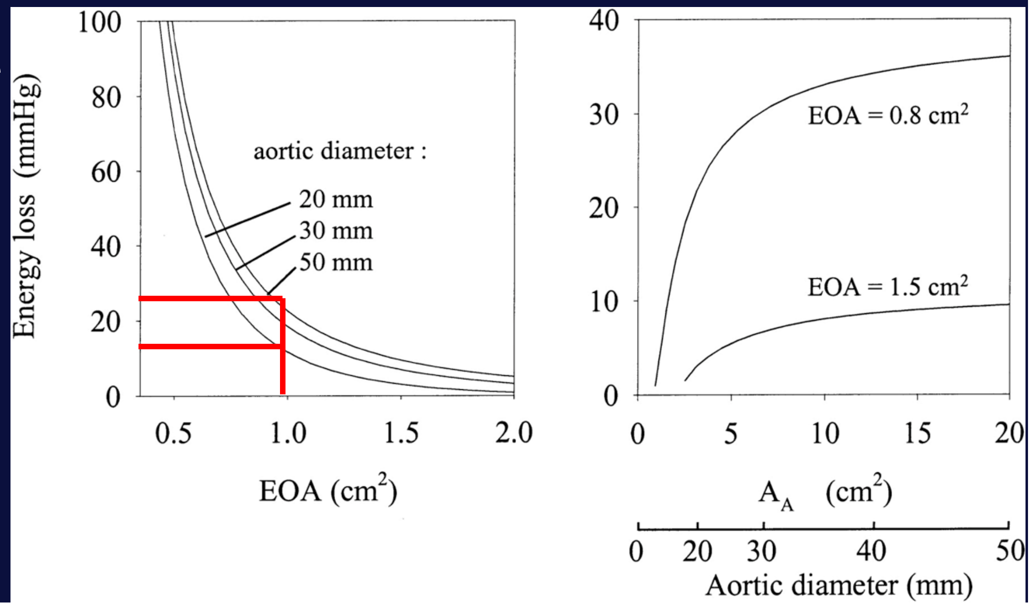


Factors Affecting Gradient

- **Aortic root diameter**
- **The larger the aortic root, the more the energy loss, the less the pressure recovery, the higher the catheter gradient. This effect plateaus at a diameter of 30 mm (area 7 cm^2)**
- **The smaller the root**

The more pressure recovery.

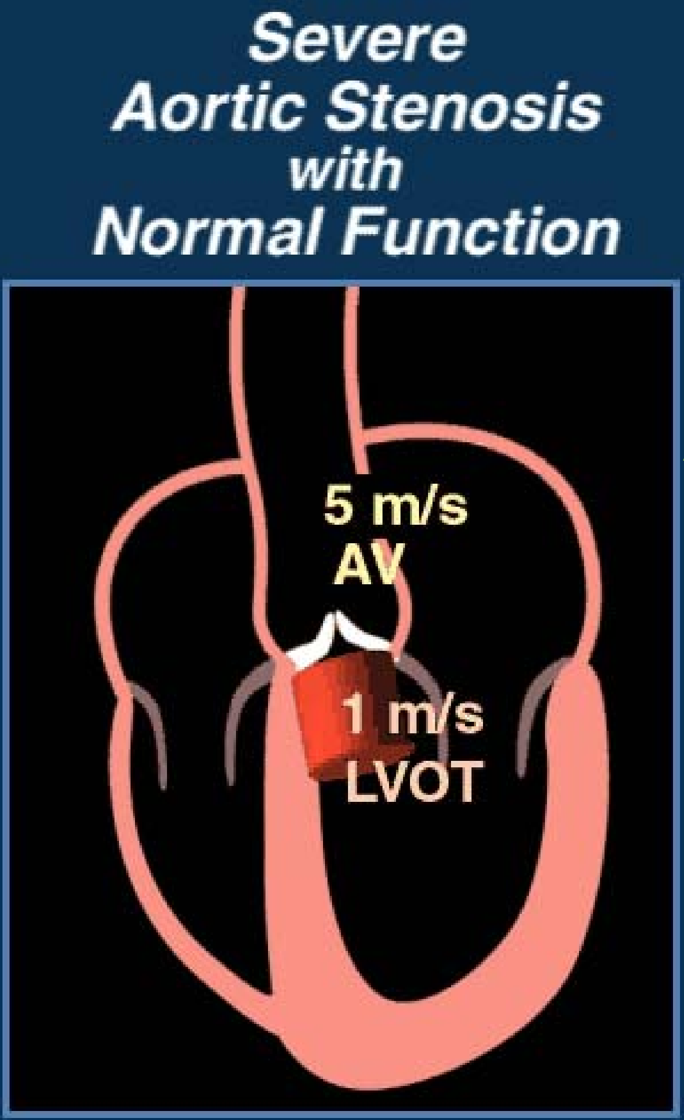
- **ELCo =** $\frac{AVA \times AAa}{AAa - AVA}$



Factors Affecting Gradient

- Doppler/Catheter Discordance
  Small Aortic Root

- Doppler/Catheter Concordance
  Eccentric Jet



Area Gradient Match

Normal Ejection Fraction
Normal Cardiac Output
Area/Gradient Match
AVA<1cm^2
ΔP_{mean}>40mmHg

Courtesy Heidi Connolly

Aortic Stenosis

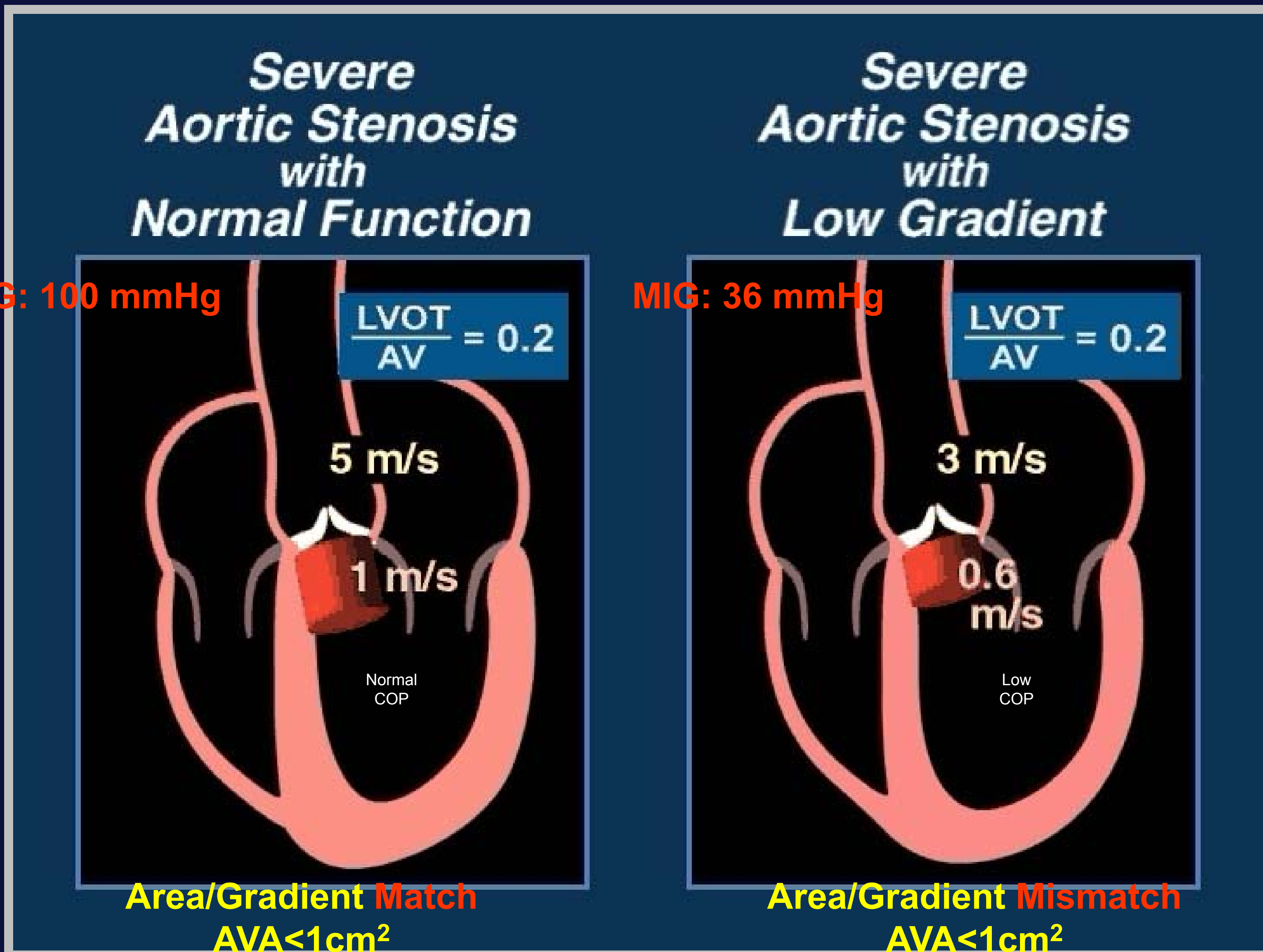
Area/Gradient Mismatch

Aortic Stenosis
Area Gradient Mismatch

Low flow (normal or reduced LVEF)
Mean Gradient <30-40mmHg
AVA <1.0cm^2

True, Severe AS

Mild-Mod AS Low Flow (pseudo AS)



MIG: 100 mmHg

Area/Gradient Match

AVA<1cm^2

ΔP_{mean}>40mmHg

MIG: 36 mmHg

Area/Gradient Mismatch

AVA<1cm^2

ΔP_{mean}<40mmHg

Low EF Area Gradient Mismatch

Risk Stratify

Dobutamine Stress

Dobutamine Stress

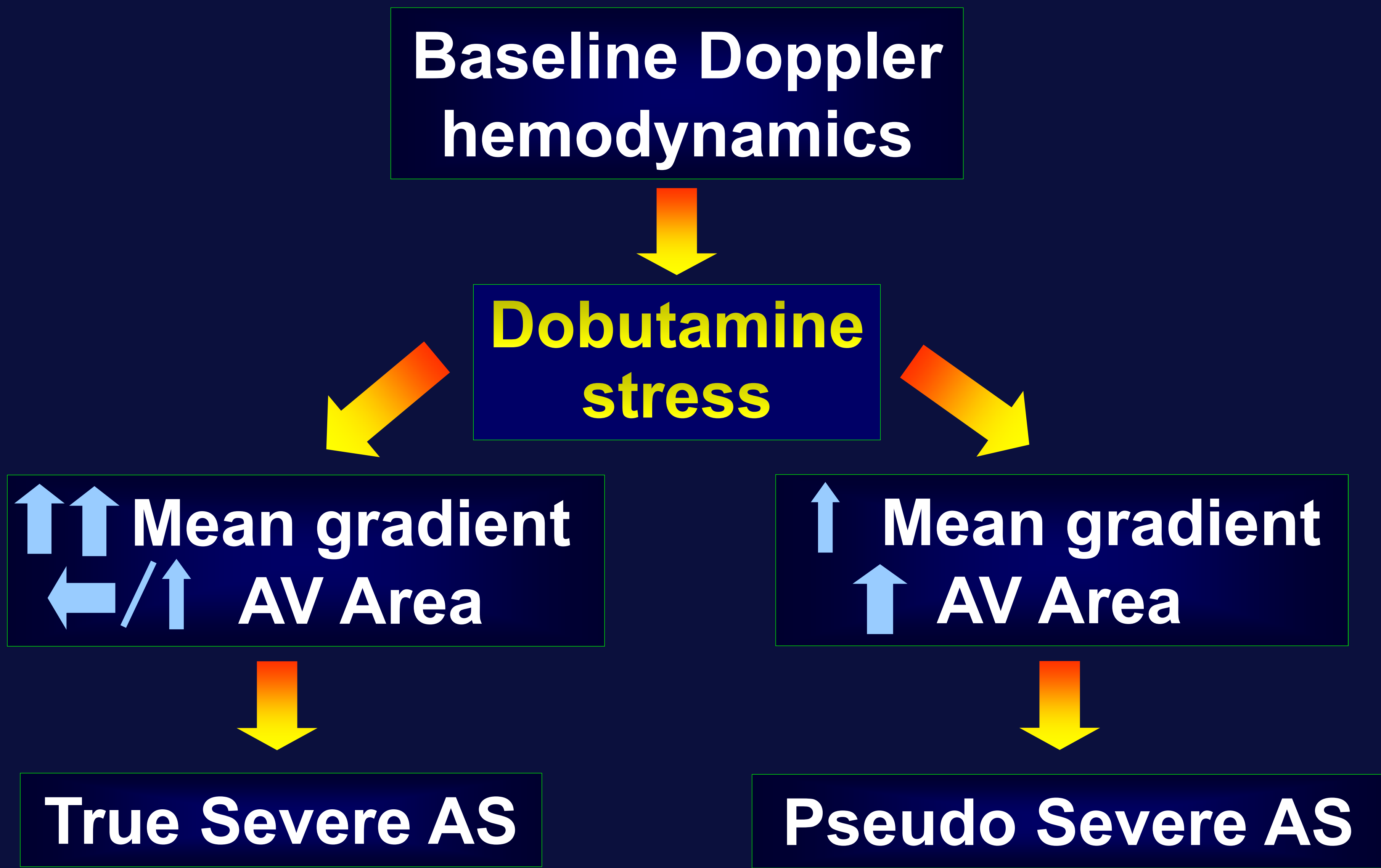
Resting Hemodynamics
HR, BP, gradient, CO, AVA

Dobutamine
2.5-5.0 mcg/kg/min

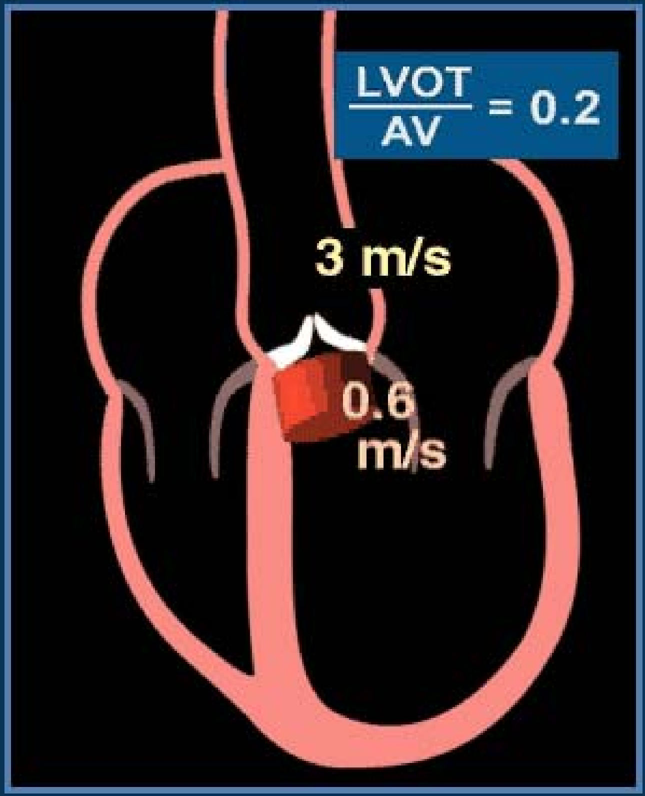
Repeat Hemodynamics
Increase by 5 mcg/kg/min

Endpoints
↓ BP, VT, HR>120, symptoms
Normalize CO, 20 mcg/kg/min

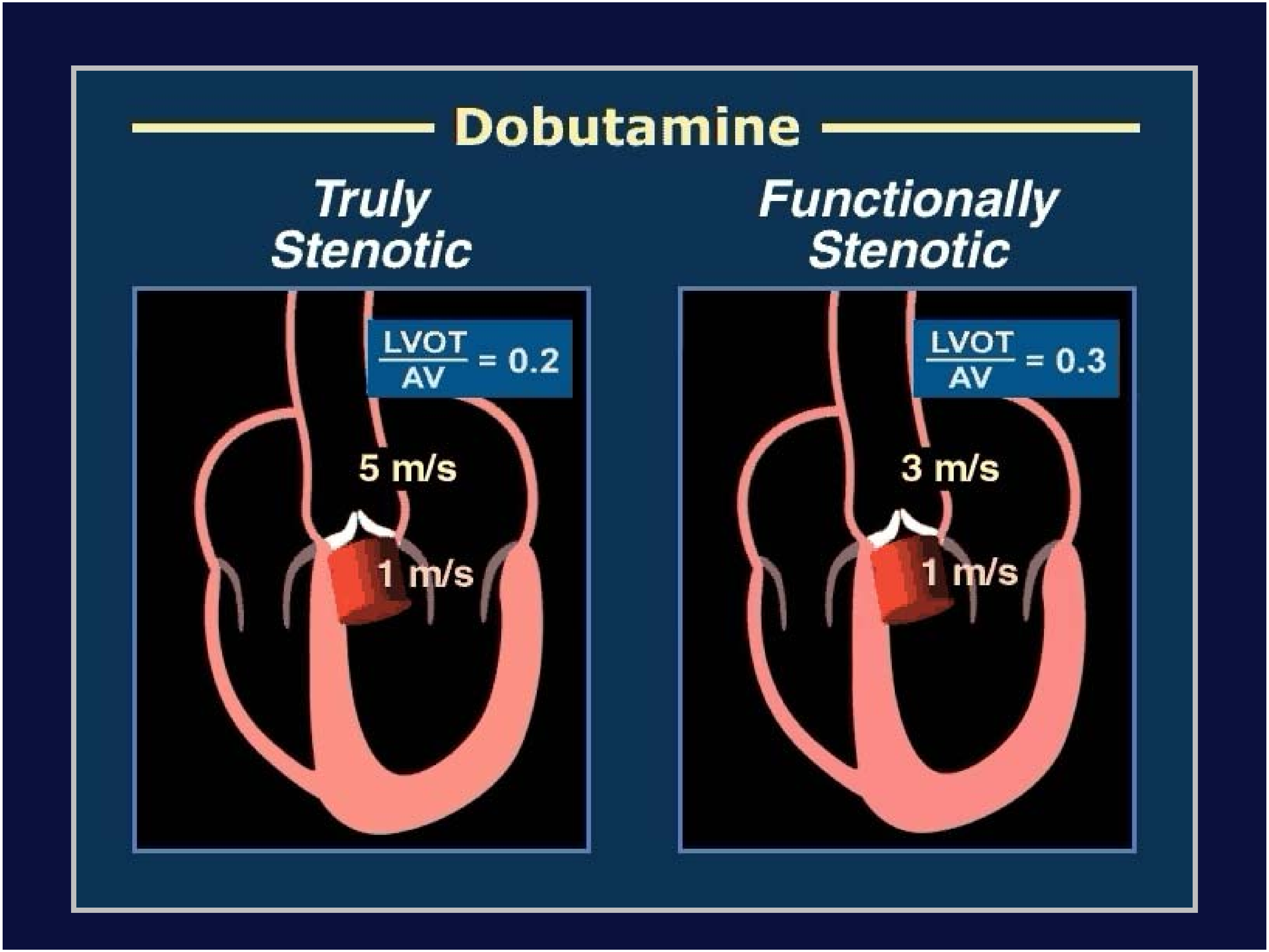
Dobutamine Echocardiography



Low Gradient Aortic Stenosis

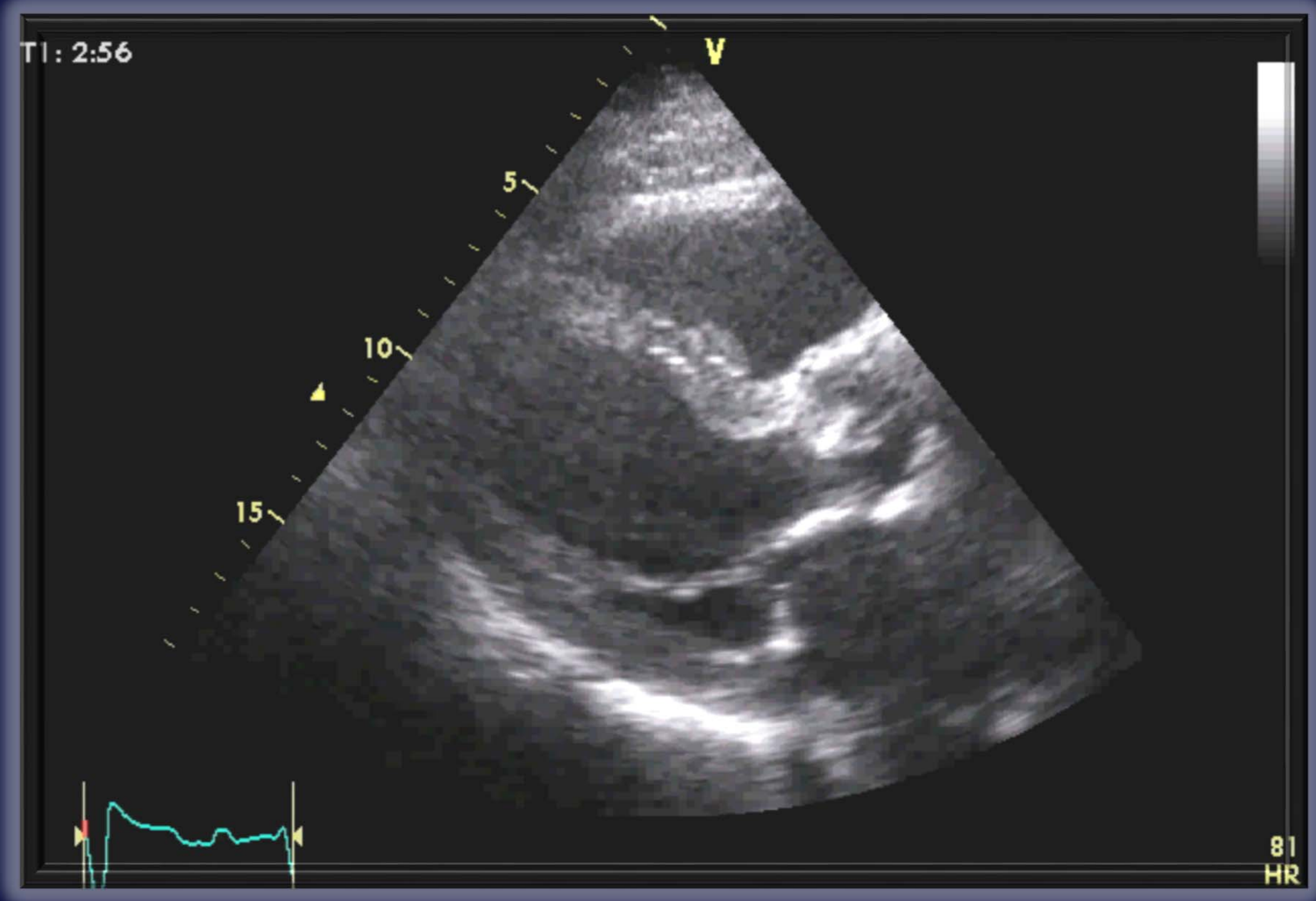


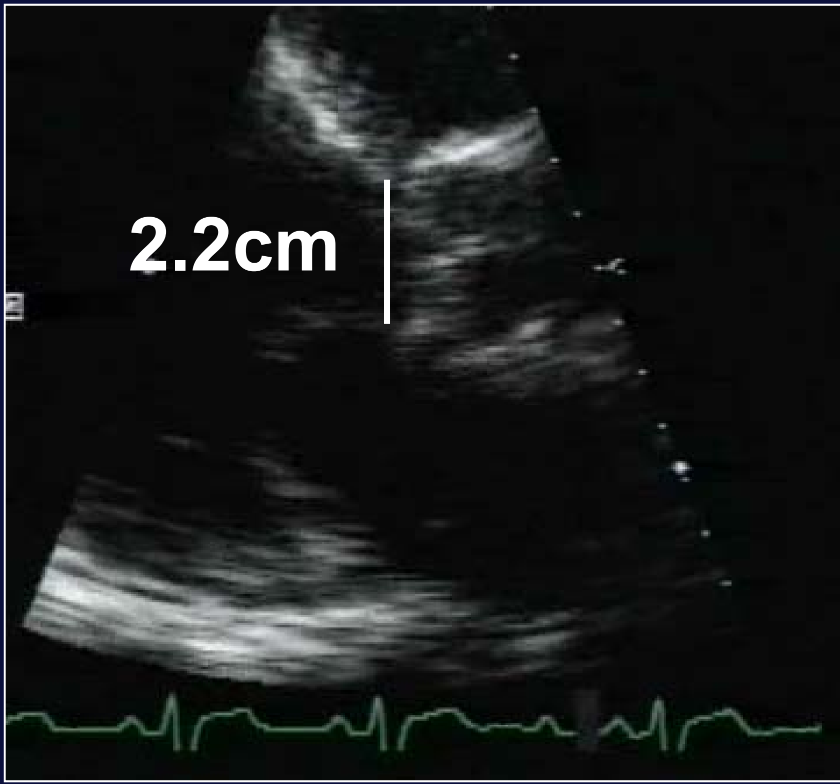
Courtesy Heidi Connolly

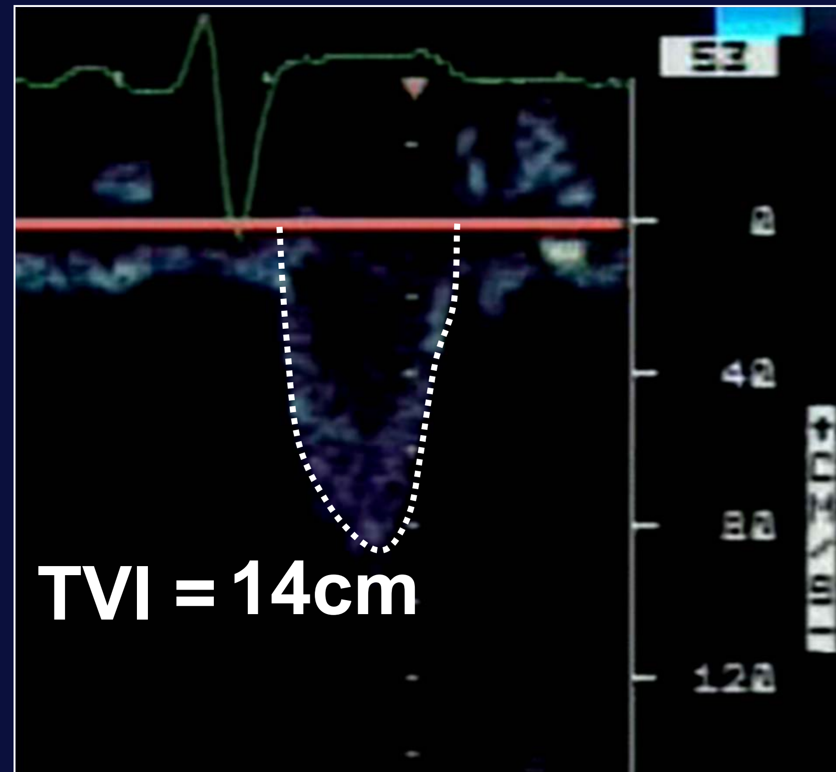

Dobutamine
Truly Stenotic
LVOT / AV = 0.2
5 m/s
1 m/s
Functionally Stenotic
LVOT / AV = 0.3
3 m/s
1 m/s

Case

- 62 y/o male
- STEMI and subsequent CABG five years ago
- Recurrent heart failure x 3 months


T1: 2:56
V
5
10
15
81
HR





Stroke Volume = CSA x TVI

= 0.785 ( )^2 x

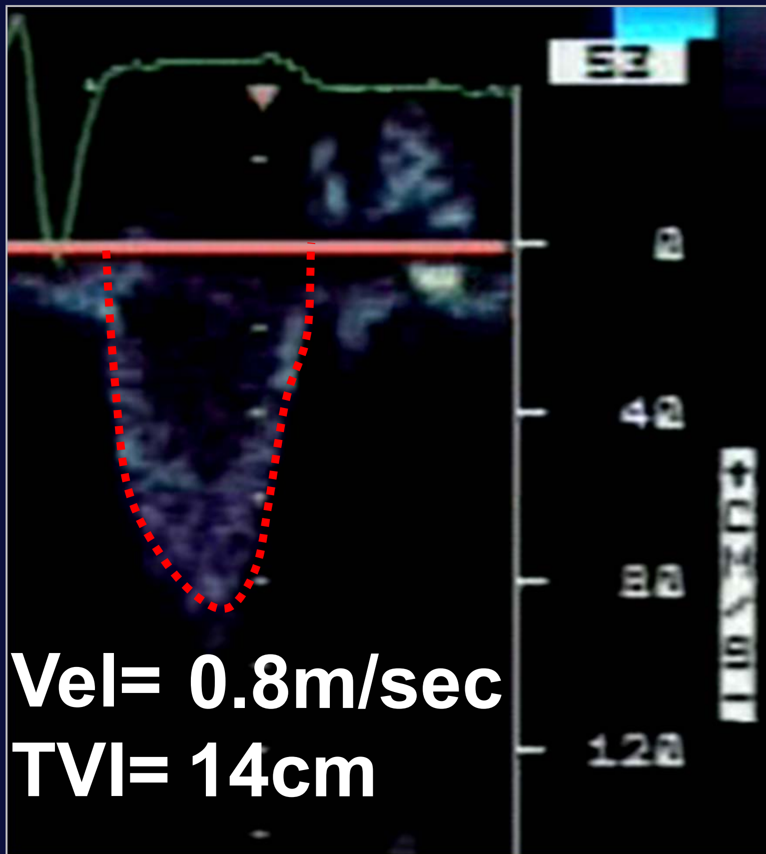
= 53cm^3

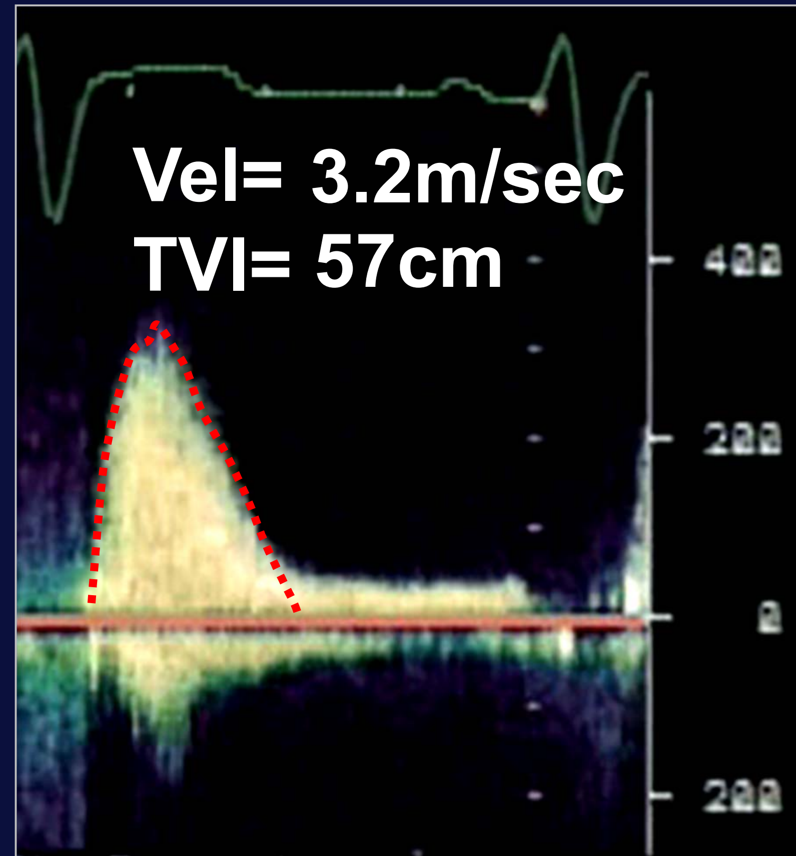
Low Flow

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

($< 35ml/m^2$)

CI = $23cm^3/\ m^2 \times 68bpm$ = $1.6\ L/min/m^2$

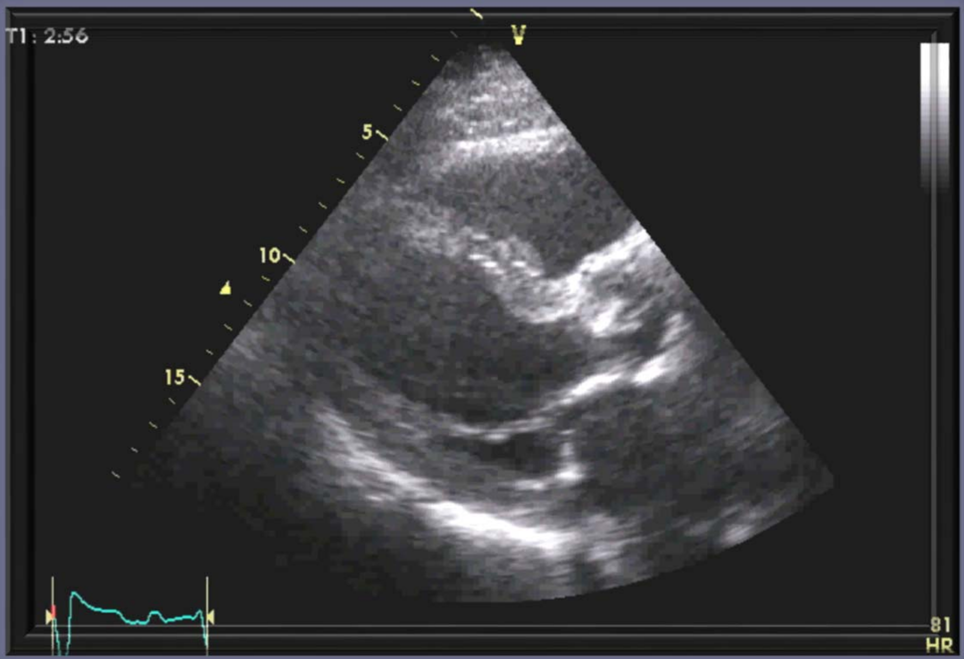




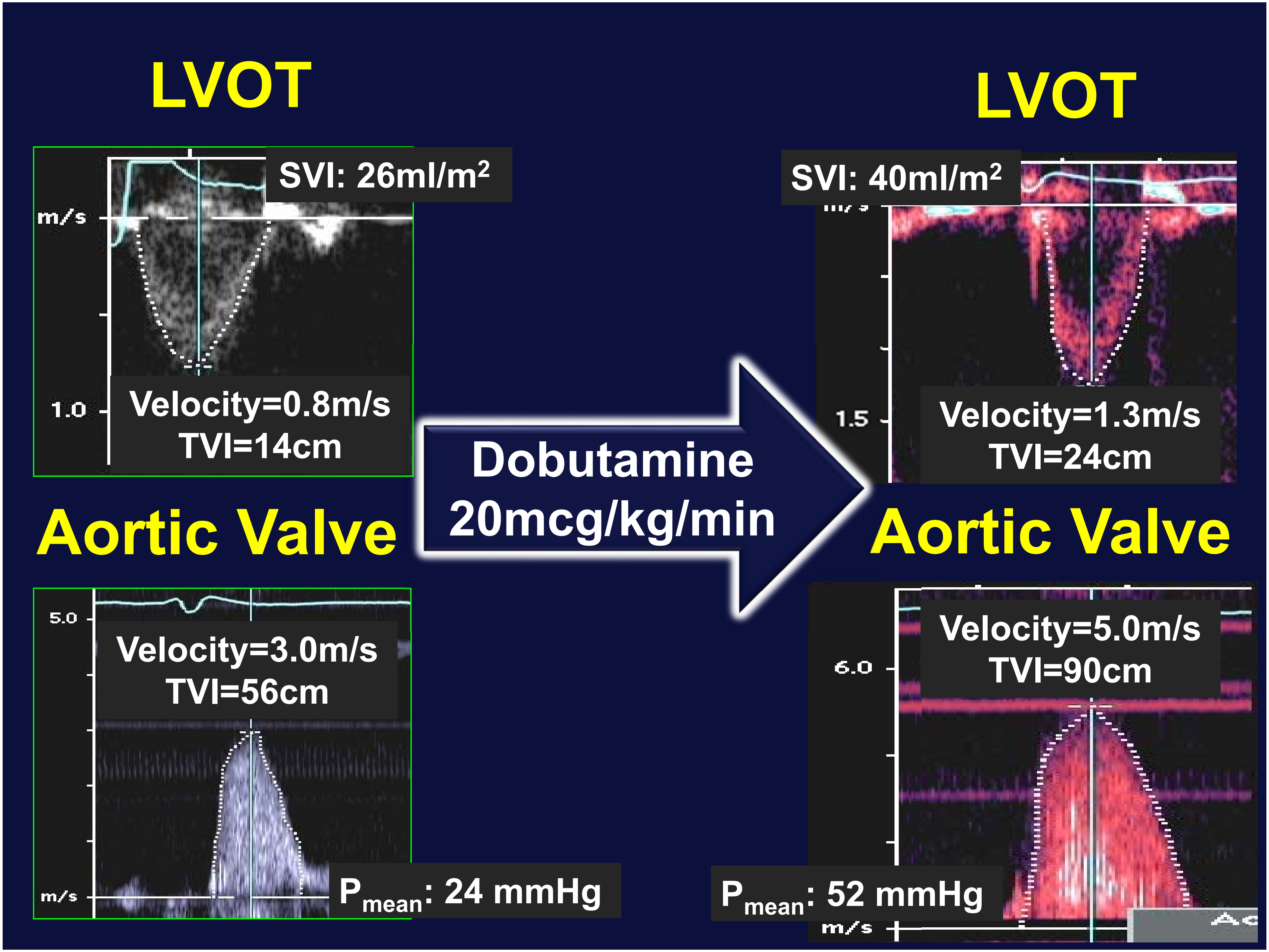
$$Area_{AV} = \frac{0.785\ (2.2cm)^{2} \times (\qquad)}{\qquad}$$

$$= 0.9\ cm^{2};\ MG\ 24mmHg$$

Low EF Area Gradient Mismatch



- LVEF 30% (<45%)
- LVSVI 23ml/m^2
- AVA 0.9cm^2
- Mean Gradient 24mmHg


LVOT
SVI: 26ml/m²
m/s
1.0
Velocity=0.8m/s
TVI=14cm
Aortic Valve
5.0
Velocity=3.0m/s
TVI=56cm
m/s
Pmean: 24 mmHg
Dobutamine
20mcg/kg/min
LVOT
SVI: 40ml/m²
1.5
Velocity=1.3m/s
TVI=24cm
Aortic Valve
Velocity=5.0m/s
TVI=90cm
6.0
Pmean: 52 mmHg
m/s

Dobutamine Stress

LV Stroke Volume Index

$26ml/m^2$ – $40ml/m^2$

Mean AV Gradient

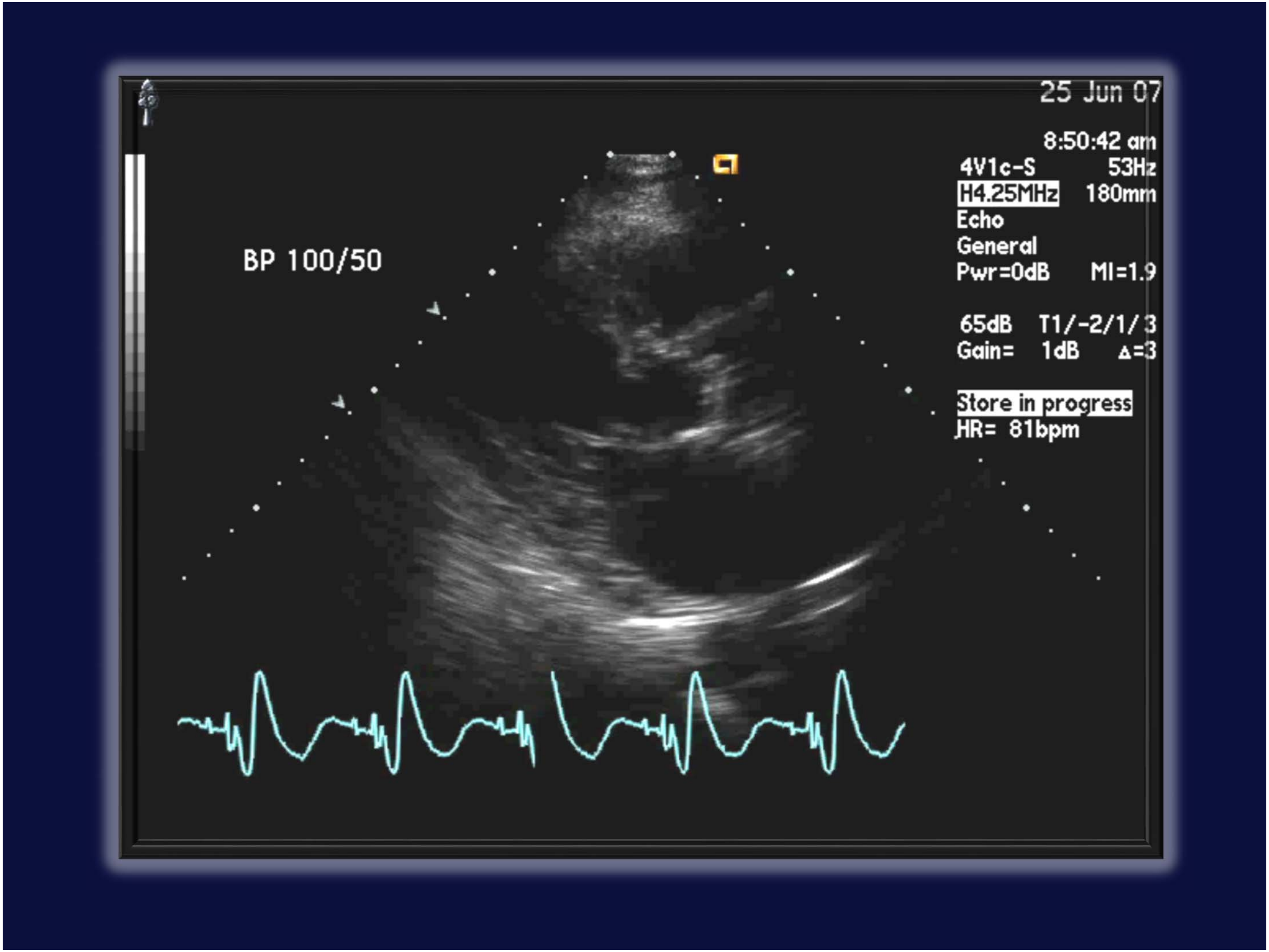
24 – 52mmHg

Valve Area

$0.9cm^2$ – $1.0cm^2$

Case

- 75 year old male
- Presents with dyspnea and syncope
- HTN (treated BP 150/75)
- Grade III/VI mid peaking systolic murmur LSB


25 Jun 07
8:50:42 am
4V1c-S 53Hz
H4.25MHz 180mm
Echo
General
Pwr=0dB MI=1.9
65dB T1/-2/1/3
Gain= 1dB Δ=3
Store in progress
HR= 81bpm
BP 100/50

Echocardiography

Normal EF Area Gradient Mismatch

• LVEF	55%
• AV Mean G	26mmHg
• AVA	$0.8 cm^2$
• AVA index	$0.45 cm^2/m^2$
• LVEDV	88ml
• SVi	$32\ ml/m^2$

Aortic Stenosis Severity?

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

Flow Versus EF

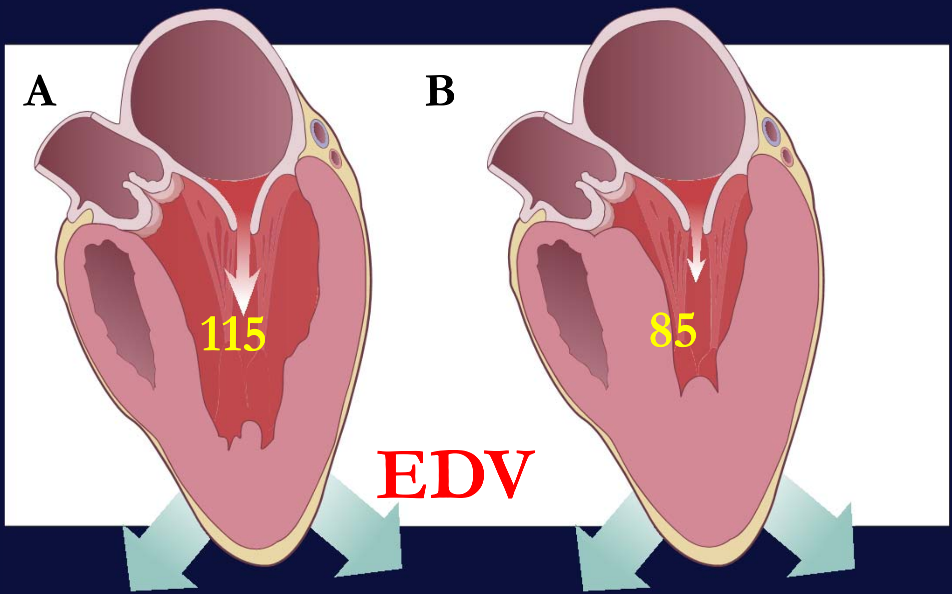
A: EDV = 115, ESV = 45,

SV= 115-45 = 70 ml

EF = 70/115 = 60%

BSA = 1.79

SVI = 39 ml/m^2



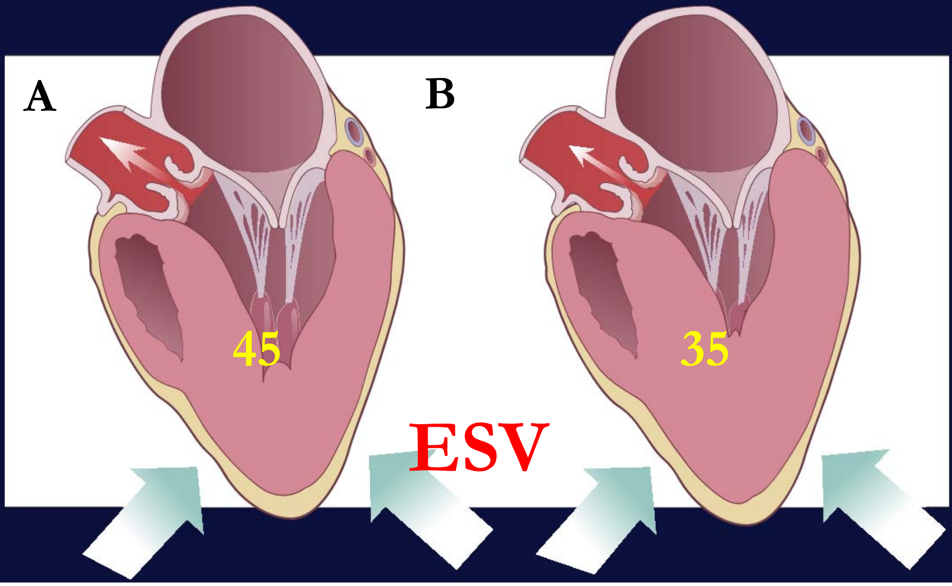
B: EDV = 85, ESV = 35,

SV= 85- 35= 50 ml

EF = 50/85 = 60%

BSA = 1.79

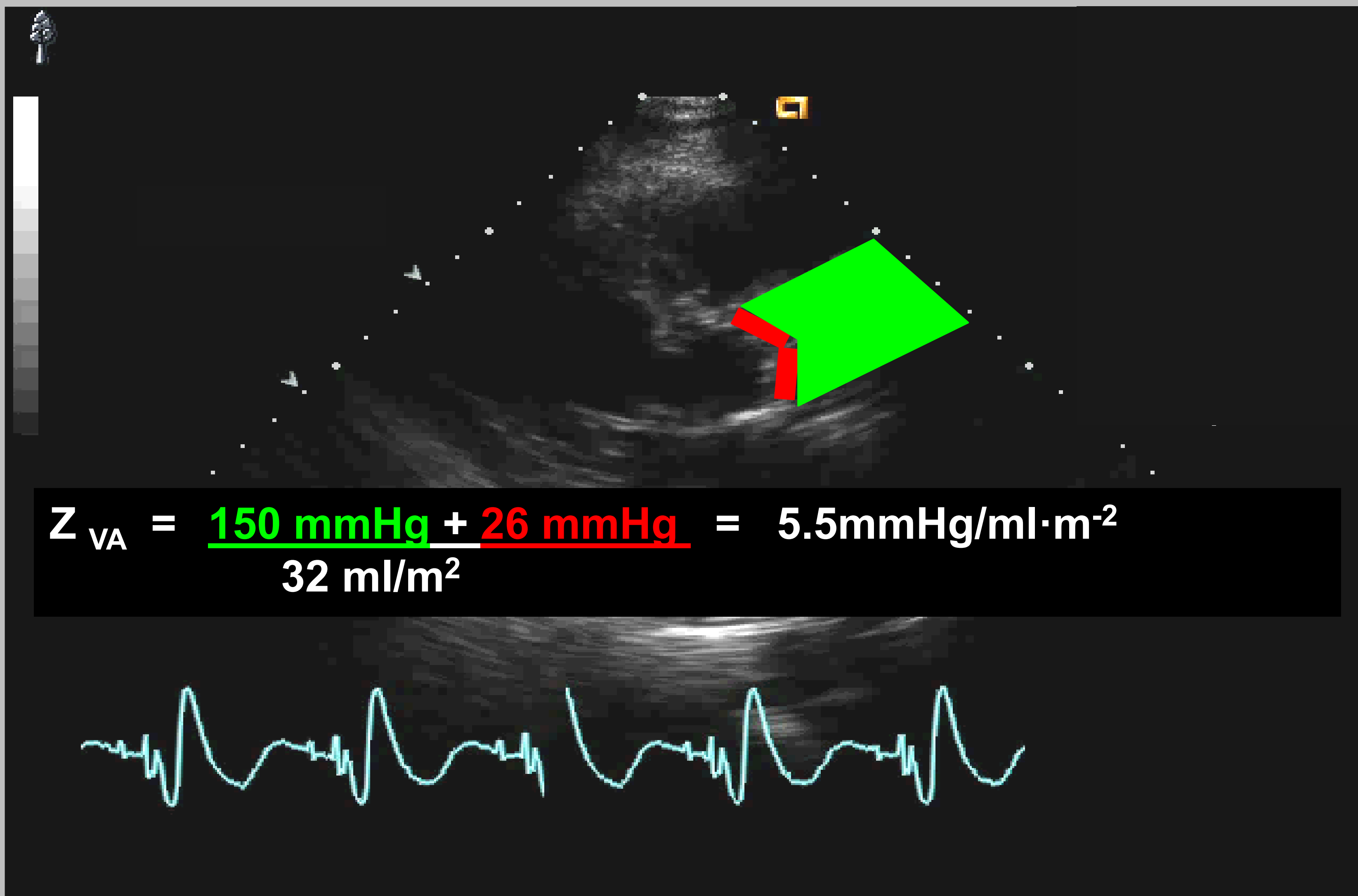
SVI = 28 ml/m^2



Paradoxical LFLG Severe AS

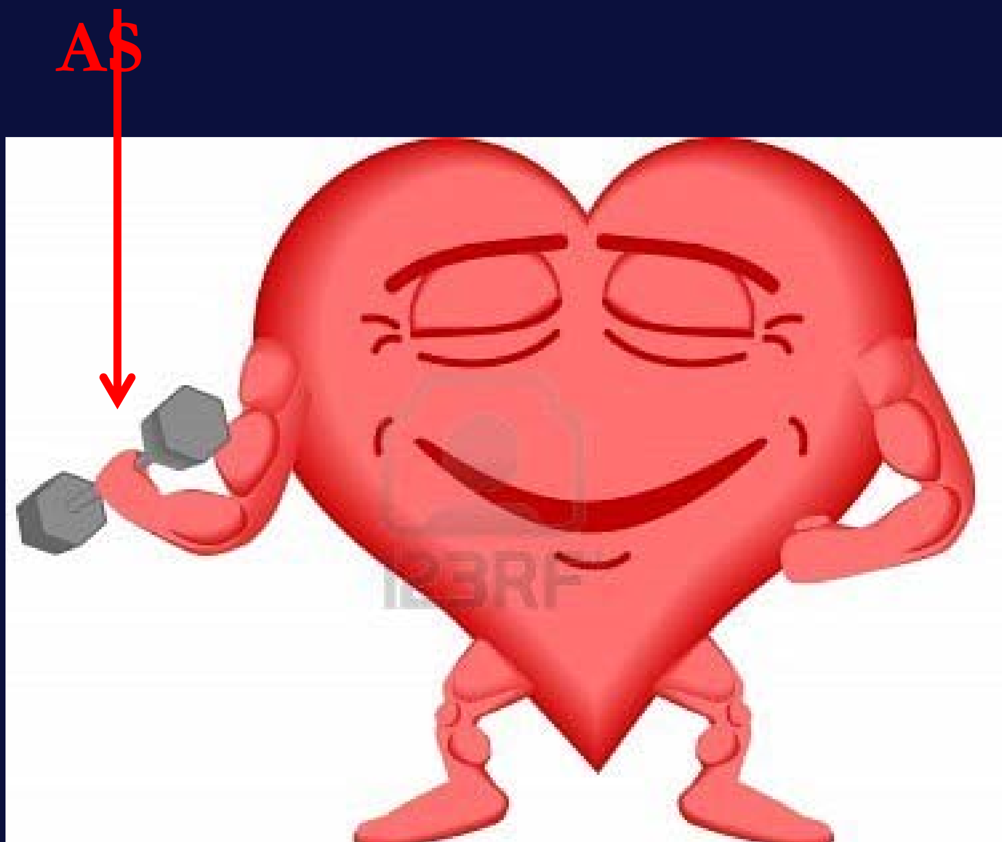
Global Left Ventricular Afterload

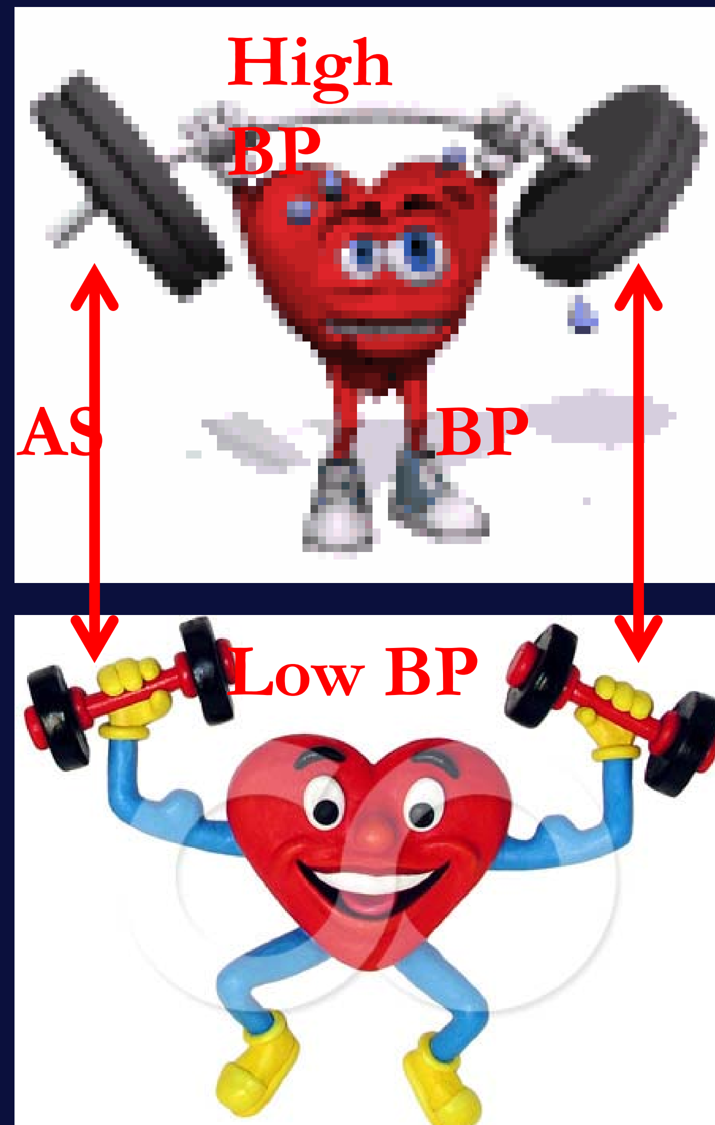
Normal EF Area Gradient Mismatch



$$Z_{VA} = \frac{150\ \text{mmHg} + 26\ \text{mmHg}}{32\ \text{ml/m}^2} = 5.5\ \text{mmHg/ml}\cdot\text{m}^{-2}$$

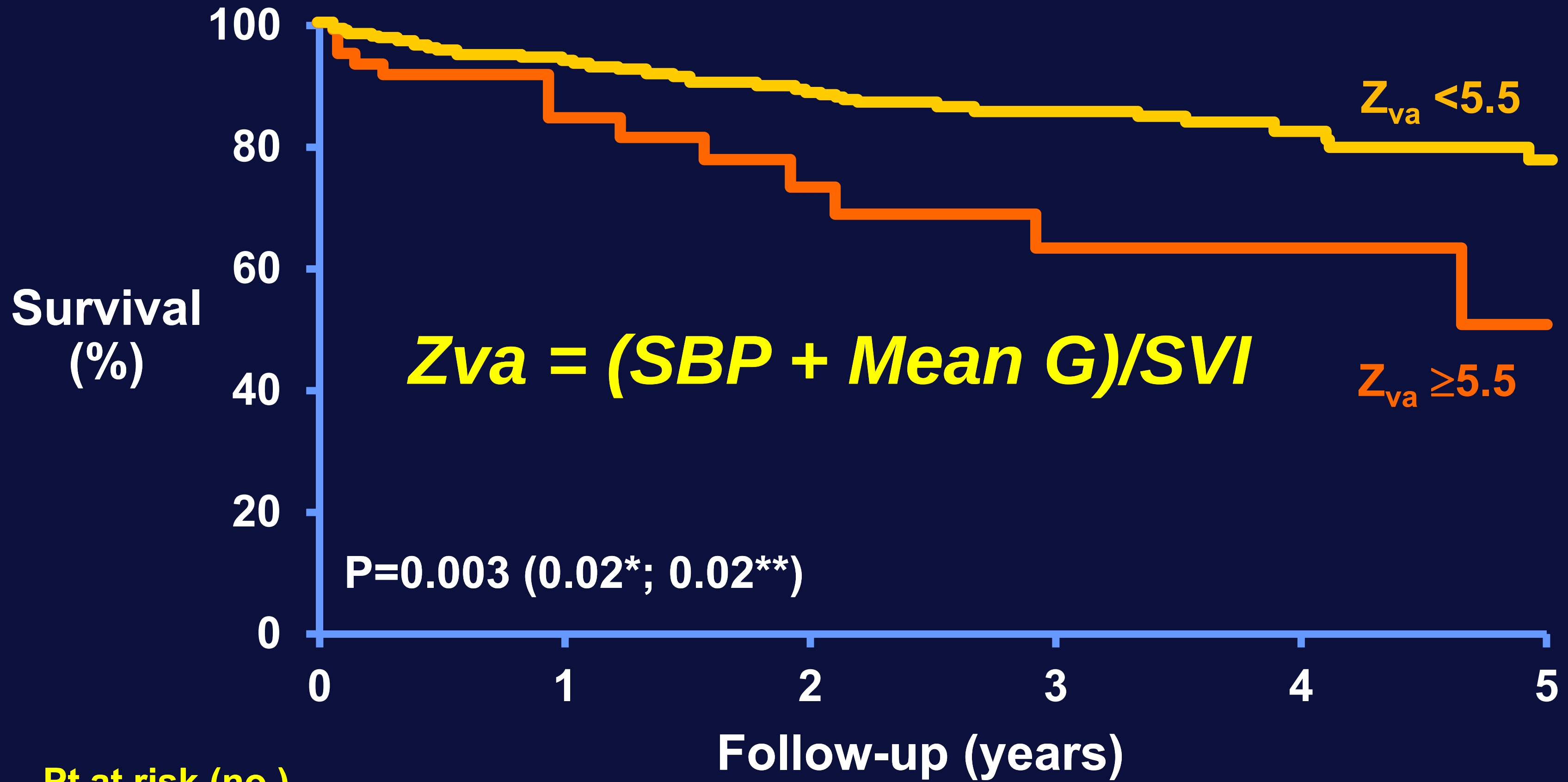
Global Left Ventricular Afterload





Moderate AS and low compliance =
Severe AS and normal compliance

Overall Survival According to Valvulo-Arterial Impedance (Z_{va})



Pt at risk (no.)

	0	1	2	3	4	5
Z_{va} <5.5	354	260	156	110	62	35
Z_{va} ≥5.5	59	33	16	11	7	2

*P value adjusted for age & gender

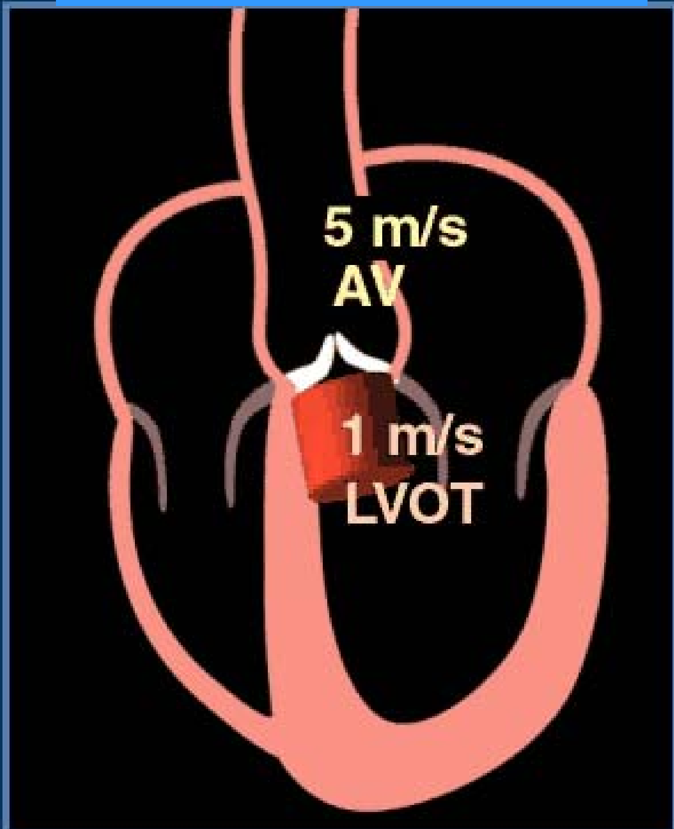
**P value adjusted for age, gender, valvulo-arterial impedance, & type of Rx

Hachicha et al: Circulation 2007

Aortic Stenosis

Reverse Area/Gradient Mismatch

Elevated Gradient
Despite non-critical AS



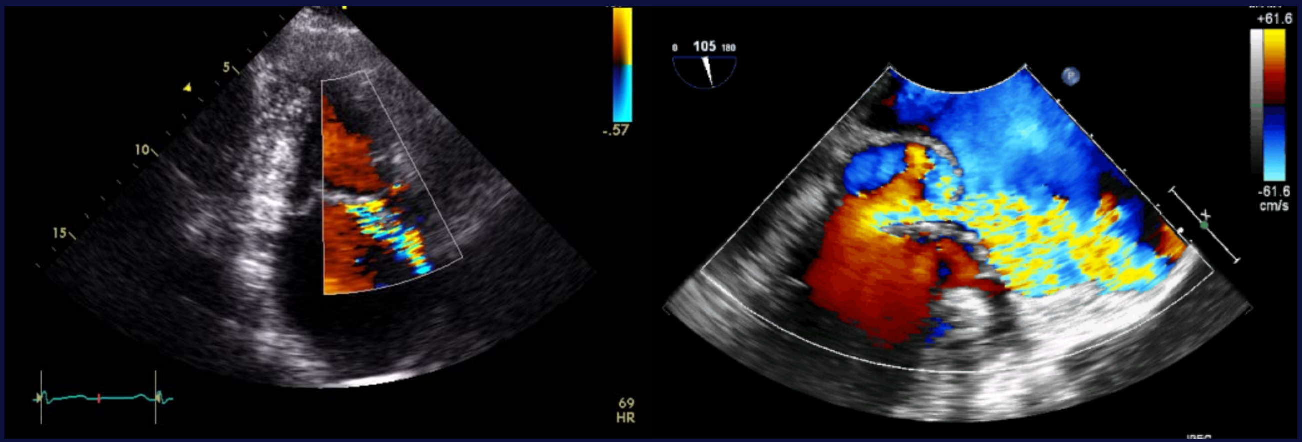
Reverse Area/Gradient Mismatch
AVA>1cm^2
ΔP_{mean}>40mmHg

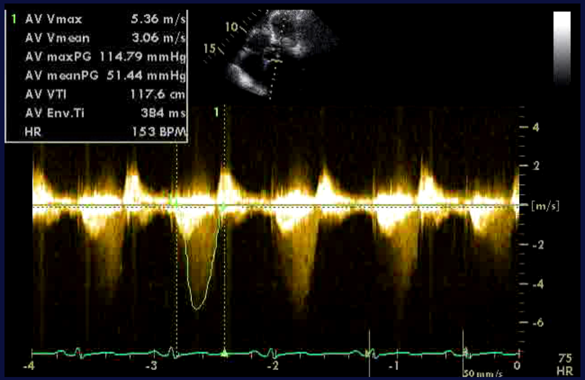
Courtesy Heidi Connolly

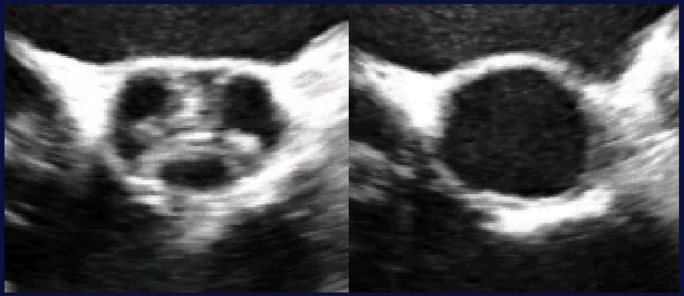
Causes of Reverse A/G Mismatch

- Errors of Measurement
- High Flow
- Pressure recovery
- Eccentric Jet
- Para-valvular Obstruction
- Prosthetic-Specific
  - Mechanical Valve Central Orifice Pressure Drop
  - Patient-prosthesis mismatch

Errors of Measurements
Eccentric Mitral

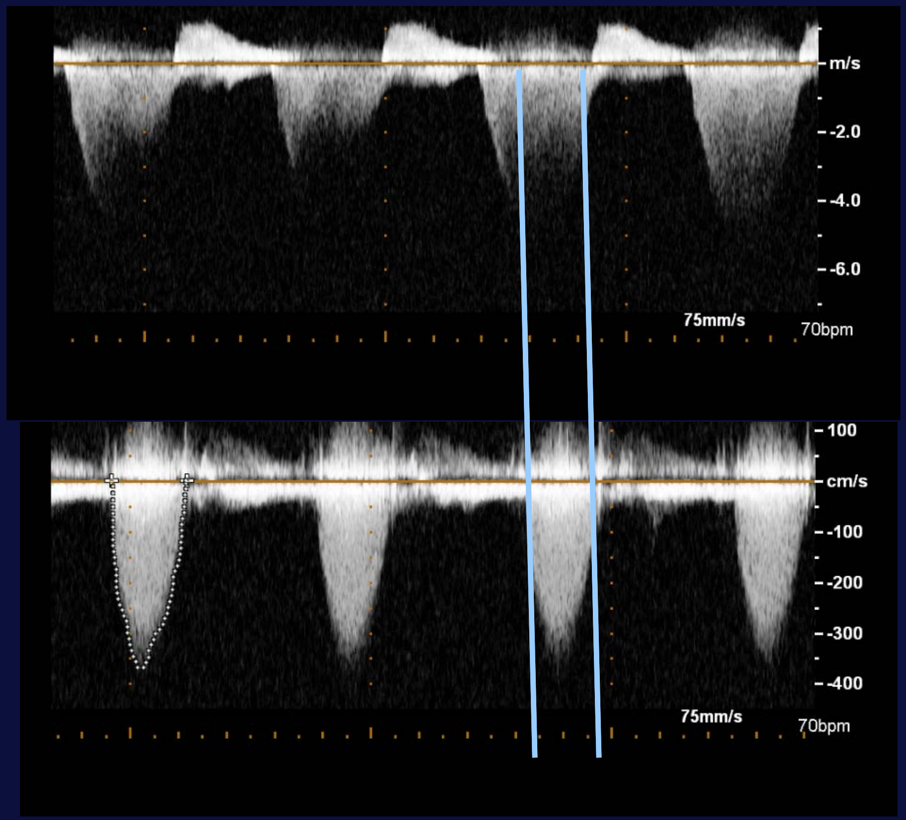




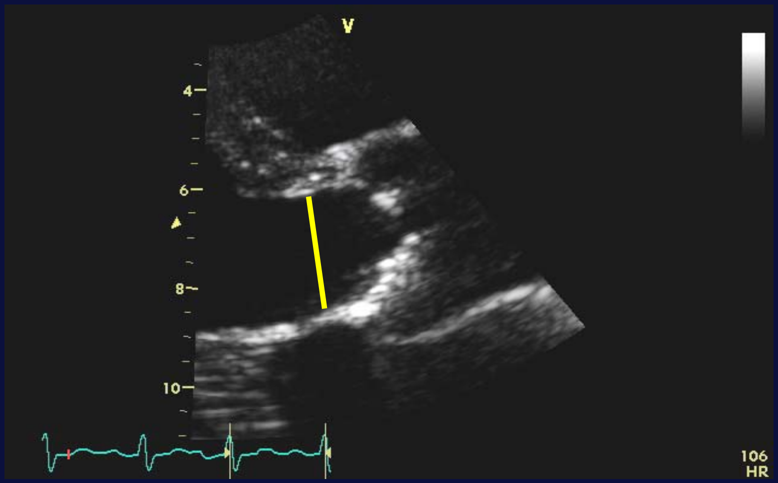


Mitral Regurgitant Jet Versus Aortic Stenosis Jet

- Mitral regurgitation occupies IVC and IVR



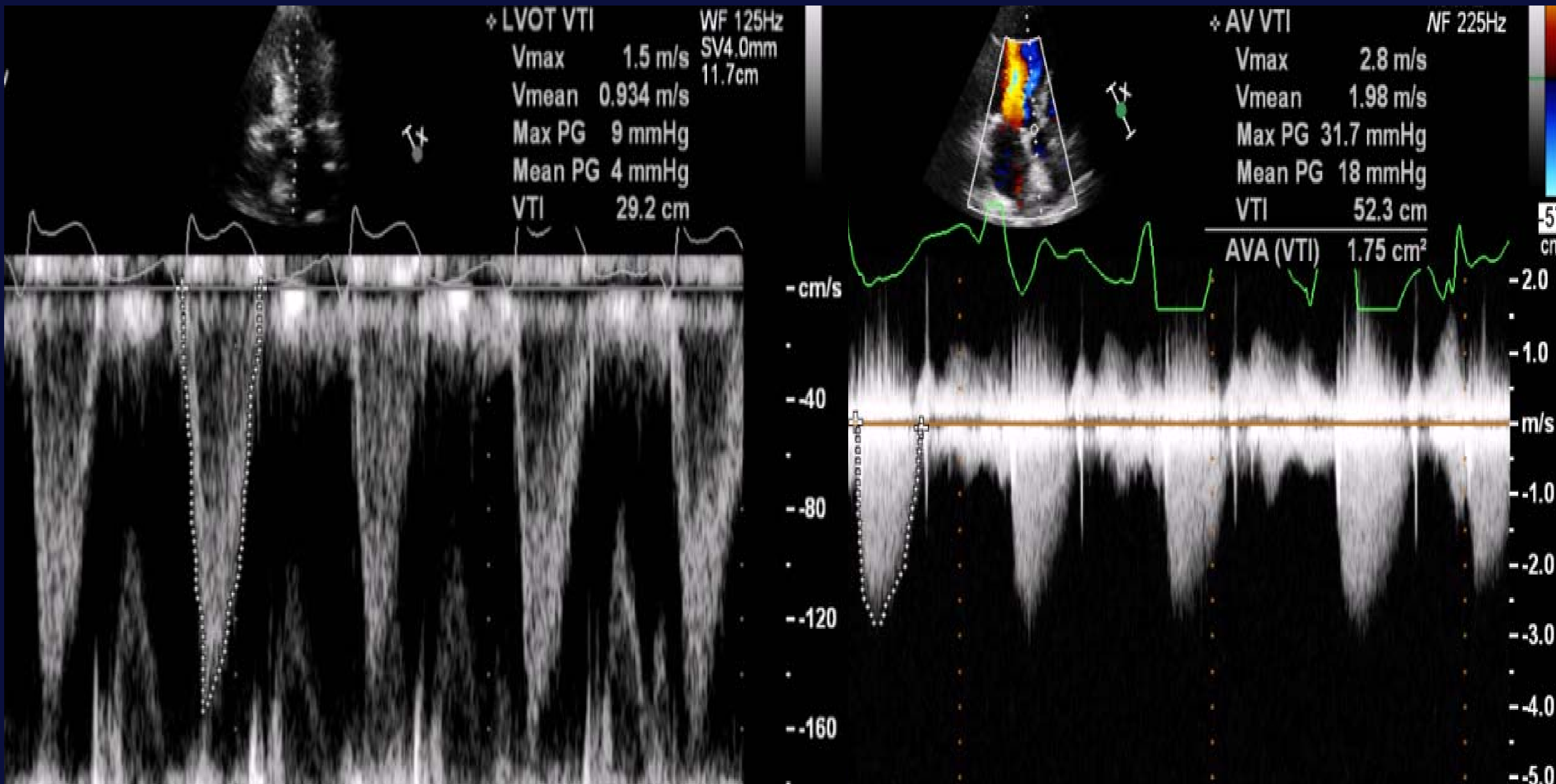
Errors of Measurements
LVOT Measurement



- Measure in systole
- At leaflet insertion
- Error squared!!
- Echo underestimates LVOT by 17%

B

High Flow



- **Aortic regurgitation**
- **Hyperdynamic states (dialysis, anemia)**
- **Dimensionless Index**

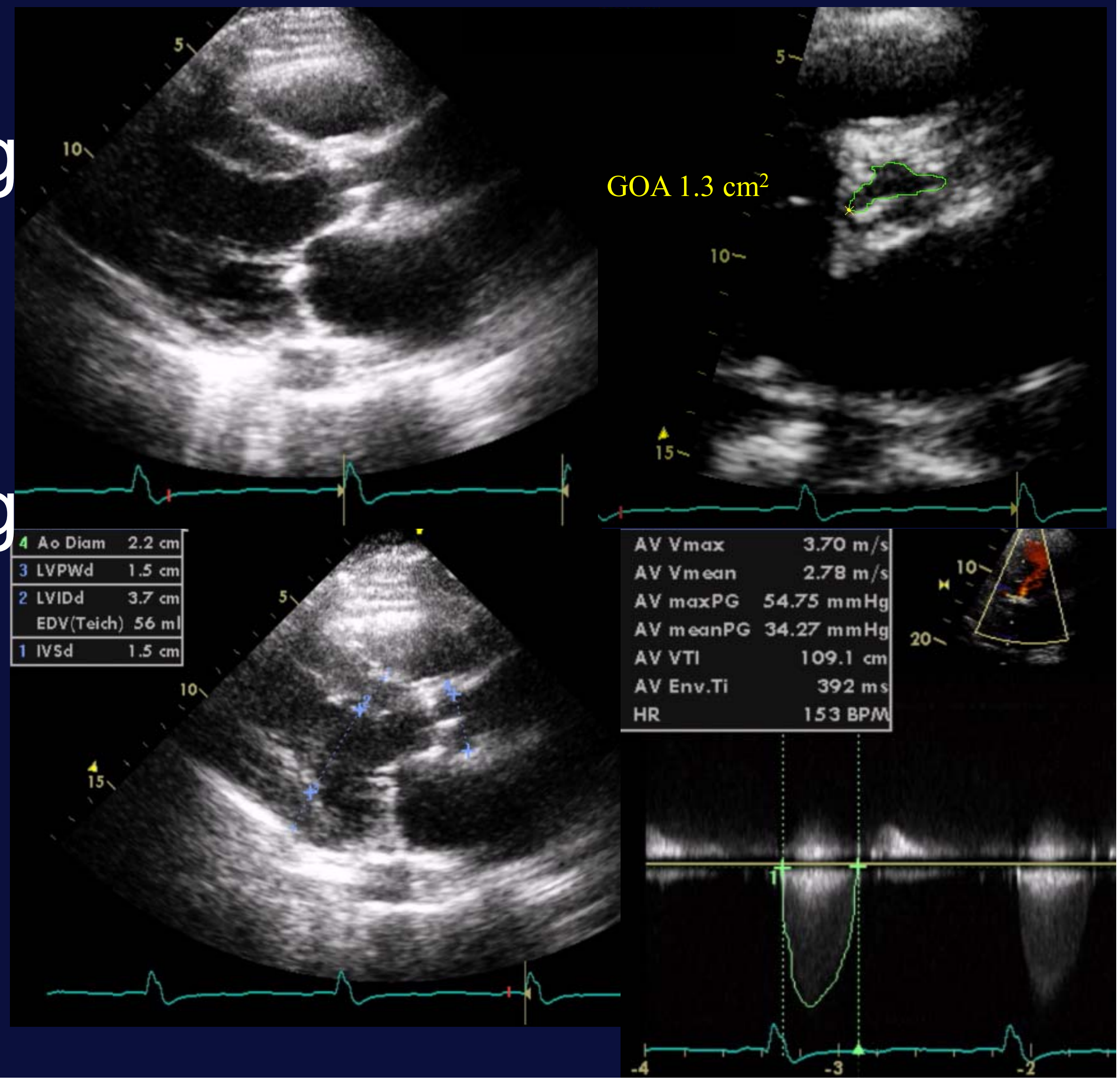
B

Pressure Recovery/High Flow

Doppler
Pmean = 34 mmHg
EOA = 0.6 cm^2

Catheterization
Pmean = 18 mmHg
EOA = 1 cm^2

APR= 34-18 = 16 mmHg
RPR= 16/34= 47%



Energy Loss Index

- Energy loss Co-efficient

$$ELCo = \frac{AVA \times AAa}{AAa - AVA}$$

- AVA = aortic valve area, AAa = aortic area
- Energy loss index: ELCo/BSA
- ELI < 0.52-0.76 cm^2 has poor outcomes and severe AS
- More significant with increase flow and moderate aortic stenosis

B

Pressure Recovery/High Flow

$EOA = 0.6\ cm^2$

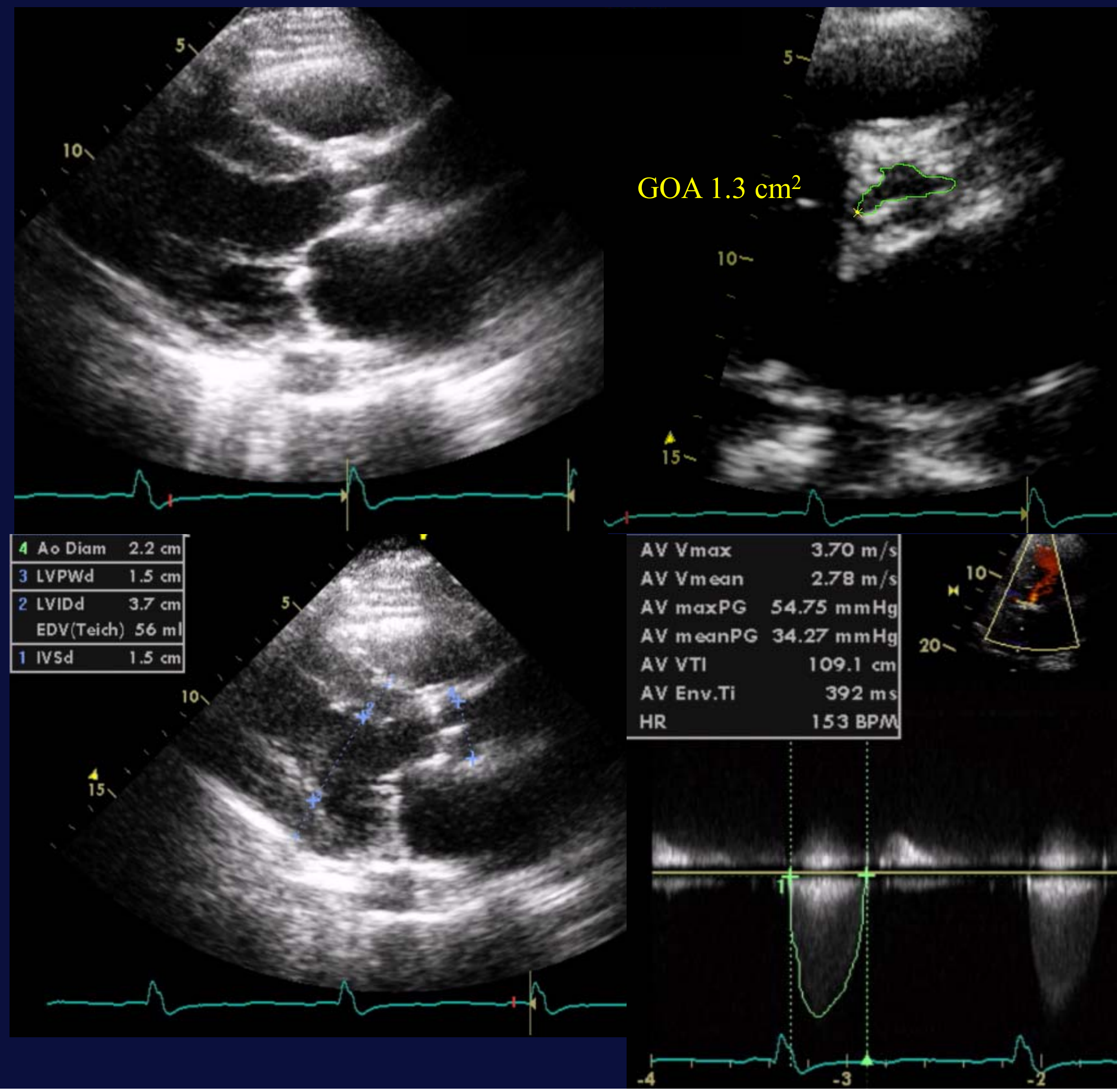
$AAd = 2.2\ cm$

$AAa = 3.8\ cm^2$

ElCo =
3.8x0.6/3.8-0.6

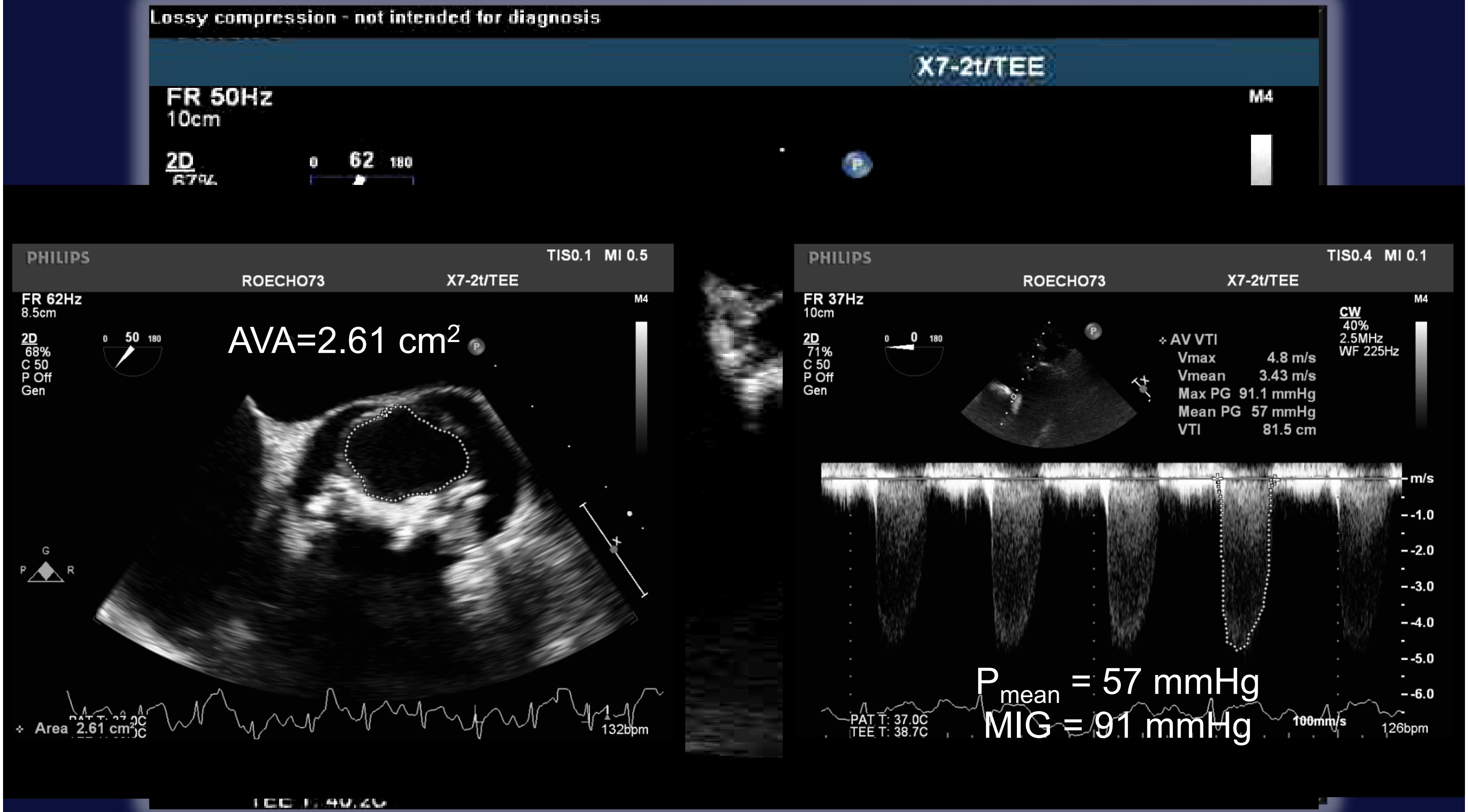
$ElCo = 0.72\ cm^2$

ELI = 0.72/BSA



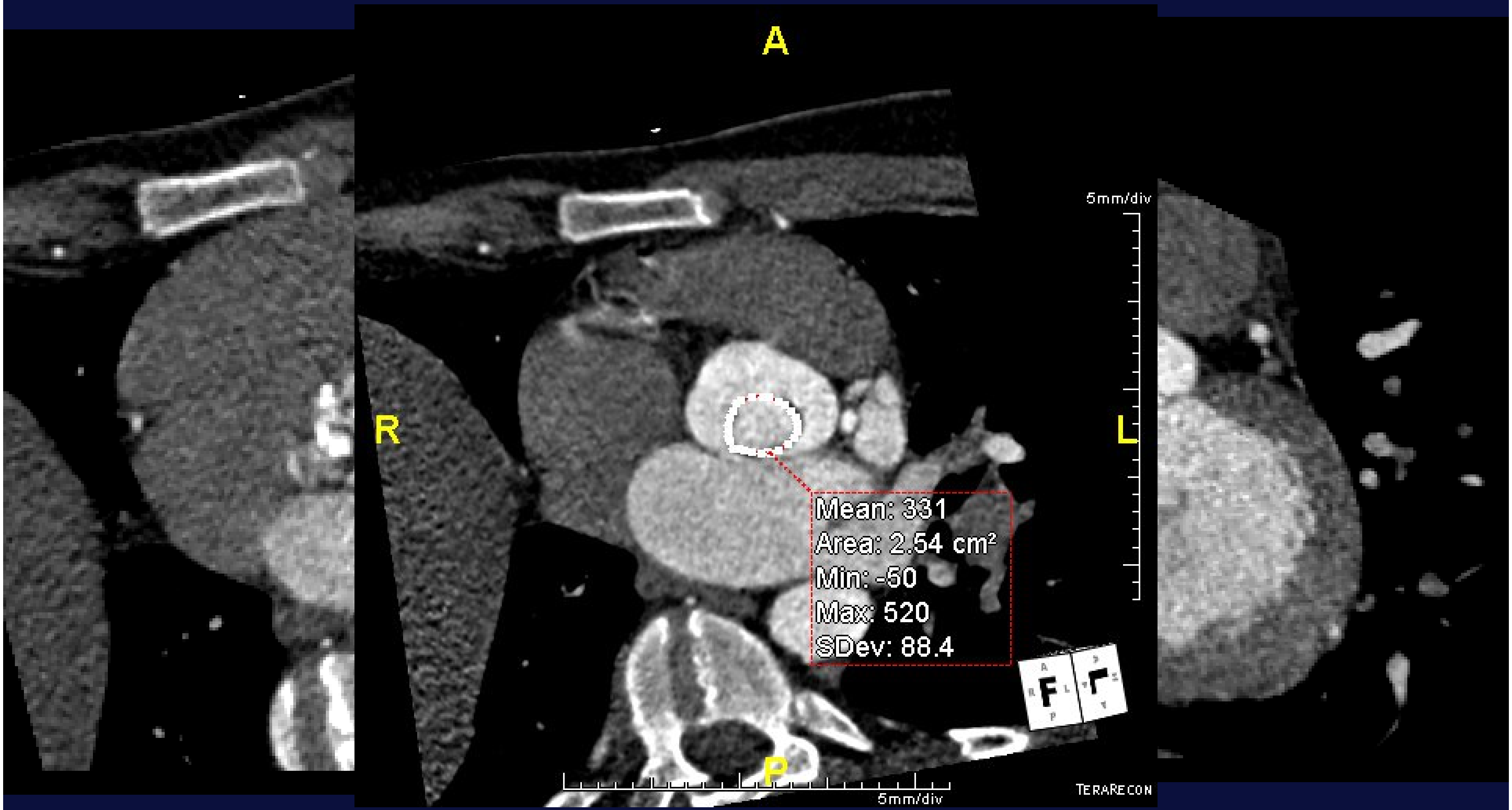
Eccentric Jet

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

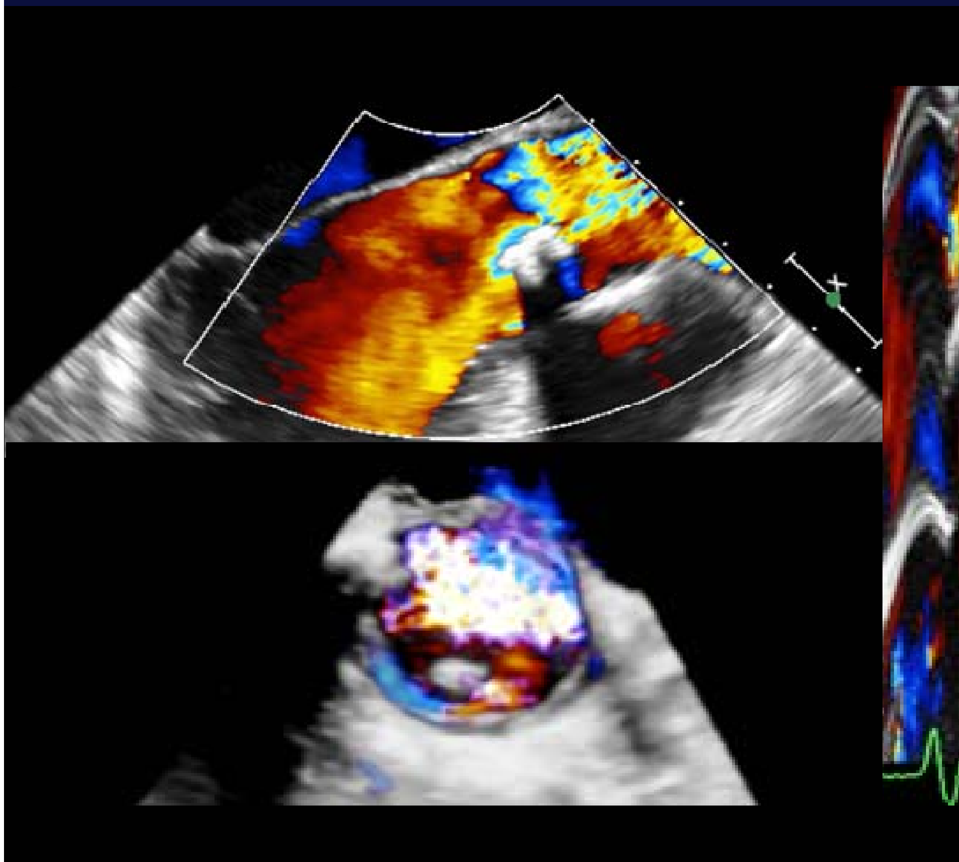


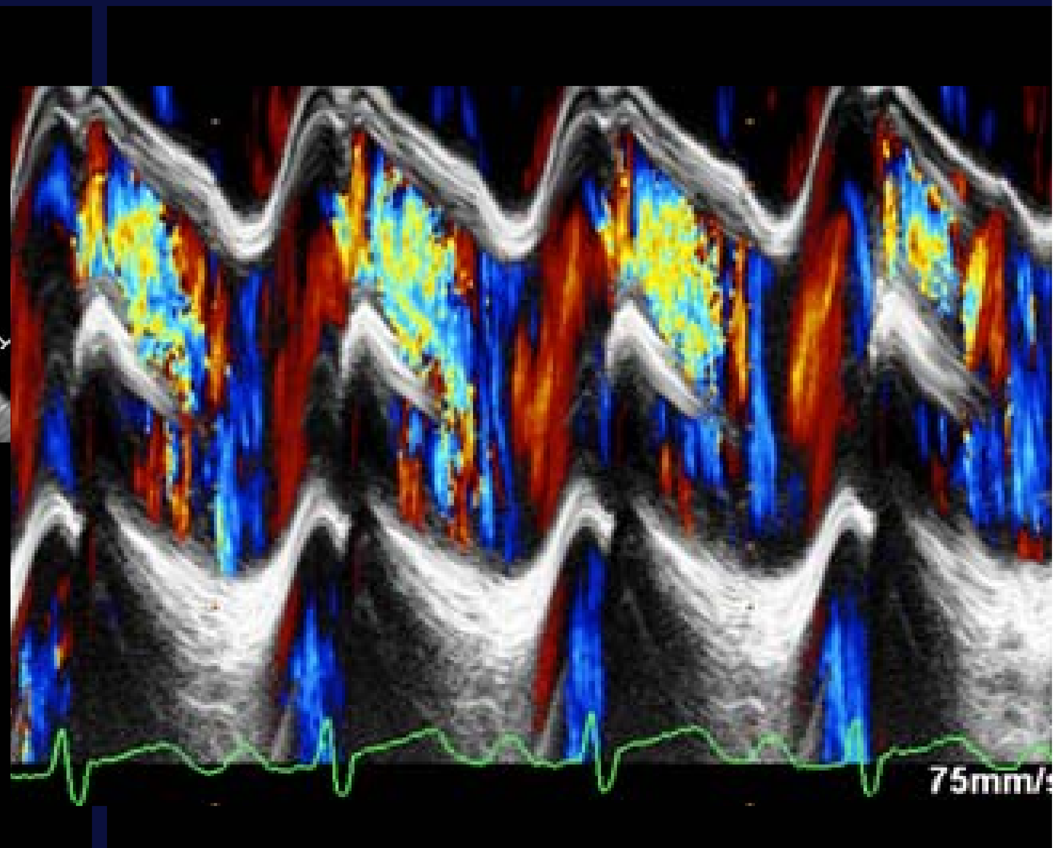
Cardiac Catheterization P_{mean} = 50 mmHg, AVA 1 cm^2

Eccentric Jet

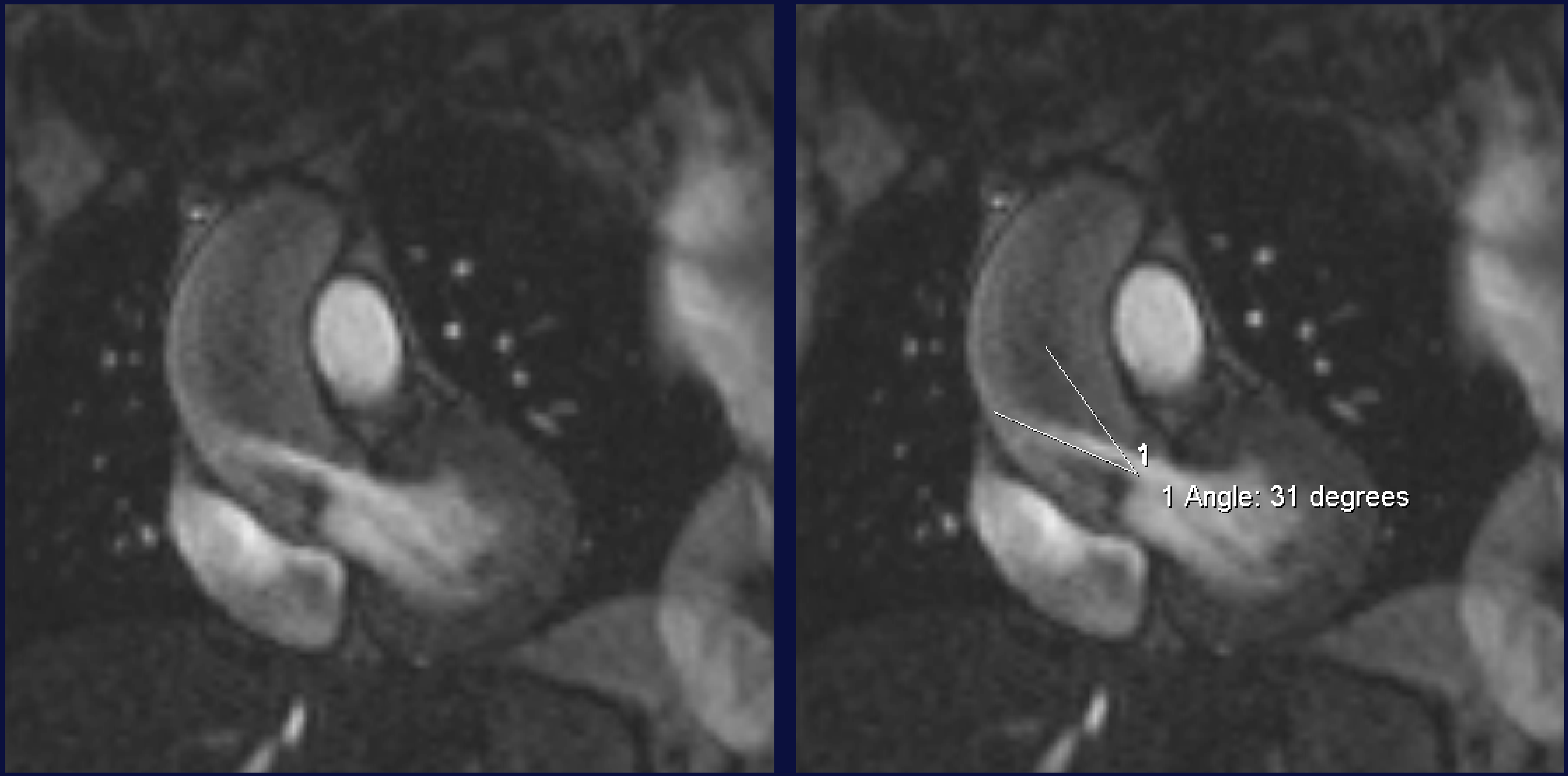


Eccentric Jet: Echo





Eccentric Jet: MRI



Aortic Stenosis

Reverse Area Gradient Mismatch

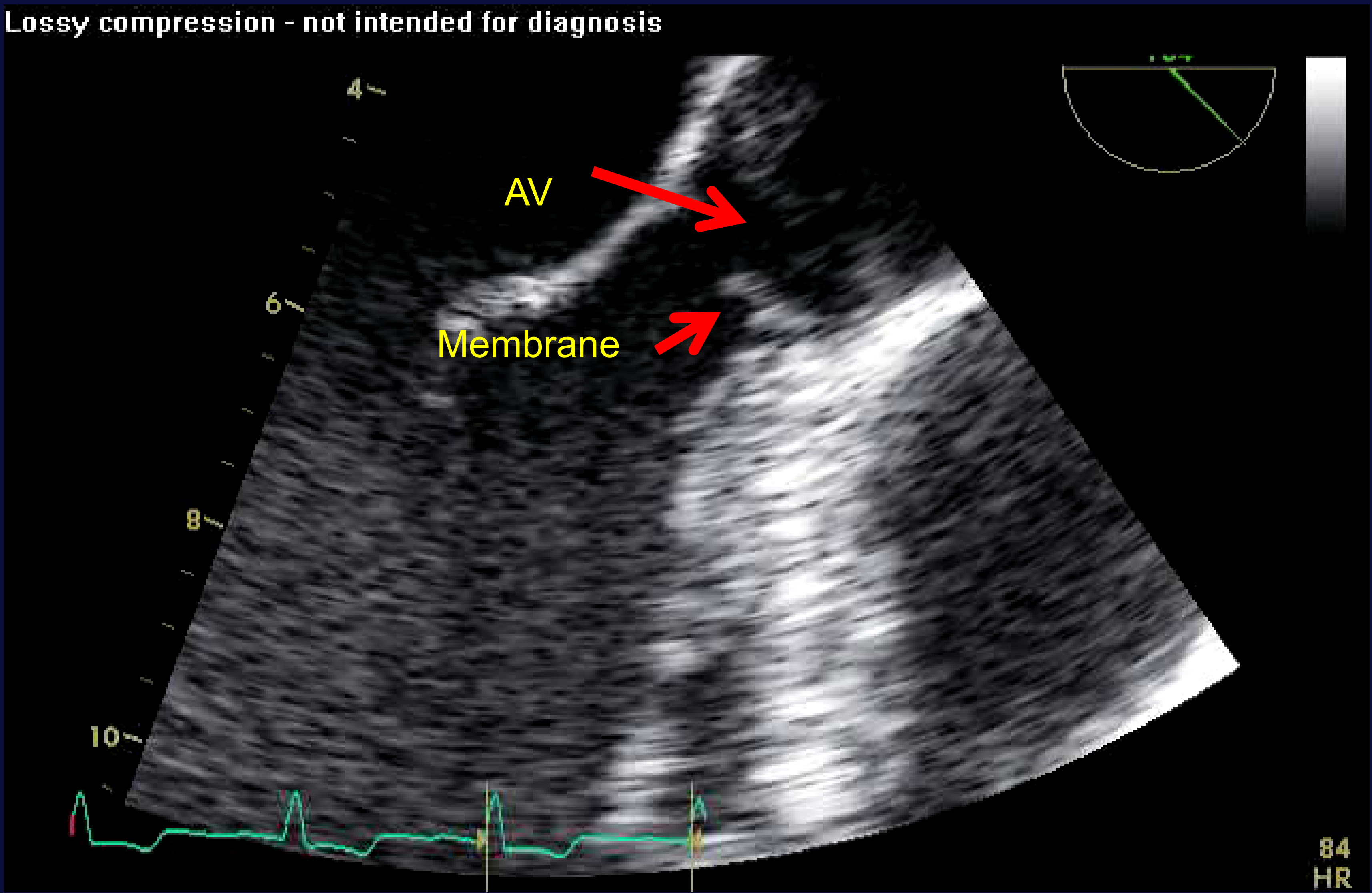
Elevated Gradient/GOA ok
Mean Gradient >40mmHg
AVA >1.0cm^2

Bicuspid Aortic Valves

Para-valvular Obstruction

- Sub-Aortic membrane
- Hypertrophic Obstructive Cardiomyopathy
- Supravalvular Obstruction
- Mitral valve Prosthesis

Sub-Aortic Membrane

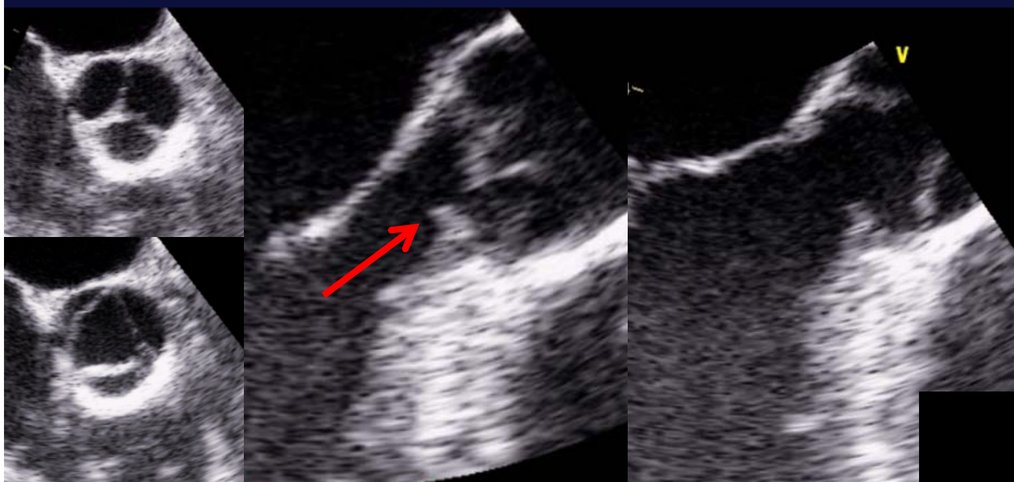


Sub-Aortic Membrane

Progressive Disease
Other congenital anomalies in 50%
- VSD/PDA/Coarctation
- Shone's Complex
- Bicuspid AV
- leftsided-SVC

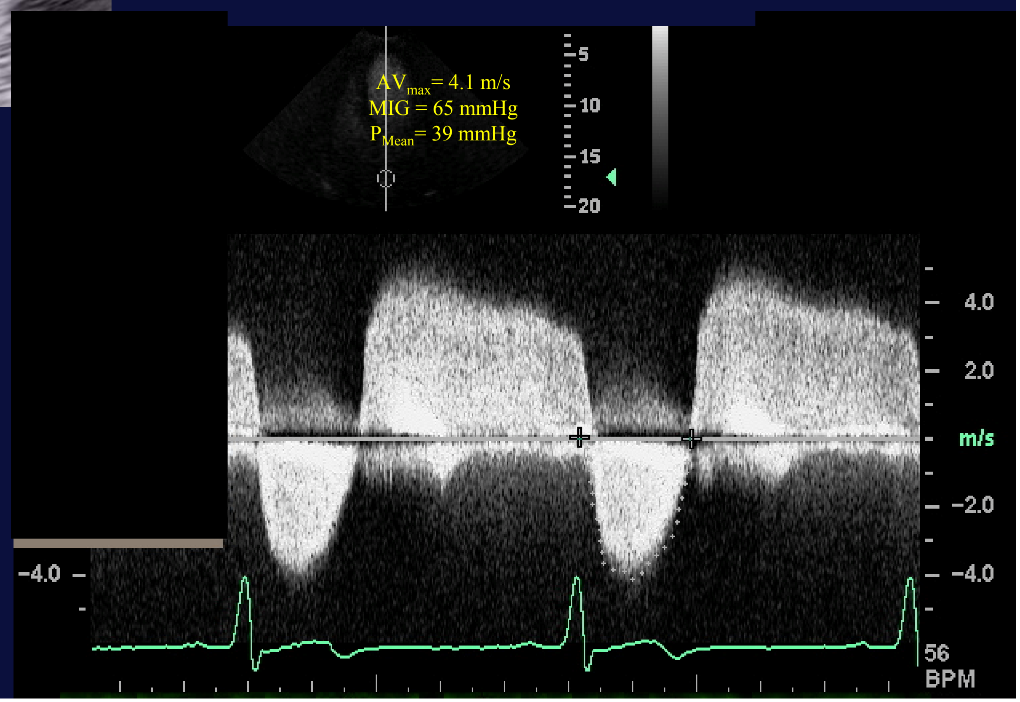
Types: Membrane, fibromuscular ridge, Diffuse tunnel narrowing, mitral tissue

B

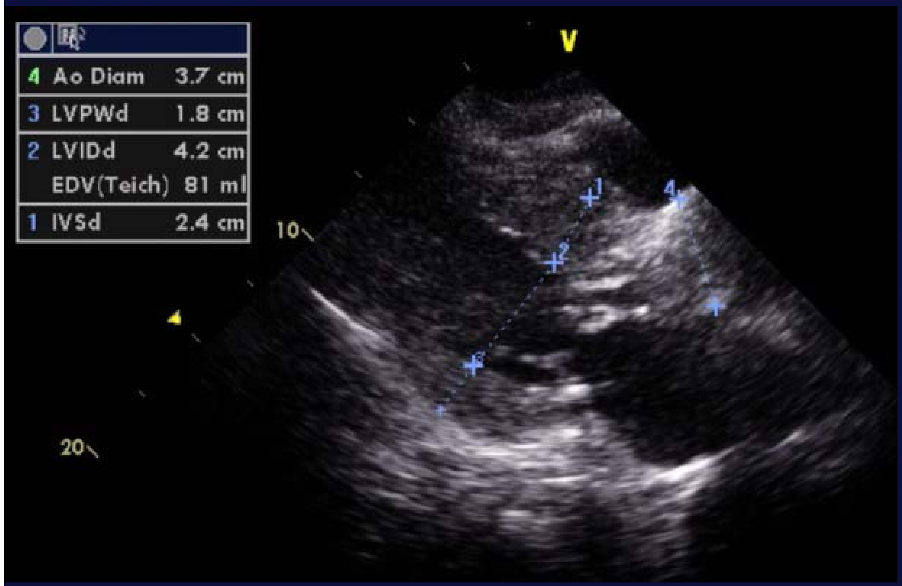


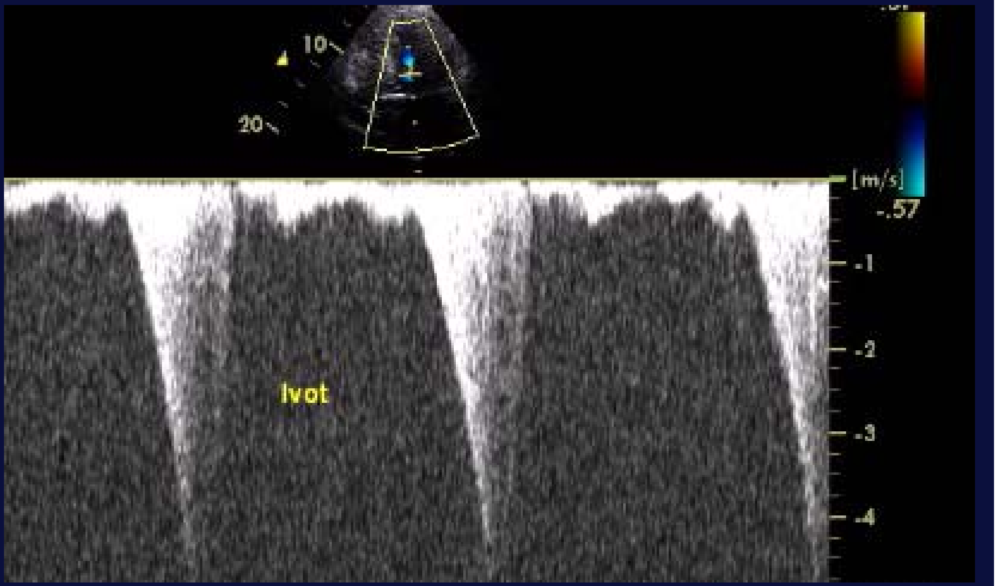
May Cause aortic regurgitation
Treatment: Surgery
No symptoms: Catheter LVOT-A peak/Doppler Mean = 50 mmHg
Symptoms: Catheter LVOT-A peak/Doppler Mean = 30-50 mmHg
Adults may use Doppler Peak > 50 mmHg
Resection/Konno procedure

B



Hypertrophic Obstructive Cardiomyopathy



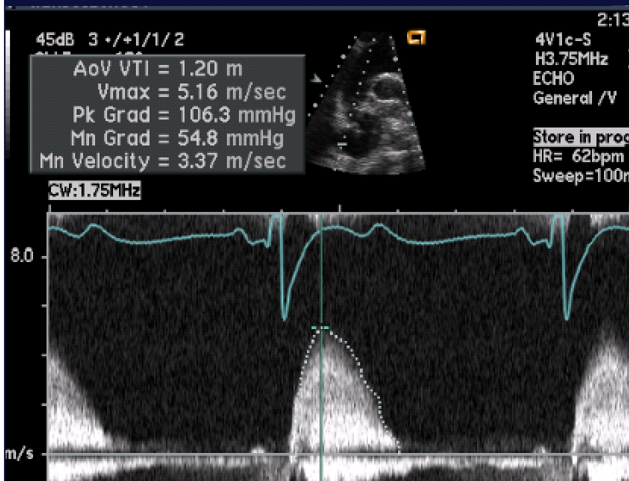


Alcohol Septal Ablation or Surgery

High Risk features

ICD

Supra-Aortic Obstruction



Non-Familial Sporadic

William syndrome:

- Elfin Facial
- Hypercalcemia
- Behavioral
- Diagnosed by CVS and fetal echo

B

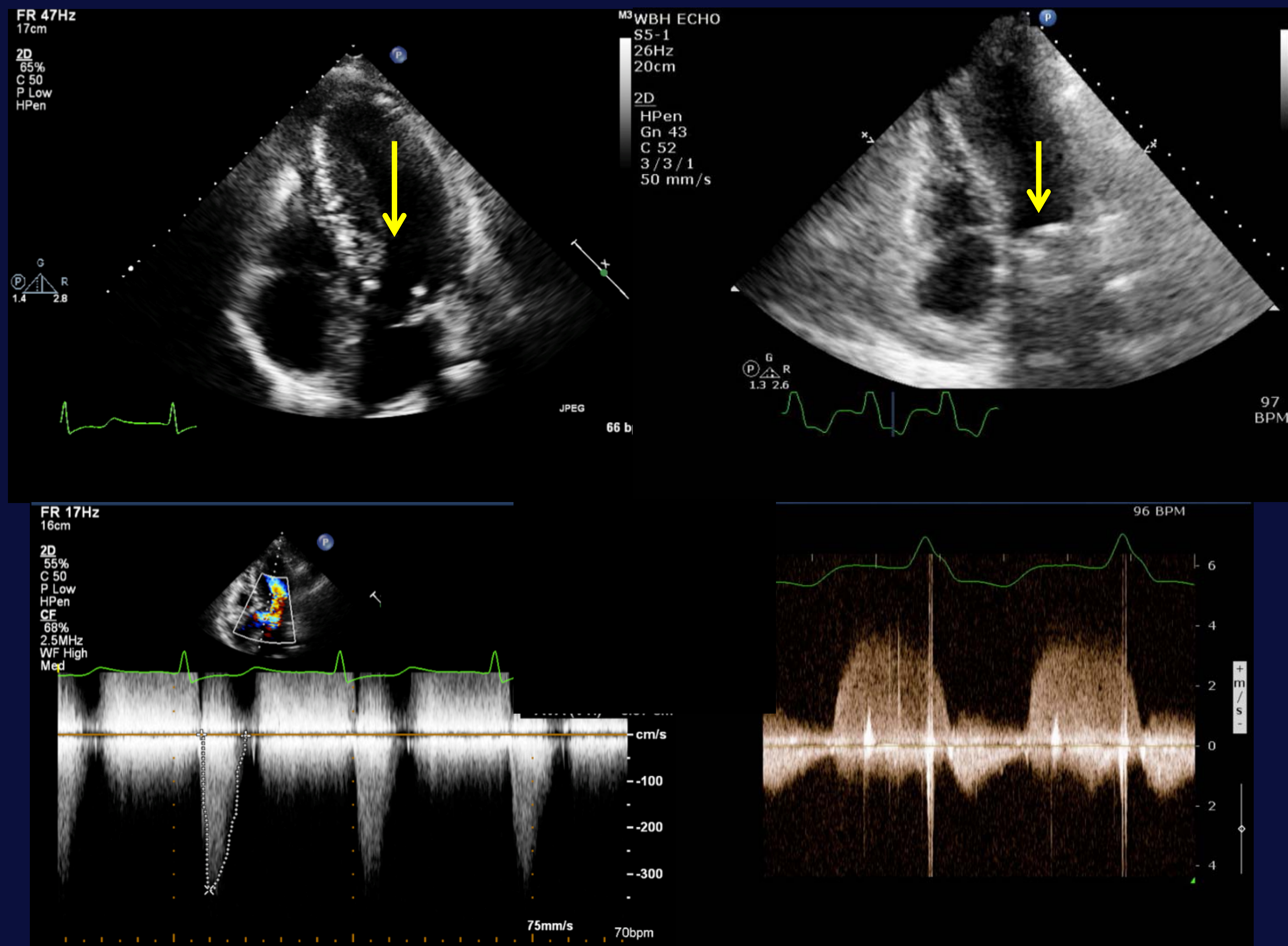
Familial Sporadic

Coronary anomalies

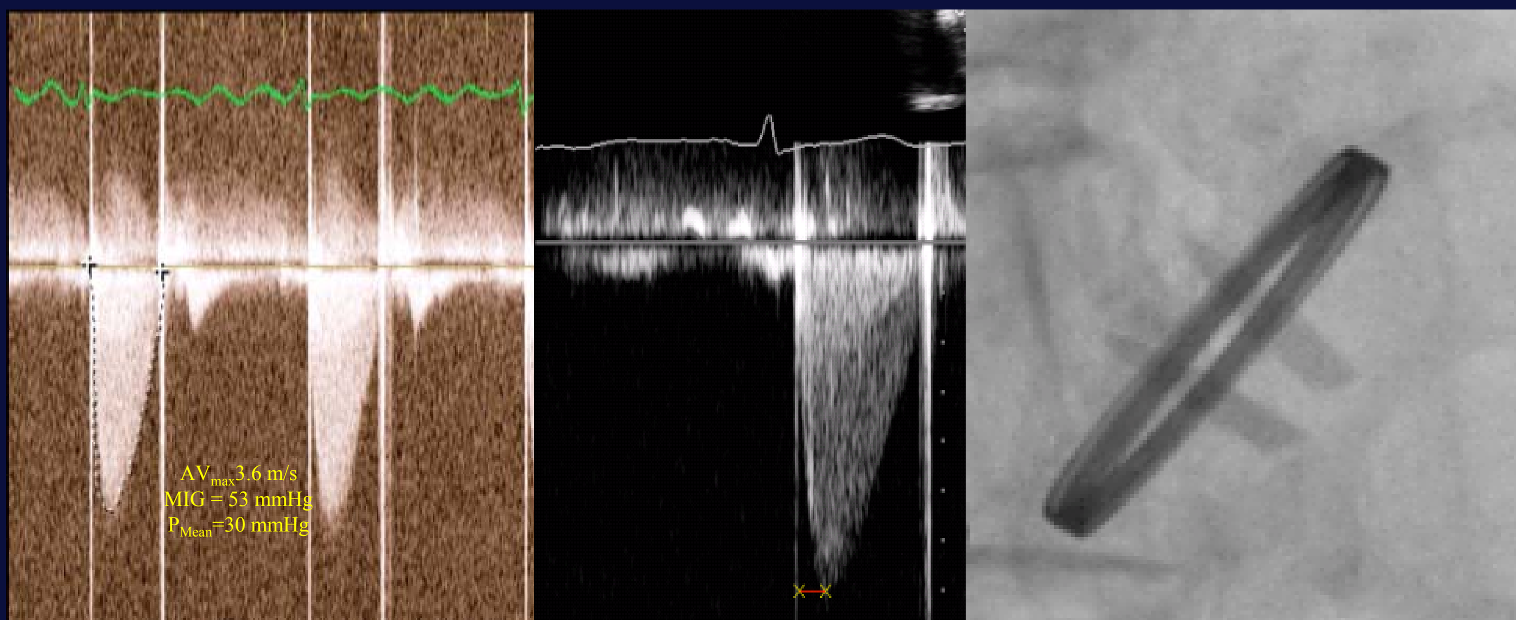
Types: Hour glass, Membrane, Diffuse narrowing

Surgery

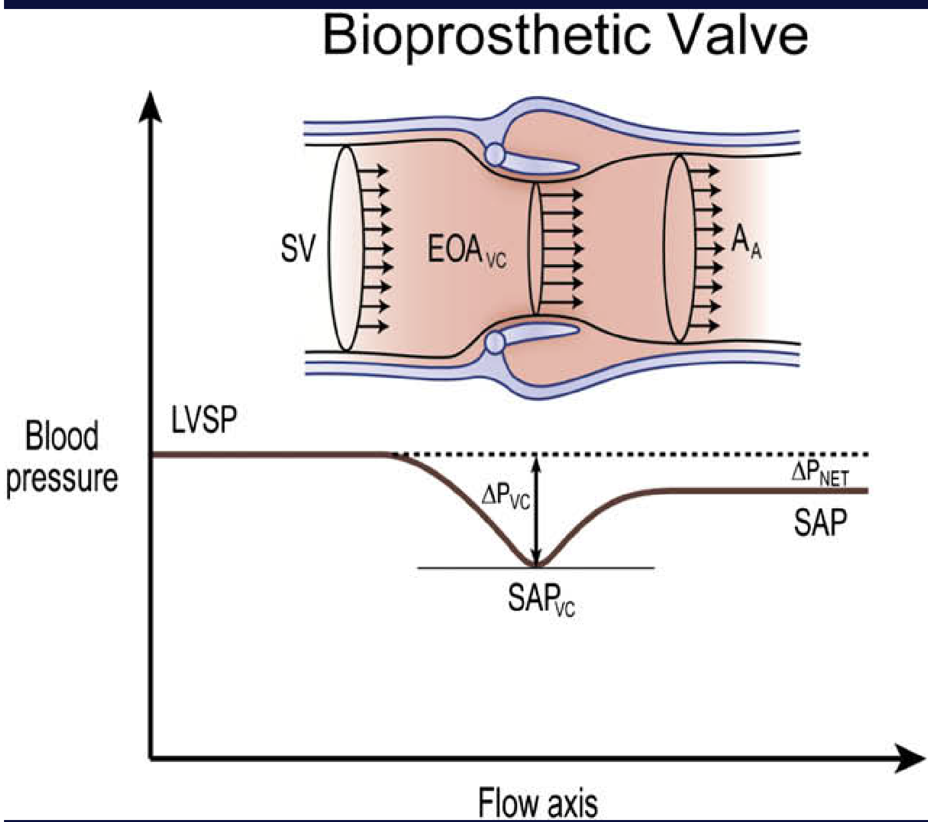
Obstruction by Mitral Valve Prosthesis



Localized Pressure Loss and High Gradient in Central Orifice of Bileaflet Mechanical Valve

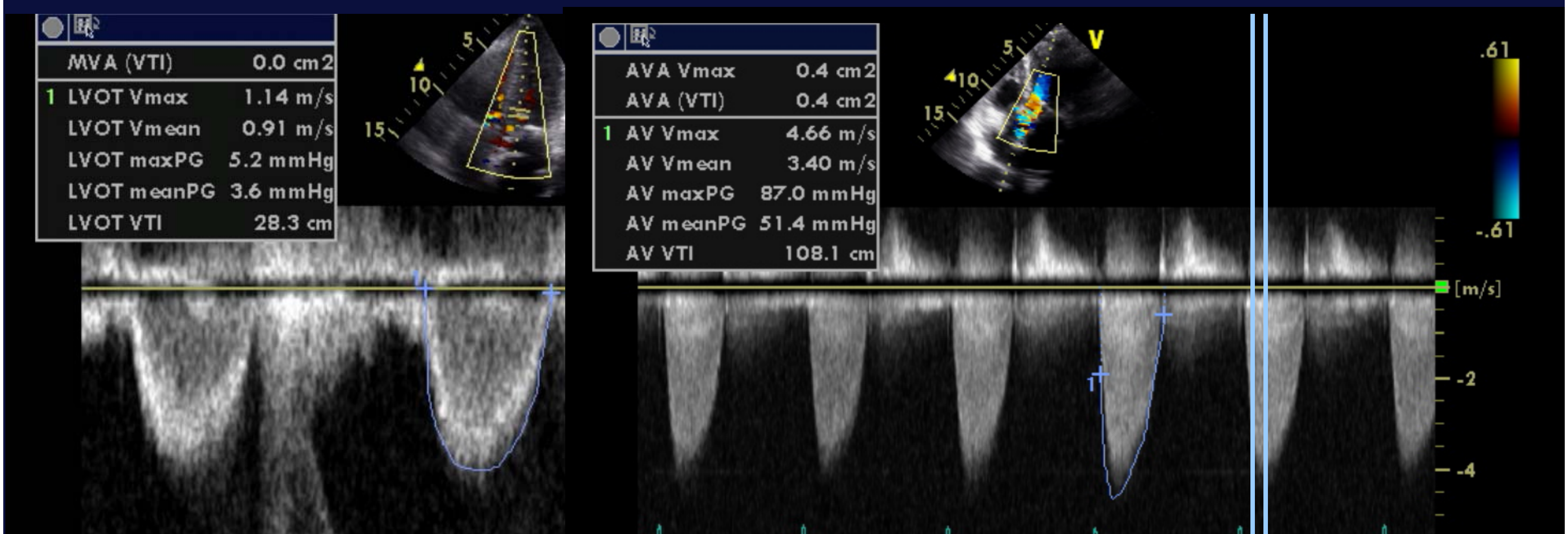


Localized Pressure Loss and High Gradient in Central Orifice of Bileaflet Mechanical Valve



- Fluoroscopy

Patient Prosthesis Mismatch



- Doppler Velocity Index: LVOT /aortic velocity
    - Acceleration Time: Jet onset to peak

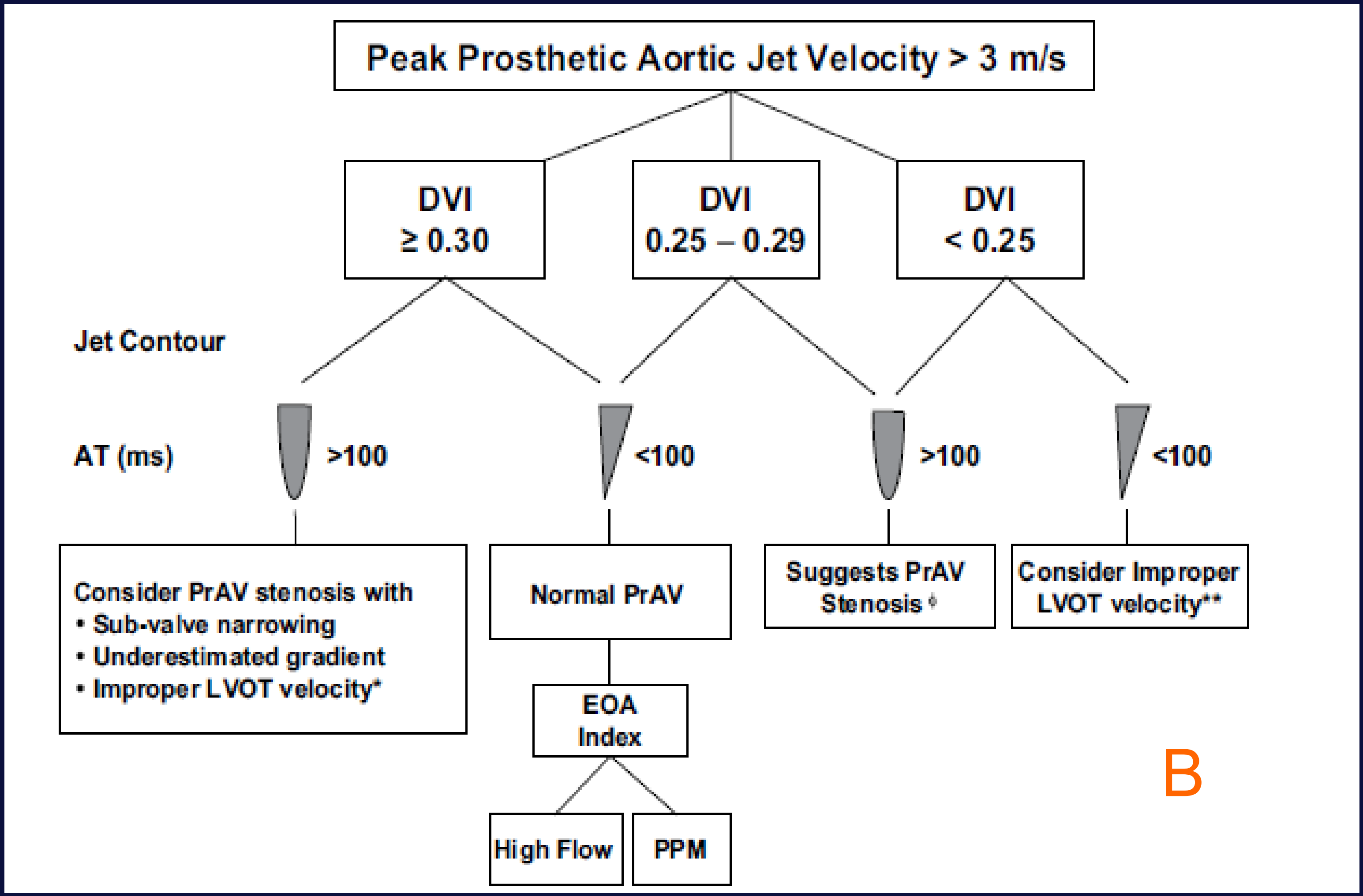
B

Patient Prosthesis Mismatch

Patient Prosthesis Mismatch

- $\Delta P = Q^2/(K \times EOA^2)$
- To keep gradient low, EOA must accommodate flow
- Under basal conditions, Basal flow depends on BSA, hence small valves = high gradients
- Normal DVI > 0.3, DVI = 28/108 = 0.26, Normal Acceleration time < 100 msec, Acceleration = 60 msec
- iEOA < 0.85 cm/m^2 = PPM
- iEOA < 0.65 cm/m^2 = severe PPM

Elevated Prosthesis Gradient



Conclusions

Reverse Area Gradient Mismatch

- **Errors:** Mitral regurgitation jet/LVOT area/angle
- **Increased flow:** systemic or due to severe aortic regurgitation; Doppler & catheter
- **Pressure Recovery:** dependent on aortic area
- **Para-valve Obstruction:** above or below the valve
- **Eccentric jets:** increased pressure loss and an elevated gradient; Doppler & catheter
- **Prosthetic Valve:** Localized pressure drop, PPM

Pre Questions (1)

- The Difference between Doppler MIG and catheterization PPG
  A. Is due to pressure recovery
  B. Is due to different measurement timing of the LV and aortic pressures
  C. Occurs only in patients with small aortas
  D. Is used to calculate aortic valve area

Answer (1)

- B. Is due to different measurement timing of the LV and aortic pressures

Pre Questions (2)

- Catheter-Doppler Discordance maybe due to
  A. Pressure recovery
  B. Eccentric jet
  C. High flow states
  D. Very severe aortic stenosis

Pre Questions (2)

- A. Pressure recovery

Conclusions

Reverse Area Gradient Mismatch

- Watch for units to avoid miscalculations
- Realize the difference between MIG and PPG and the mean gradient by both
- EOA is not GOA.

  GOA is measured by planimetry

  EOA by continuity equation and is the area at the vena contracta

Aortic Stenosis Classification

- **Area/Gradient Match**
  - Area/Gradient Match NF/HG
  - Area/Gradient Match LF/HG
- **Area/Gradient Mismatch Normal EF**
  - Area/Gradient Mismatch NF/LG
  - Area/Gradient Mismatch LF/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

THANK YOU