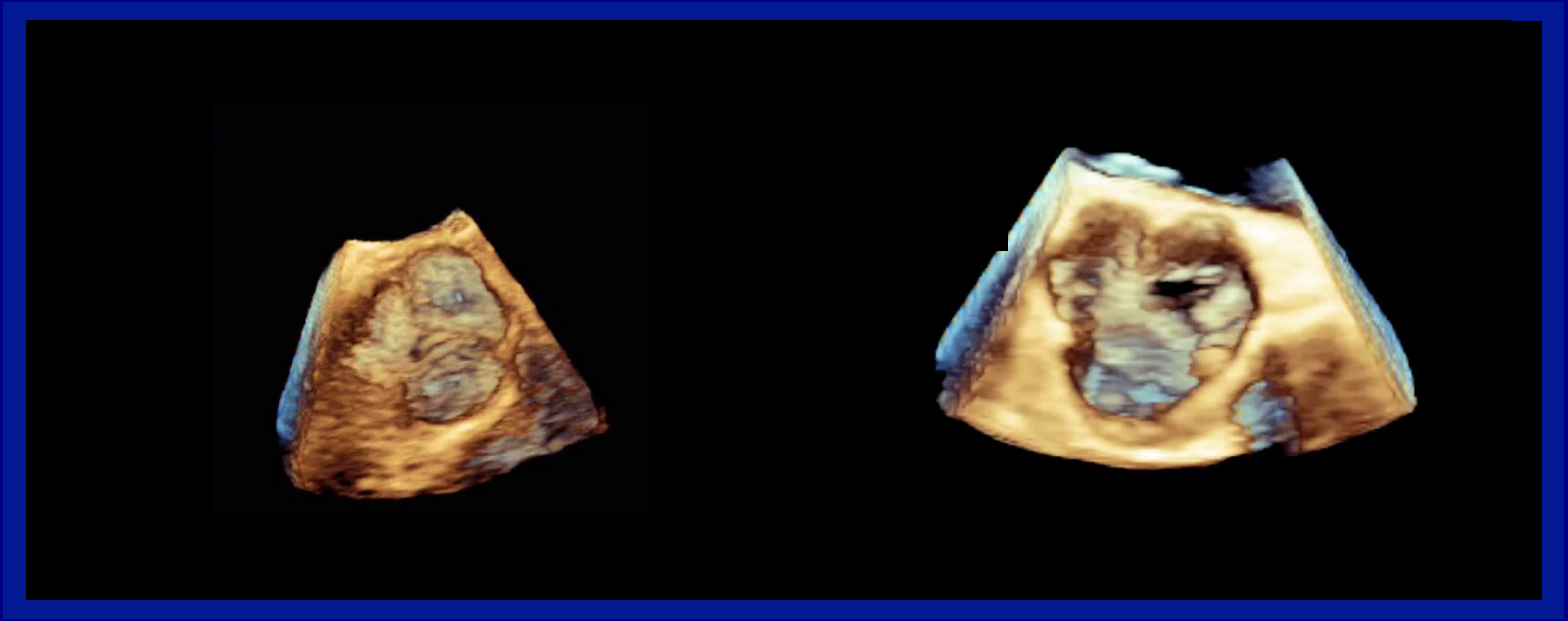
Echocardiographic Assessment of the Native Aortic Valve & Aortic Valve Replacement/Repair

Dr Adrian Chong
FRACP, FASE, FCSANZ, MBBS (Hons I), BPharm
Senior Staff Cardiologist
Princess Alexandra and Mater Adult Hospitals, Brisbane
Senior Lecturer
University of Queensland

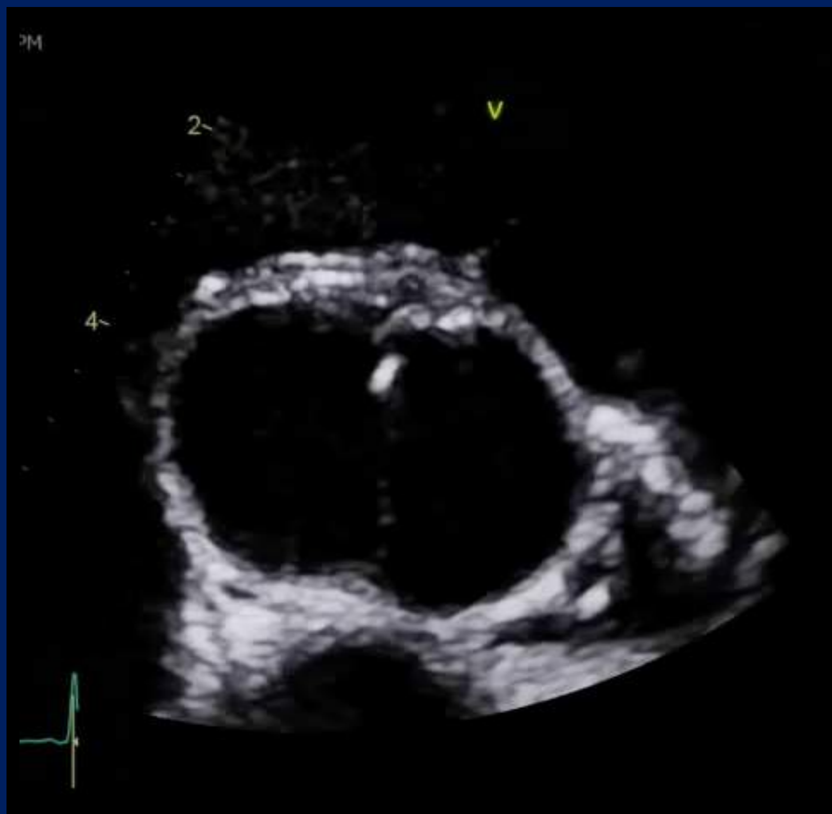


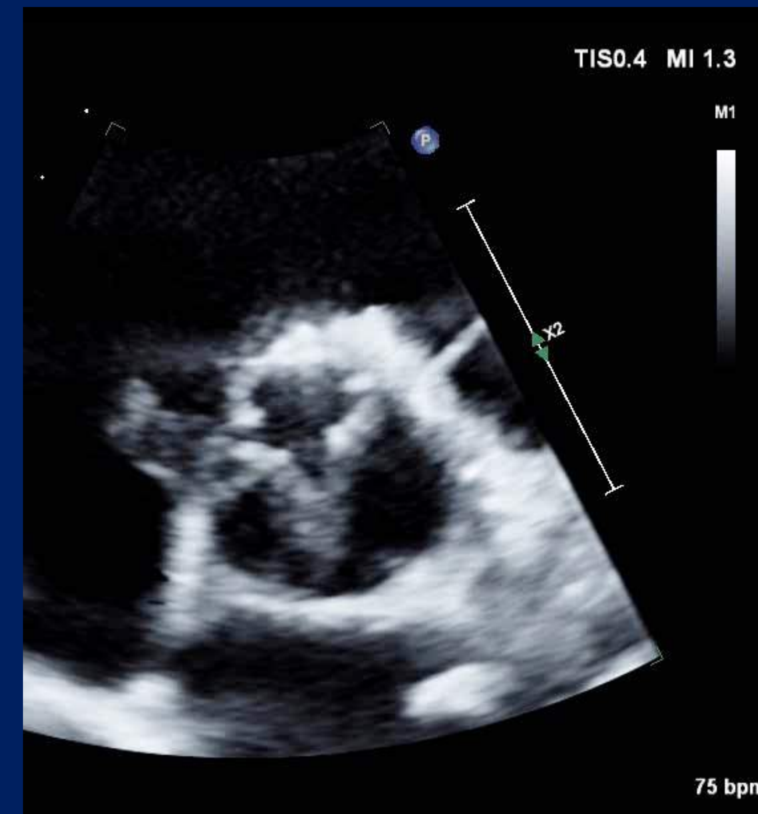
Echocardiographic Assessment

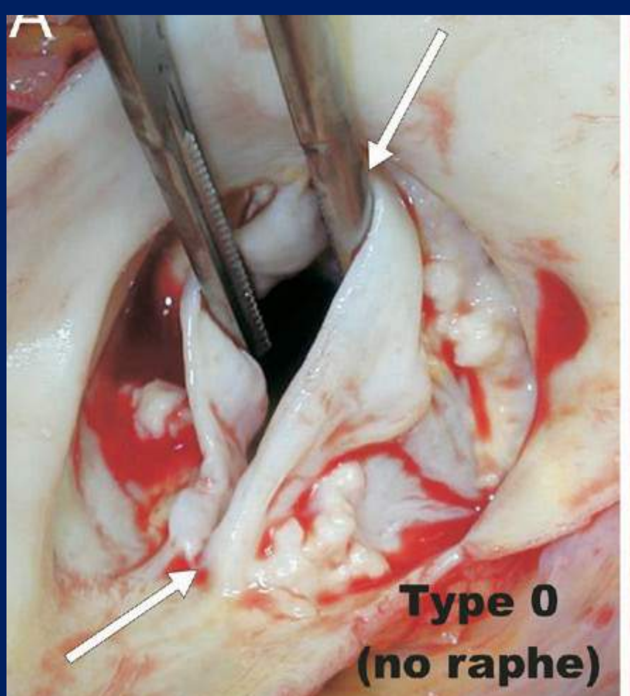
1. Aortic valves and functional aortic annulus
2. AS (Valvular)
3. AR
4. AVR (SAVR, TAVR)
5. Aortic valve repair

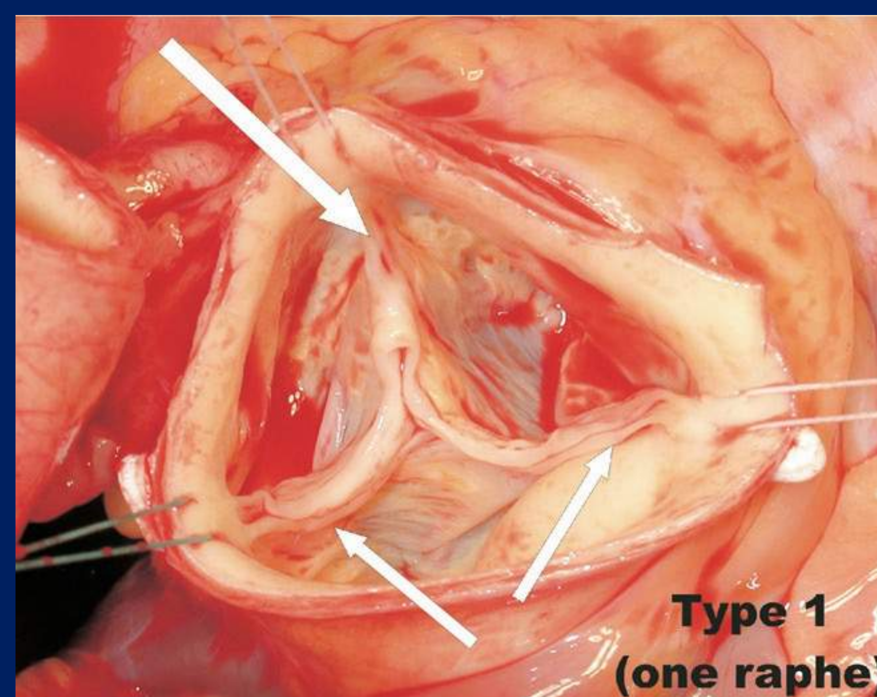
Native Aortic Valve

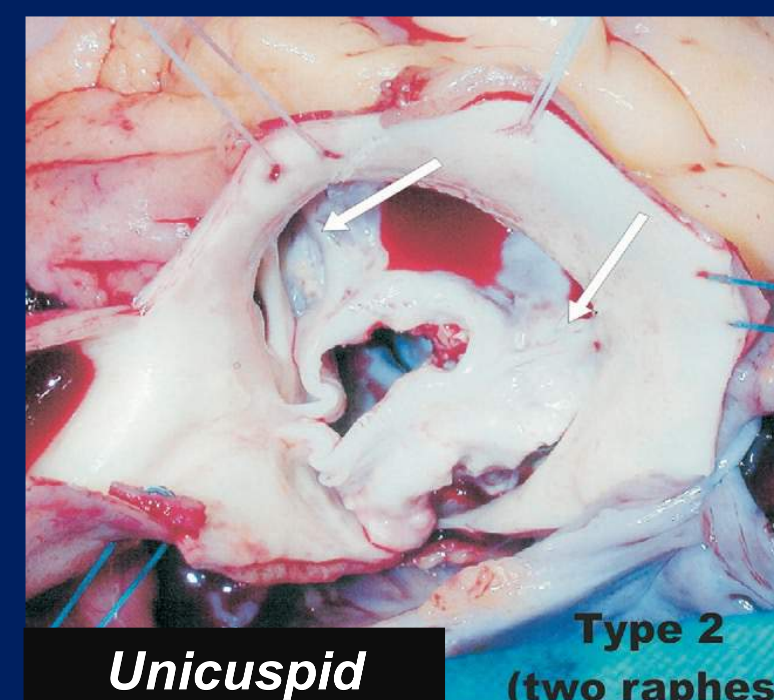
Morphology





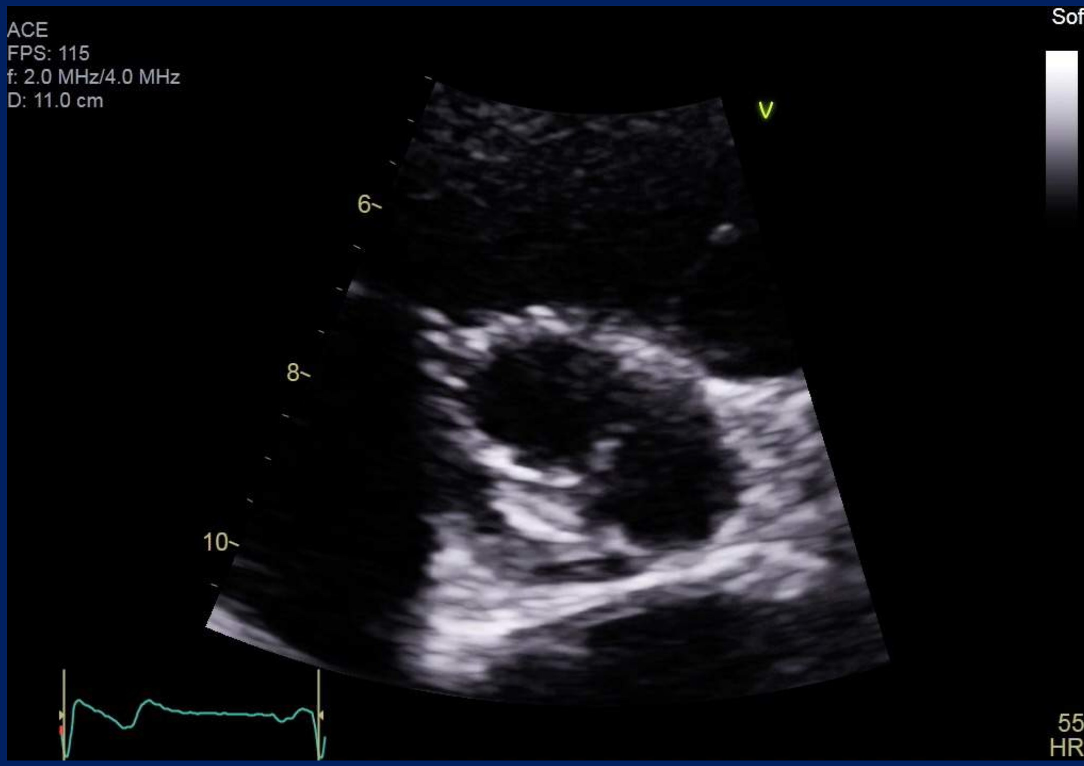




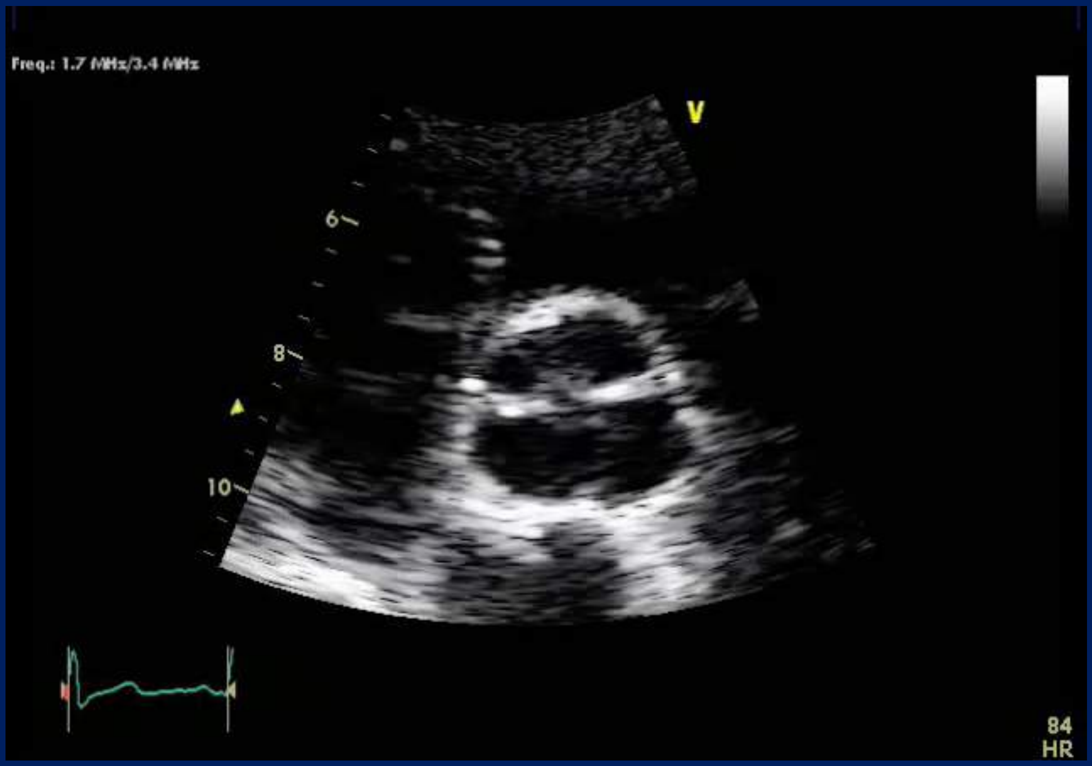


Sievers & Schmidtke. A classification system for the bicuspid aortic valve from 304 surgical specimens. J Thorac Cardiovasc Surg 2007;133:1226-1233.
Berrebi A, et al. Systematic echocardiographic assessment of aortic regurgitation – what should the surgeon know for aortic valve repair. Ann Cardiothorac Surg 2019;8:331-341.

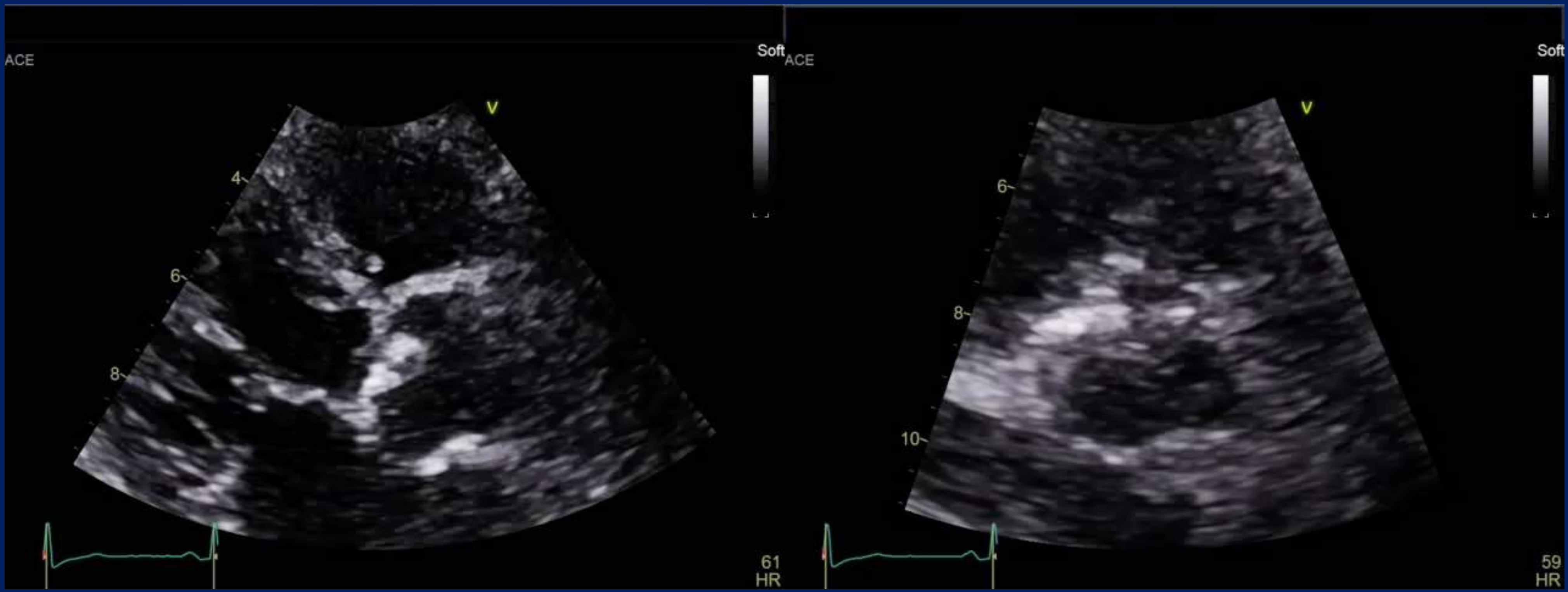
Morphology



Tricuspid

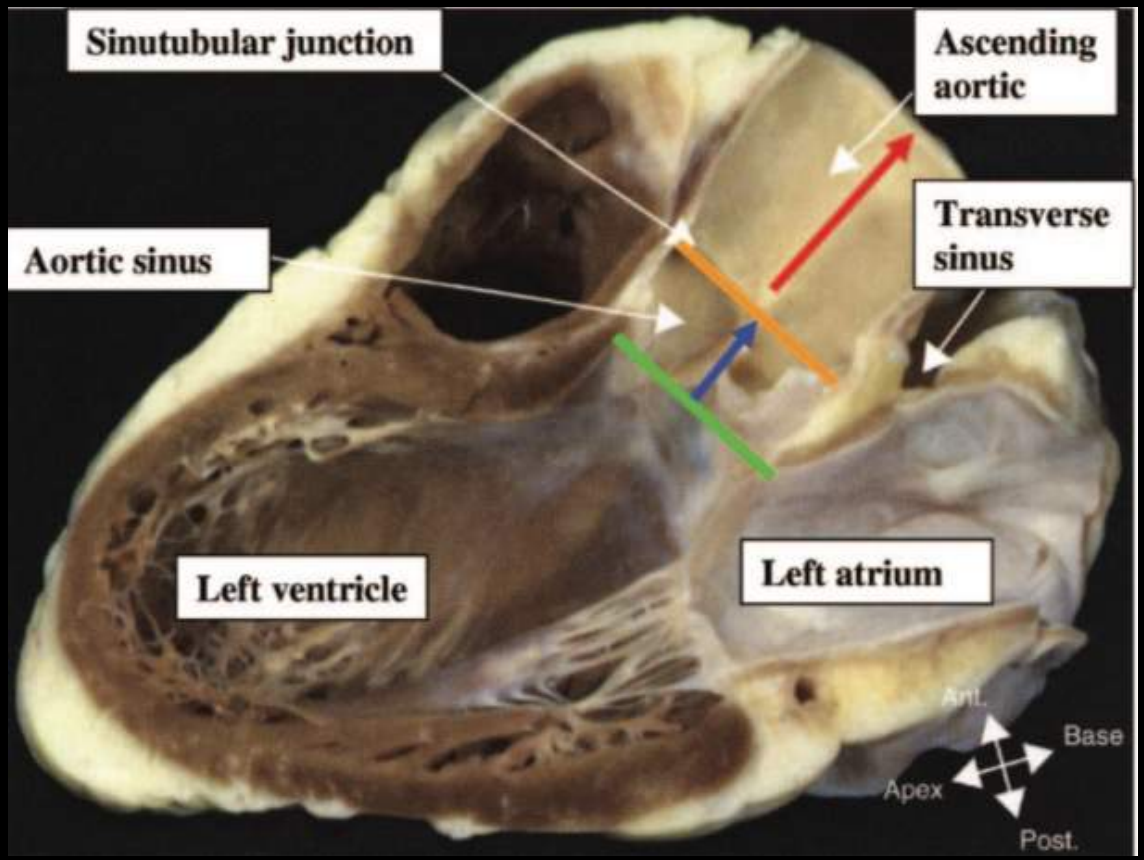


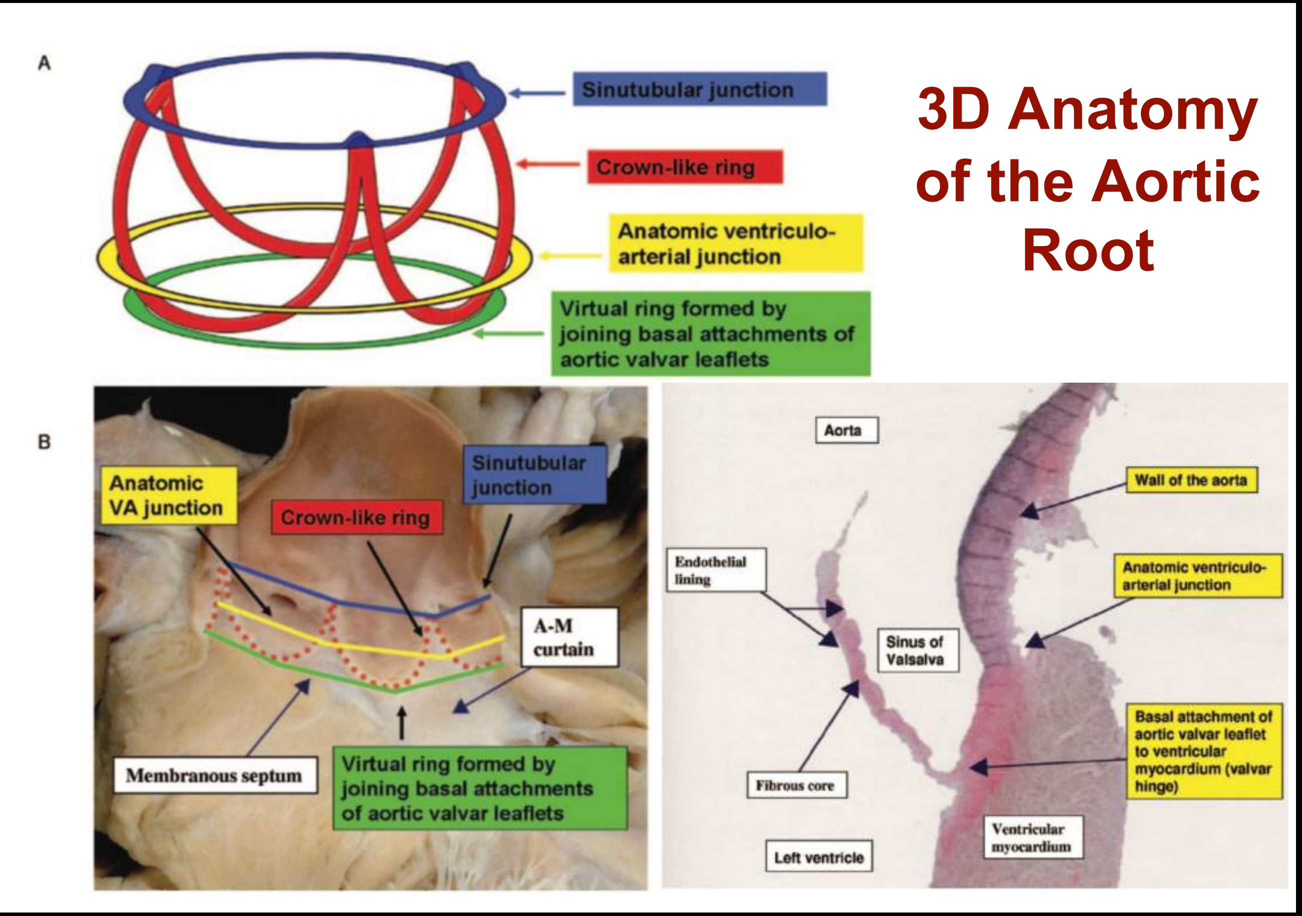
Quadricuspid

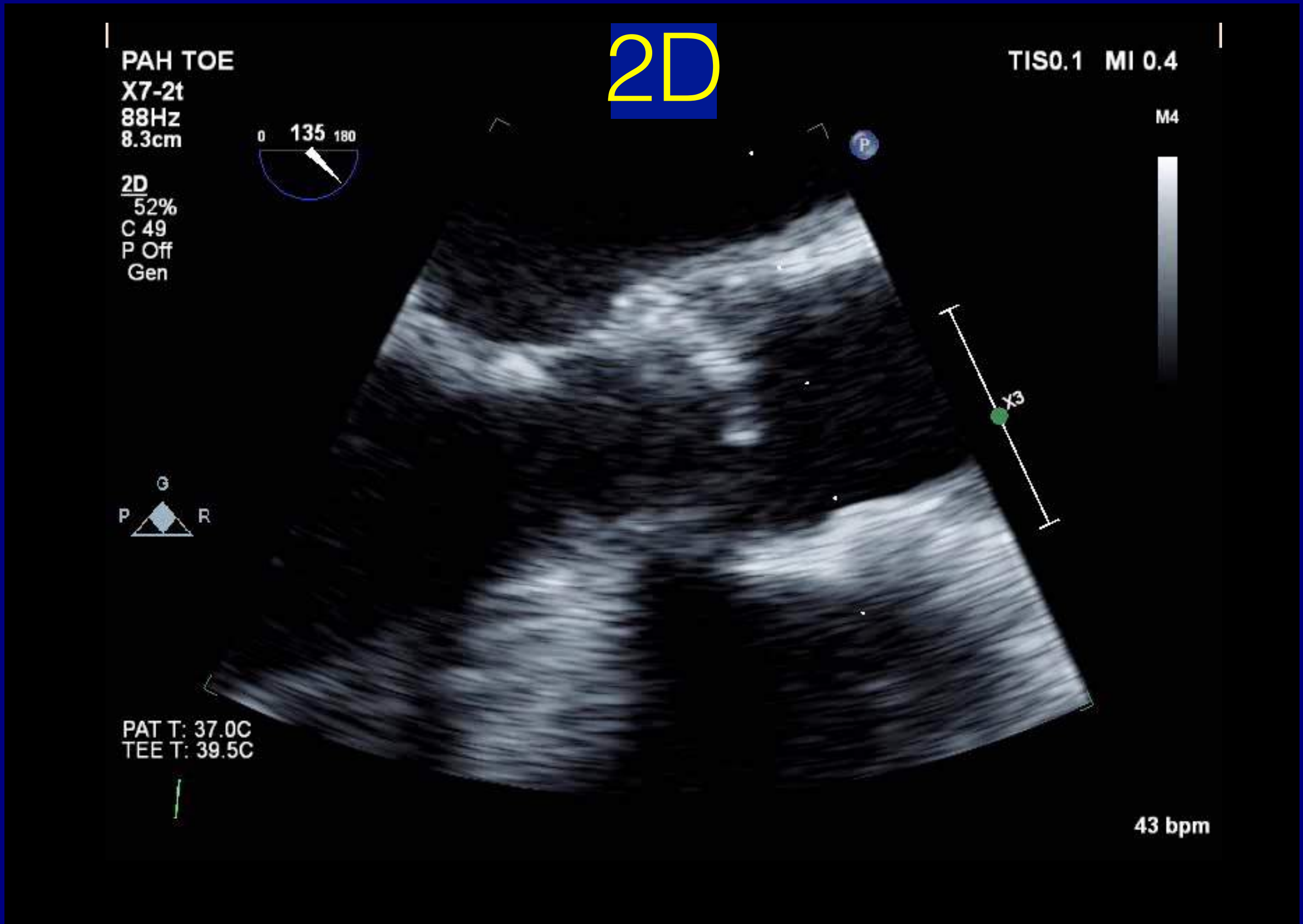


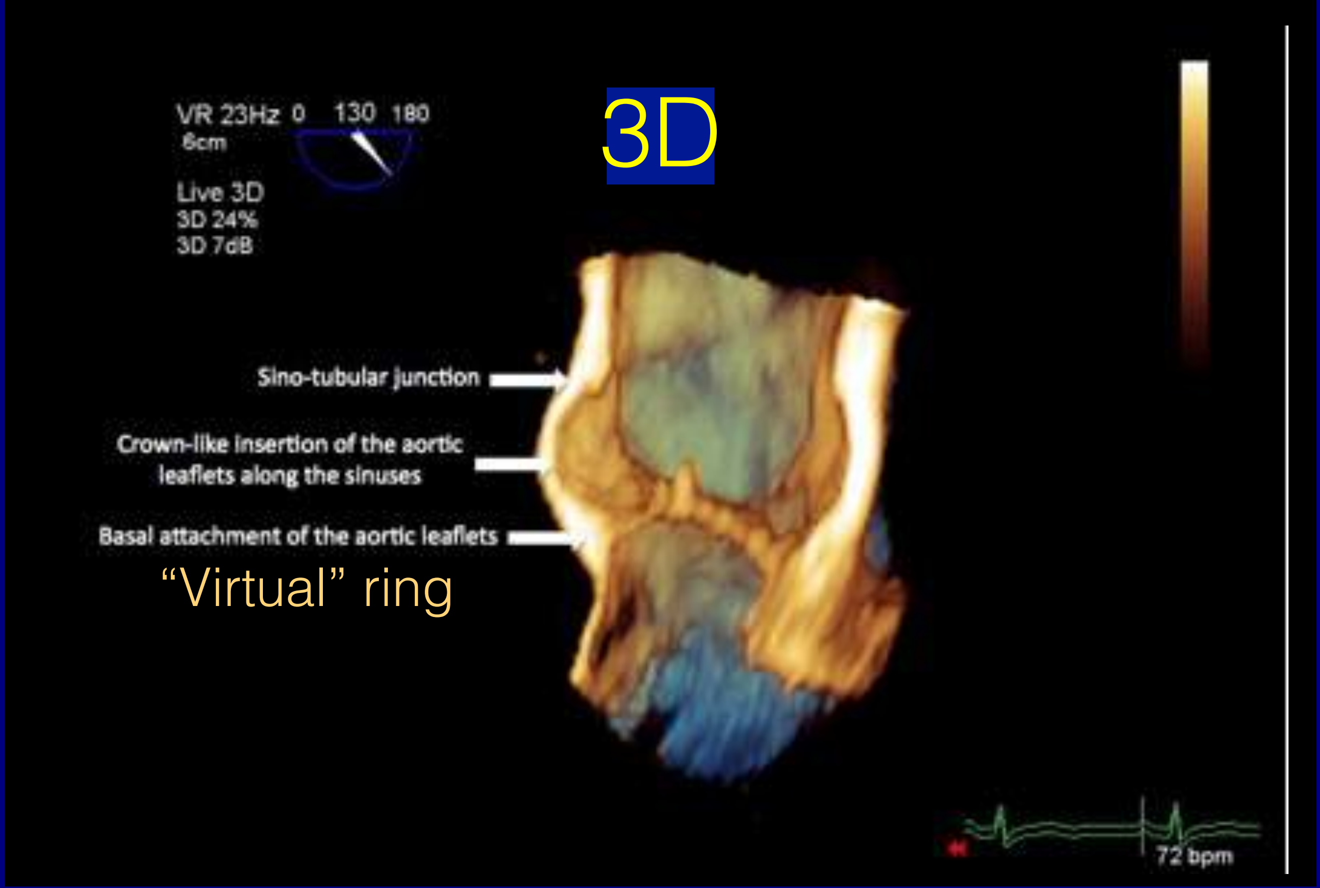
Thickening, calcification, mobility

Aortic Valve Complex (“Aortic Root”; Functional Aortic Annulus)





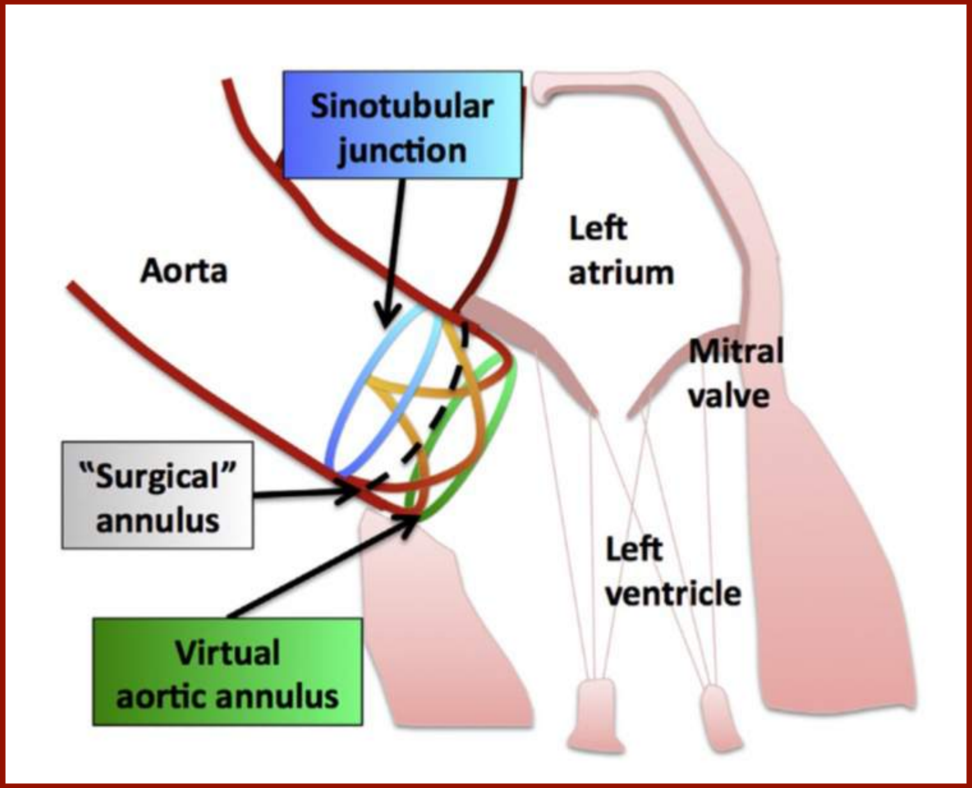


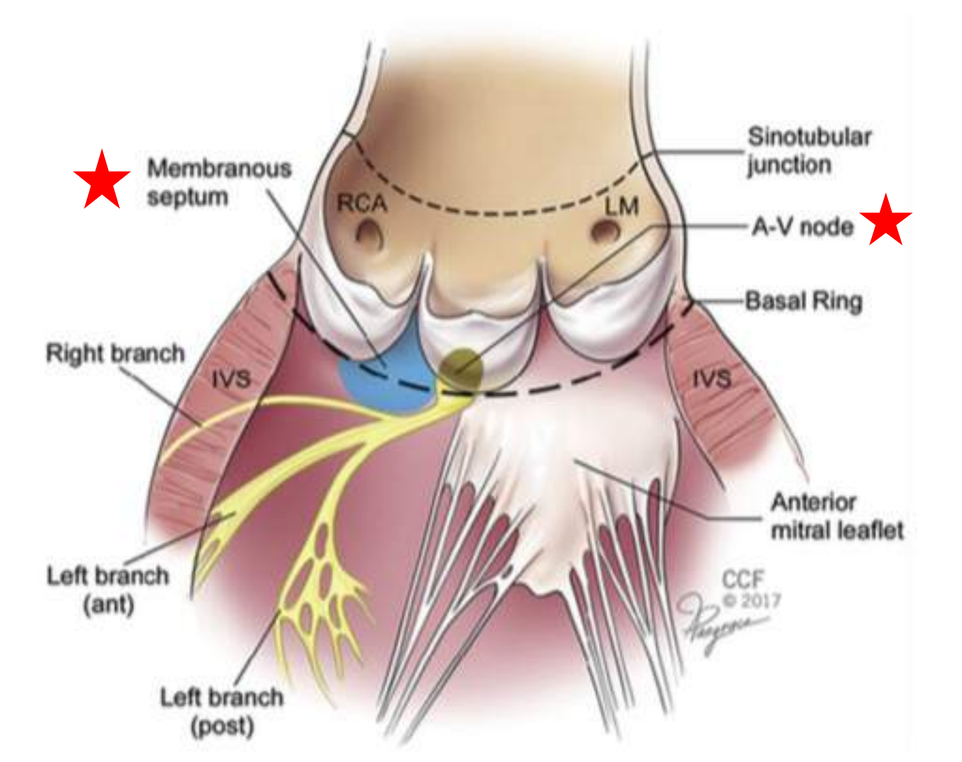


Piazza N, et al. Anatomy of the aortic valvar complex and its implications for transcatheter implantation of the aortic valve. Circ Cardiovasc Intervent 2008;1:74-81
Piazza N, et al. Patient selection for transcatheter aortic valve implantation: Patient risk profile and anatomical selection criteria. Arch Card Dis 2012;1-5:165-173
Leon MB, et al. Standardized endpoint definitions for transcatheter aortic valve implantation clinical trials: a consensus report from the Valve Academic Research Consortium. Eur Heart J 2011;32:205–217.

Predictors of Complications

Complication	*Predictor*
Paravalvular AR	• Severe LZ calcification • LVOT non-tubularity and annular ellipticity
Conduction disturbance	• LVOT and mitral annular calcification (Esp beneath the NCC★) • Short membranous septum★
Coronary obstruction	• Low coronary height (<10mm) • Small SOV (<30mm)
Aortic trauma	• Severe leaflet and STJ calcification





Corrigan F, et al. Imaging for predicting, detecting, and managing complications after transcatheter aortic valve replacement. J Am Coll Cardiol Img 2019;12:904-920.
Hahn RT, et al. Echocardiographic imaging for transcatheter aortic valve replacement. J Am Soc Echocardiogr 2018;31:405-433.
Sinning JM, et al. Evaluation and management of paravalvular aortic regurgitation after transcatheter aortic valve replacement. Am Coll Cardiol 2013;62:11–20 .

Valvular AS

Echo Assessment

Medical and interventional approaches to the management of patients with valvular AS depend on accurate diagnosis of the cause and stage of the disease process (severity)

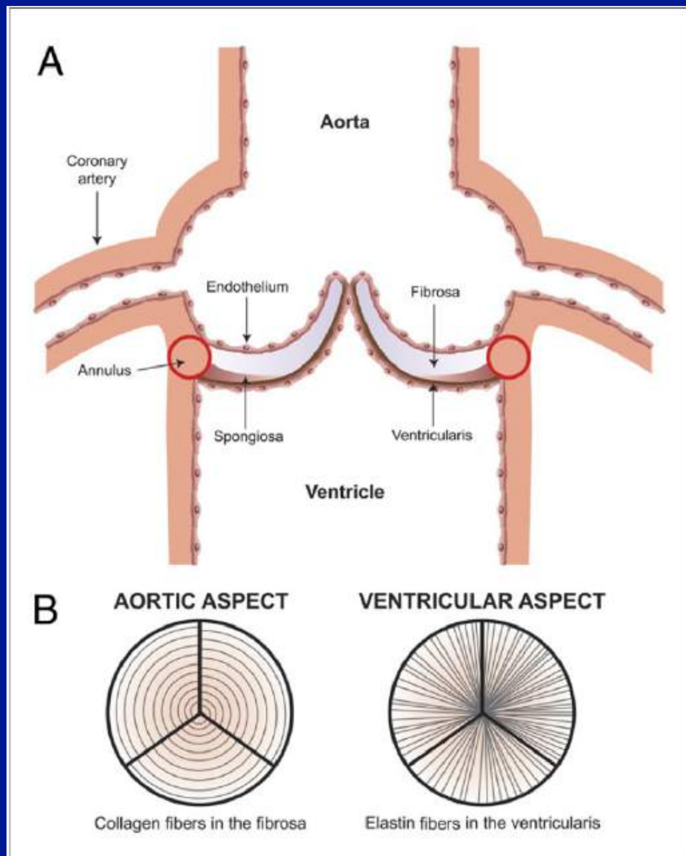
Stages of Valvular AS

C: Asymptomatic severe AS					
C1	Asymptomatic severe AS	Severe leaflet calcification/fibrosis or congenital stenosis with severely reduced leaflet opening	■ Aortic V_{max} ≥4 m/s or mean ΔP ≥40 mm Hg ■ AVA typically is ≤1.0 cm^2 (or AVAi 0.6 cm^2/m^2) but not required to define severe AS ■ Very severe AS is an aortic V_{max} ≥5 m/s or mean P ≥60 mm Hg	■ LV diastolic dysfunction ■ Mild LV hypertrophy ■ Normal LVEF	■ None ■ Exercise testing is reasonable to confirm symptom status
C2	Asymptomatic severe AS with LV systolic dysfunction	Severe leaflet calcification/fibrosis or congenital stenosis with severely reduced leaflet opening	■ Aortic V_{max} ≥4 m/s or mean ΔP ≥40 mm Hg ■ AVA typically ≤1.0 cm^2 (or AVAi 0.6 cm^2/m^2) but not required to define severe AS	LVEF <50%	None
D: Symptomatic severe AS					
D1	Symptomatic severe high-gradient AS	Severe leaflet calcification/fibrosis or congenital stenosis with severely reduced leaflet opening	■ Aortic V_{max} ≥4 m/s or mean ΔP ≥40 mm Hg ■ AVA typically ≤1.0 cm^2 (or AVAi ≤0.6 cm^2/m^2) but may be larger with mixed AS/AR	■ LV diastolic dysfunction ■ LV hypertrophy ■ Pulmonary hypertension may be present	■ Exertional dyspnea, decreased exercise tolerance, or HF ■ Exertional angina ■ Exertional syncope or presyncope
D2	Symptomatic severe low-flow, low-gradient AS with reduced LVEF	Severe leaflet calcification/fibrosis with severely reduced leaflet motion	■ AVA ≤1.0 cm^2 with resting aortic V_{max} <4 m/s or mean ΔP <40 mm Hg ■ Dobutamine stress echocardiography shows AVA <1.0 cm^2 with V_{max} ≥4 m/s at any flow rate	■ LV diastolic dysfunction ■ LV hypertrophy ■ LVEF <50%	■ HF ■ Angina ■ Syncope or presyncope
D3	Symptomatic severe low-gradient AS with normal LVEF or paradoxical low-flow severe AS	Severe leaflet calcification/fibrosis with severely reduced leaflet motion	■ AVA ≤1.0 cm^2 (indexed AVA ≤0.6 cm^2/m^2) with an aortic V_{max} <4 m/s or mean ΔP <40 mm Hg AND ■ Stroke volume index <35 mL/m^2 ■ Measured when patient is normotensive (systolic blood pressure <140 mm Hg)	■ Increased LV relative wall thickness ■ Small LV chamber with low stroke volume ■ Restrictive diastolic filling ■ LVEF ≥50%	■ HF ■ Angina ■ Syncope or presyncope

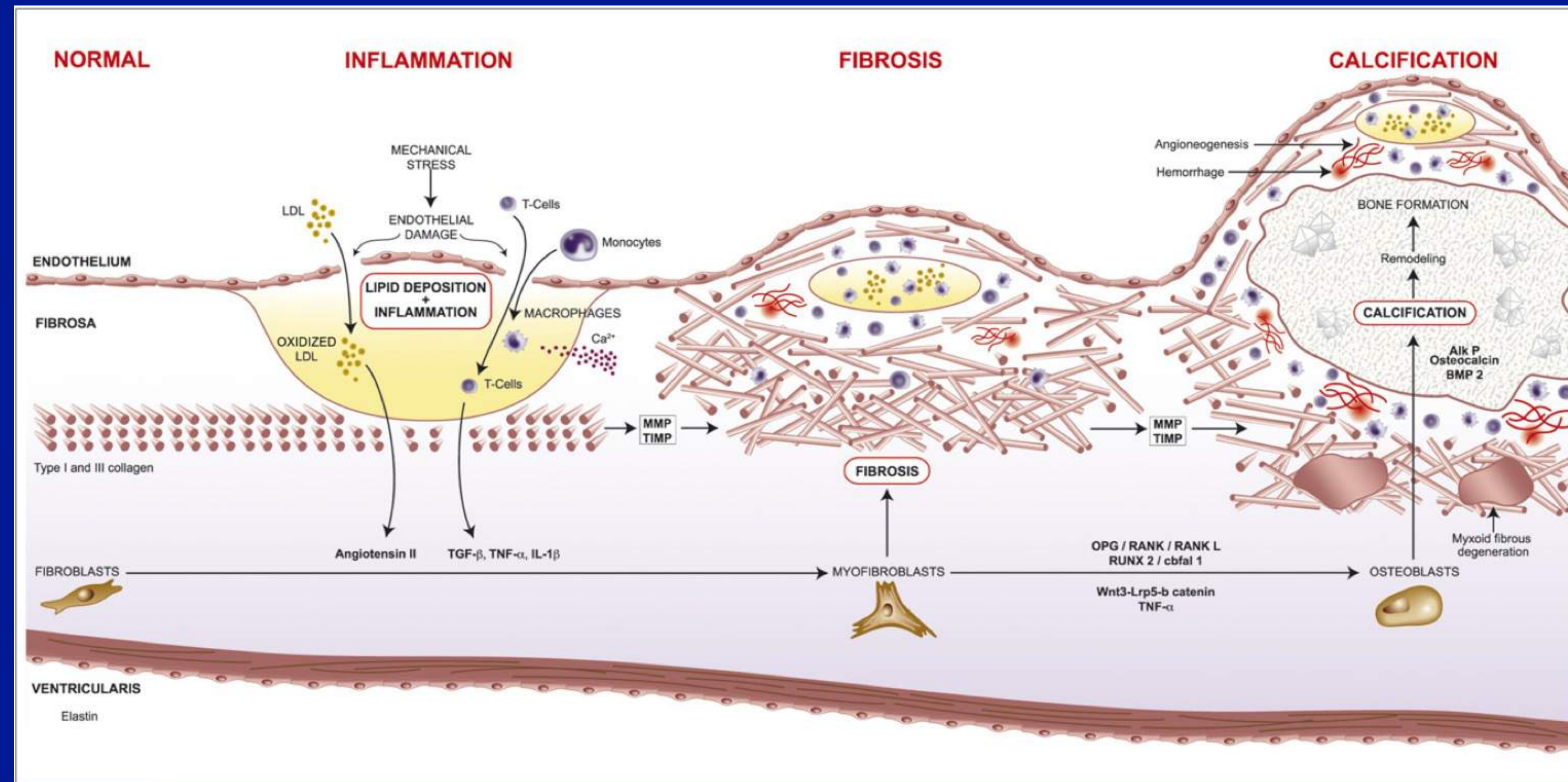
AR indicates aortic regurgitation; AS, aortic stenosis; AVA, aortic valve area circulation; AVAi, AVA indexed to body surface area; BAV, bicuspid aortic valve; ΔP, pressure gradient between the LV and aorta HF, heart failure; LV, left ventricular; LVEF, left ventricular ejection fraction; and V_{max}, maximum velocity.

ACC/AHA 2020

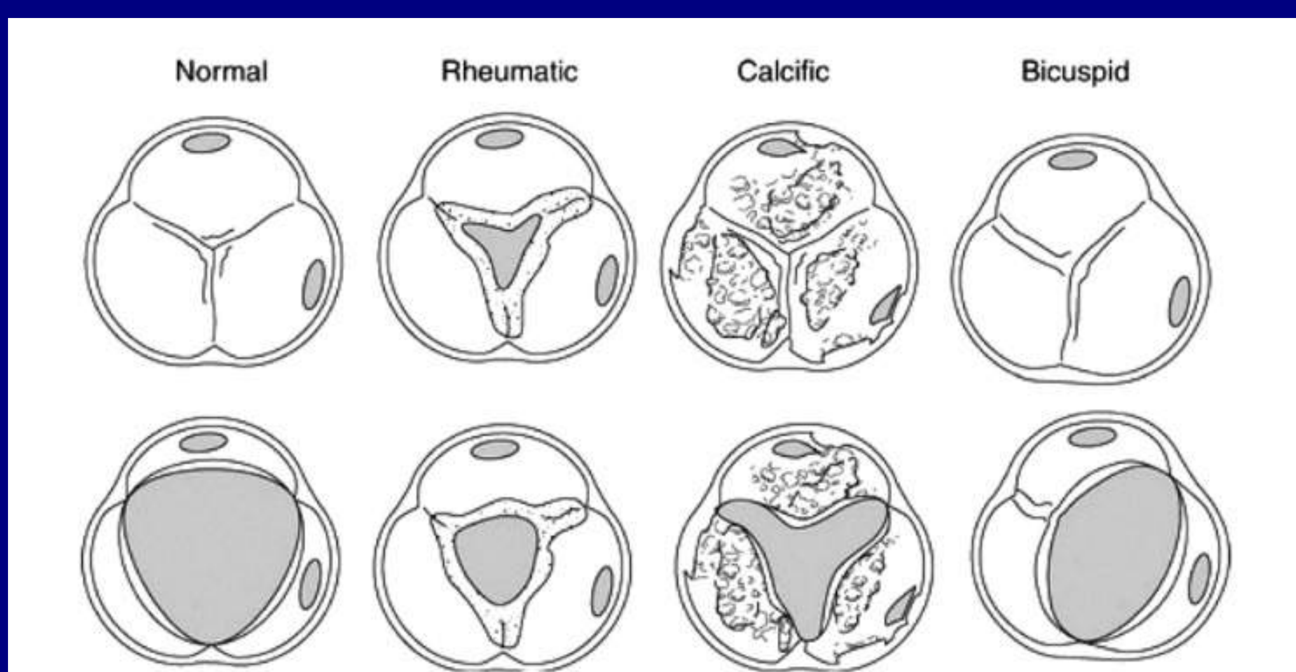
"Syndrome" of AS – Complex Anatomic Disease



Trileaflet aortic valve



Pathological processes occurring within the valve during aortic stenosis

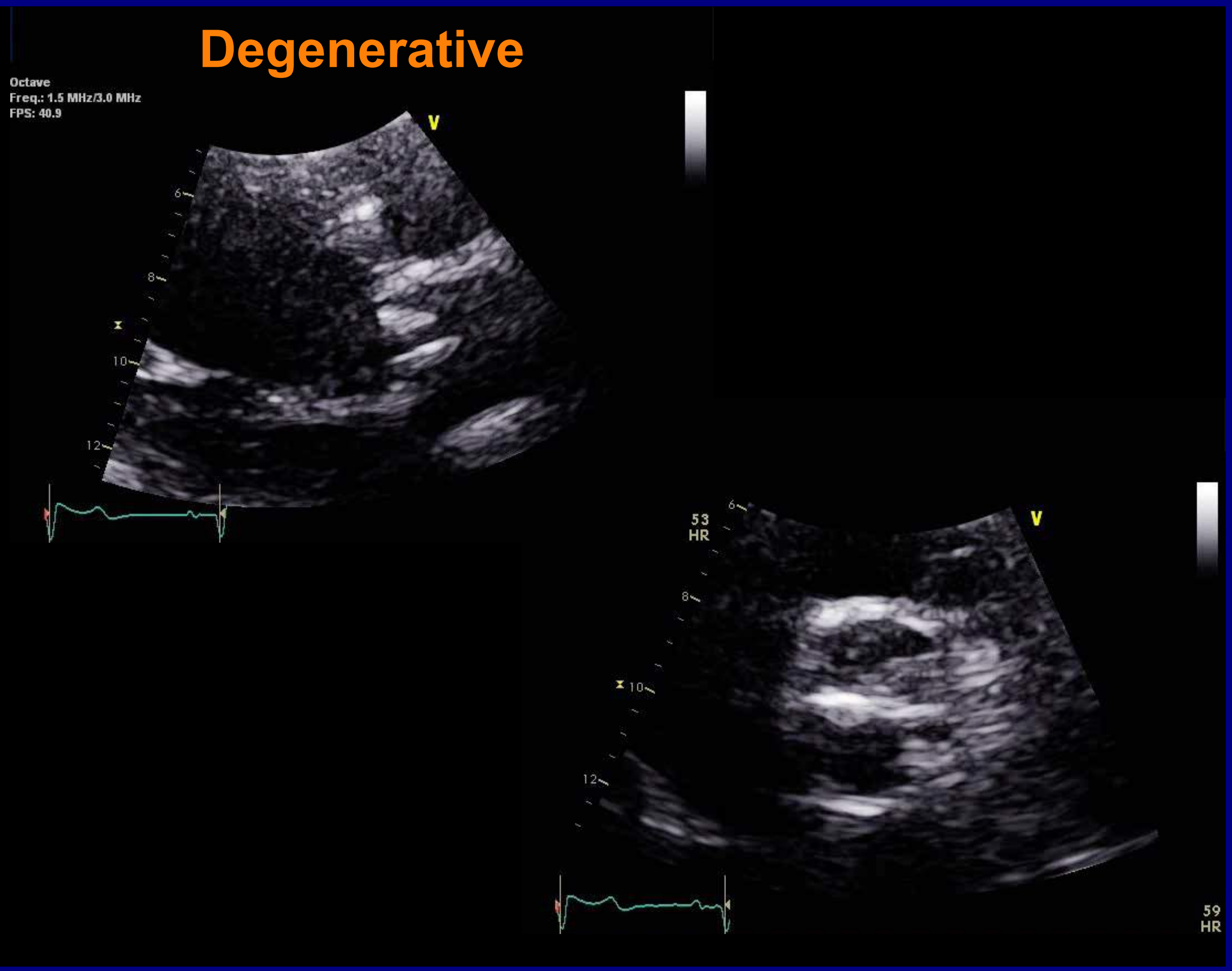


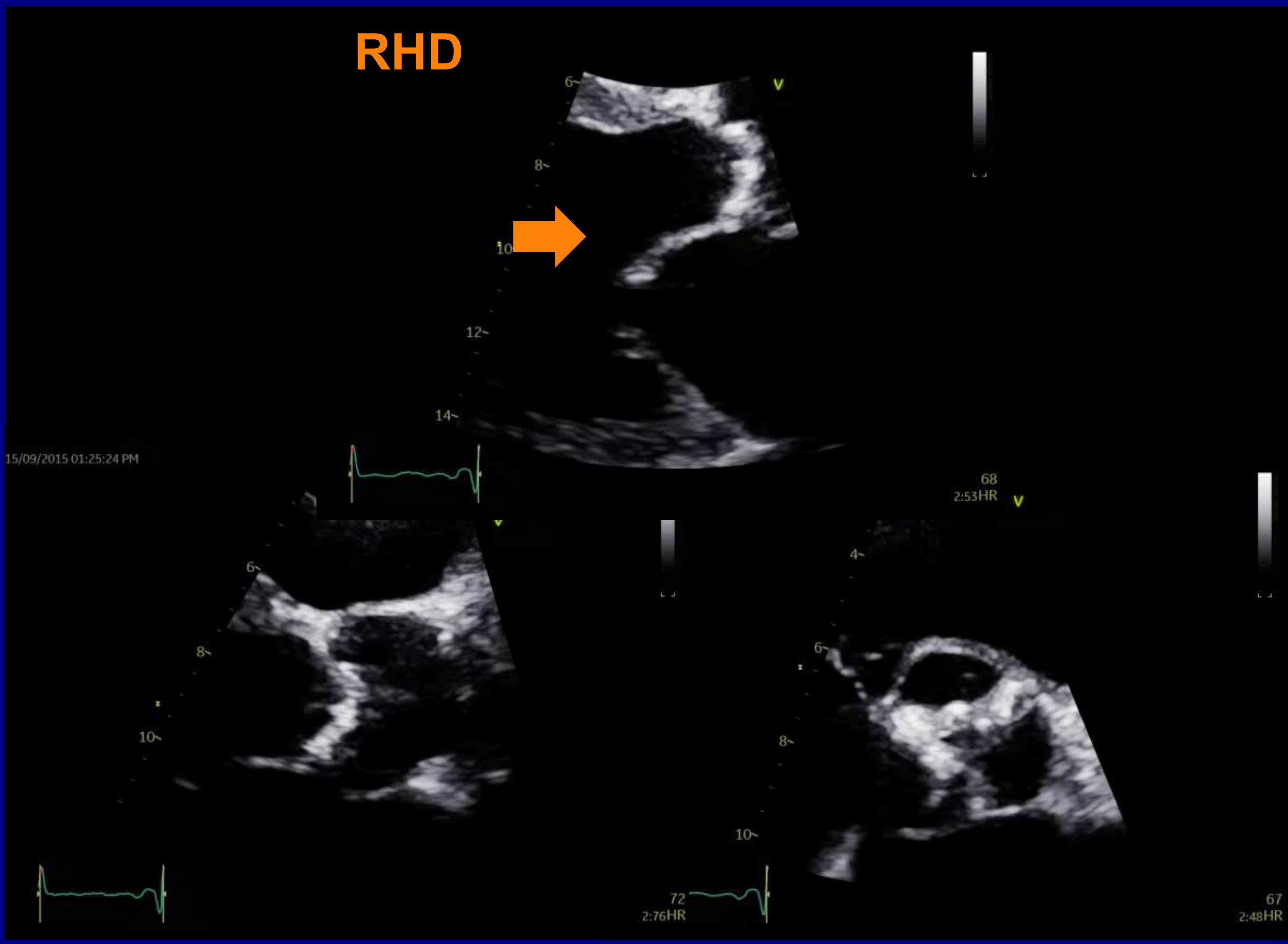
Common etiologies:

- Calcific [Trileaflet (>75yoa) or bicuspid (<65yoa)]
- Rheumatic

Dweck MR, et al. ***Calcific aortic stenosis – a disease of the valve and myocardium***. JACC 2012;60:1854-1863.
Baumgartner H, et al. Recommendations on the echocardiographic assessment of aortic valve stenosis. JASE 2017;30:372-392.

2D Assessment





Maximal Aortic Cusp Separation (MACS by M-Mode or 2D):

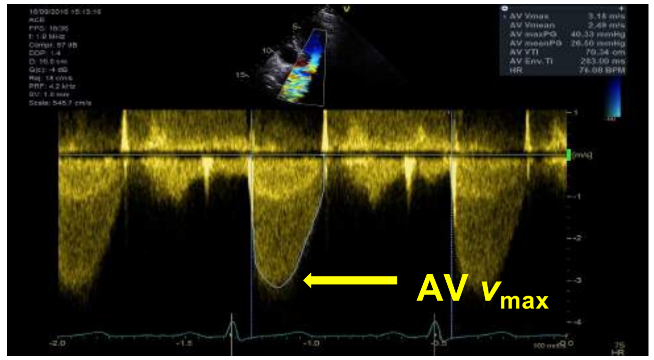
- MACS <8mm = AVA <0.75cm^2
- MACS >12mm = AVA >1.0cm^2
- ***But:***
  - Assumes perpendicular alignment
  - Does not consider asymmetric valve involvement, eccentric orifice, distorted leaflets

Ca^{2+}:

- ***Mild*** (Few areas of dense echogenicity; Little acoustic shadowing)
- ***Moderate*** (Multiple large areas of dense echogenicity)
- ***Severe*** (Extensive thickening and increased echogenicity + Prominent acoustic shadowing

Primary Hemodynamic Parameters for Evaluation of AS

Peak jet velocity (m/sec)



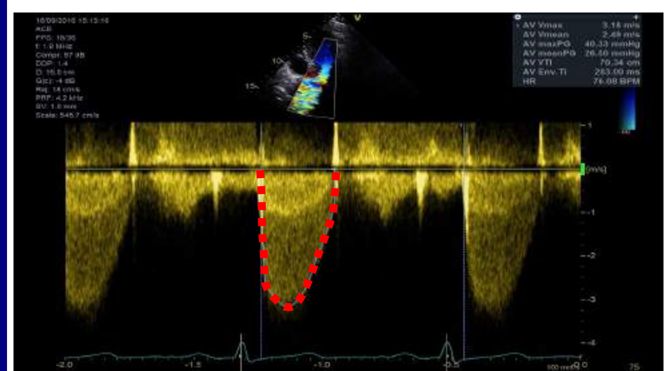
Bernoulli Equation:

$$\Delta P_{max} = 4(v_{max}^2 - v_{proximal}^2)$$

$$\Delta P = 4v^2$$

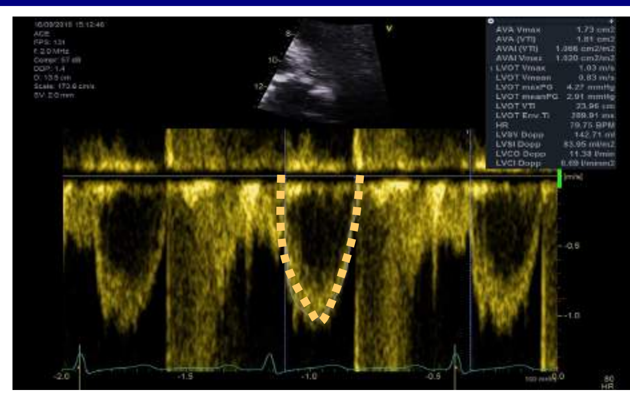
$$\boxed{\Delta P_{max} = 4v_{max}^2}$$

Mean Transvalvular Pressure Gradient (mmHg)



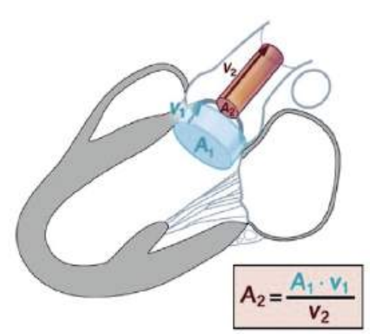
Mean Gradient: Average of the instantaneous gradients along the CW *Doppler velocity curve* over the ejection time period

Dimensionless Severity Index (DSI)



$$\text{VTI ratio} = \frac{VTI_{LVOT}}{VTI_{AV}}$$

Aortic Valve Area (AVA; cm^2)



$$CSA_{LVOT} = \pi\left(\frac{D}{2}\right)^2$$

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

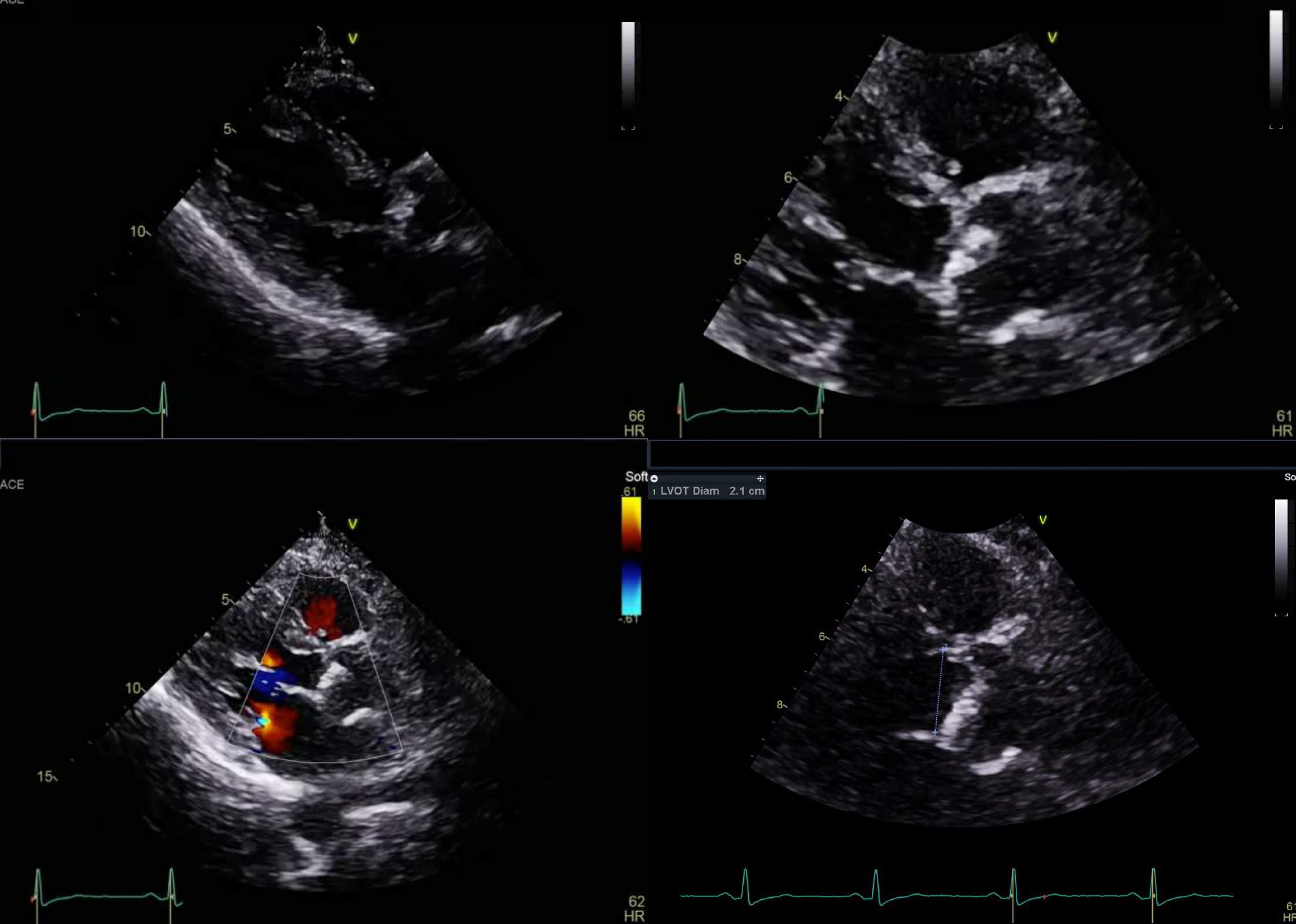
$$SV_{AV} = SV_{LVOT}$$

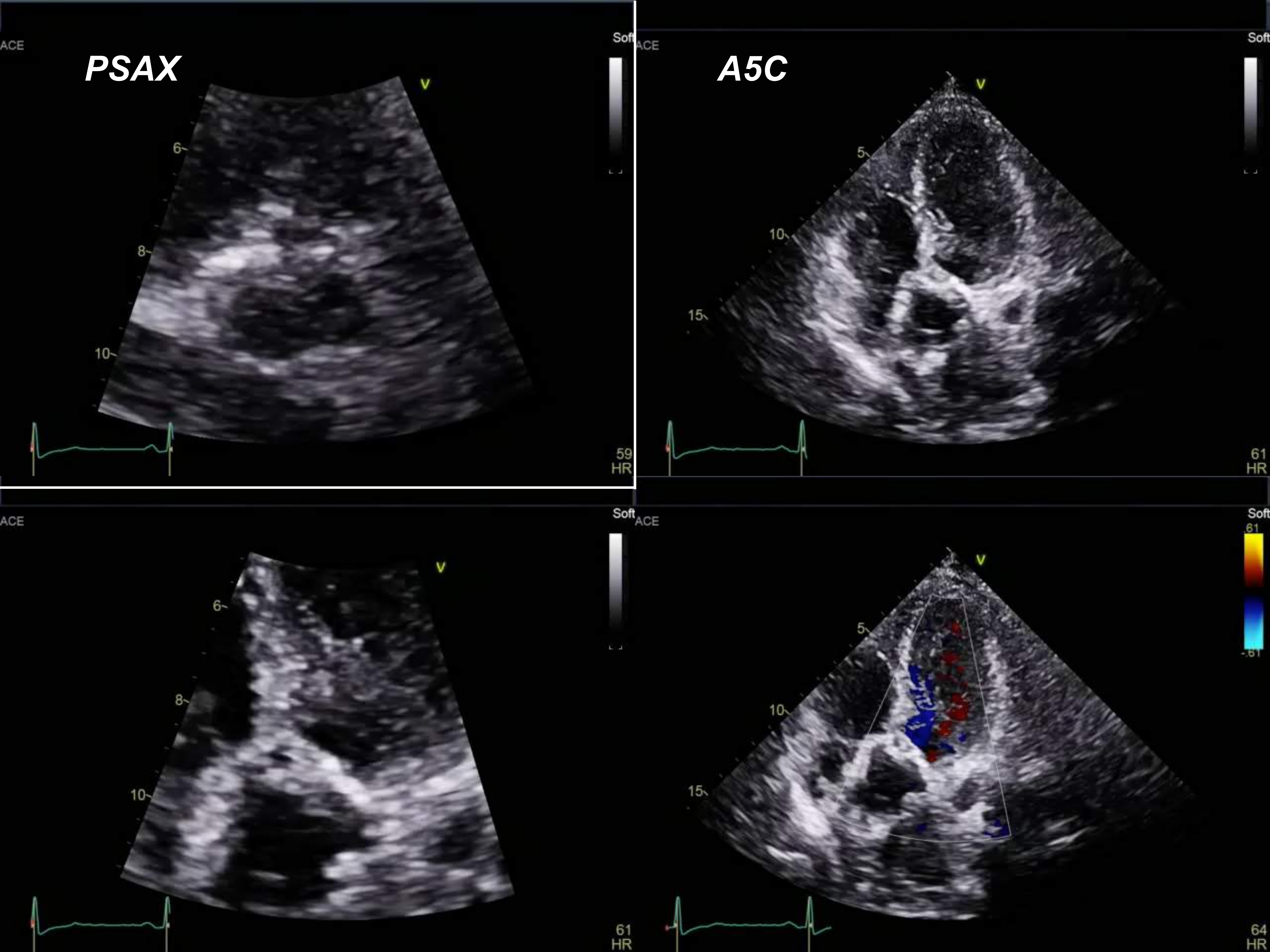
$$AVA = \frac{CSA_{LVOT} \times VTI_{LVOT}}{VTI_{AV}}.$$

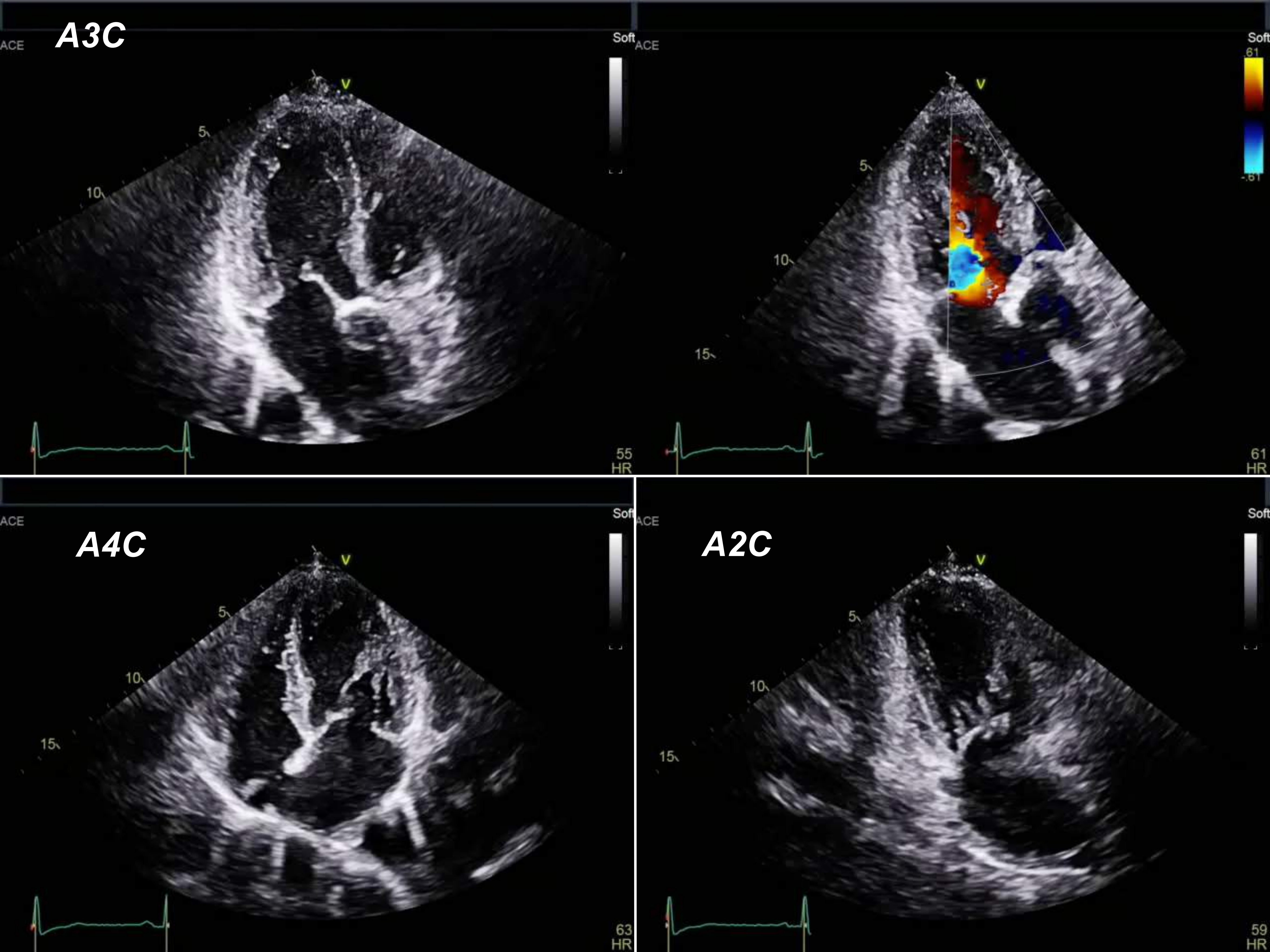
Primary Hemodynamic Parameters for Grading AS Severity

	Aortic Sclerosis	Mild AS	Moderate AS	Severe AS
Peak velocity (m/sec)	≤2.5	2.6 - 2.9	3.0 - 4.0	≥4.0
Mean gradient (mmHg)	-	<20	20 - 40	≥40
DSI	-	>0.50	0.25 - 0.50	<0.25
AVA (cm^2)	-	>1.5	1.0 - 1.5	<1.0
AVA indexed for BSA (cm^2/m^2)	-	>0.85	0.60 - 0.85	<0.60

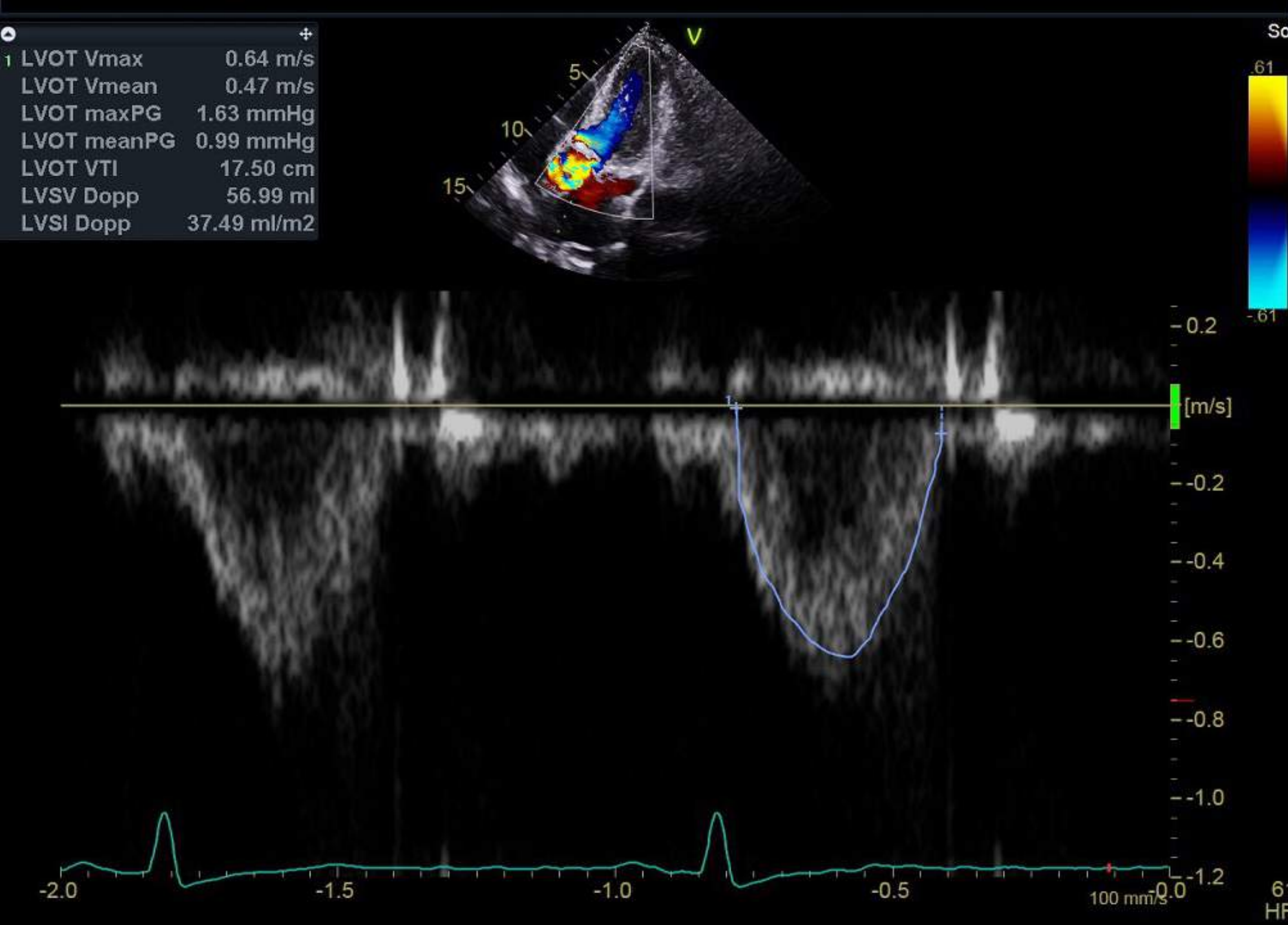
83yo Female; Ht 157cm; Wt 53kd; BSA 1.52cm^2; BP 128/70mmHg

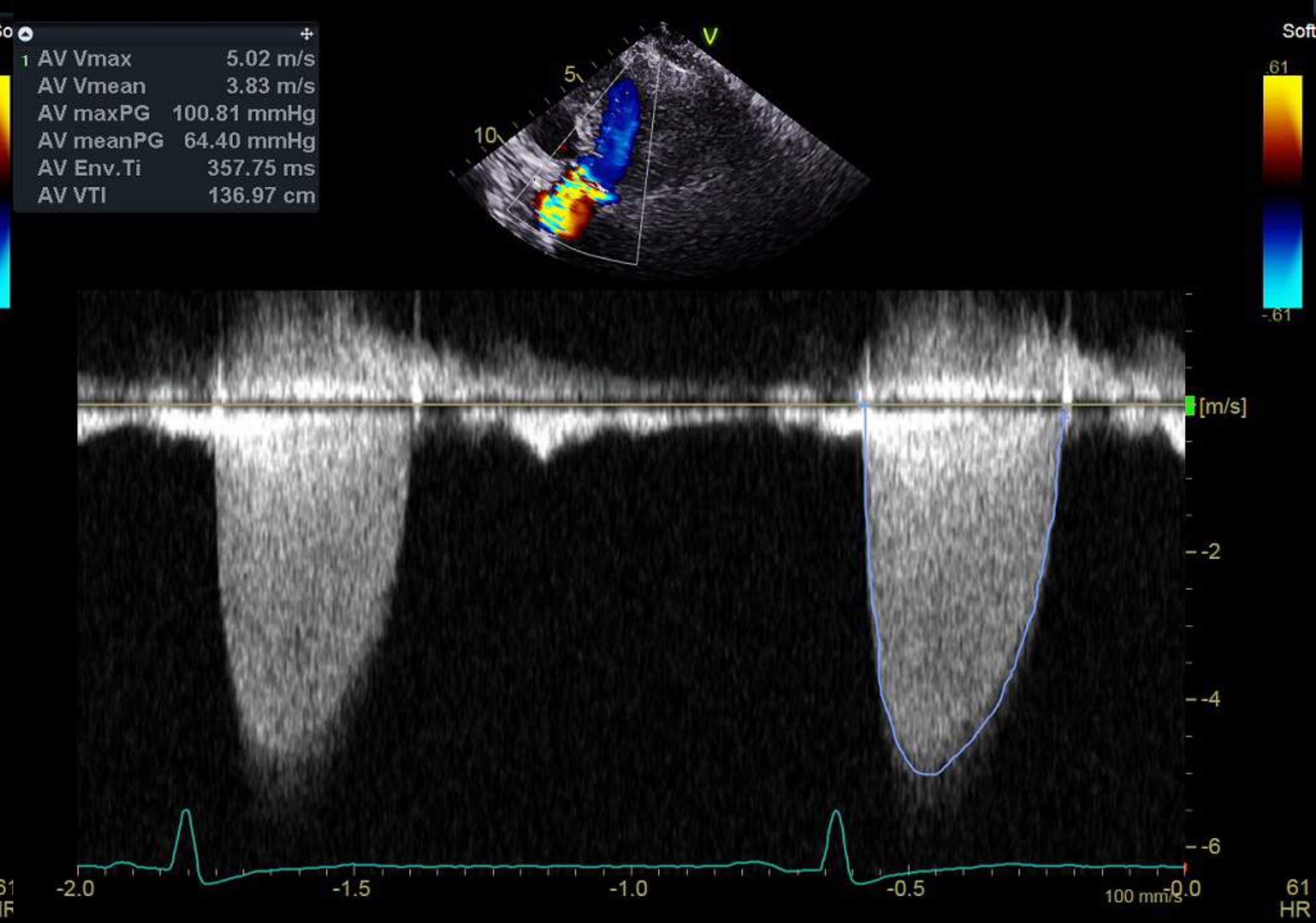



PSAX
A5C
ACE
Soft
59 HR
61 HR
61 HR
64 HR



A3C
A4C
A2C

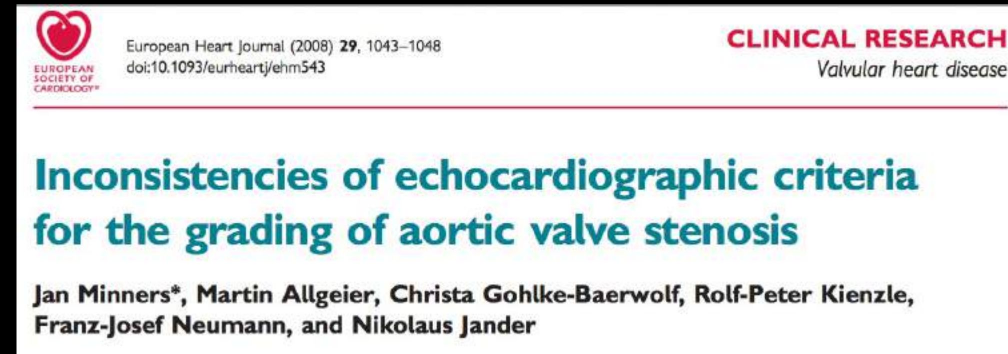




$LVOT_d$	2.1cm
LVOT VTI	17.5cm
AV v_{max}	5.0m/sec
AV Peak/Mean Gradients	101/64mmHg
AV VTI	137cm
DSI	0.13
AVA	0.44cm^2
AVA indexed for BSA	0.20cm^2/m^2

Severe Valvular (Calcific) AS

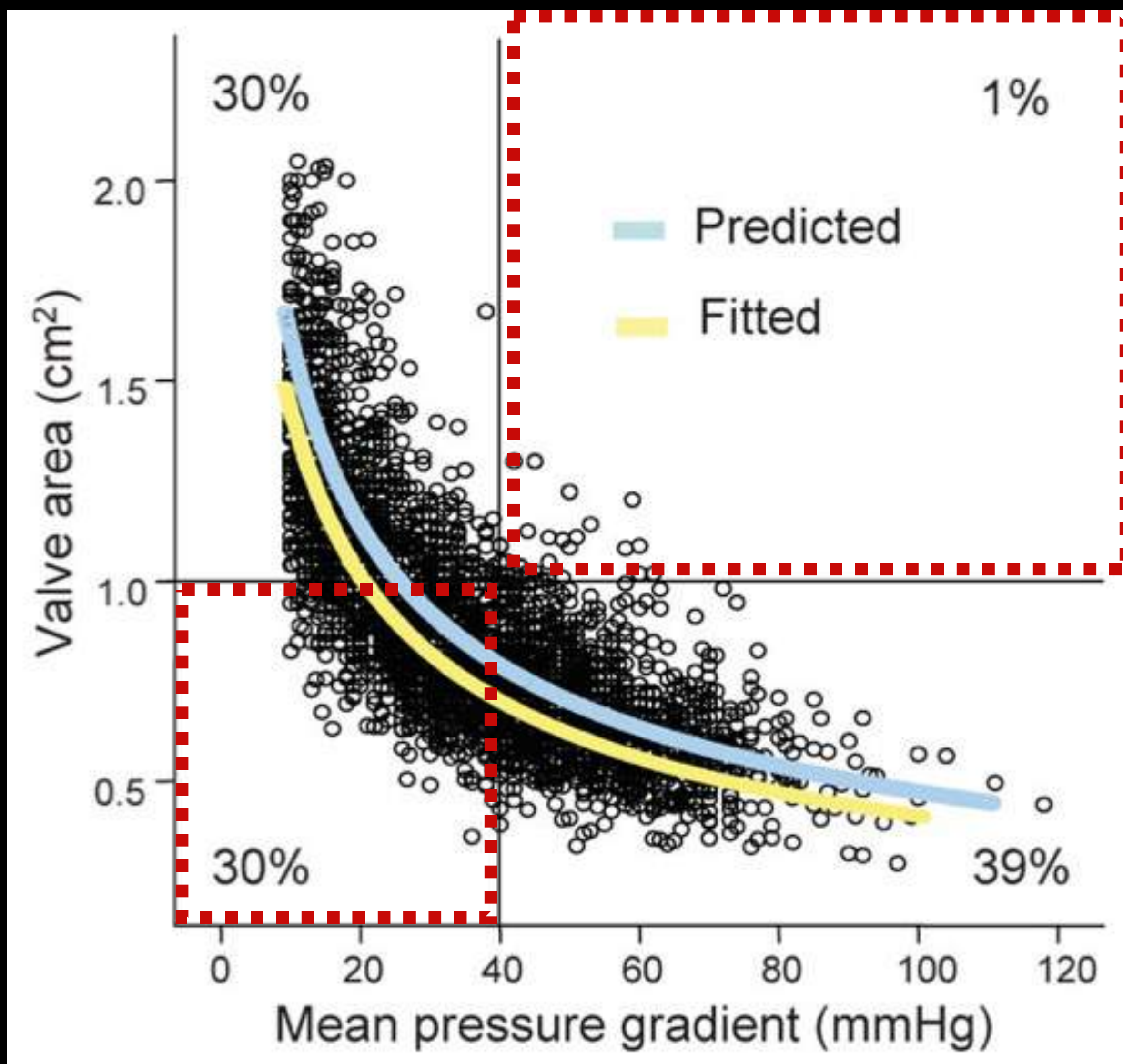
Stage D1


European Heart Journal (2008) 29, 1043–1048
doi:10.1093/eurheartj/ehm543

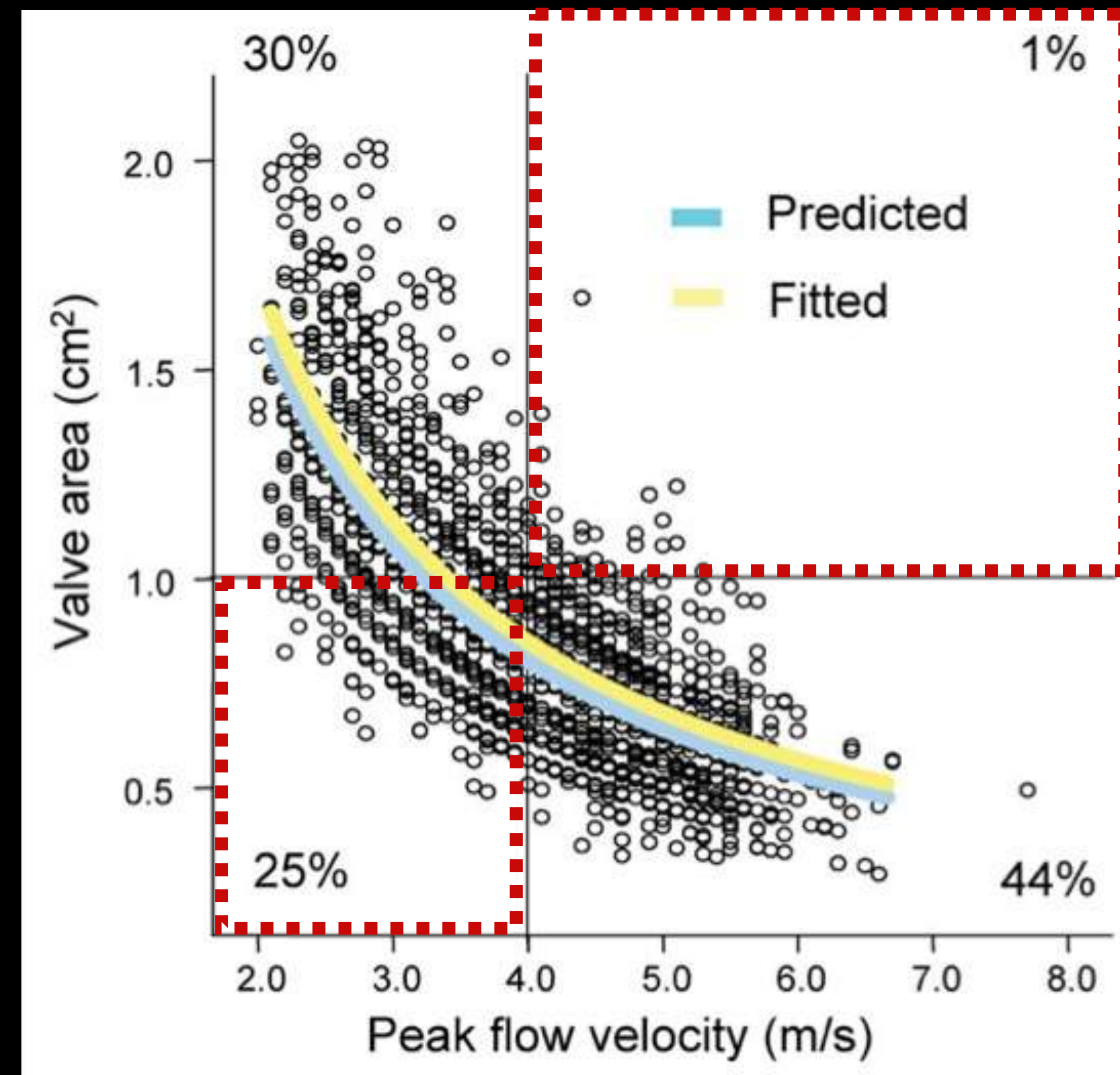
CLINICAL RESEARCH
Valvular heart disease

Inconsistencies of echocardiographic criteria for the grading of aortic valve stenosis

Jan Minners*, Martin Allgeier, Christa Gohlke-Baerwolf, Rolf-Peter Kienzle, Franz-Josef Neumann, and Nikolaus Jander



30% diagnosed with severe AS based on AVA (Gorlin) but not MG



25% diagnosed with severe AS based on AVA (Continuity) but not Vmax

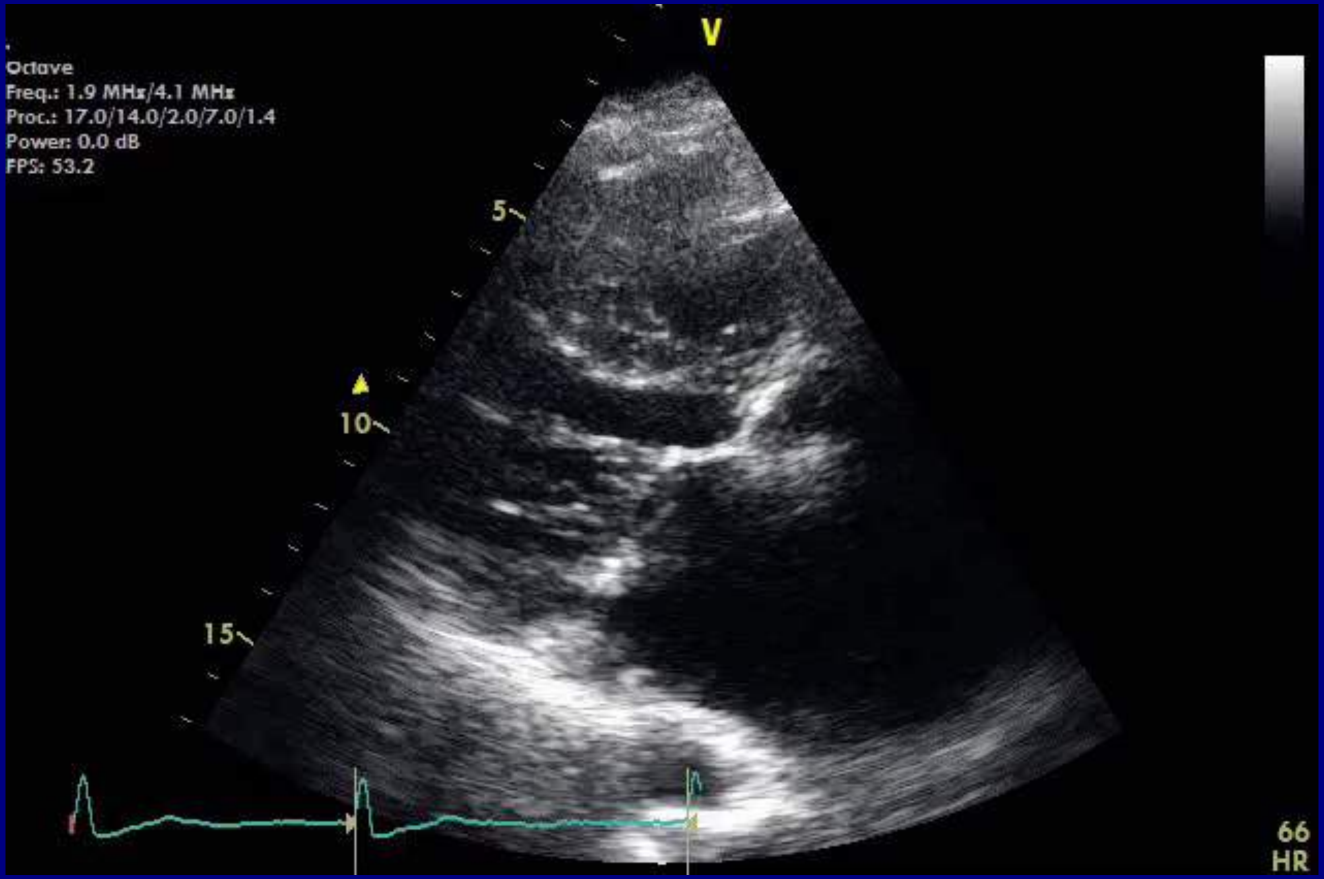
◆ *Quadrants are based on current guidelines for severe AS*

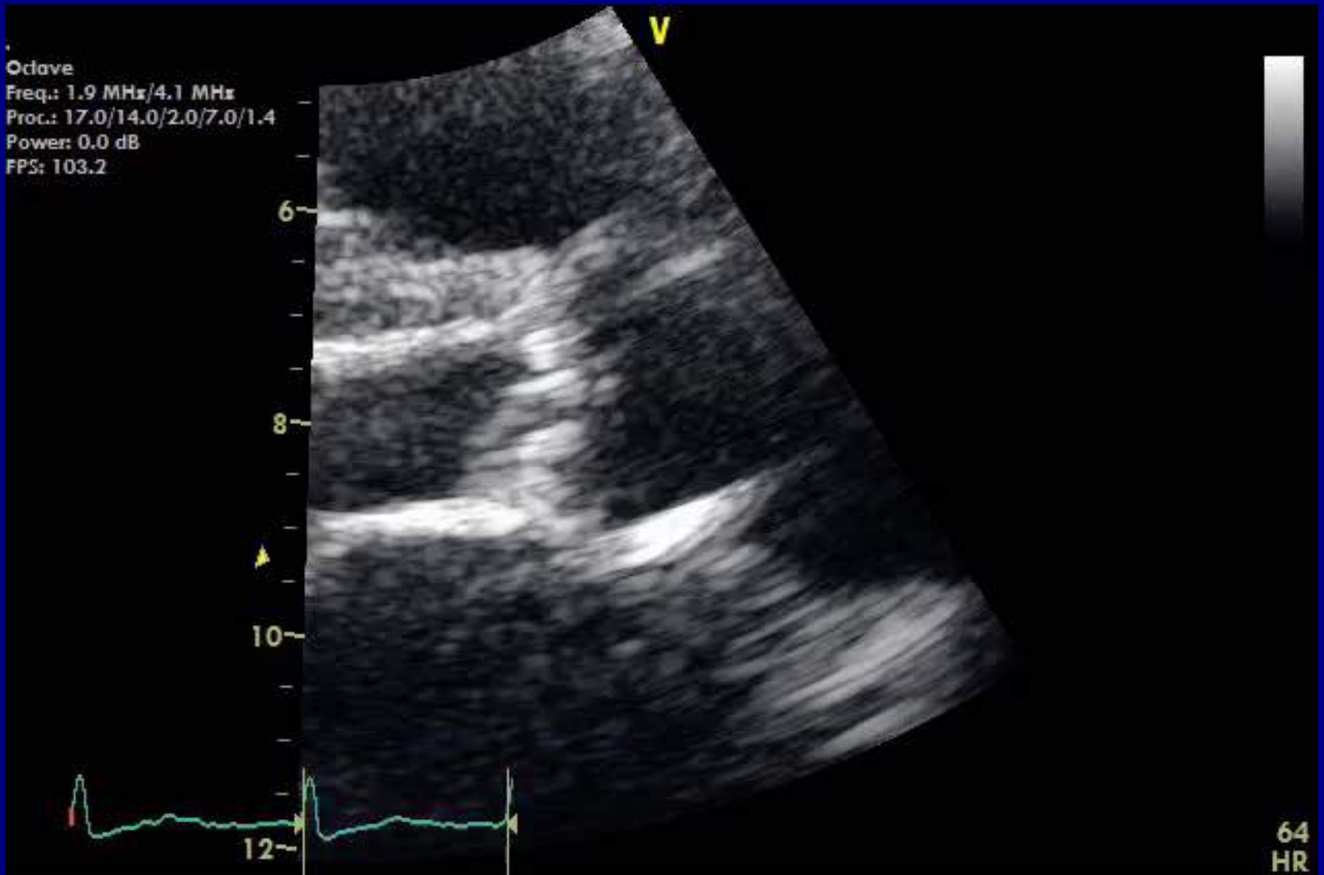
Discrepant Results

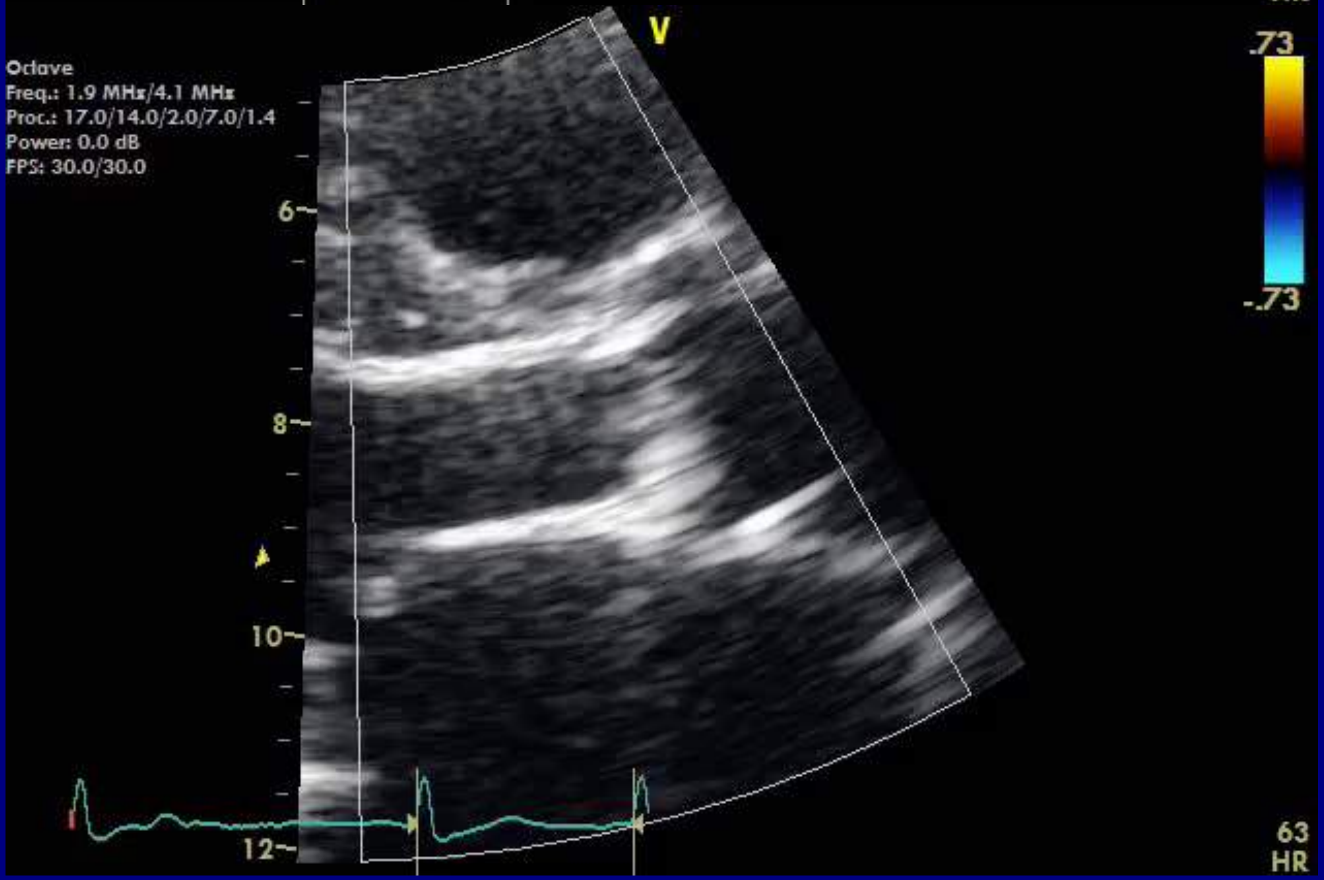
Measurement Errors	
• $LVOT_{Diameter}$	• Commonly underestimated (Squared error)
• Poor Doppler alignment (No use of PEDOF)	• Underestimation of AV v_{max}, gradients & VTI
• Over-tracing of continuous wave Doppler signal	• Overestimation of AV vmax, gradients & VTI
Pressure recovery	
• Small aortic root or AscAo (≤3.0cm)	• Overestimated pressure drop from LV to vena contracta vs actual net pressure from from LV to AscAo
High-flow states	
• Significant AR	• Increased transaortic volume (flow)
• High output states	• Dialysis, anemia, CLD, pregnancy etc
Low-flow states	
• Significant MR	• Low transaortic flow
• Hypertension	• May reduce stroke volume
• LVEF<50%	• ***Classical LFLG AS (Stage D2)***
• Stroke volume indexed for BSA <35mL/m2 (Or Flow rate <?200mL/sec)	• ***Paradoxical LFLG AS (Stage D3)***

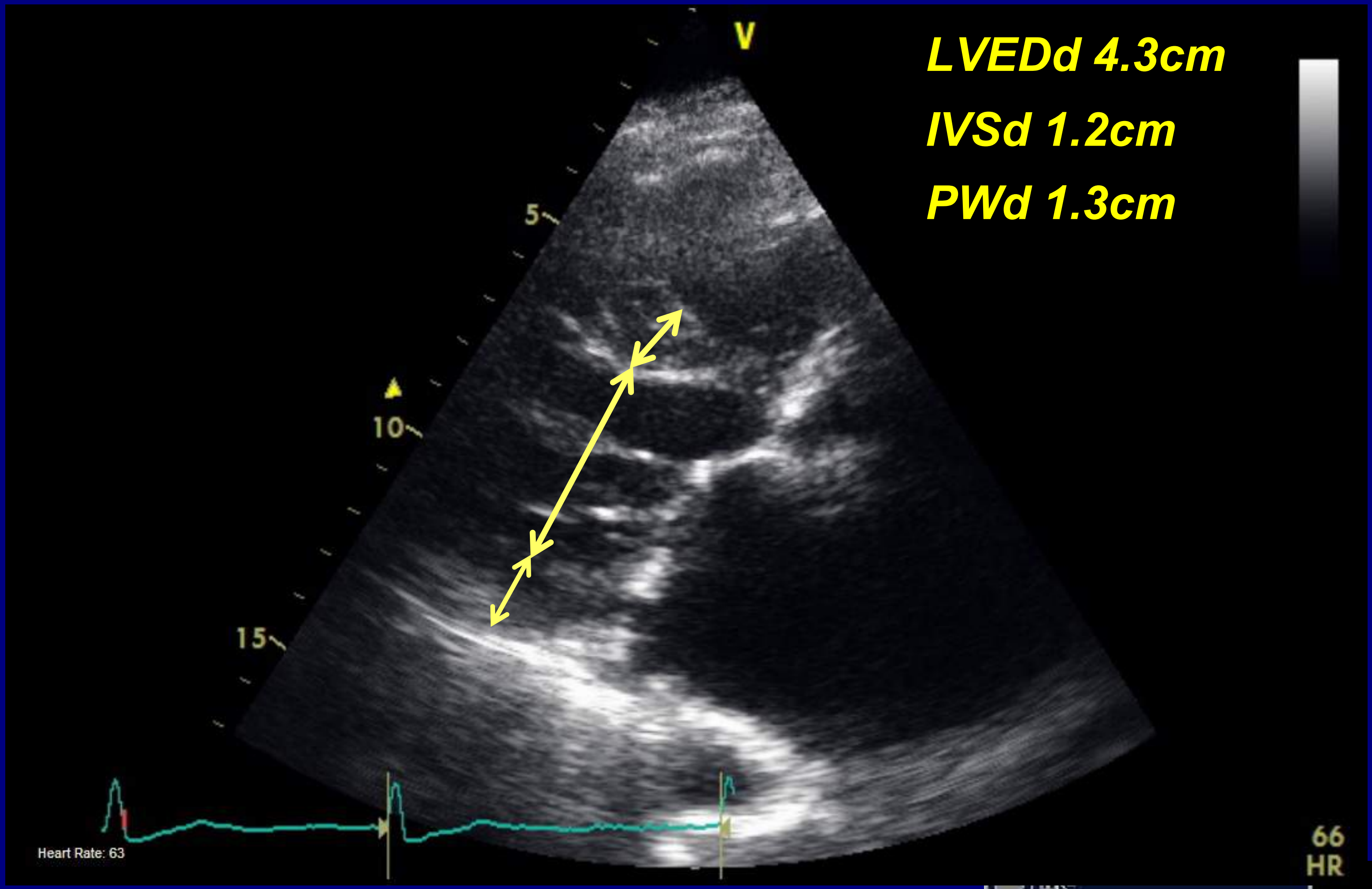
St Elsewhere

83 yo lady
Indication for TTE: Chest pain + SOB
Height: 154cm, Weight: 63kg, BSA 1.61m^2
BP 126/62mmHg
Rhythm: AF

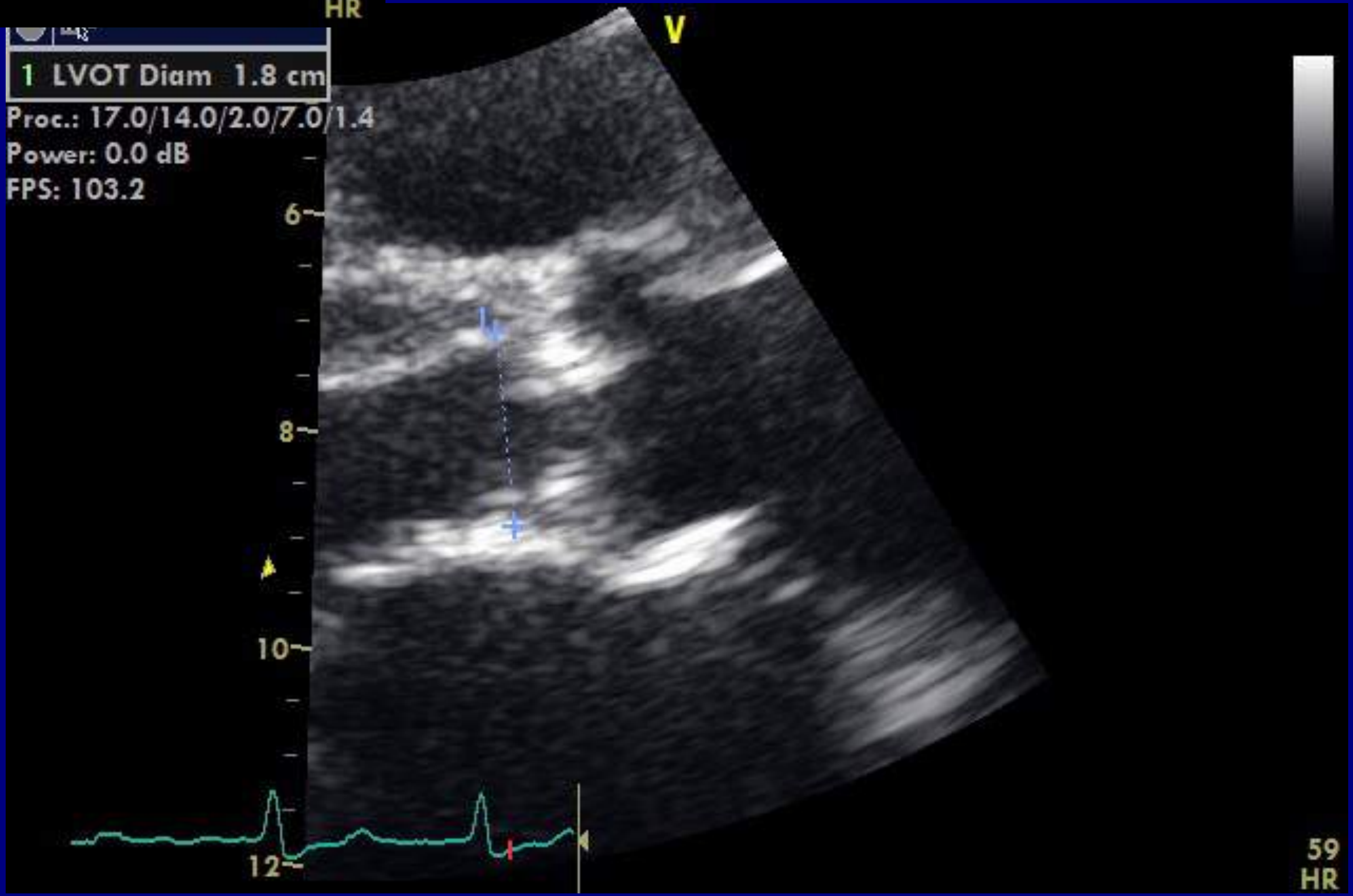




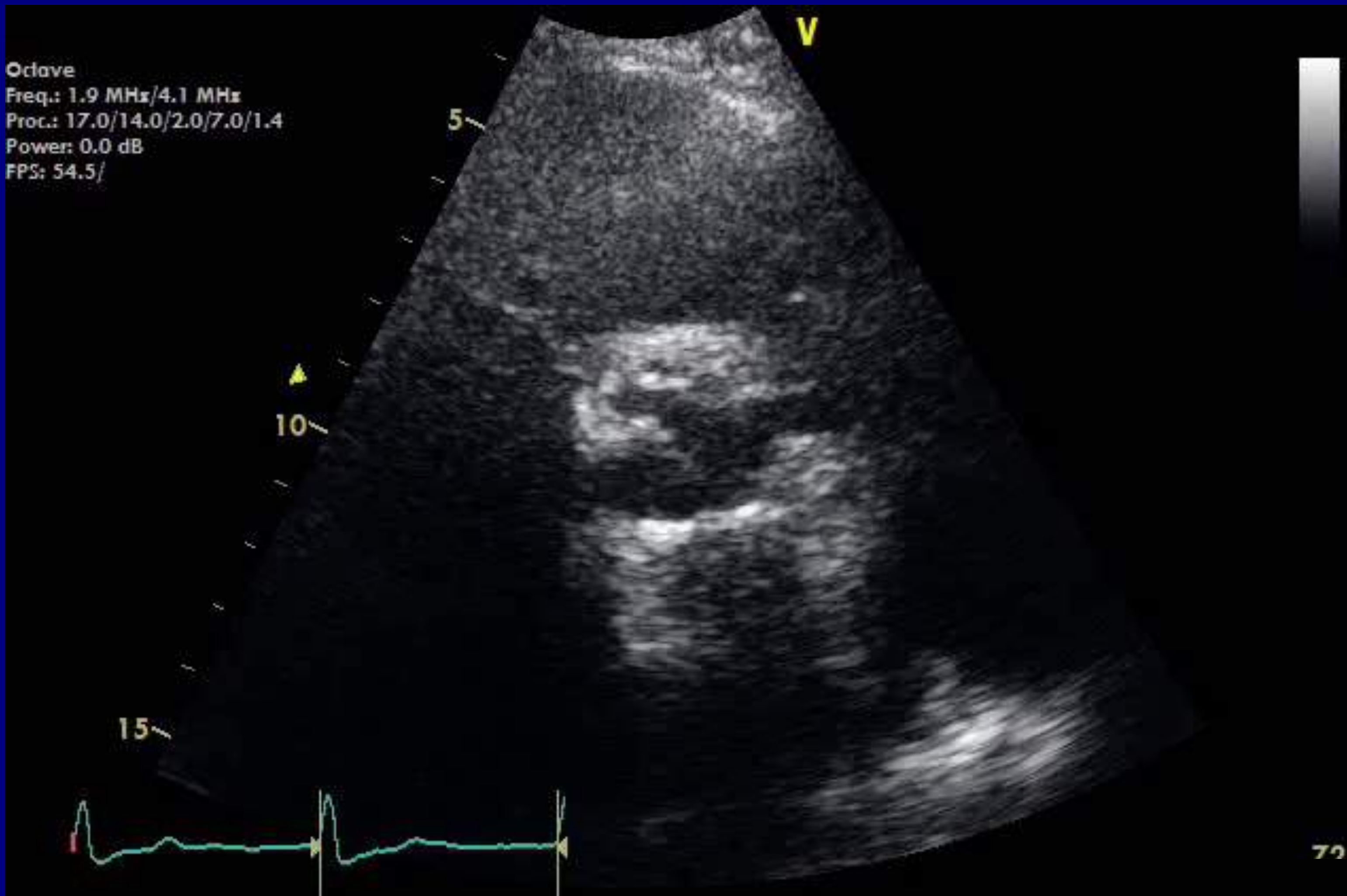


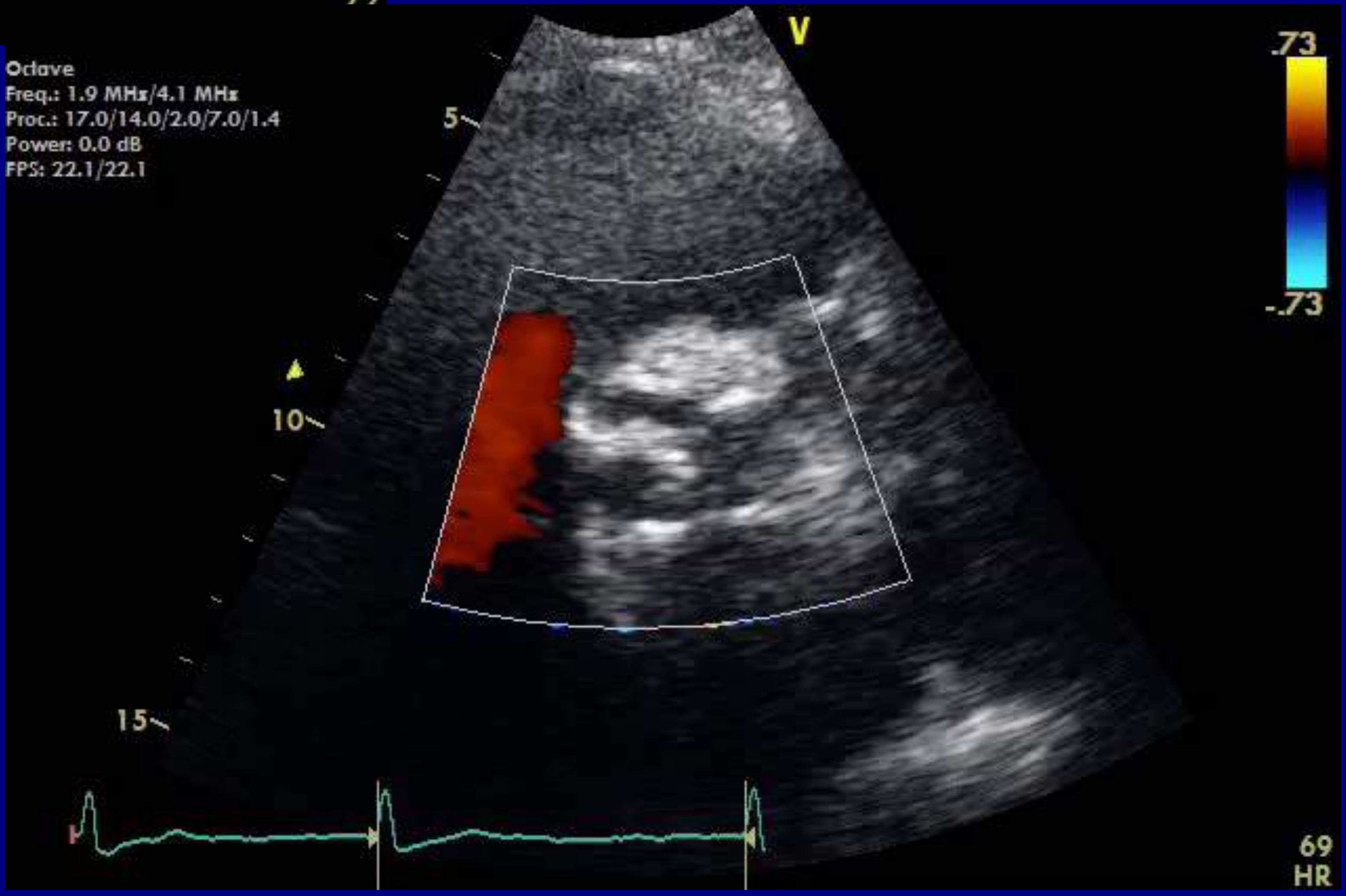


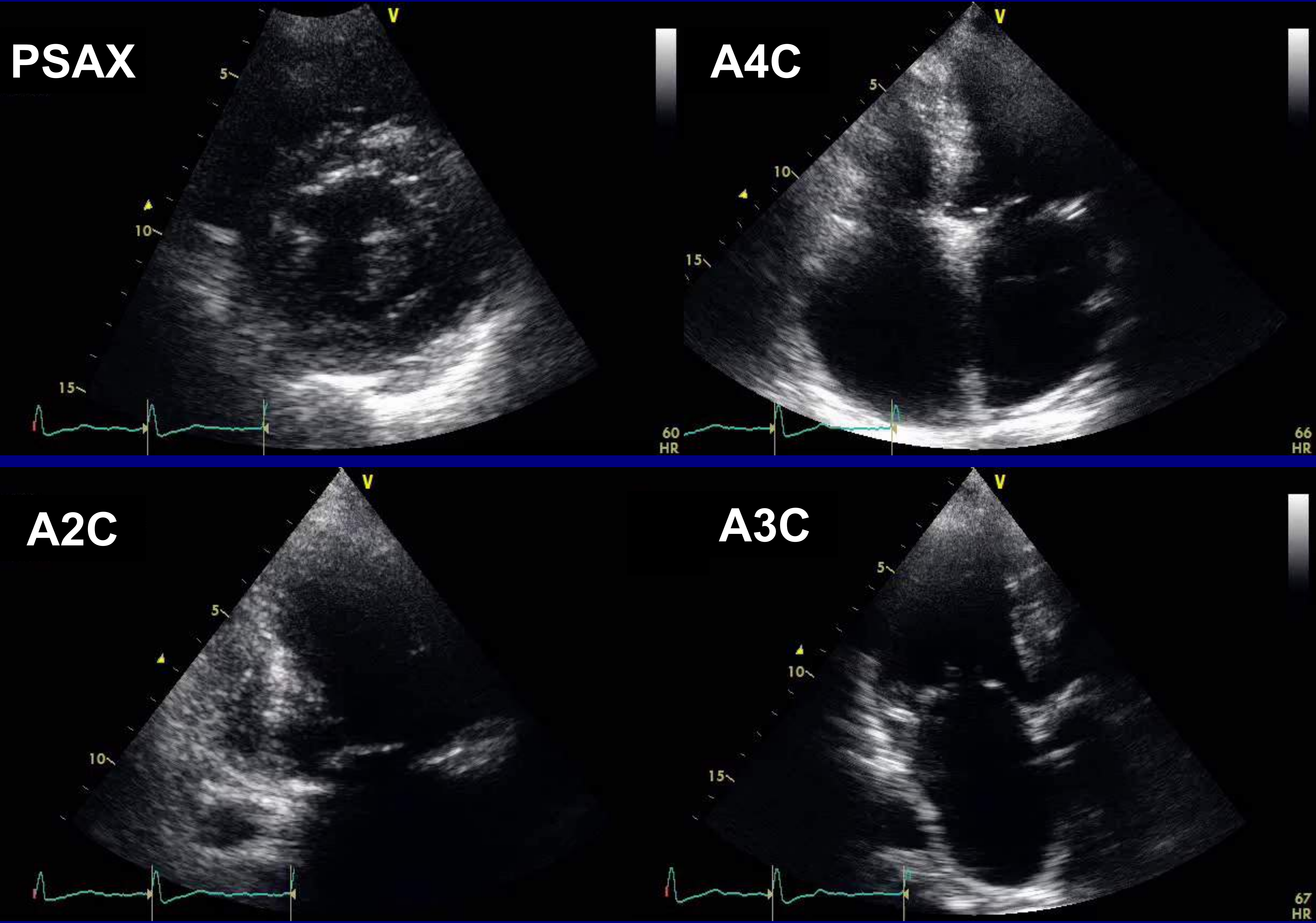
V
LVEDd 4.3cm
IVSd 1.2cm
PWd 1.3cm
5
10
15
Heart Rate: 63
66
HR

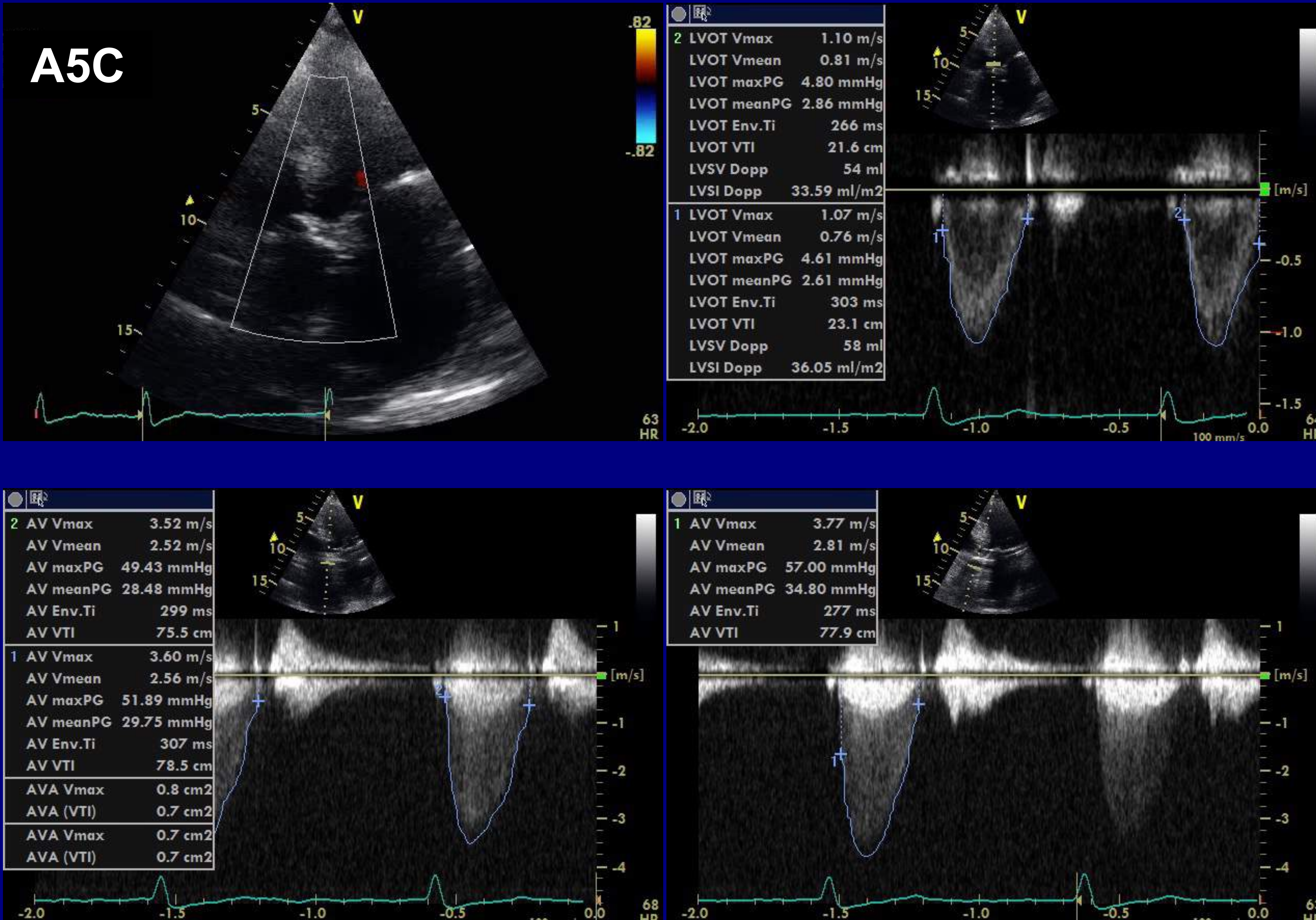


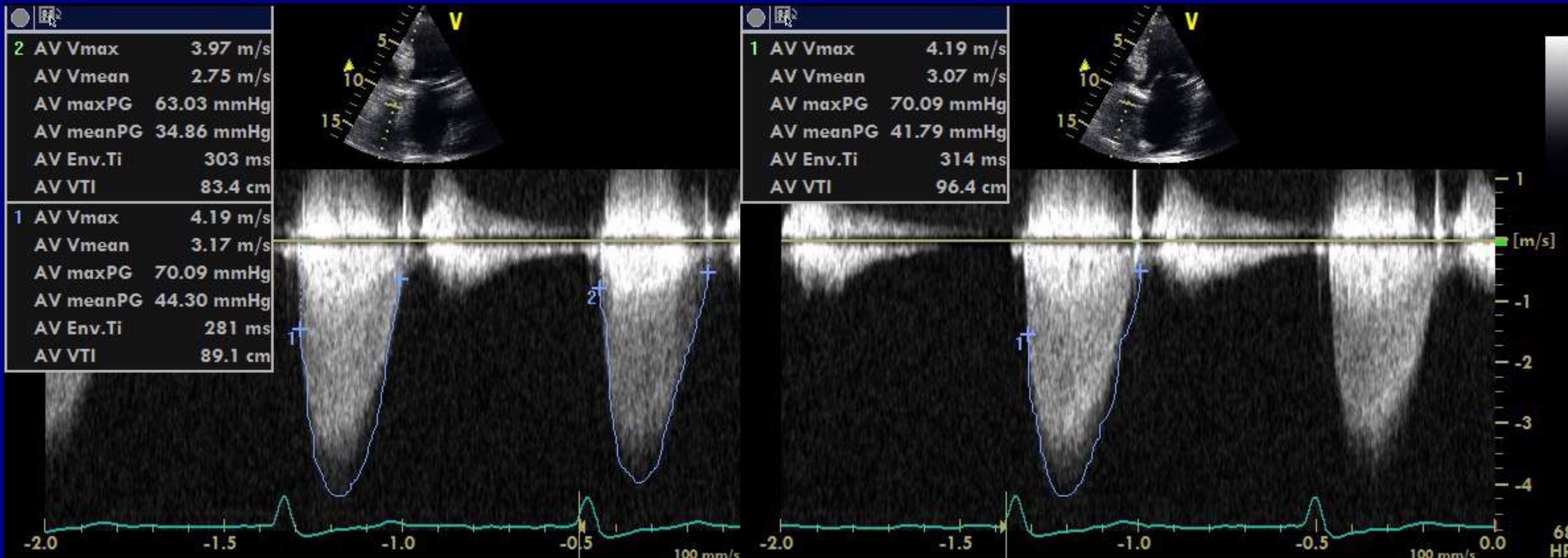
V
1 LVOT Diam 1.8 cm
Proc.: 17.0/14.0/2.0/7.0/1.4
Power: 0.0 dB
FPS: 103.2
6
8
10
12
59
HR

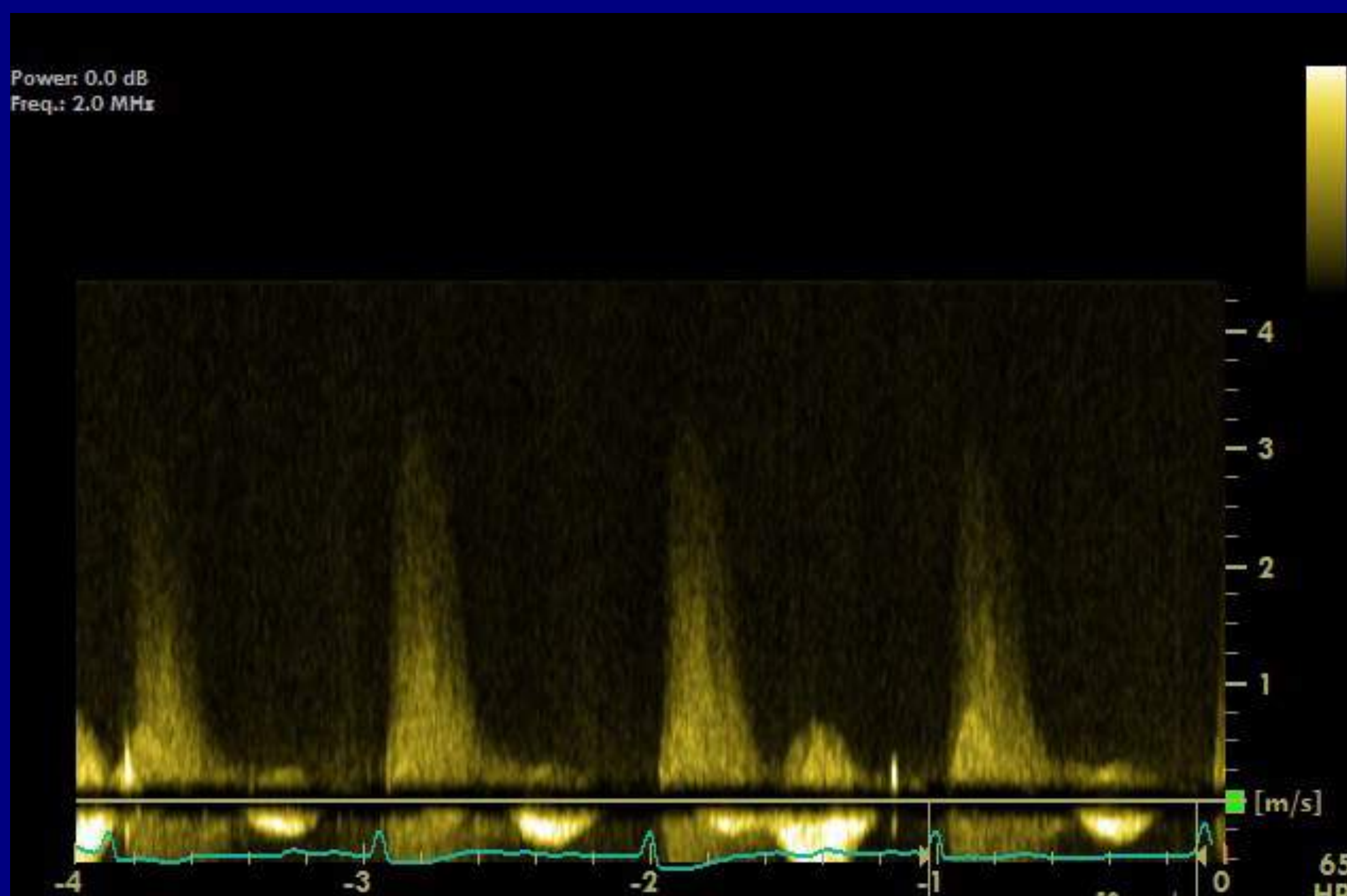

Octave
Freq.: 1.9 MHz/4.1 MHz
Proc.: 17.0/14.0/2.0/7.0/1.4
Power: 0.0 dB
FPS: 54.5/
V
5
10
15


Octave
Freq.: 1.9 MHz/4.1 MHz
Proc.: 17.0/14.0/2.0/7.0/1.4
Power: 0.0 dB
FPS: 22.1/22.1
V
5
10
15
.73
-.73
69
HR


PSAX
A4C
A2C
A3C
60 HR
66 HR
67 HR


A5C
2 LVOT Vmax 1.10 m/s
LVOT Vmean 0.81 m/s
LVOT maxPG 4.80 mmHg
LVOT meanPG 2.86 mmHg
LVOT Env.Ti 266 ms
LVOT VTI 21.6 cm
LVSV Dopp 54 ml
LVSI Dopp 33.59 ml/m2
1 LVOT Vmax 1.07 m/s
LVOT Vmean 0.76 m/s
LVOT maxPG 4.61 mmHg
LVOT meanPG 2.61 mmHg
LVOT Env.Ti 303 ms
LVOT VTI 23.1 cm
LVSV Dopp 58 ml
LVSI Dopp 36.05 ml/m2
2 AV Vmax 3.52 m/s
AV Vmean 2.52 m/s
AV maxPG 49.43 mmHg
AV meanPG 28.48 mmHg
AV Env.Ti 299 ms
AV VTI 75.5 cm
1 AV Vmax 3.60 m/s
AV Vmean 2.56 m/s
AV maxPG 51.89 mmHg
AV meanPG 29.75 mmHg
AV Env.Ti 307 ms
AV VTI 78.5 cm
AVA Vmax 0.8 cm2
AVA (VTI) 0.7 cm2
AVA Vmax 0.7 cm2
AVA (VTI) 0.7 cm2
1 AV Vmax 3.77 m/s
AV Vmean 2.81 m/s
AV maxPG 57.00 mmHg
AV meanPG 34.80 mmHg
AV Env.Ti 277 ms
AV VTI 77.9 cm
63 HR
64 HR
68 HR
63 HR
100 mm/s


2 AV Vmax 3.97 m/s
AV Vmean 2.75 m/s
AV maxPG 63.03 mmHg
AV meanPG 34.86 mmHg
AV Env.Ti 303 ms
AV VTI 83.4 cm
1 AV Vmax 4.19 m/s
AV Vmean 3.17 m/s
AV maxPG 70.09 mmHg
AV meanPG 44.30 mmHg
AV Env.Ti 281 ms
AV VTI 89.1 cm
1 AV Vmax 4.19 m/s
AV Vmean 3.07 m/s
AV maxPG 70.09 mmHg
AV meanPG 41.79 mmHg
AV Env.Ti 314 ms
AV VTI 96.4 cm
V
[m/s]
100 mm/s
68
HR


Power: 0.0 dB
Freq.: 2.0 MHz
[m/s]
50 mm/s
65
HR

Height	154 cm	Weight	63 kg	BSA	1.61 m²	BP		Page	5/6

Parameter	Value	Mth	m1	m2	m3	m4	m5
Doppler Measurements							
Aortic							
LVOT Diam	1.8 cm	Av	1.8				
LVOT Trace							
LVOT Vmax	1.08 m/s	Av	1.07	1.10			
LVOT Vmean	0.79 m/s	Av	0.76	0.81			
LVOT maxPG	4.70 mmHg	Av	4.61	4.80			
LVOT meanPG	2.73 mmHg	Av	2.61	2.86			
LVOT Env.Ti	285 ms	Av	303	266			
LVOT VTI	22.4 cm	Av	23.1	21.6			
LVSV Dopp	56 ml		58	54			
LVSI Dopp	34.82 ml/m2		36.05	33.59			
AV Trace							
AV Vmax	3.87 m/s	Av	3.60	3.52	3.77	4.19	3.97
AV Vmean	2.81 m/s	Av	2.56	2.52	2.81	3.17	2.75
AV maxPG	60.26 mmHg	Av	51.89	49.43	57.00	70.09	63.03

Height	154 cm	Weight	63 kg	BSA	1.61 m²	BP		Page	6/6

Parameter	Value	Mth	m1	m2	m3	m4	m5
Doppler Measurements							
Aortic							
AV Trace							
AV meanPG	35.66 mmHg	Av	29.75	28.48	34.80	44.30	34.86
AV Env.Ti	297 ms	Av	307	299	277	281	303
AV VTI	83.5 cm	Av	78.5	75.5	77.9	89.1	83.4
AVA Vmax	0.7 cm2		0.7	0.8			
AVA (VTI)	0.7 cm2		0.7	0.7			
Tricuspid Valve							
TR Vmax							
TR Vmax	3.38 m/s	Av	3.11	3.65			
TR maxPG	46.01 mmHg	Av	38.65	53.36			
Pulmonic							
PV Vmax							
PV Vmax	1.37 m/s	Av	1.37				
PV maxPG	7.49 mmHg	Av	7.49				

Formal Report

AORTIC VALVE

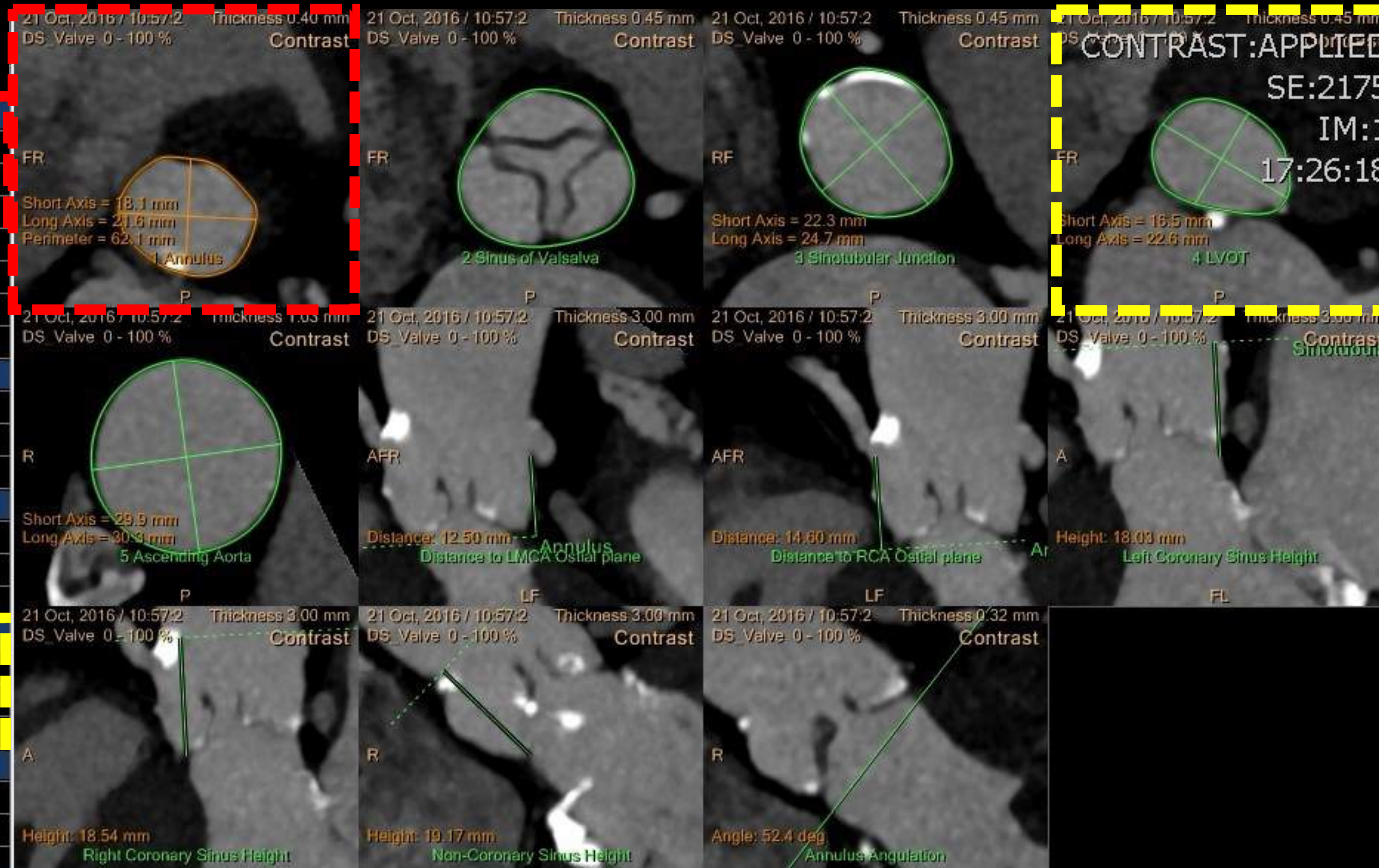
Thickened leaflets with reduced leaflet excursion. Severe aortic stenosis with trivial regurgitation. LVOT diam: 1.8 cm; LVOT vel.: 1.1 m/s; LVOT VTI: 22 cm; AV vel.: 4.2 m/s; AV VTI: 96 cm; Peak gradient: 60 mmHg; Mean gradient: 36mmHg; Orifice area (continuity equation): 0.7 cm2; DSI: 0.23.

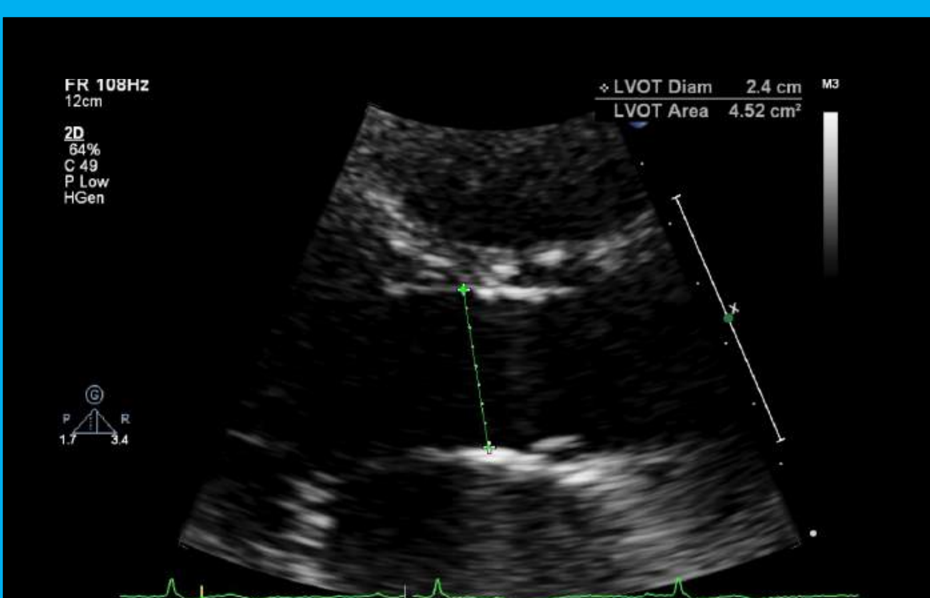
CONCLUSION:

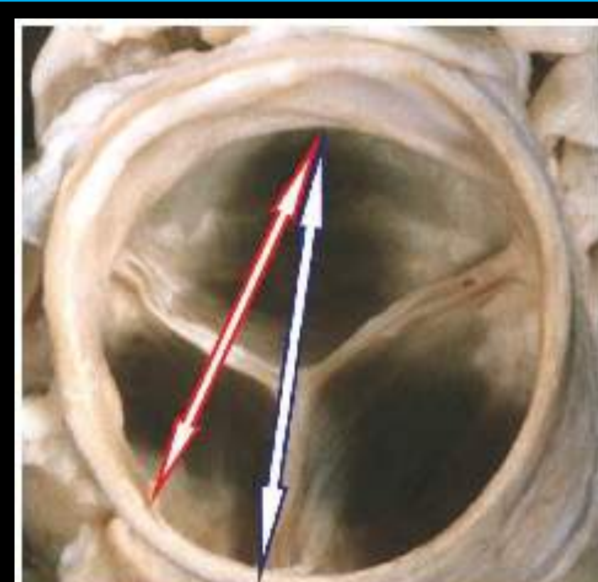
… Severe aortic stenosis.

Common Source of Error – LVOT Diameter

Annulus	
Short axis	18.1 mm
Long axis	21.6 mm
Area	306.7 mm²
Perimeter	62.1 mm
Effective diameter based on area	19.8 mm
Effective diameter based on perimeter	19.8 mm
(Long Axis + Short Axis) / 2	19.8 mm
Sinus of Valsalva	
Short Axis	24.6 mm
Long Axis	27.1 mm
(Long Axis + Short Axis) / 2	25.9 mm
Sinotubular Junction	
Short Axis	22.3 mm
Long Axis	24.7 mm
(Long Axis + Short Axis) / 2	23.5 mm
LVOT	
Short Axis	16.5 mm
Long Axis	22.6 mm
(Long Axis + Short Axis) / 2	19.6 mm
Ascending Aorta	
Short Axis	29.9 mm
Long Axis	30.3 mm
(Long Axis + Short Axis) / 2	30.1 mm







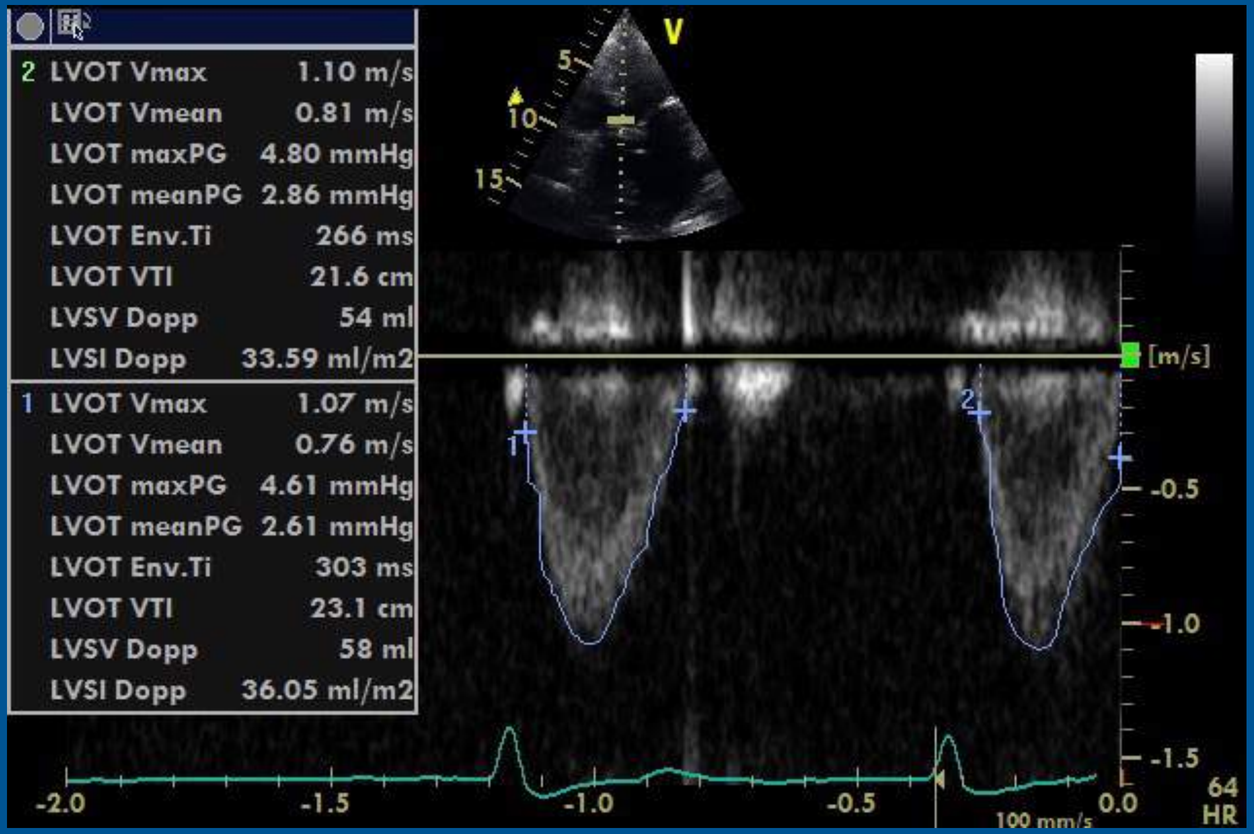
2D often underestimates the LVOTd (Ant-Post; Oval)

Error is *SQUARED* by *continuity*

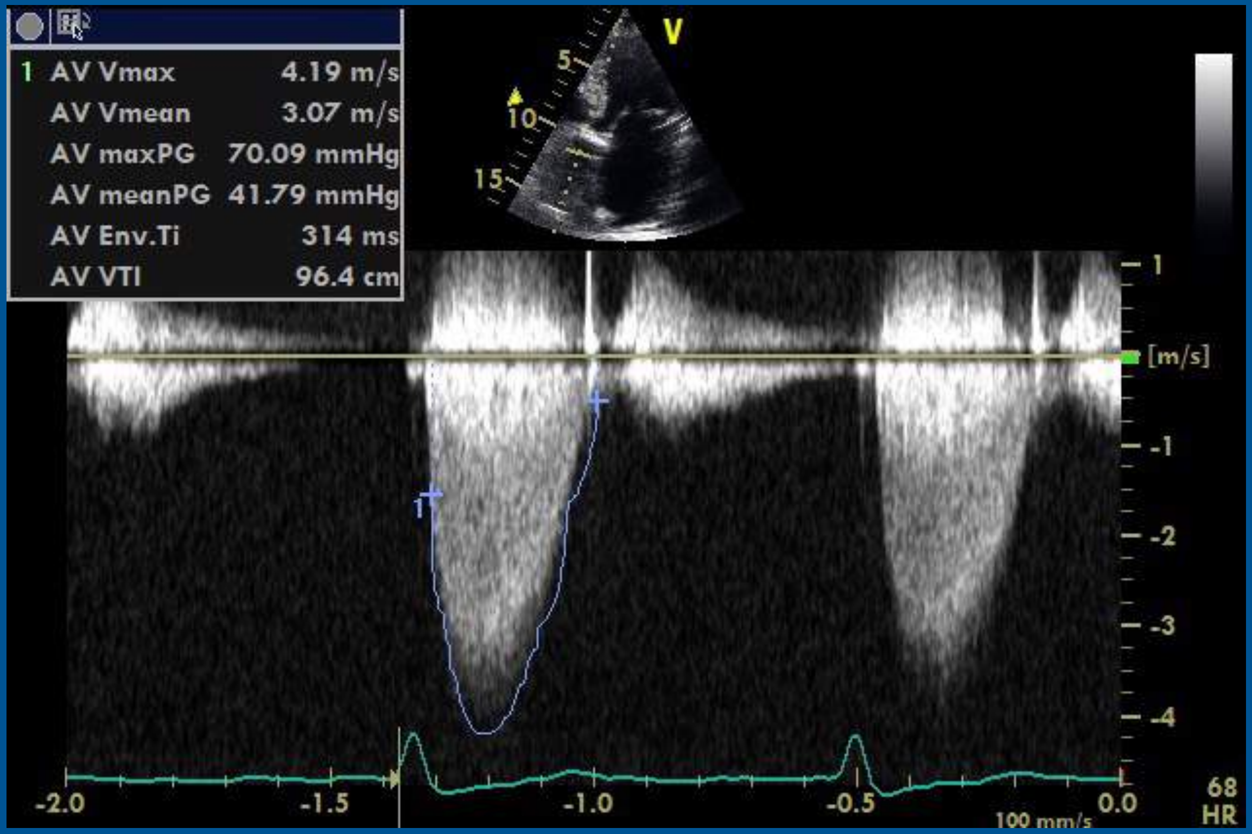
[7]$LVOTd_{Predicted}$ (mm) = 5.7*BSA + 12.1

1. Baumgartner H, et al. 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. J Am Soc Echocardiogr 2017;30:372-392.
2. Baumgartner H, et al. Echocardiographic assessment of valve stenosis: EAE/ ASE recommendations for clinical practice. Eur J Echocardiogr 2009; 10:1-25.
3. Otto CM, et al. Determination of the stenotic aortic valve area in adults using Doppler echocardiography. J Am Coll Cardiol 1986;7:509-17.
4. Pibarot P, et al. Left Ventricular Outflow Tract Geometry and Dynamics in Aortic Stenosis: Implications for the Echocardiographic Assessment of Aortic Valve Area. J Am Soc Echocardiogr 2015;28:1267-1269.
5. LaBounty TM, et al. Annulus instead of LVOT diameter improves agreement between echocardiography effective orifice area and invasive aortic valve area. JACC Cardiovasc Imaging 2014;7:1065-6 .
6. Hahn R, et al. Recommendations for comprehensive intraporocedural echocardiographic imaging during TAVR. J Am Coll Cardiol Img 2015;8:261-287.
7. Leye M, Brochet E, Lepage L, et al. Size-adjusted left ventricular outflow tract diameter reference values: a safeguard for the evaluation of the severity of aortic stenosis. J Am Soc Echocardiogr 2009;22:445-451

Source of Error - Overtracing



- LVOT VTI is measured by *tracing the modal velocity* (middle of the dense signal) for use in the continuity equation or calculation of SV



- Maximum velocity is measured at the outer edge of the dark signal
- *Fine linear signals at the peak of the curve (transit-time effects) should NOT BE INCLUDED*

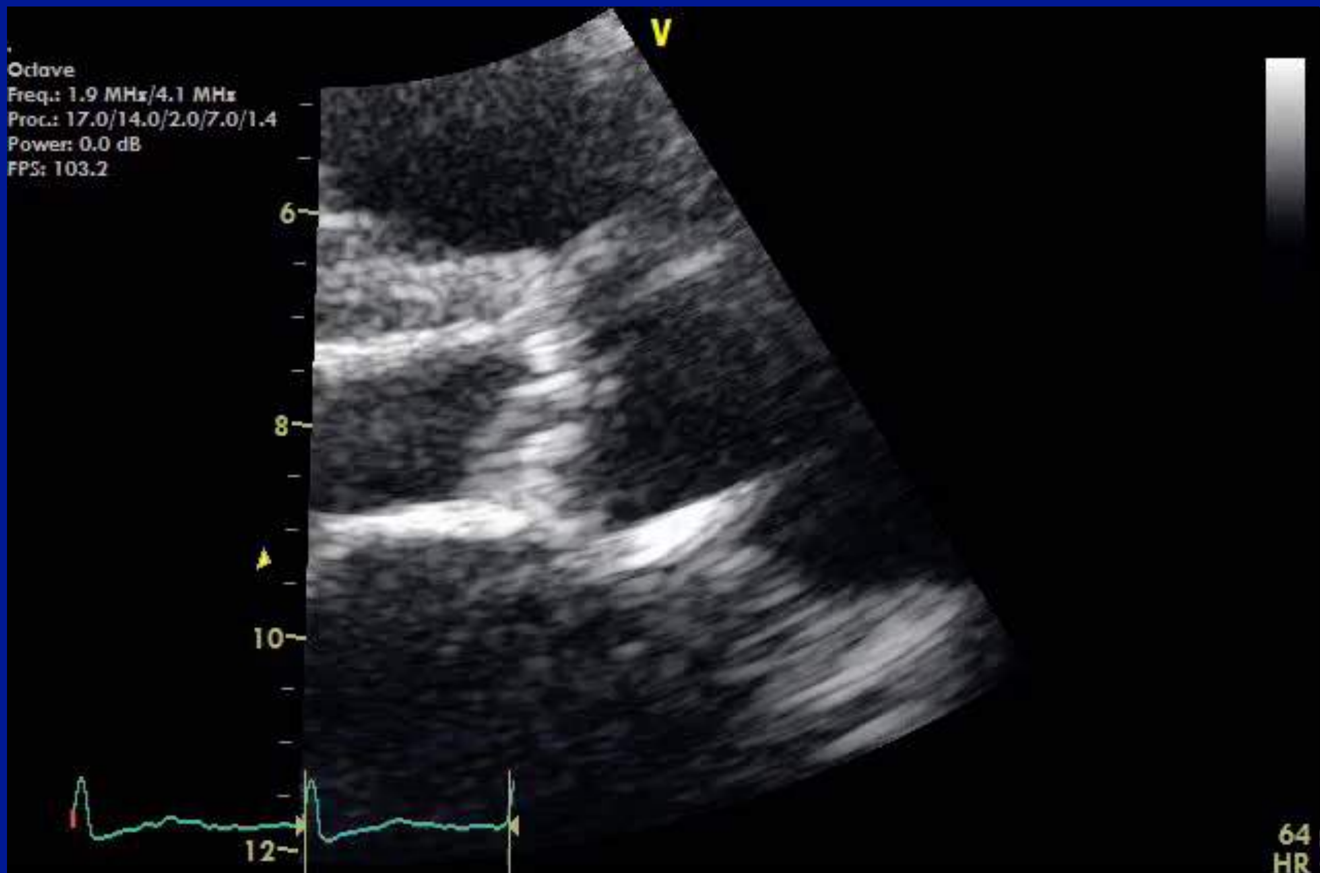
≥3 beats averaged for patients in SR

≥5 consecutive beats averaged for irregular rhythms (Avoid post-extrasystolic beats)

****Average of velocities from the ONE window with the highest velocities***

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

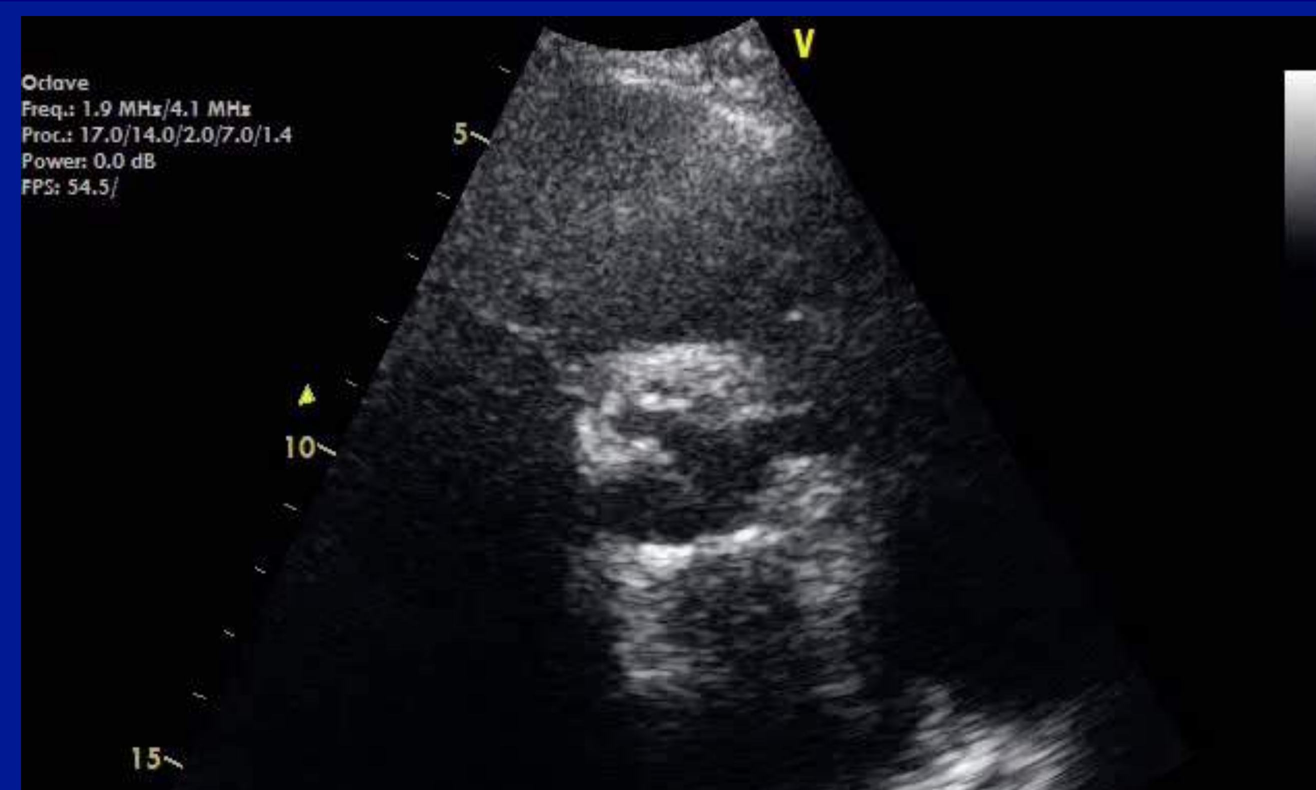
Re-traced and Re-calculated



- ***AV peak vel. 3.6m/sec***
- ***AV mean vel. 2.6m/sec***
- ***AV peak gradient 51mmHg***
- ***AV mean gradient 30mmHg***
- ***AV VTI 72cm***

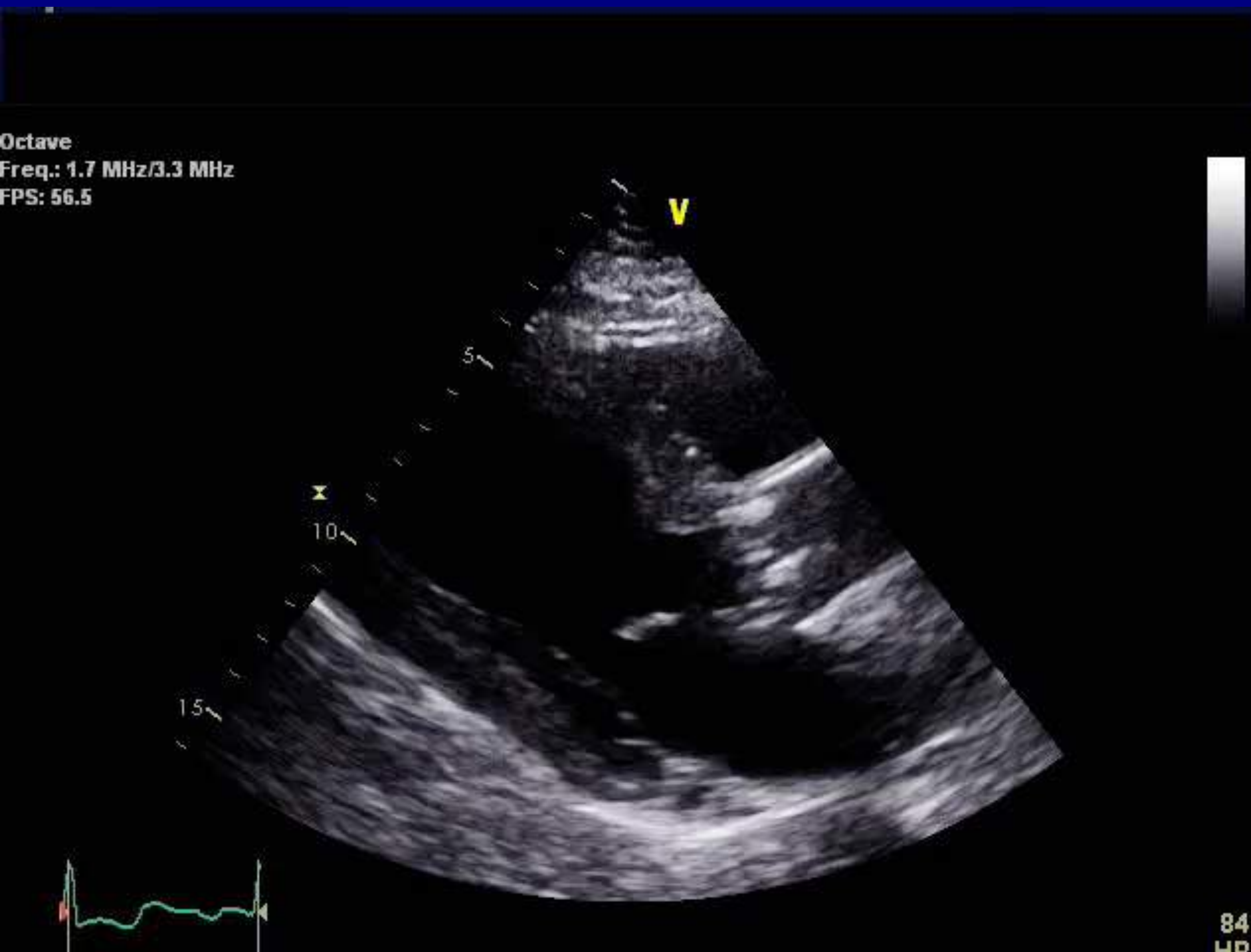
- ***LVOT peak vel. 0.98m/sec***
- ***LVOT VTI 21cm***

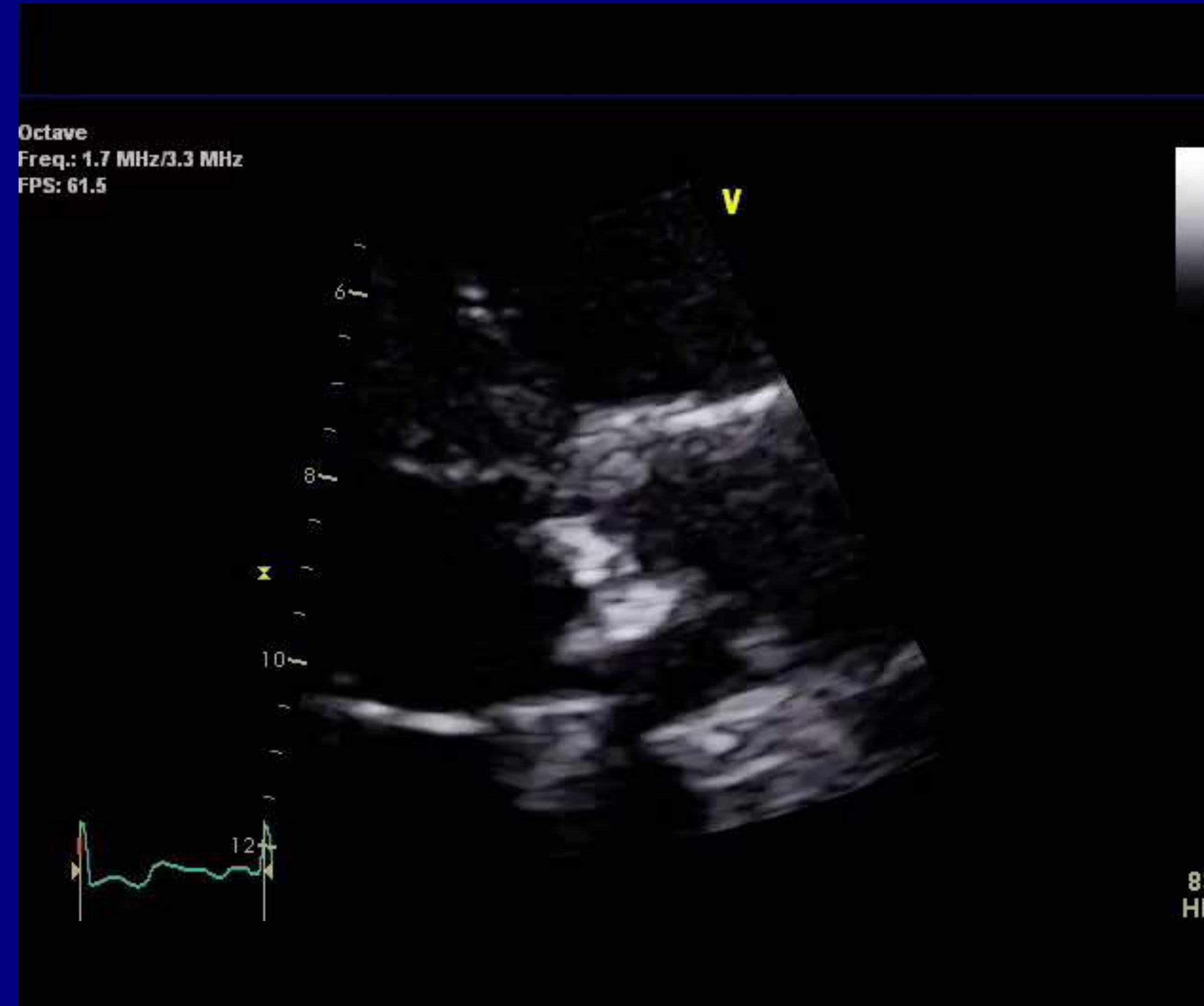
- ***DSI 0.29***
- ***$LVOTd_{Predicted}$ = 2.13cm***
- ***AVA = 1.03cm²***
- ***$AVAi_{BSA}$ = 0.64cm²/m²***

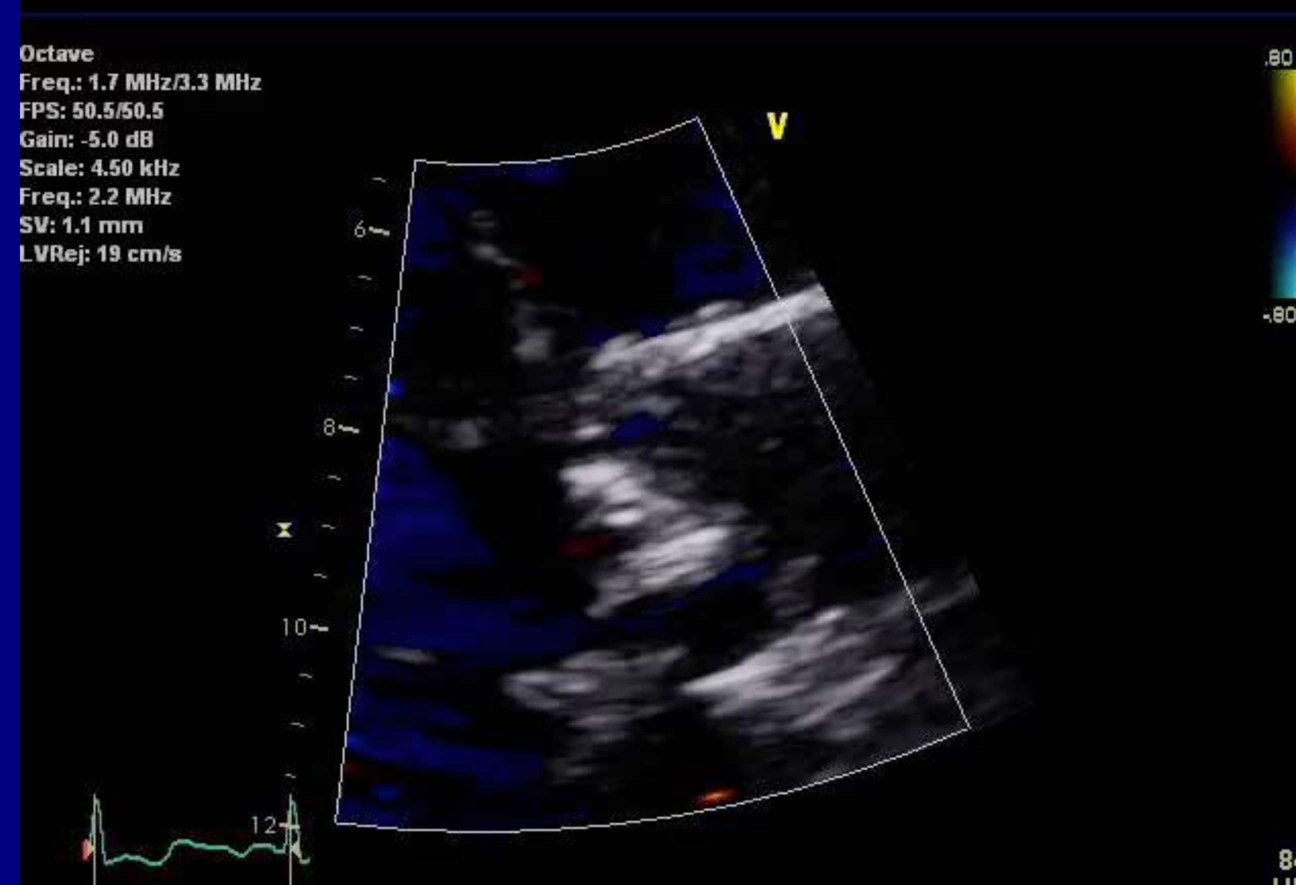


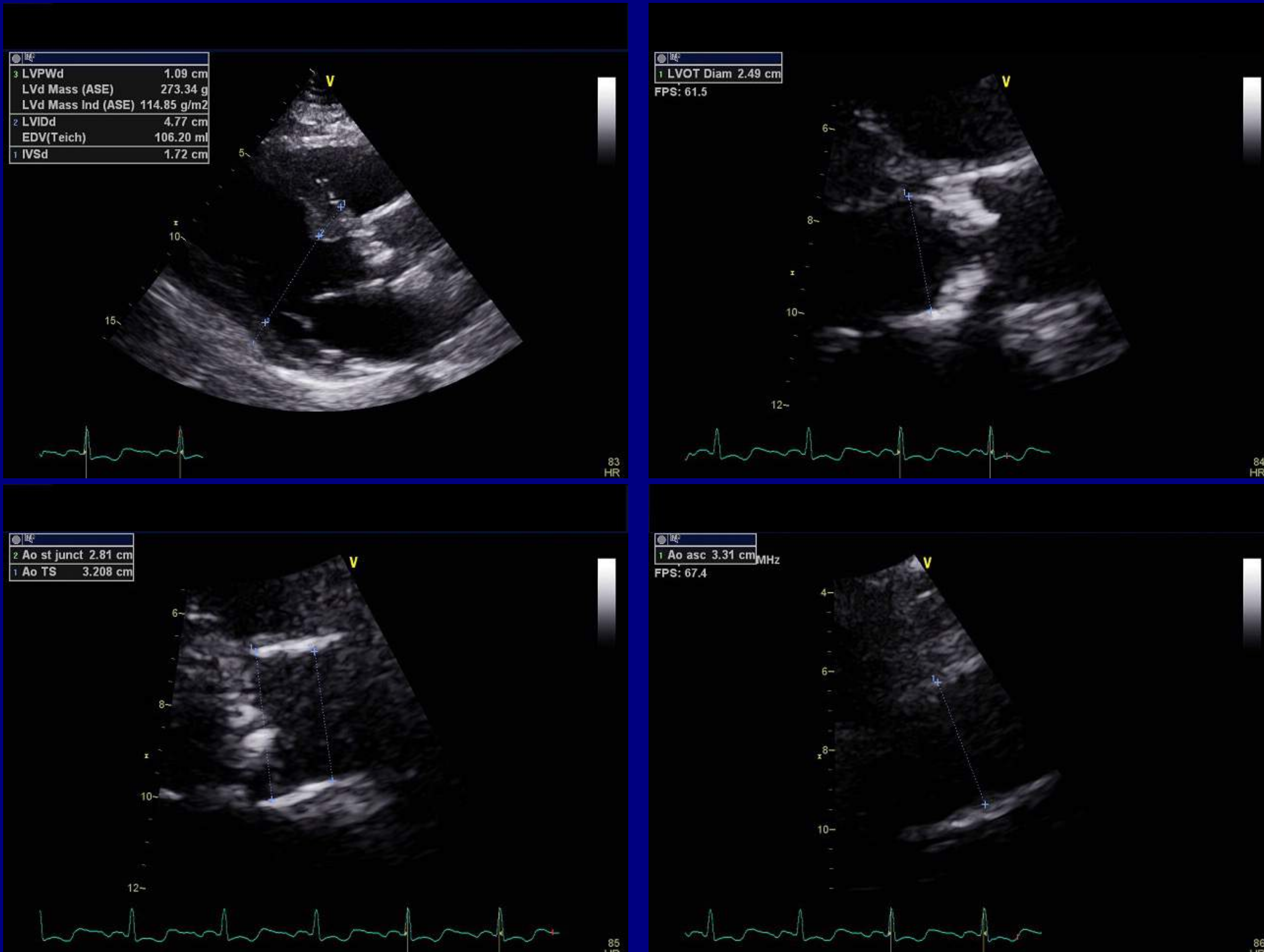
Moderate AS

62 yo male
Indication for TTE:
Previous aortic sclerosis (2013); Now dizzy and SOBOE; TTE in Perth showed severe AS

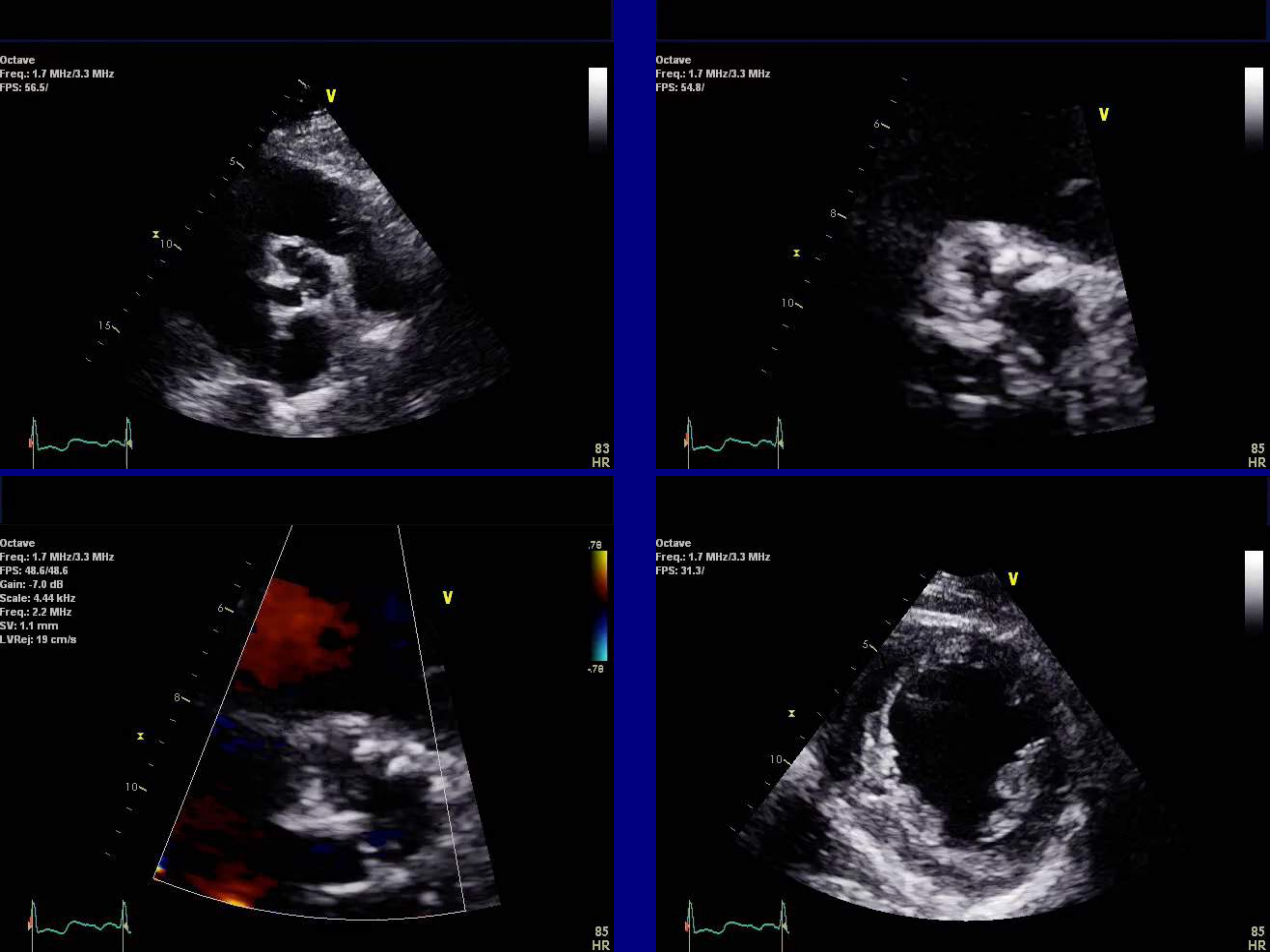


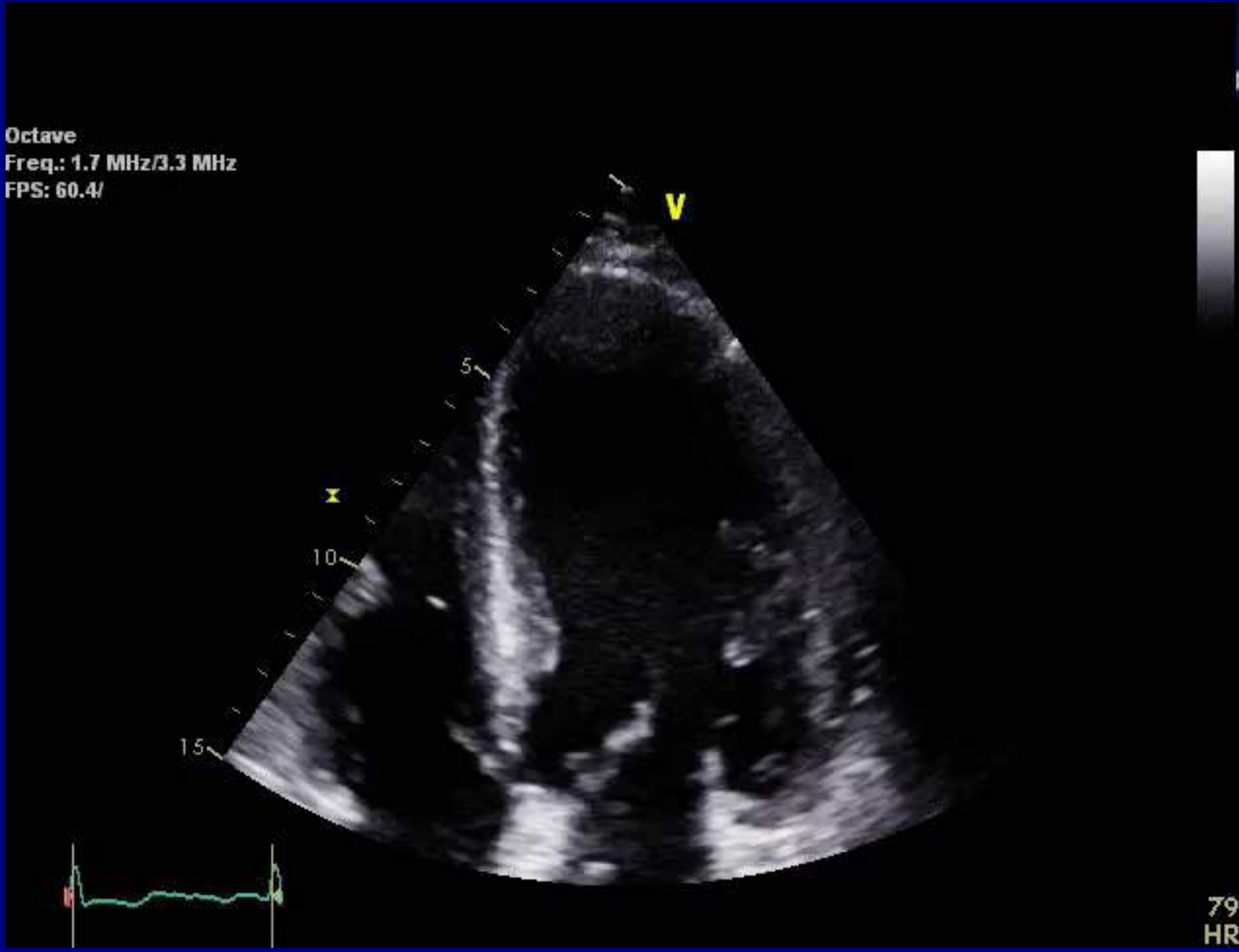


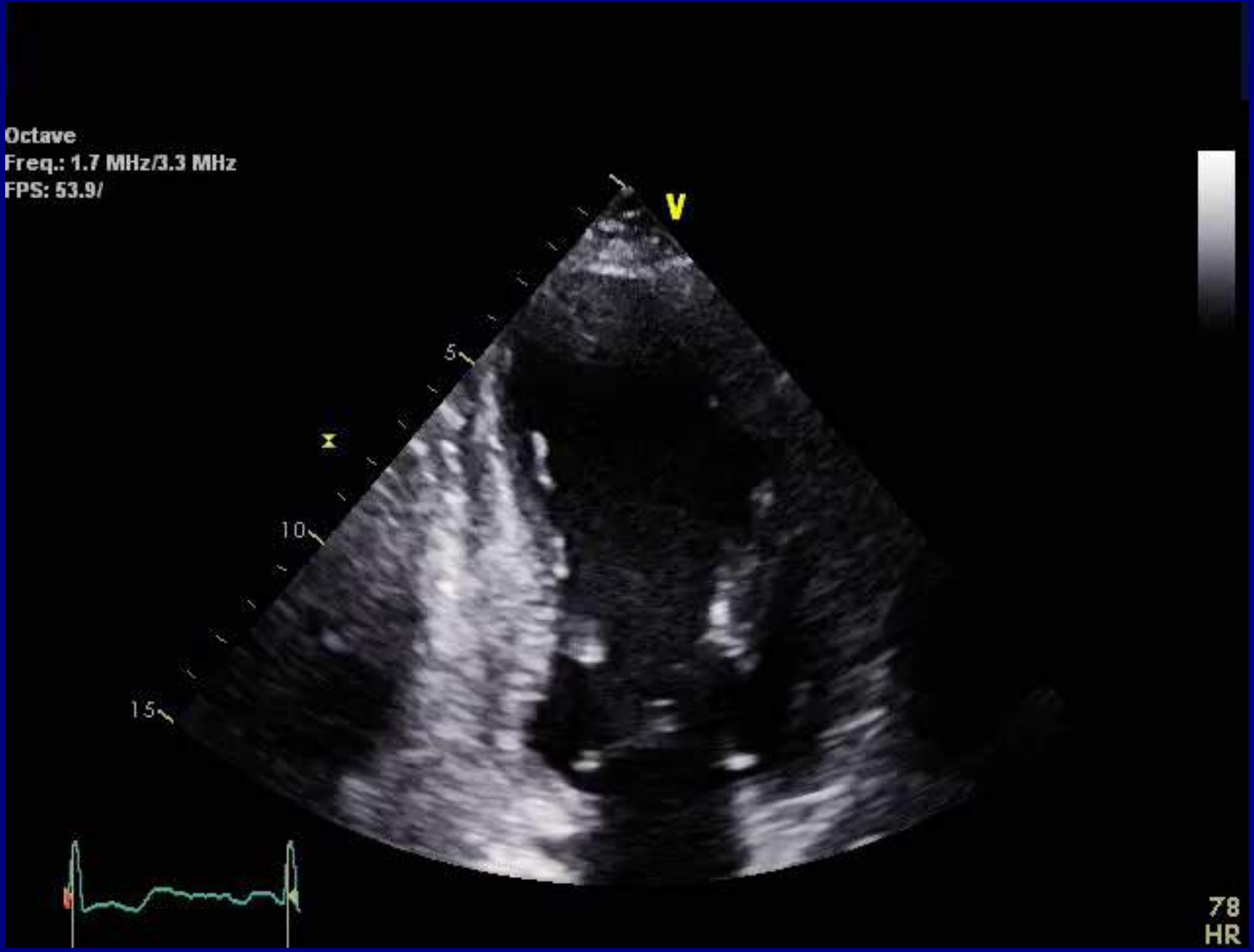




LVPWd 1.09 cm
LVd Mass (ASE) 273.34 g
LVd Mass Ind (ASE) 114.85 g/m2
LVIDd 4.77 cm
EDV(Teich) 106.20 ml
IVSd 1.72 cm
83 HR
LVOT Diam 2.49 cm
FPS: 61.5
84 HR
Ao st junct 2.81 cm
Ao TS 3.208 cm
85 HR
Ao asc 3.31 cm
MHz
FPS: 67.4
86 HR


Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 56.5/
V
5
10
15
83
HR
Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 54.8/
V
6
8
10
85
HR
Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 48.6/48.6
Gain: -7.0 dB
Scale: 4.44 kHz
Freq.: 2.2 MHz
SV: 1.1 mm
LVRej: 19 cm/s
.78
-.78
V
6
8
10
85
HR
Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 31.3/
V
5
10
85
HR





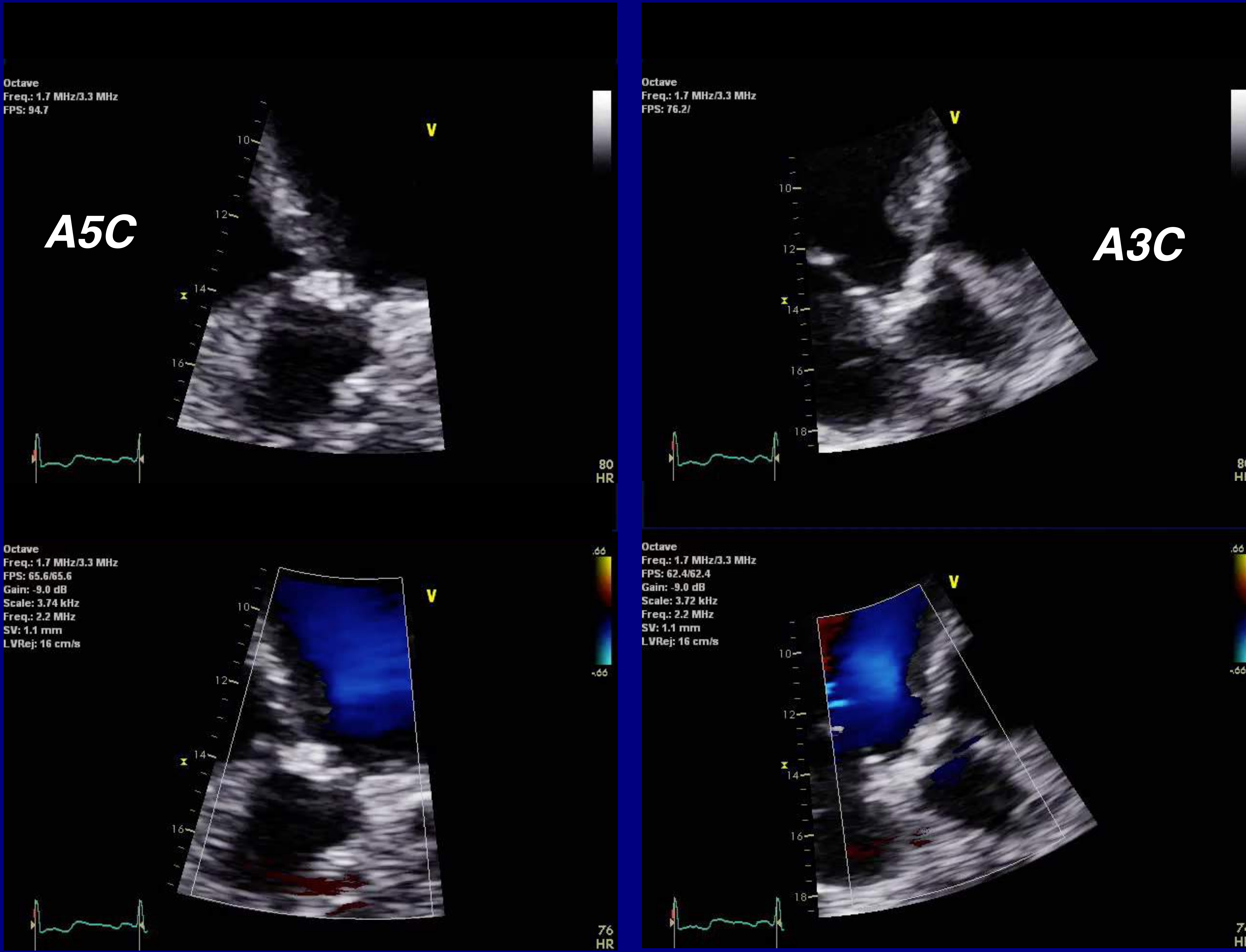
Biplane Simpson's:

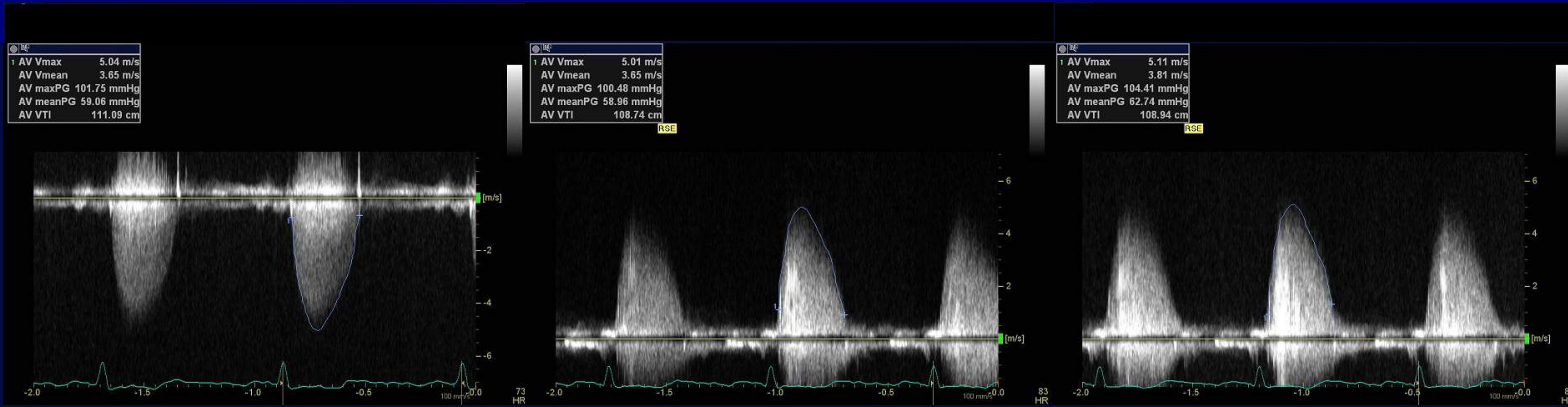
LVEDV 244mL

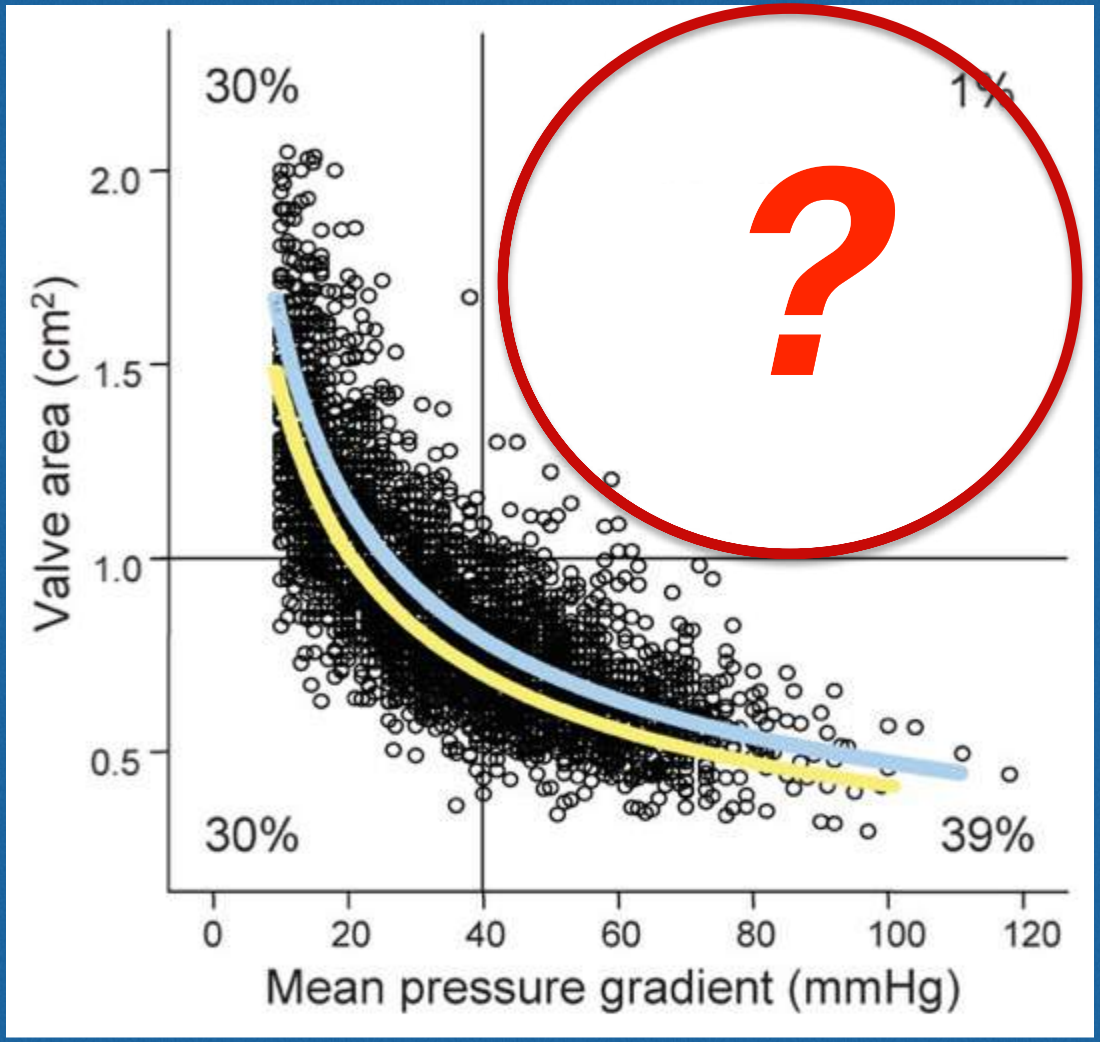
LVESV 118mL

LVEF 52%

{BSA 2.1m^2}


A5C
A3C
Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 94.7
Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 76.2/
80
HR
80
HR
Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 65.6/65.6
Gain: -9.0 dB
Scale: 3.74 kHz
Freq.: 2.2 MHz
SV: 1.1 mm
LVRej: 16 cm/s
Octave
Freq.: 1.7 MHz/3.3 MHz
FPS: 62.4/62.4
Gain: -9.0 dB
Scale: 3.72 kHz
Freq.: 2.2 MHz
SV: 1.1 mm
LVRej: 16 cm/s
76
HR
74
HR

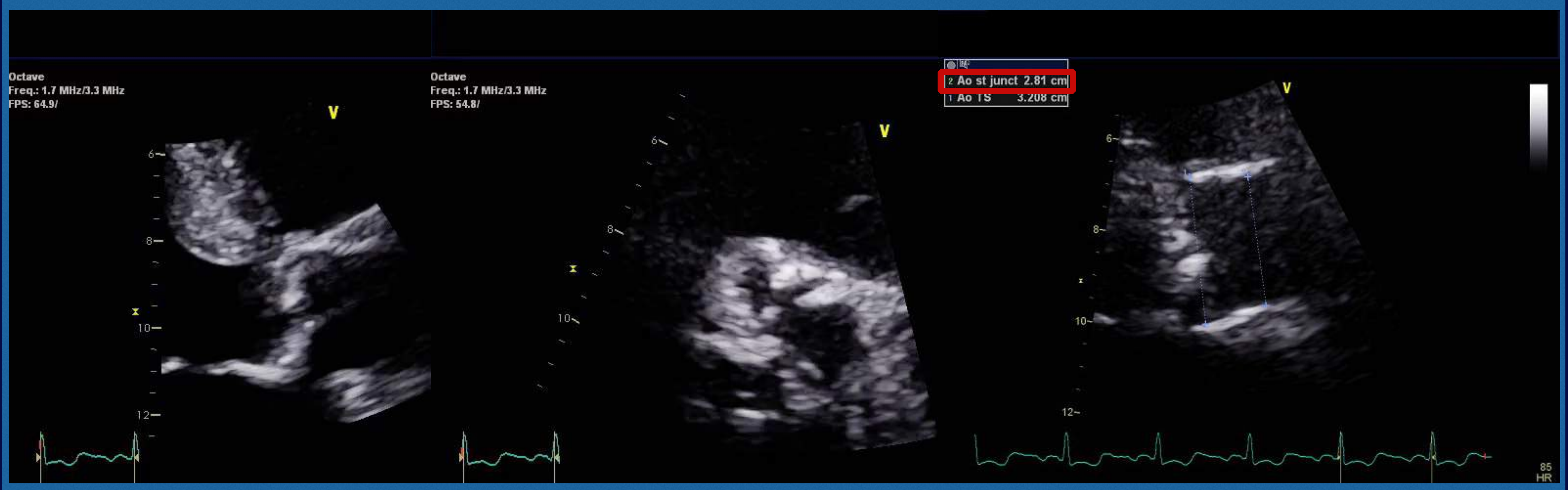

AV Vmax 5.04 m/s
AV Vmean 3.65 m/s
AV maxPG 101.75 mmHg
AV meanPG 59.06 mmHg
AV VTI 111.09 cm
AV Vmax 5.01 m/s
AV Vmean 3.65 m/s
AV maxPG 100.48 mmHg
AV meanPG 58.96 mmHg
AV VTI 108.74 cm
RSE
AV Vmax 5.11 m/s
AV Vmean 3.81 m/s
AV maxPG 104.41 mmHg
AV meanPG 62.74 mmHg
AV VTI 108.94 cm
RSE
[m/s]
HR



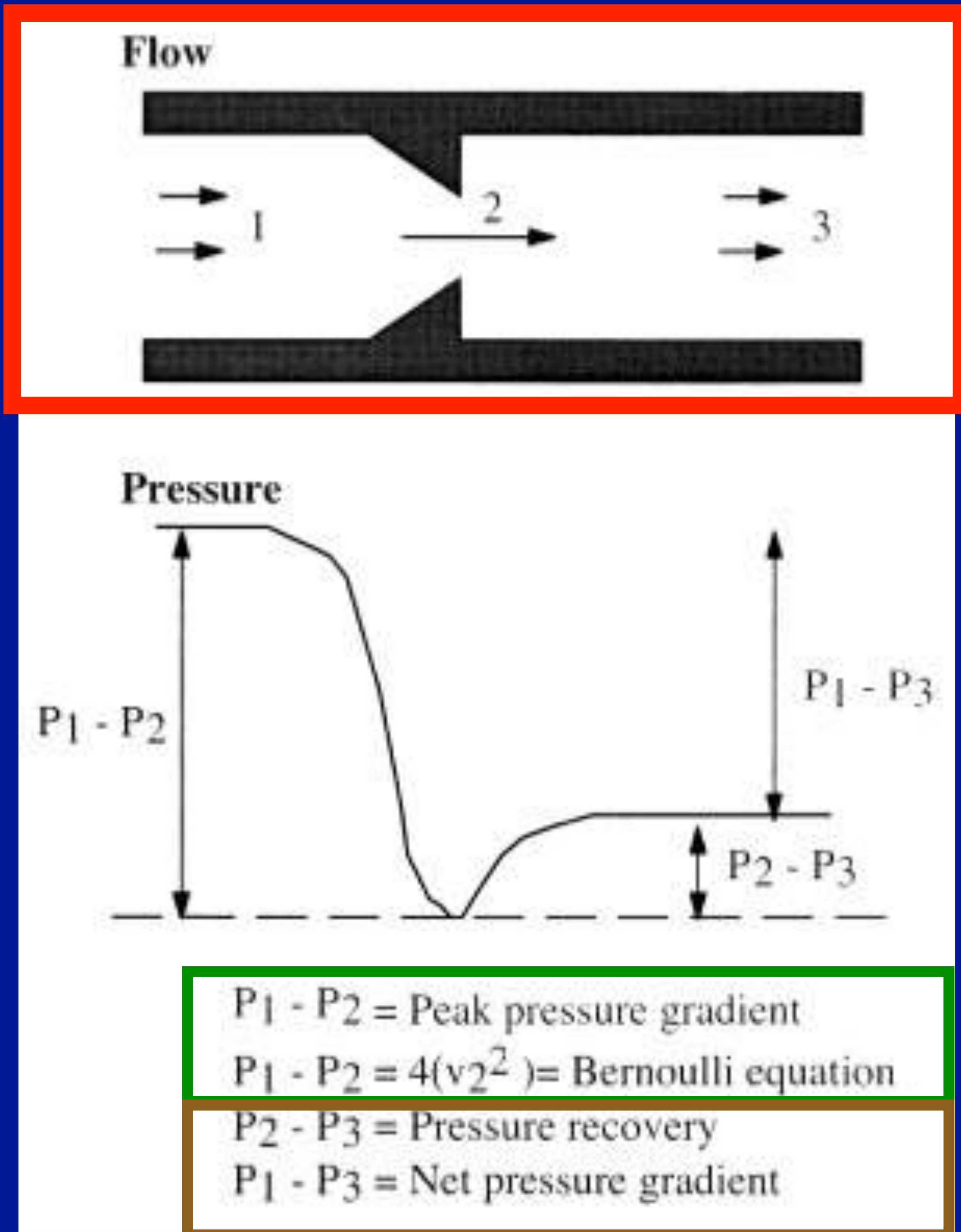
- LVOT peak vel. 1.2m/sec
- LVOT VTI 27cm
- (LVOTd 2.5cm)

- AV peak vel. 4.8m/sec
- AV mean vel. 3.4m/sec
- AV VTI 105cm
- AV peak/mean gradient 92/51mmHg

- **DSI 0.26**
- **AVA 1.26cm^2 (AVAi 0.63cm^2/m^2)**

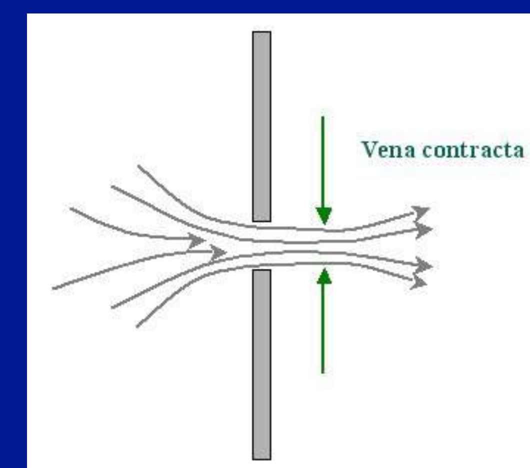


Rapid Pressure Recovery



- *[1-2] Flow convergence through the stenotic AV to vena contracta -> Converts PE to KE*
- *[3] Streamlines then diverge and slow, there is reconversion of KE to PE:*

  "Recovery" of a proportion of the pressure loss



- ***Doppler method** = Measures peak flow velocity at the vena contracta (i.e. EOA)*

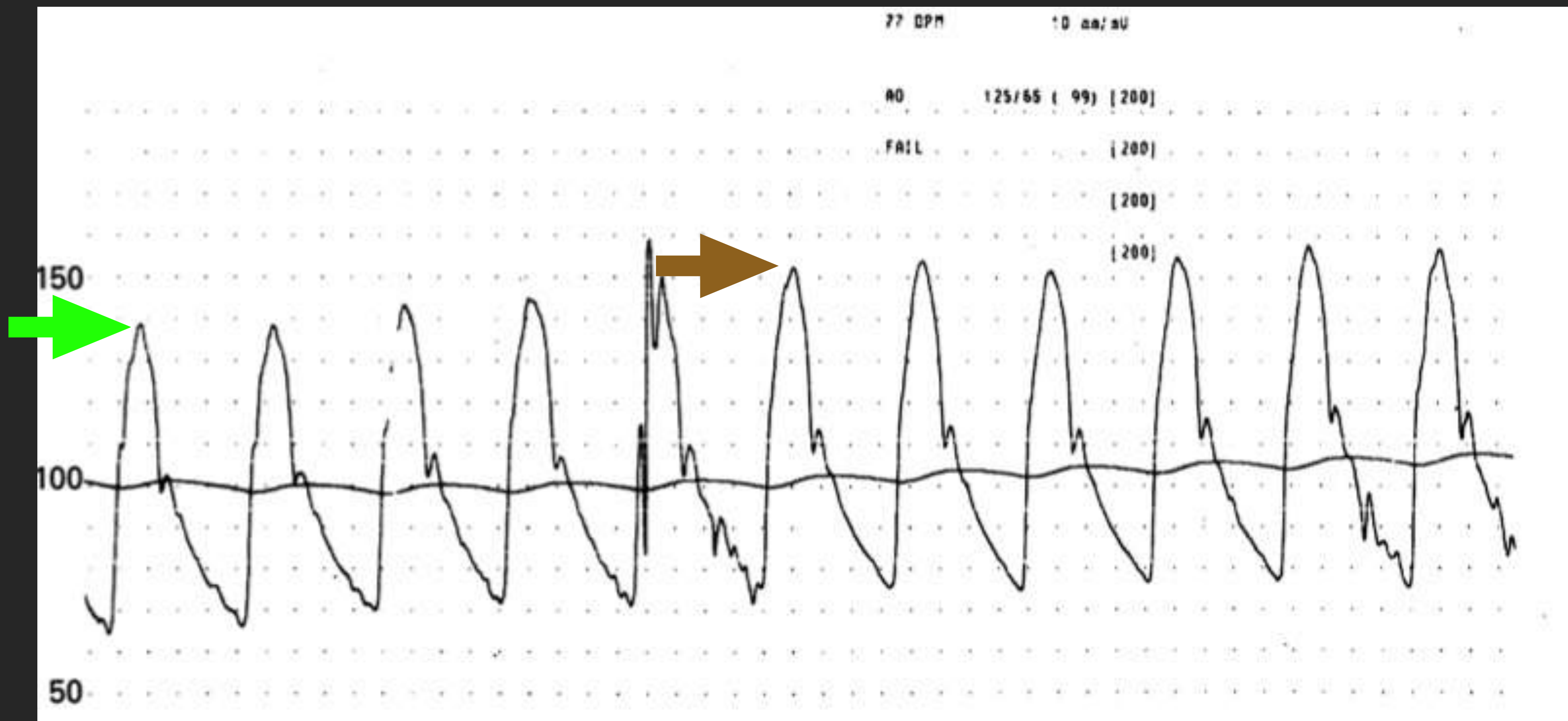
- ***Recovered pressure** reflects the true load (pressure burden & wall stress) on the LV*

Most useful in moderate AS and small aortic roots (STJ <3.0cm OR EOA : AscAo diameter ≥0.20cm)

Gjertsson P, Caidahl K, Svensson G, et al. Patients with aortic stenosis and high Doppler gradients. Am J Cardiol 2001;88:139-144.

Normal gradual pressure recovery:

Pigtail catheter pulled back from just beyond the aortic valve to the arch



Chambers J. Is pressure recovery an important cause of "Doppler aortic stenosis" with no gradient at cardiac catheterisation? *Heart* 1996;76:381-383.

Pressure Recovery for Gradient(s)

$$PR = 4V^2 \times 2\left(\frac{AVA}{AAA}\right) \times \left(1 - \left(\frac{AVA}{AAA}\right)\right)$$

Pressure Recovery for AVA

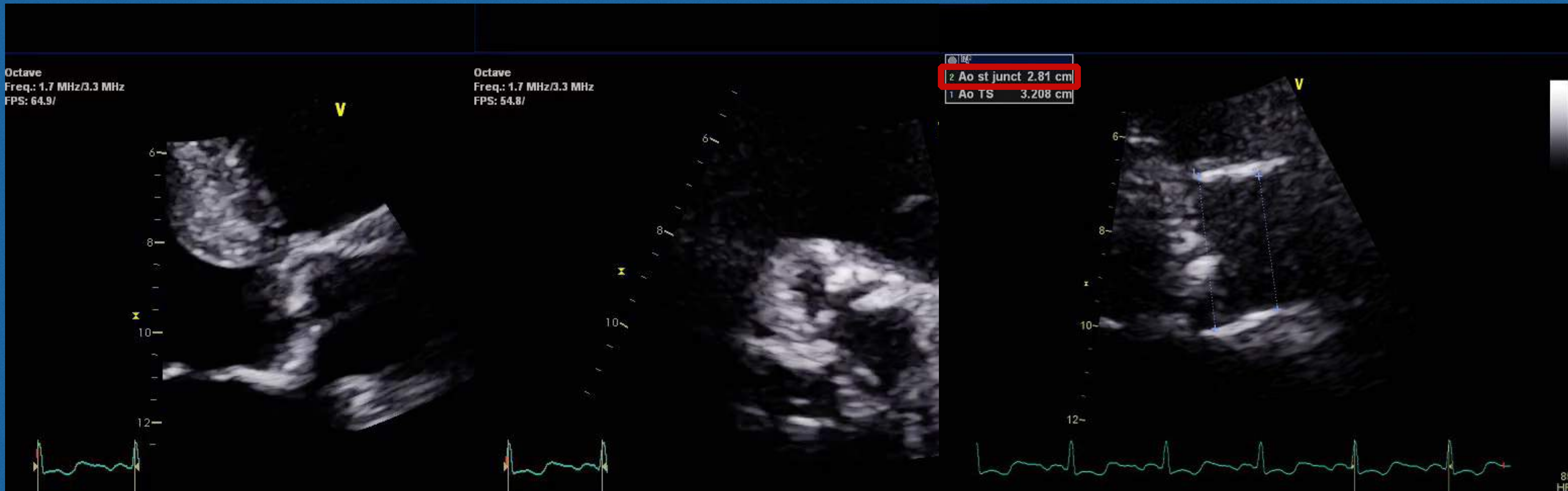
$$\frac{EOA \times A_A}{A_A - EOA} = \frac{Q}{50 \times \sqrt{E_L}}$$

$$AVA_{pr} = \frac{(AAA \times AVA_{Dopp})}{(AAA - AVA_{Dopp})}$$

AVA_{PR} indexed for BSA = Energy Loss Index (ELI)

Aorta diameter ≥3.0cm = Minimal pressure recovery

- Niederberger J, Schima H, Maurer G, et al. Importance of pressure recovery for the assessment of aortic stenosis by Doppler ultrasound. Role of aortic size, aortic valve area, and direction of the stenotic jet in vitro. Circulation 1996;94:1934-1940.
- Baumgartner H, Stefanelli T, Niederberger J, et al. "Overestimation" of catheter gradients by Doppler ultrasound in patients with aortic stenosis: a predictable manifestation of pressure recovery. J Am Coll Cardiol 1999;33:1655-1661.
- Garcia D, Pibarot P, Dumesnil JG, et al. Assessment of aortic valve stenosis severity: a new index based on the energy loss concept. Circulation 2000;101:765-771.



STJ 2.8cm

- LVOT peak vel. 1.2m/sec
- LVOT VTI 27cm
- (LVOTd 2.5cm)

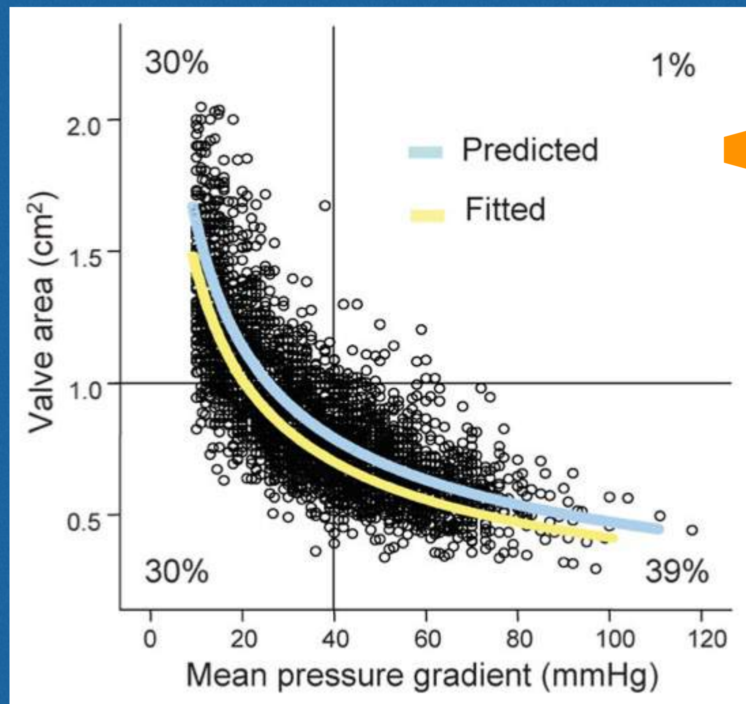
- AV peak vel. 4.8m/sec
- AV mean vel. 3.4m/sec
- AV VTI 105cm
- AV peak/mean gradient 92/51mmHg

- DSI 0.26
- AVA 1.26cm^2 (AVAi 0.63cm^2/m^2)

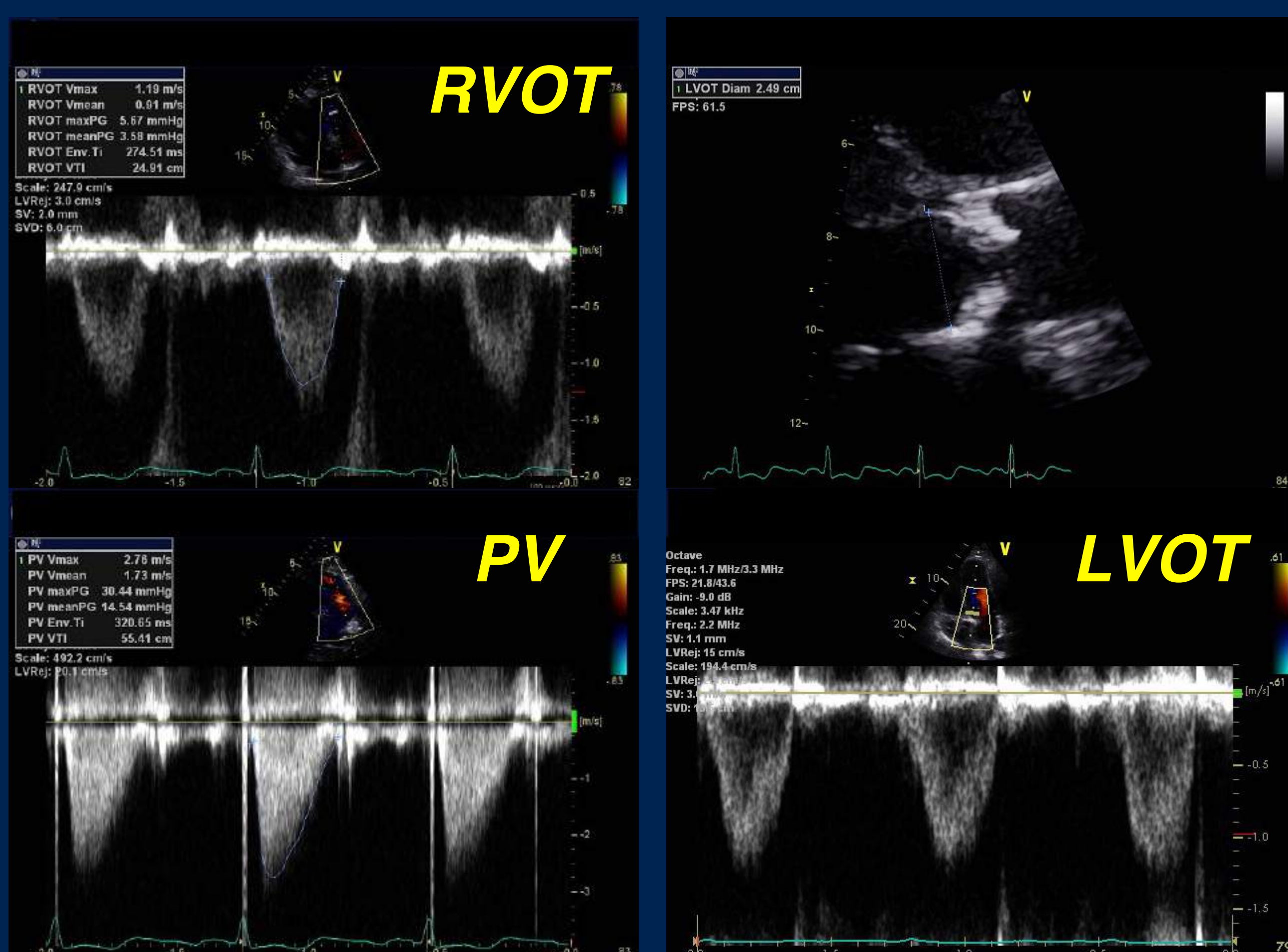
STJ (cm)	*2.8*
PG (mmHg)	62
MG (mmHg)	36
AVA (cm^2)	1.59
AVAi (cm^2/m^2)	0.76

Moderate AS

High output state



Consistent grading		Inconsistent grading	
AVA (cm^2)	≥1	AVA (cm^2)	≥1
ΔPm (mmHg)	≤40	ΔPm (mmHg)	>40
n	983	*n*	[illegible]
stroke volume (mL)	79 ± 15*	stroke volume (mL)	107 ± 15*
Inconsistent grading		**Consistent grading**	
AVA (cm^2)	<1	AVA (cm^2)	<1
ΔPm (mmHg)	≤40	ΔPm (mmHg)	>40
n	997	*n*	1338
stroke volume (mL)	66 ± 11*	stroke volume (mL)	70 ± 14*



LVOT peak vel. 1.2m/sec
LVOT VTI 27cm
(LVOTd 2.5cm)
SV (Doppler) 132mL
SVi 63mL/m2

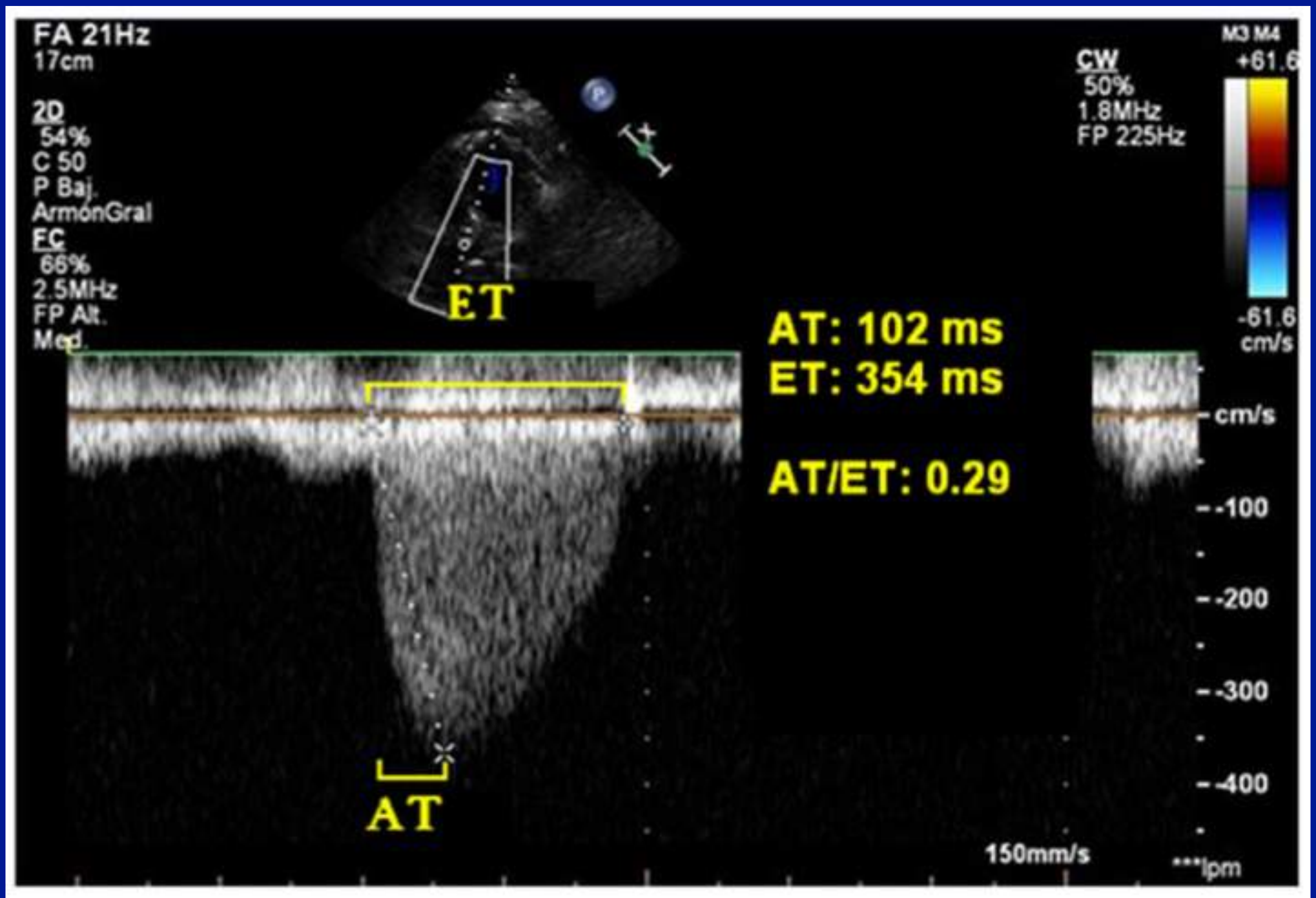
Biplane Simpson's:
LVEDV 244mL
LVESV 118mL
SV (2D) 126mL

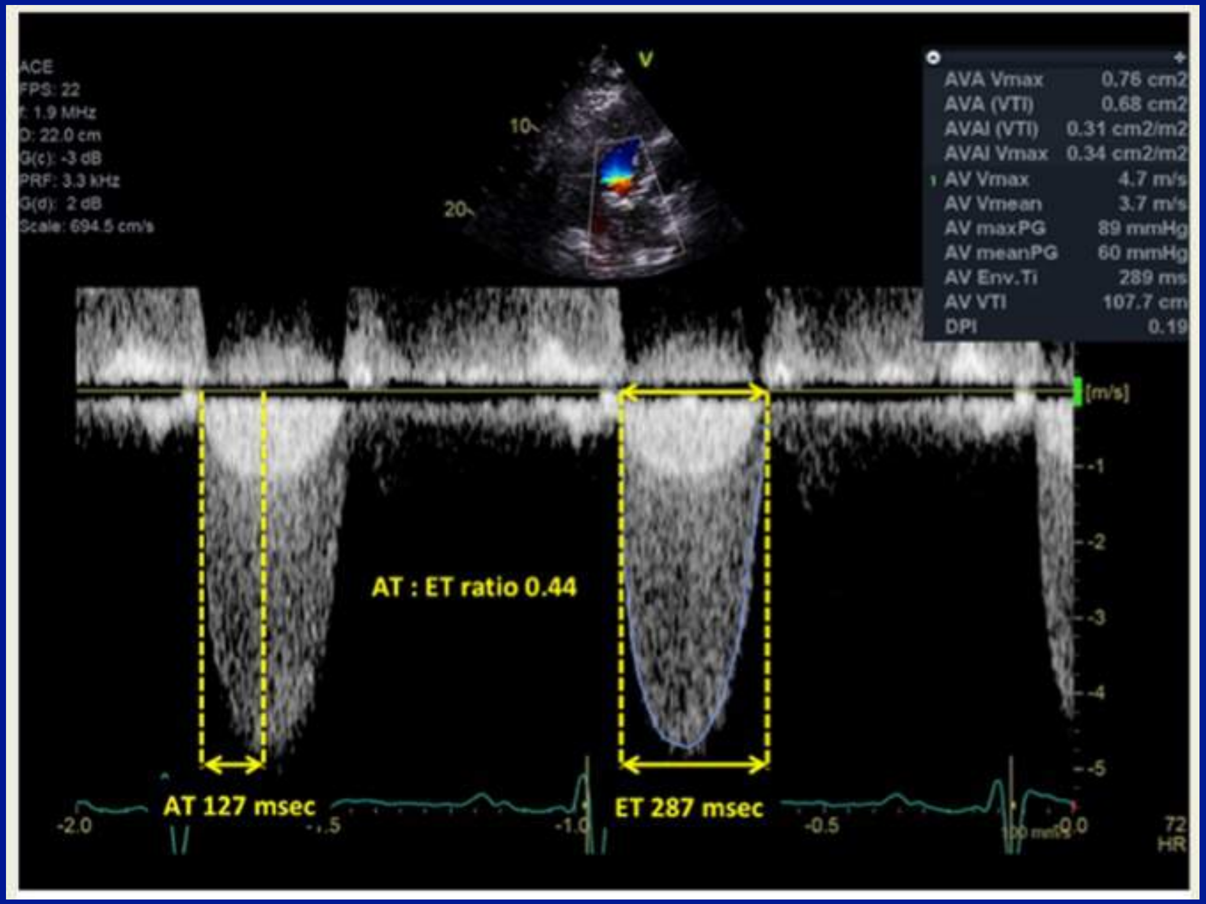
CO ~10-11L/min

Shape of the Doppler signal ("Late peaking" = Increasing severity)

Ratio of Acceleration Time to Ejection Time for Assessing Aortic Stenosis Severity

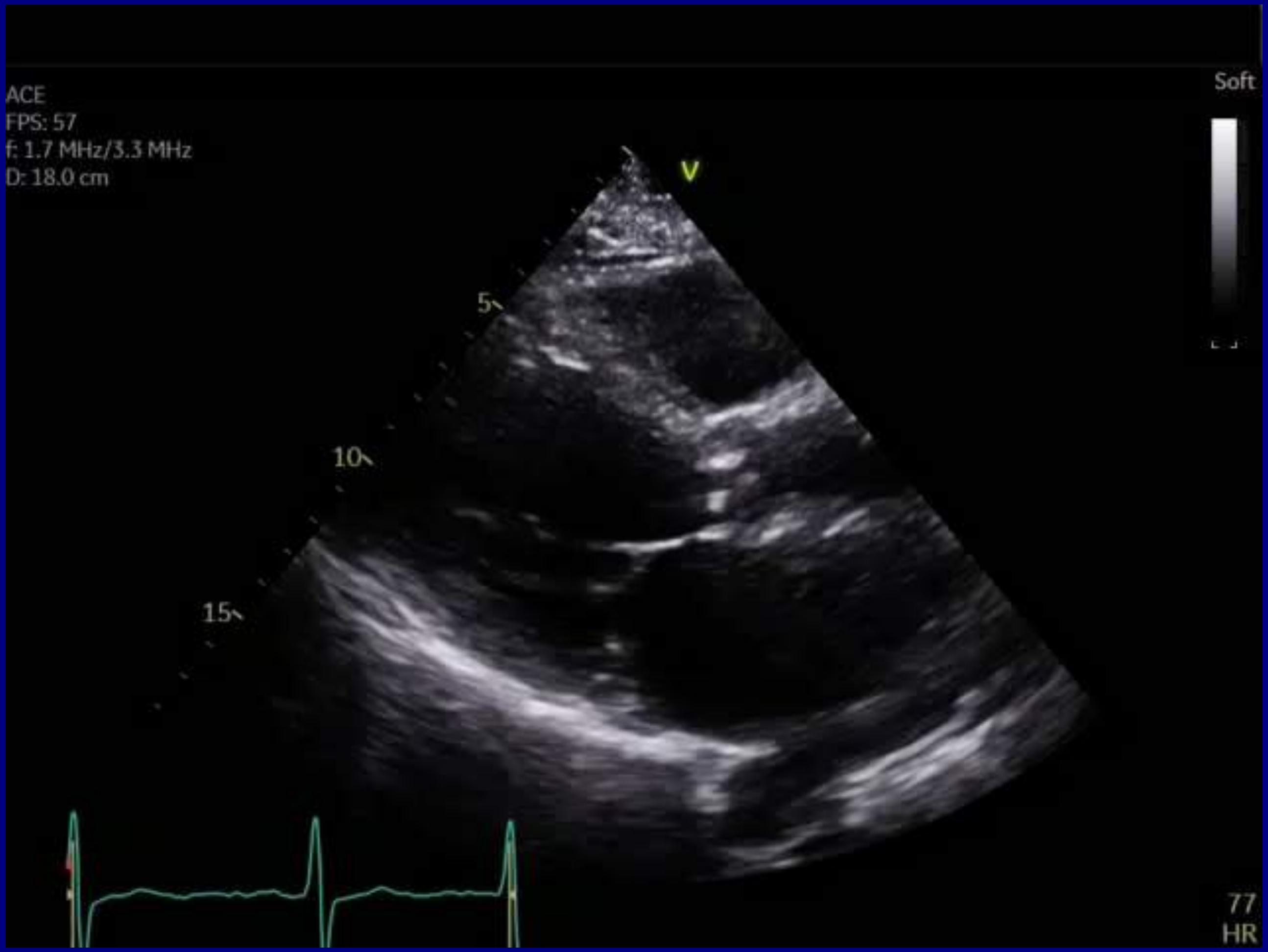
Gamaza-Chulian S, et al. Echocardiography 2015;32:1754– 1761

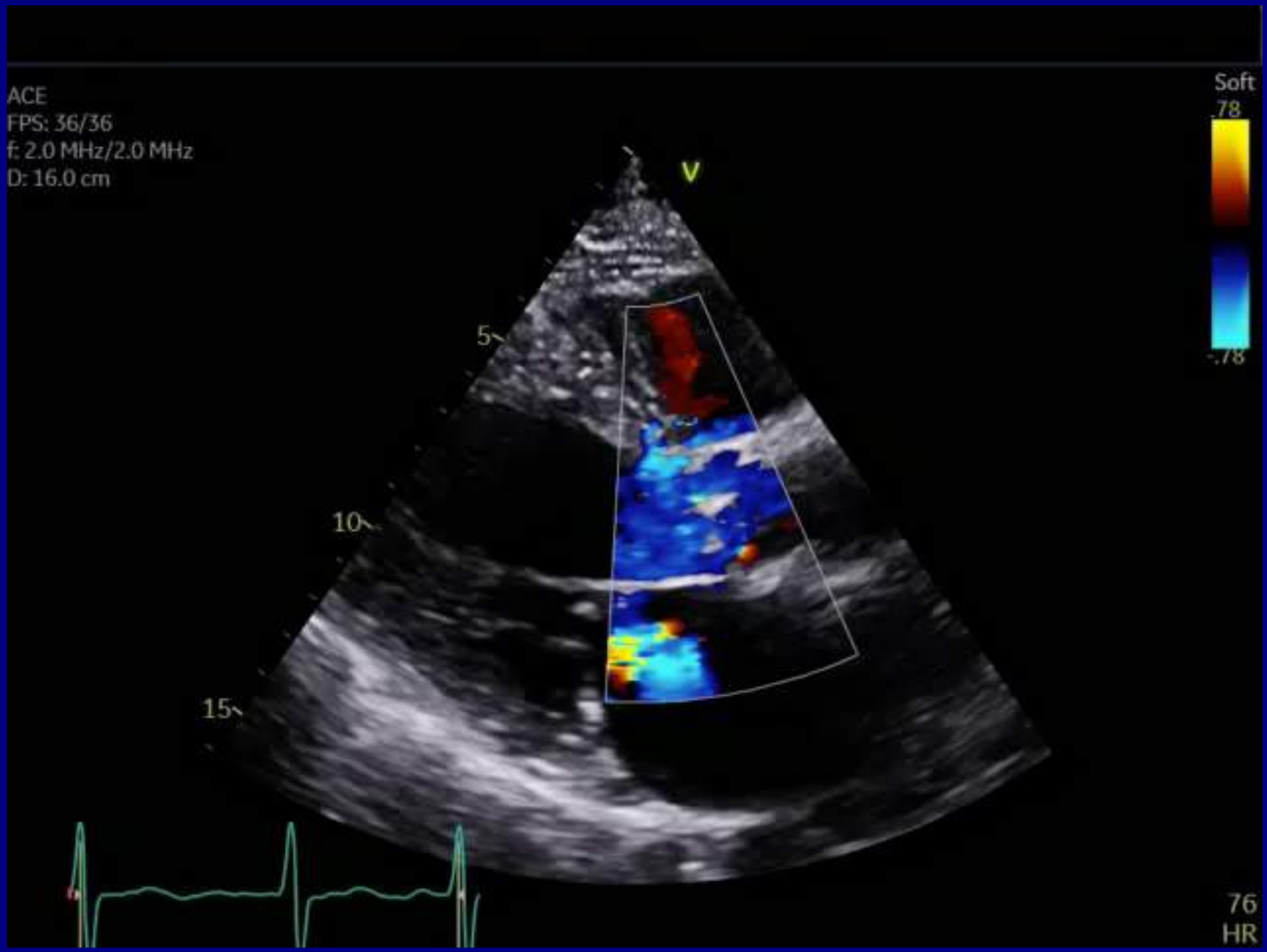




- AT/ET discriminates symptomatic from asymptomatic patients (AUC ROC 0.91)
  - Cutoff AT/ET >0.35
    - Sn 77% and Sp 100%
    - Higher NT-proBNP levels (9885±3111 vs 2600±1175, *P*<0.001)

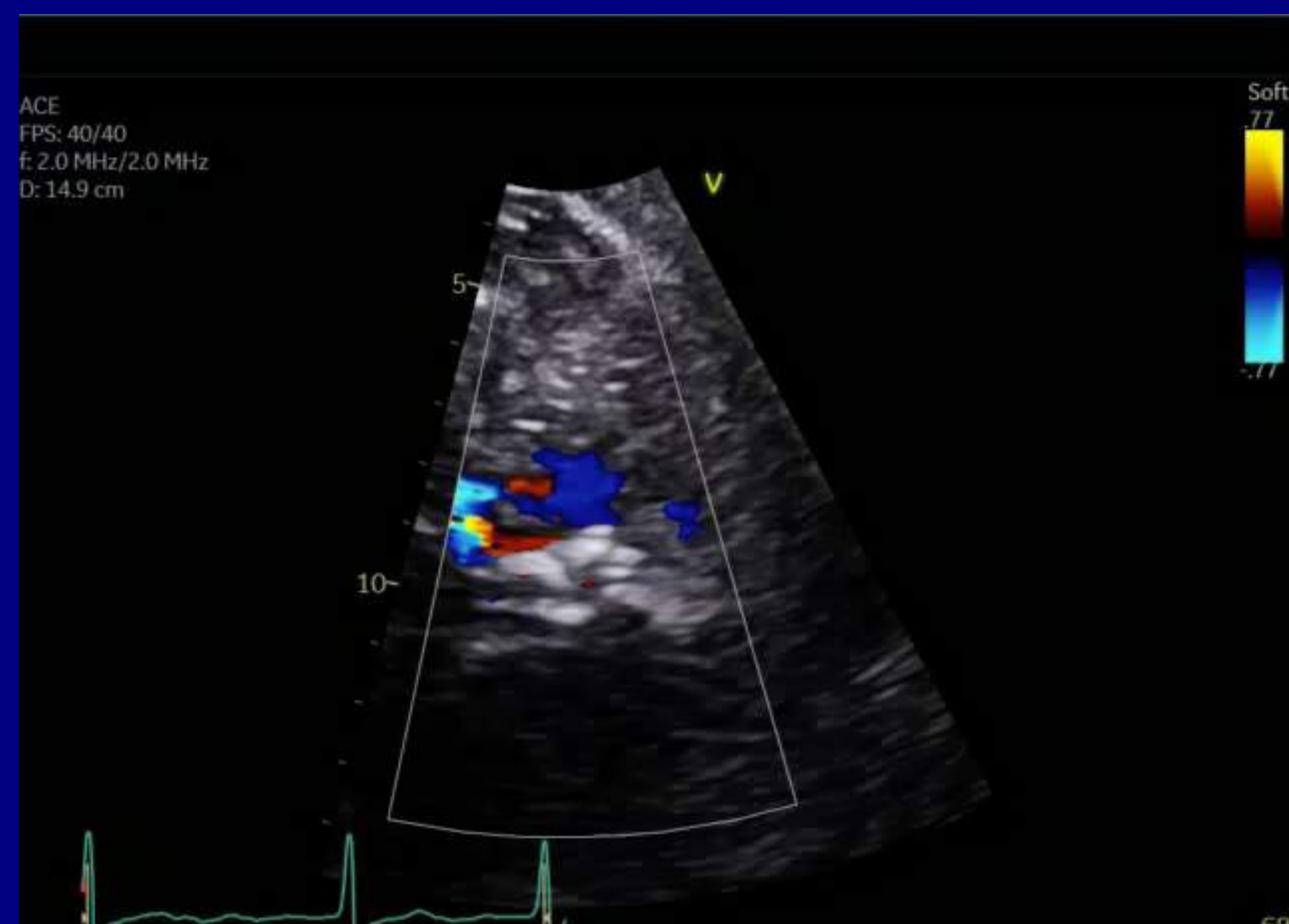
88yo male SOB

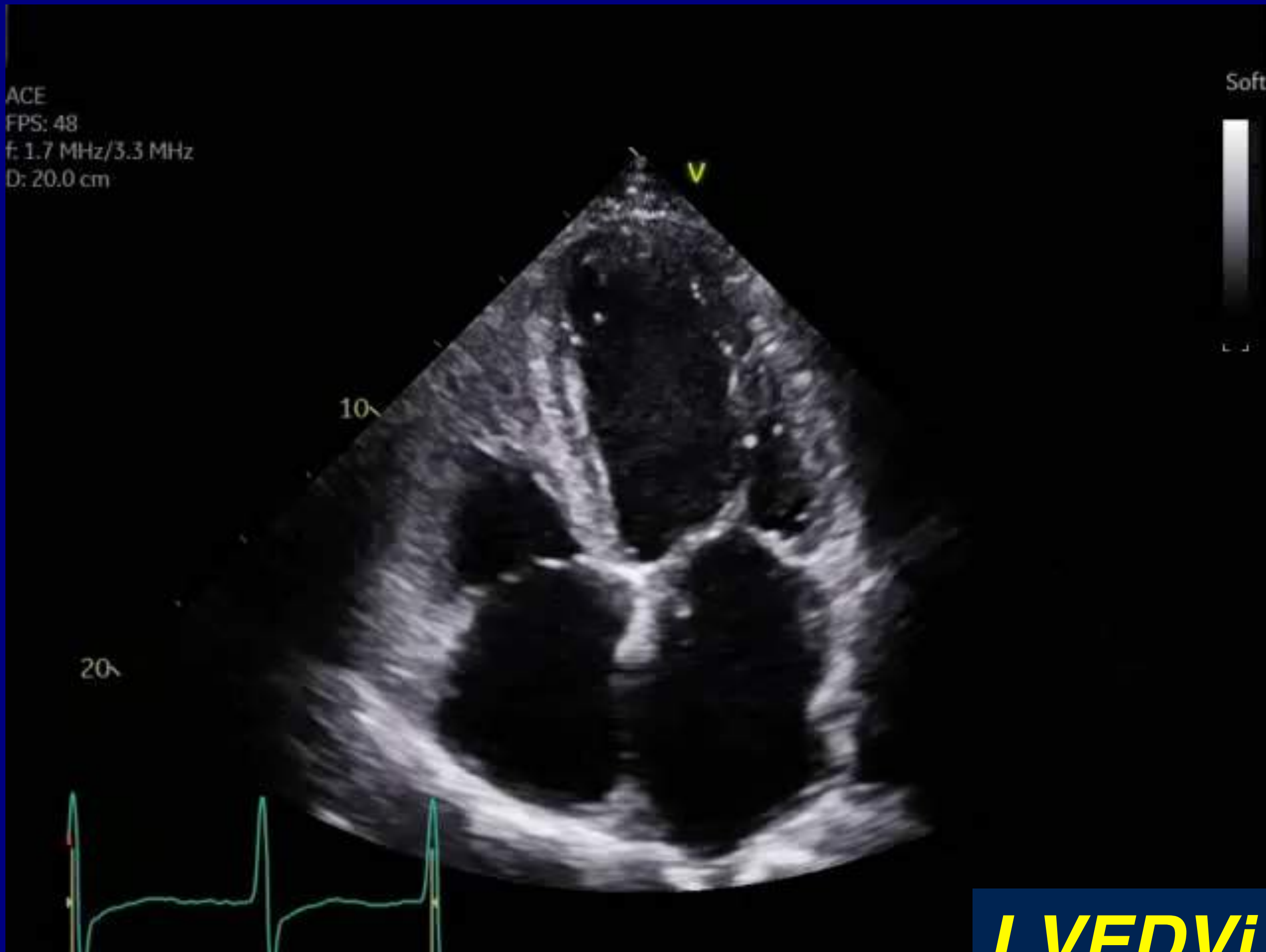




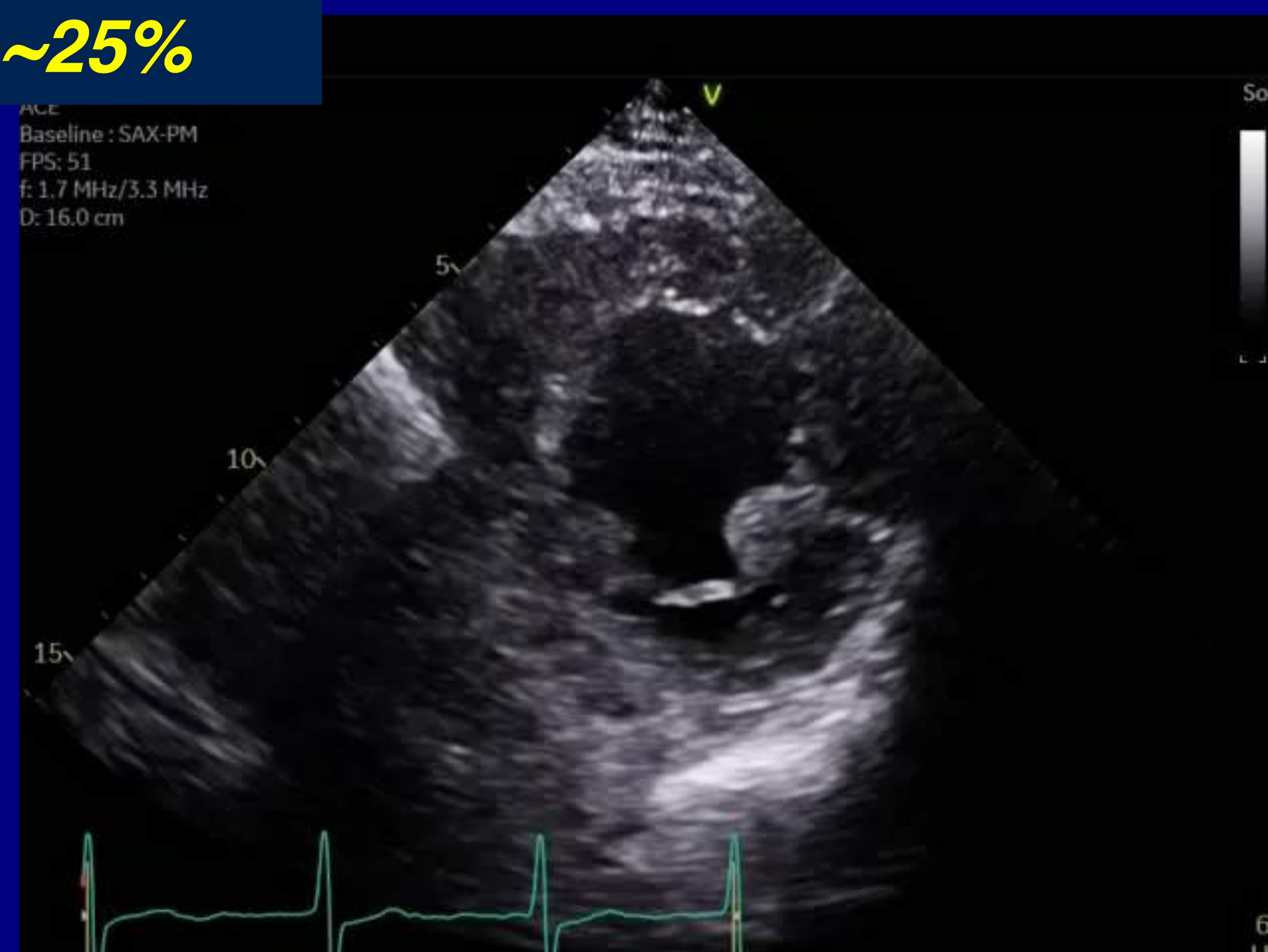

Soft
97
MHz/3.3 MHz
.8 cm
V
5
10
74
HR

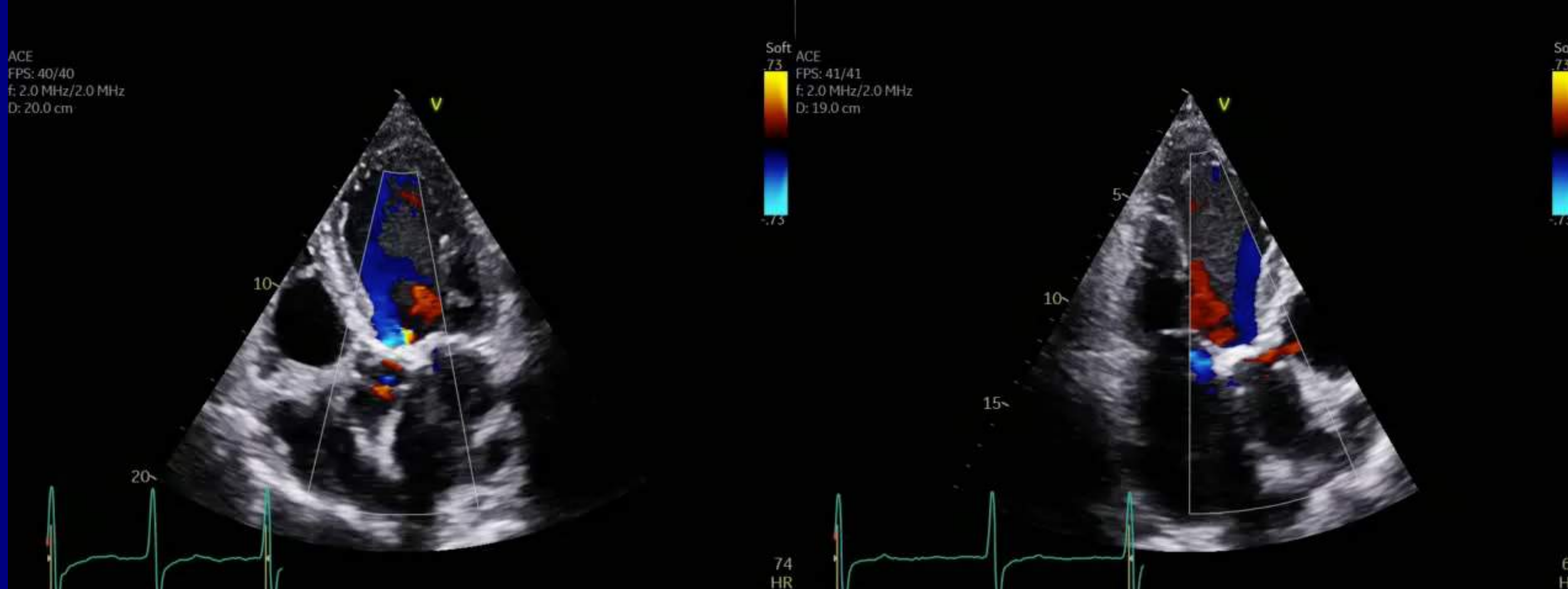

1 LVOT Diam 2.2 cm
f: 1.7 MHz/3.3 MHz
D: 13.1 cm
Soft
V
LVOT$_D$ 2.2cm
5
10
81
HR

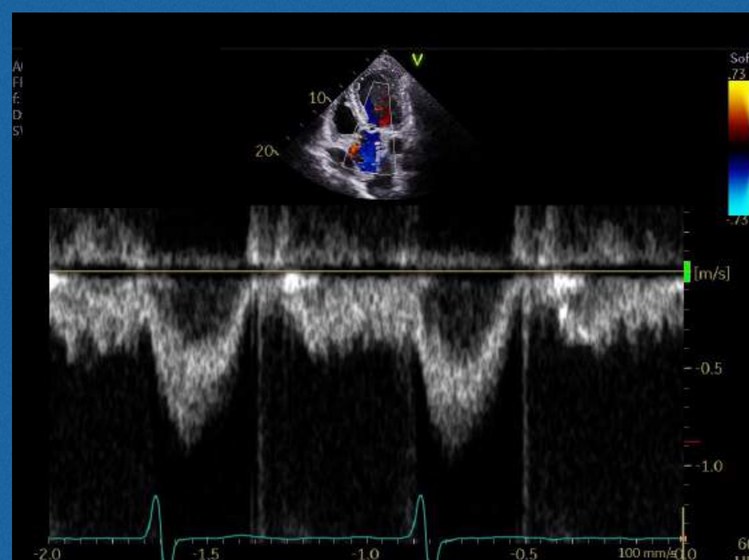

ACE
FPS: 40/40
f: 2.0 MHz/2.0 MHz
D: 14.9 cm
Soft
77
-.77
V
5
10



LVEDVi 106mL/m^2
LVEF ~25%



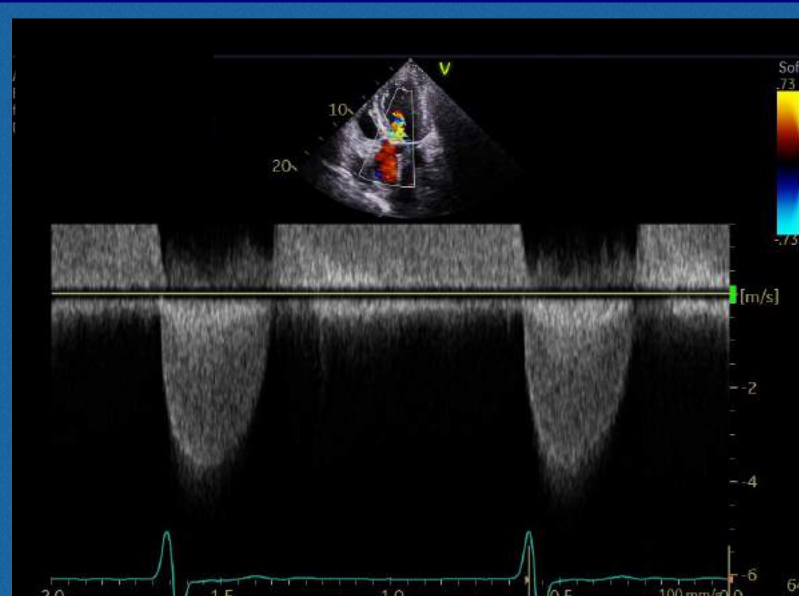




LVOT peak vel. 0.9m/s

LVOT VTI 18cm

($LVOT_D$ 2.2cm)



AV peak vel. 3.6m/sec
AV VTI 91cm
AV peak gradient 52mmHg
AV mean gradient 35mmHg
DSI 0.20
AVA 0.75cm^2
SV 68mL

LFLG AS with reduced LVEF

(Classical LFLG AS)

True Severe AS

Severe valvular stenosis
Wall stress exceeds compensatory hypertrophy
Afterload mismatch
Secondary LV systolic dysfunction

Pseudo-Severe AS

Moderate (or less) valvular stenosis
Underlying primary contractile dysfunction
Inadequate valve opening forces
Reduced cusp mobility and "apparent" stenosis

BOTH are low-flow states resulting in low pressure gradients but calculated EOA in the severe range

Hemodynamic Definition:

AVA <1.0cm^2
Mean gradient <40mmHg
LVEF <50% (<40% 2009)
SVi <35mL/m^2 (2017)

1. Nishimura RA, et al. JACC 2014;63:357-185.
2. Baumgartner H, et al. JASE 2017;30:372-392.
3. Baumgartner H, et al. Eur Heart J 2017;38:2739-2791.

Low-Dose Dobutamine Stress Echocardiography (C-LFLG AS)

Protocol for assessment of AS severity:

Starting dose 2.5-5.0mcg/kg/min

Incremental increases q3-5minutes

Maximum dose of 20mcg/kg/min

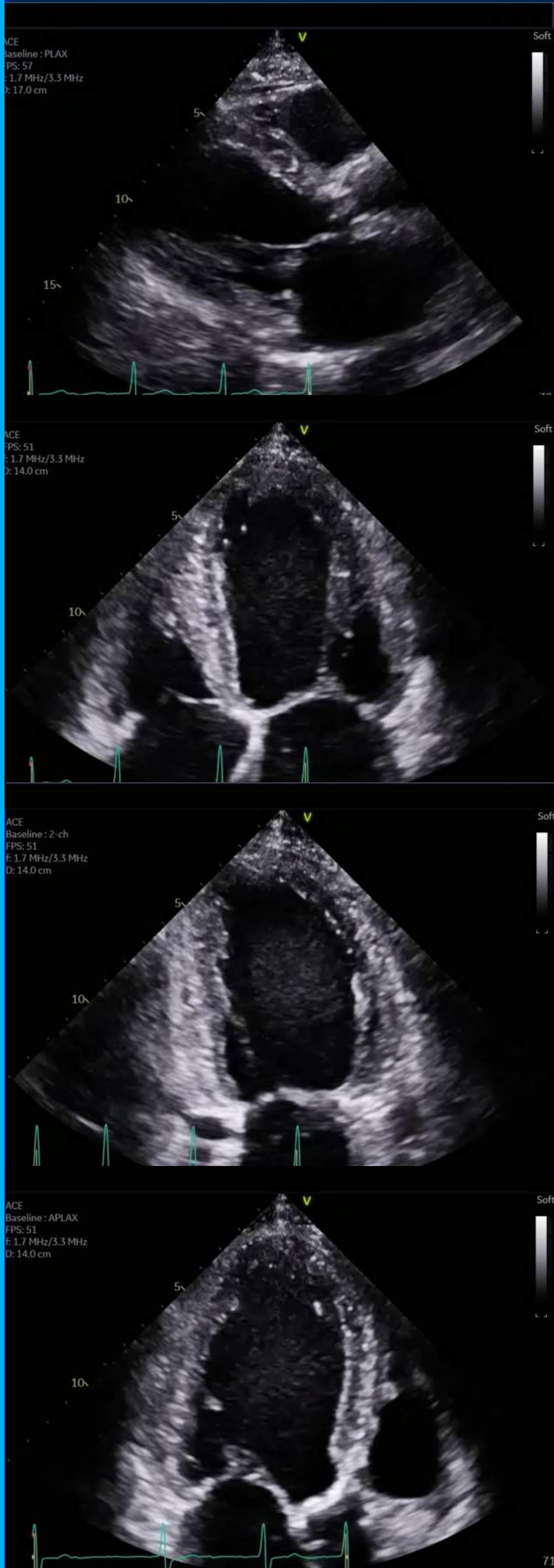
End-points:

1. Positive result
2. HR increases ***≥10-20bpm over baseline or ≥100bpm***
3. Symptomatic, hypotension, arrhythmias

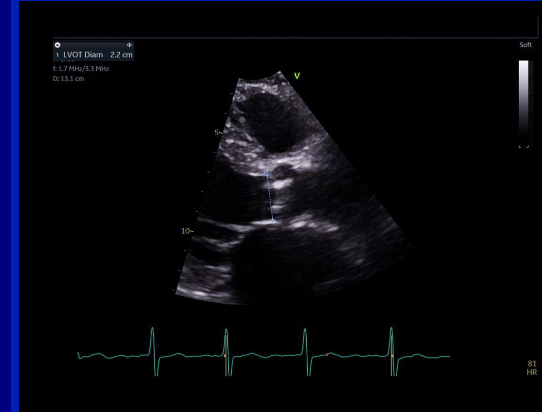
	True Severe AS	***Pseudo-Severe AS***	***Indeterminate***
AVA	Incr by <0.2cm² Remains <1.0cm²	Incr by ≥0.3cm² Incr to ≥1.0cm²	No change
Mean Gradient	Incr to (>30)-40mmHg *(Peak vel. ≥4.0m/sec)*	No change	No change
Incr SV >20% (FR {*CR*} +)	Yes	Yes	No

1. Nishimura RA, et al. JACC 2014;63:357-185. 2. Baumgartner H, et al. JASE 2009;22:1-22. 3. Baumgartner H, et al. Eur Heart J 2017;38:2739-2791. 4. Baumgartner H, et al. JASE 2017;30:372-392.

Baseline



Db 15mcg/kg/min



LVOTd 2.2cm

Baseline

LVOT VTI 18cm
AV peak vel. 3.6ms^{-1}
AV VTI 91cm
PG/MG 52/35mmHg
DSI 0.20
AVA 0.75cm^2
SV 68mL

Db 15mcg/kg/min

LVOT VTI 25cm
AV peak vel. 4.6ms^{-1}
AV VTI 100cm
PG/MG 85/56mmHg
DSI 0.24
AVA 0.92cm^2
SV 95mL

%Δ SV 40%

True severe AS with FR {CR+} ACC D2

Paradoxical LFLG AS (Preserved EF):

European Heart Journal (2010) 31, 281–289
doi:10.1093/eurheartj/ehp361

REVIEW

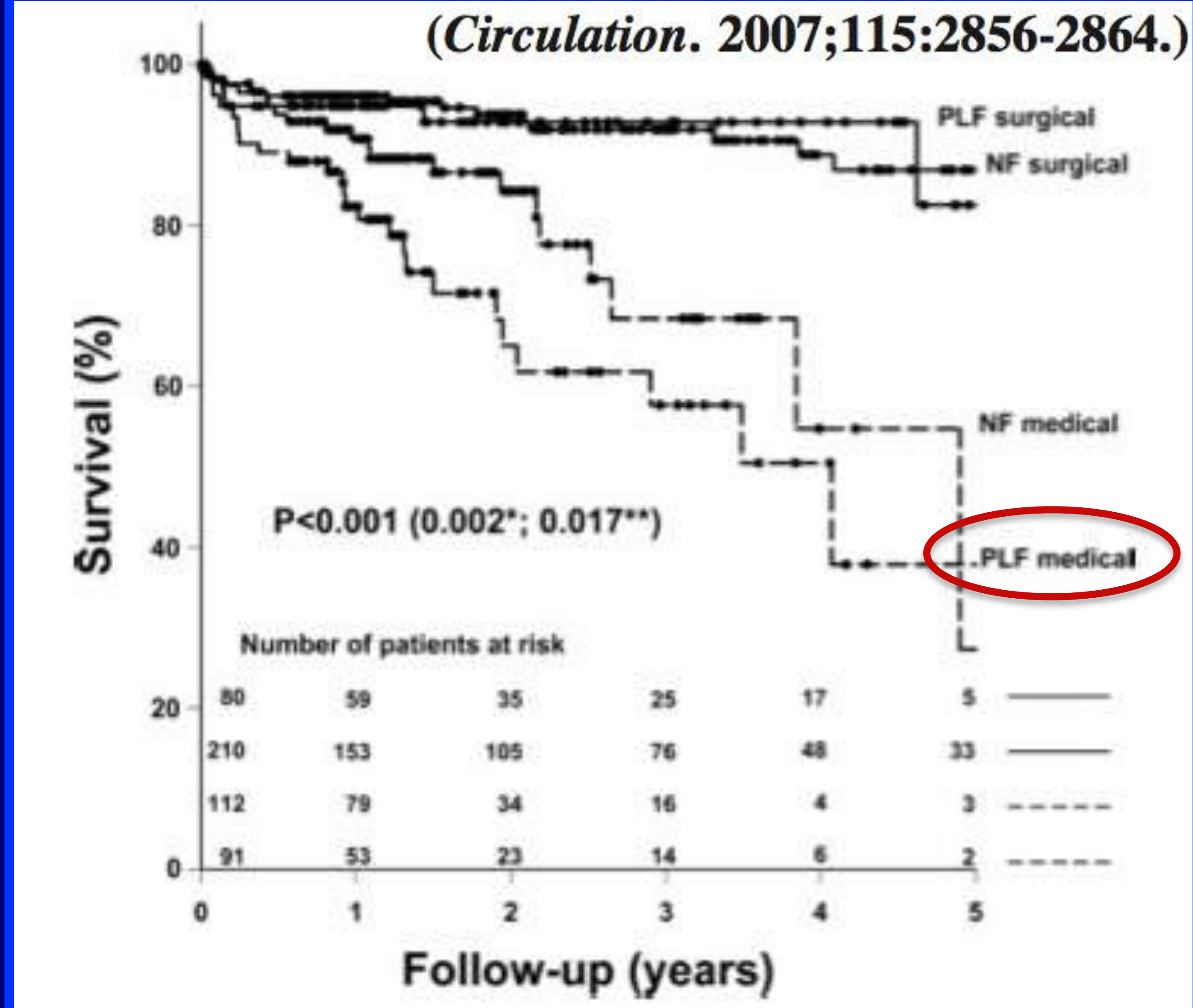
Paradoxical low flow and/or low gradient severe aortic stenosis despite preserved left ventricular ejection fraction: implications for diagnosis and treatment

Jean G. Dumesnil[1*], Philippe Pibarot[1*], and Blase Carabello[2]

Paradoxical Low-Flow, Low-Gradient Severe Aortic Stenosis Despite Preserved Ejection Fraction Is Associated With Higher Afterload and Reduced Survival

Zeineb Hachicha, MD; Jean G. Dumesnil, MD; Peter Bogaty, MD; Philippe Pibarot, DVM, PhD

(*Circulation*. 2007;115:2856-2864.)



1. AVA <1.0cm^2; Indexed AVA <0.6cm^2/m^2
2. LVEF >50%
3. SVi <35mL/m^2
4. *Other features:*
   - Female
   - **Higher valvulo-arterial impedence**
     - **{ Z_{Va} (mmHg/mL/m^2) = (SBP + Mean gradient) / SVi }**
   - Smaller and thicker ventricles (LVEDd<50mm; LVEDVi <60mL/m^2; RWT>0.45)
   - Lower mid-wall radius shortening (%)

ACC D3

** 30-40% have pseudo-severe AS*

Clavel 2013

Criteria that increase the likelihood of severe AS in patients with AVA <1.0cm² and MG <40mmHg in the presence of preserved EF (P-LFLG AS)

Clinical	*1. Physical examination consistent with severe AS* *2. Typical symptoms without other explanation* *3. Elderly (>70yoa)*
Qualitative data	*1. LVH* *2. Reduced longitudinal function without other explanation*
Quantitative data	*1. Mean gradient 30-40mmHg* *2. SVi <35mL/m² confirmed by other techniques (LVOTd measured by 3D TEE or MSCT; cMRI; Invasive data)*

Caveats to AVC by CT:

- *Anatomic severity (vs hemodynamic)*
- *Does not quantify leaflet fibrosis (underestimates severity in young and BAV)*

Pibarot P. JASE Oct 2016

ACC 2020 VHD Guidelines - CT-AVC thresholds for diagnosis of severe AS:

- 2000 in men
- 1300 in women

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

AR

Stages of Chronic AR

Stage	Definition	Valve Anatomy	Valve Hemodynamics	Hemodynamic Consequences	Symptoms
A	At risk of AR	■ BAV (or other congenital valve anomaly) ■ Aortic valve sclerosis ■ Diseases of the aortic sinuses or ascending aorta ■ History of rheumatic fever or known rheumatic heart disease ■ IE	AR severity: none or trace	None	None
B	Progressive AR	■ Mild to moderate calcification of a trileaflet valve BAV (or other congenital valve anomaly) ■ Dilated aortic sinuses ■ Rheumatic valve changes ■ Previous IE	■ Mild AR: ■ Jet width <25% of LVOT ■ Vena contracta <0.3 cm ■ Regurgitant volume <30 mL/beat ■ Regurgitant fraction <30% ■ ERO <0.10 cm^2 ■ Angiography grade 1 ■ Moderate AR: ■ Jet width 25%-64% of LVOT ■ Vena contracta 0.3-0.6 cm ■ Regurgitant volume 30-59 mL/beat ■ Regurgitant fraction 30% to 49% ■ ERO 0.10-0.29 cm^2 ■ Angiography grade 2	■ Normal LV systolic function ■ Normal LV volume or mild LV dilation	None
C	Asymptomatic severe AR	■ Calcific aortic valve disease ■ Bicuspid valve (or other congenital abnormality) ■ Dilated aortic sinuses or ascending aorta ■ Rheumatic valve changes ■ IE with abnormal leaflet closure or perforation	■ Severe AR: ■ Jet width ≥65% of LVOT ■ Vena contracta >0.6 cm ■ Holodiastolic flow reversal in the proximal abdominal aorta ■ Regurgitant volume ≥60 mL/beat ■ Regurgitant fraction ≥50% ■ ERO ≥0.3 cm^2 ■ Angiography grade 3 to 4 ■ In addition, diagnosis of chronic severe AR requires evidence of LV dilation	■ C1: Normal LVEF (>55%) and mild to moderate LV dilation (LVESD <50 mm) ■ C2: Abnormal LV systolic function with depressed LVEF (≤55%) or severe LV dilation (LVESD >50 mm or indexed LVESD >25 mm/m^2)	None; exercise testing is reasonable to confirm symptom status
D	Symptomatic severe AR	■ Calcific valve disease ■ Bicuspid valve (or other congenital abnormality) ■ Dilated aortic sinuses or ascending aorta ■ Rheumatic valve changes ■ Previous IE with abnormal leaflet closure or perforation	■ Severe AR: ■ Doppler jet width ≥65% of LVOT ■ Vena contracta >0.6 cm ■ Holodiastolic flow reversal in the proximal abdominal aorta ■ Regurgitant volume ≥60 mL/beat ■ Regurgitant fraction ≥50% ■ ERO ≥0.3 cm^2 ■ Angiography grade 3 to 4 ■ In addition, diagnosis of chronic severe AR requires evidence of LV dilation	■ Symptomatic severe AR may occur with normal systolic function (LVEF >55%), mild to moderate LV dysfunction (LVEF 40% to 55%), or severe LV dysfunction (LVEF <40%) ■ Moderate to severe LV dilation is present	■ Exertional dyspnea or angina or more severe HF symptoms

AR indicates aortic regurgitation; BAV, bicuspid aortic valve; ERO, effective regurgitant orifice; HF, heart failure; IE, infective endocarditis; LV, left ventricular; LVEF, left ventricular ejection fraction; LVESD, left ventricular end-systolic dimension; and LVOT, left ventricular outflow tract.

ACC/AHA 2020

Chronic Severe AR

Echo Assessment

Role of Echo

Define:

1. **Etiology & Mechanism**
2. **Morphology**
3. **Severity**
4. Impact of regurgitant lesion on cardiac remodeling

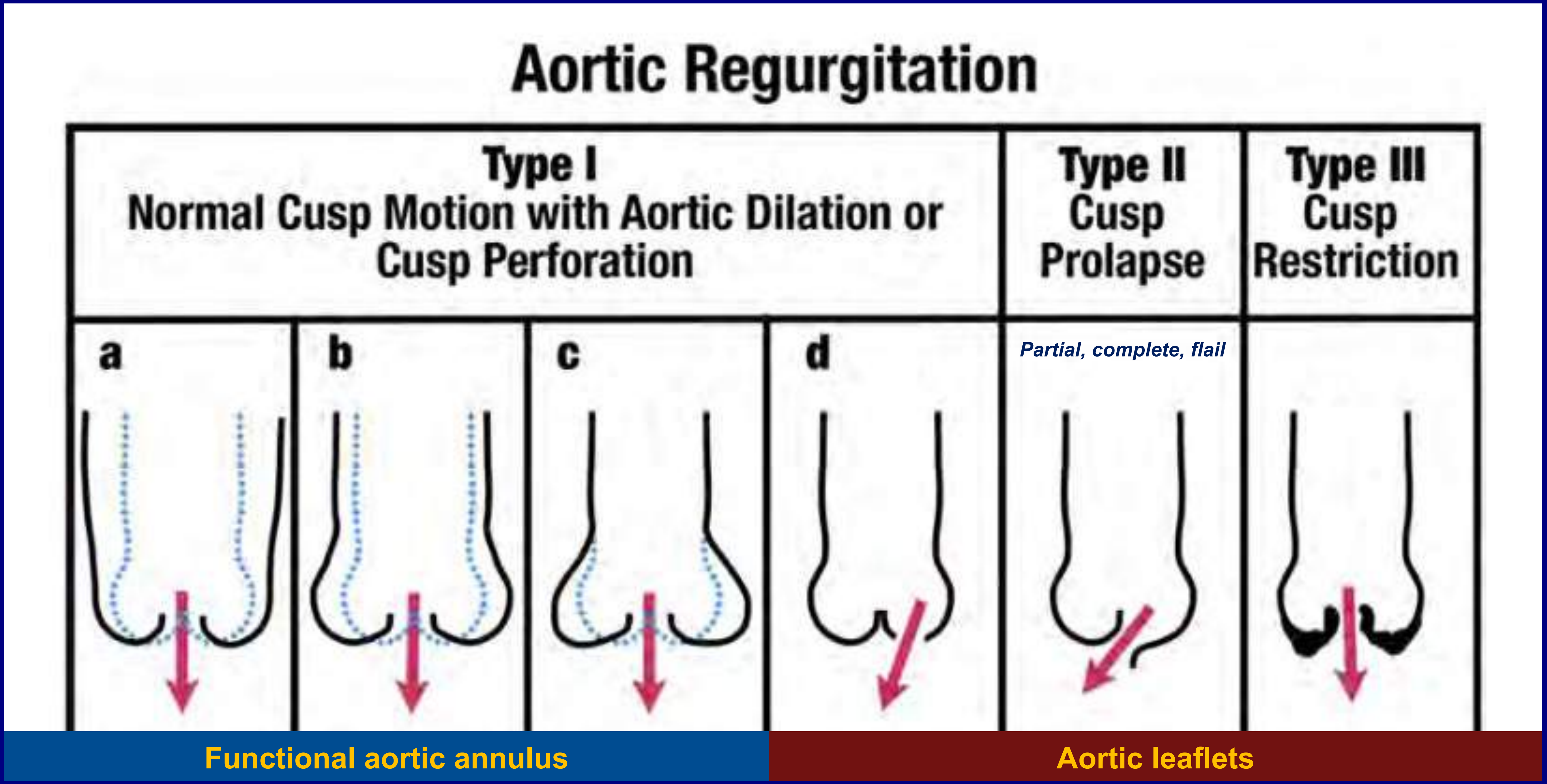
Zoghbi WA, et al. Recommendations for noninvasive evaluation of native valvular regurgitation. JASE 2017;30:303-371.

Mechanisms & Etiology of AR

Mechanism	Etiology
Congenital ***leaflet*** abnormalities	• Unicuspid, bicuspid, quadricuspid valves • VSD
Acquired ***leaflet*** abnormalities	• Senile calcification • IE • Rheumatic disease • Radiation- or toxin-induced valvulopathy (Anorectic drugs, carcinoid)
Congenital/genetic ***aortic root*** abnormalities	• Annuloaortic ectasia • CTD (Loeys Deitz, Ehlers-Danlos, Marfan, Osteogenesis imperfecta)
Acquired ***aortic root*** abnormalities	• Idiopathic root dilatation • Systemic hypertension • Autoimmune disease (SLE, Ankylosing spondylitis, Reiter's) • Aortitis (Syphilitic, Takayasu's) • Aortic dissection • Trauma

Zoghbi WA, et al. Recommendations for noninvasive evaluation of native valvular regurgitation. JASE 2017;30:303-371.

Classification of AR Morphology



Type 1a = Sinotubular junction enlargement and dilatation of the ascending aorta

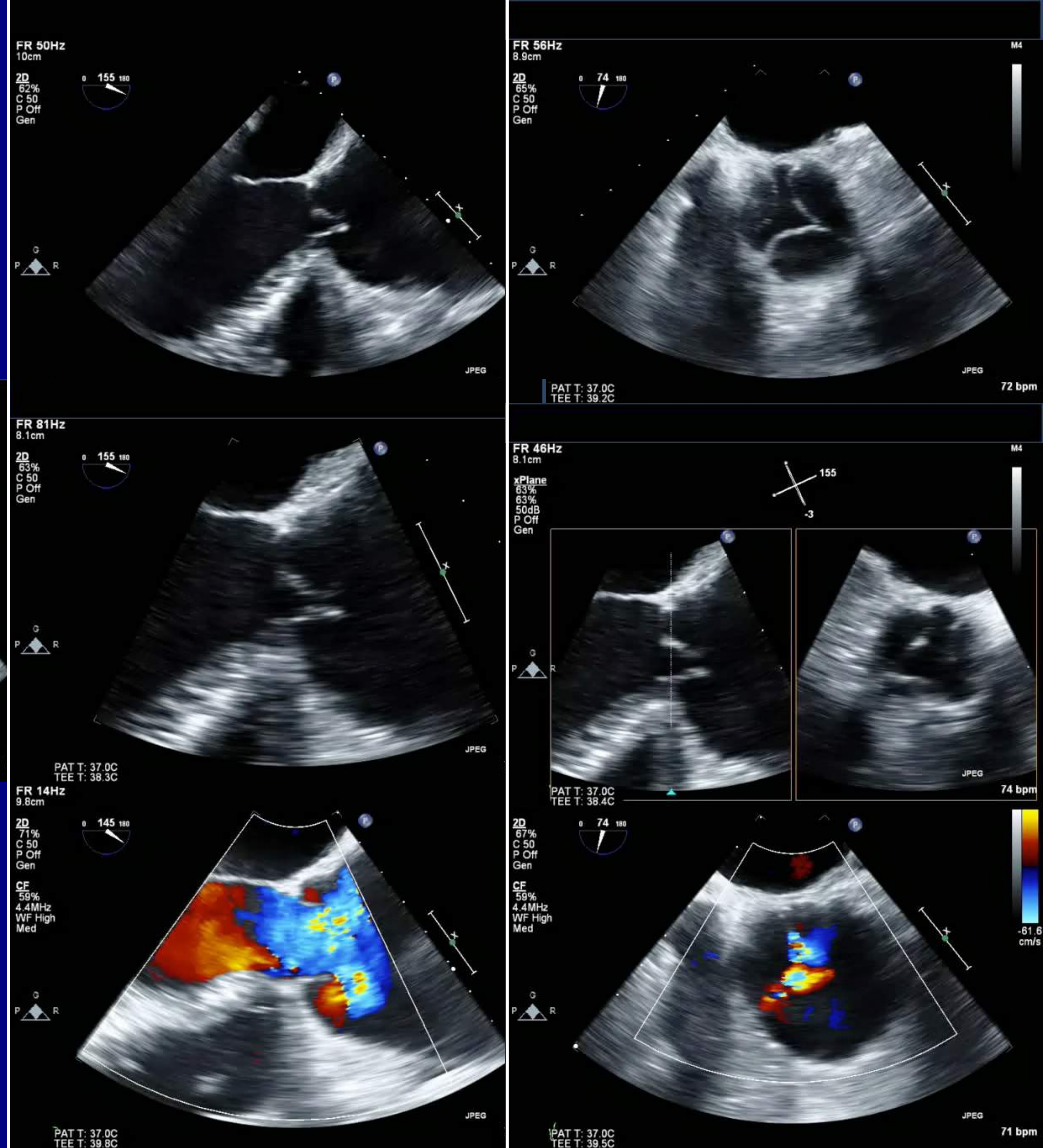
Type 1b = Dilatation of the sinuses of Valsalva and sinotubular junction (BAV, Marfan, E-D)

Type 1c =Dilatation of the ventriculoarterial junction ("Annulus")

Type 1d = Cusp perforation or fenestration without a primary functional aortic annular lesion

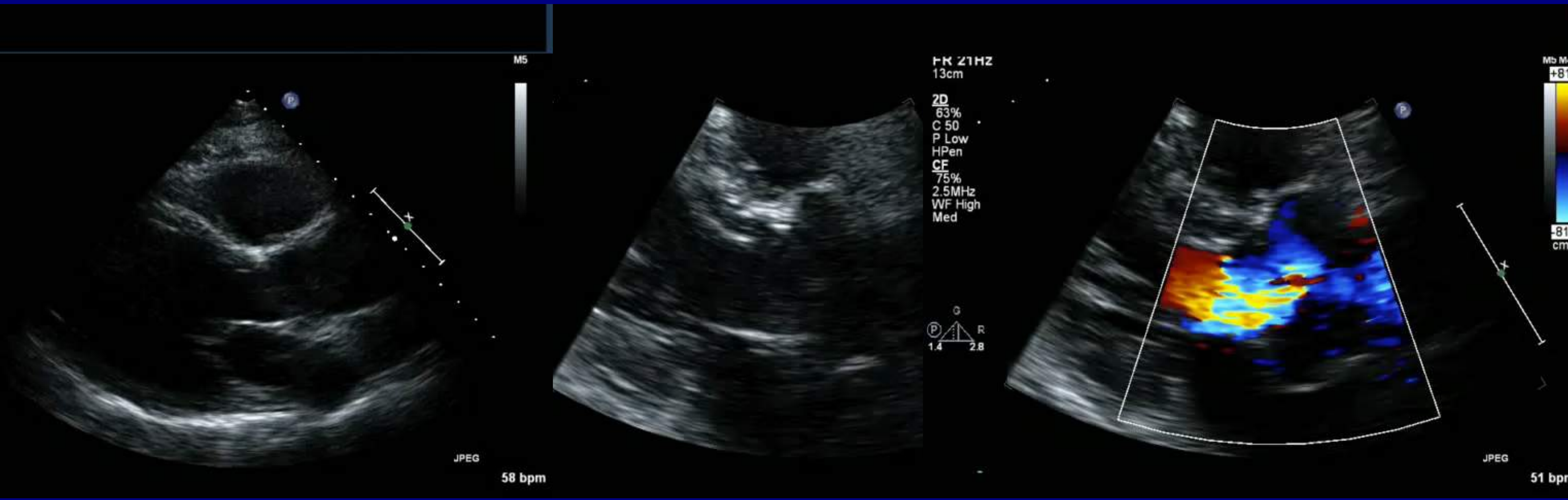
Zoghbi WA, et al. Recommendations for noninvasive evaluation of native valvular regurgitation. JASE 2017;30:303-371.

TYPE IA



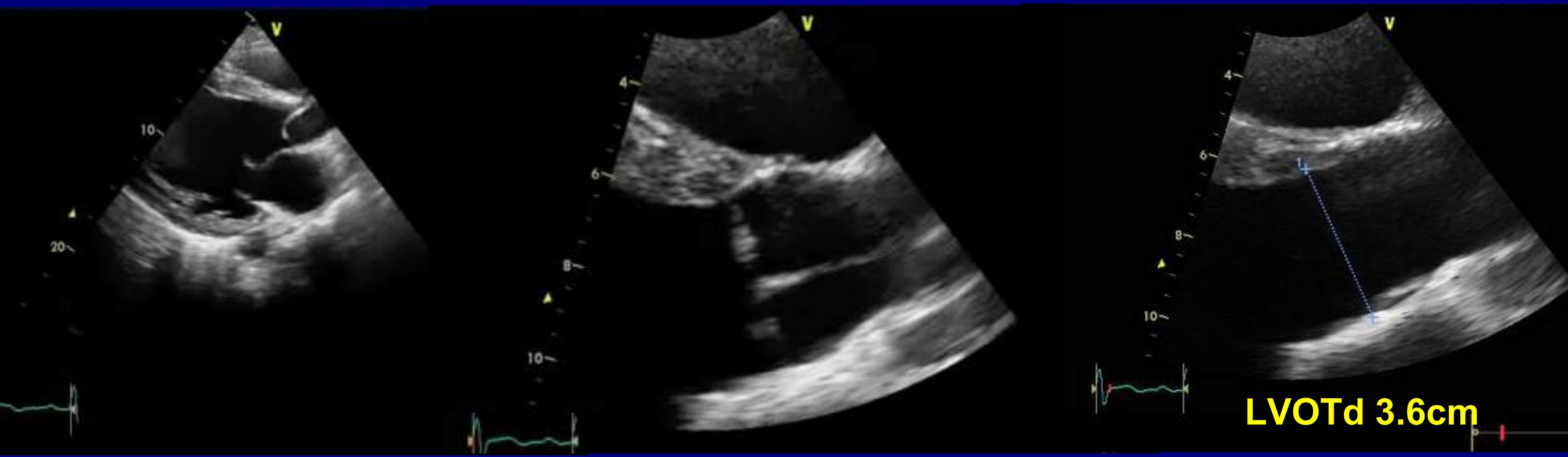
AscAo Diameter
7.3cm

TYPE IB

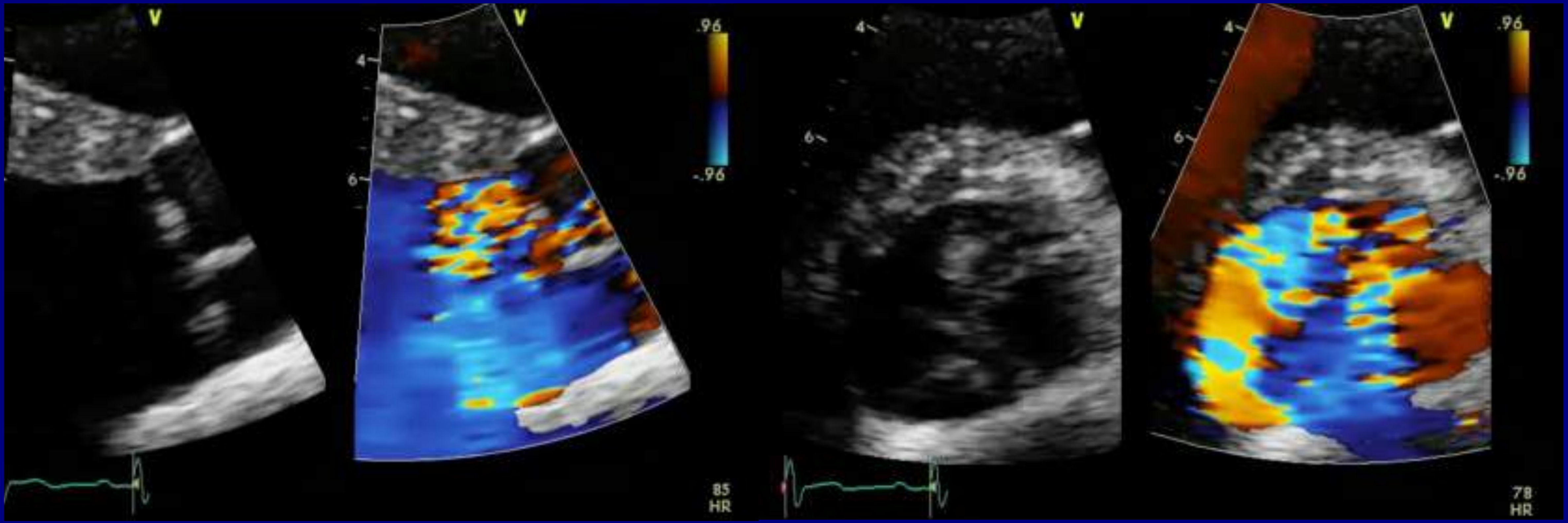


Trans-sinus diameter 4.9cm; STJ diameter 3.7cm; AscAo diameter 4.0cm

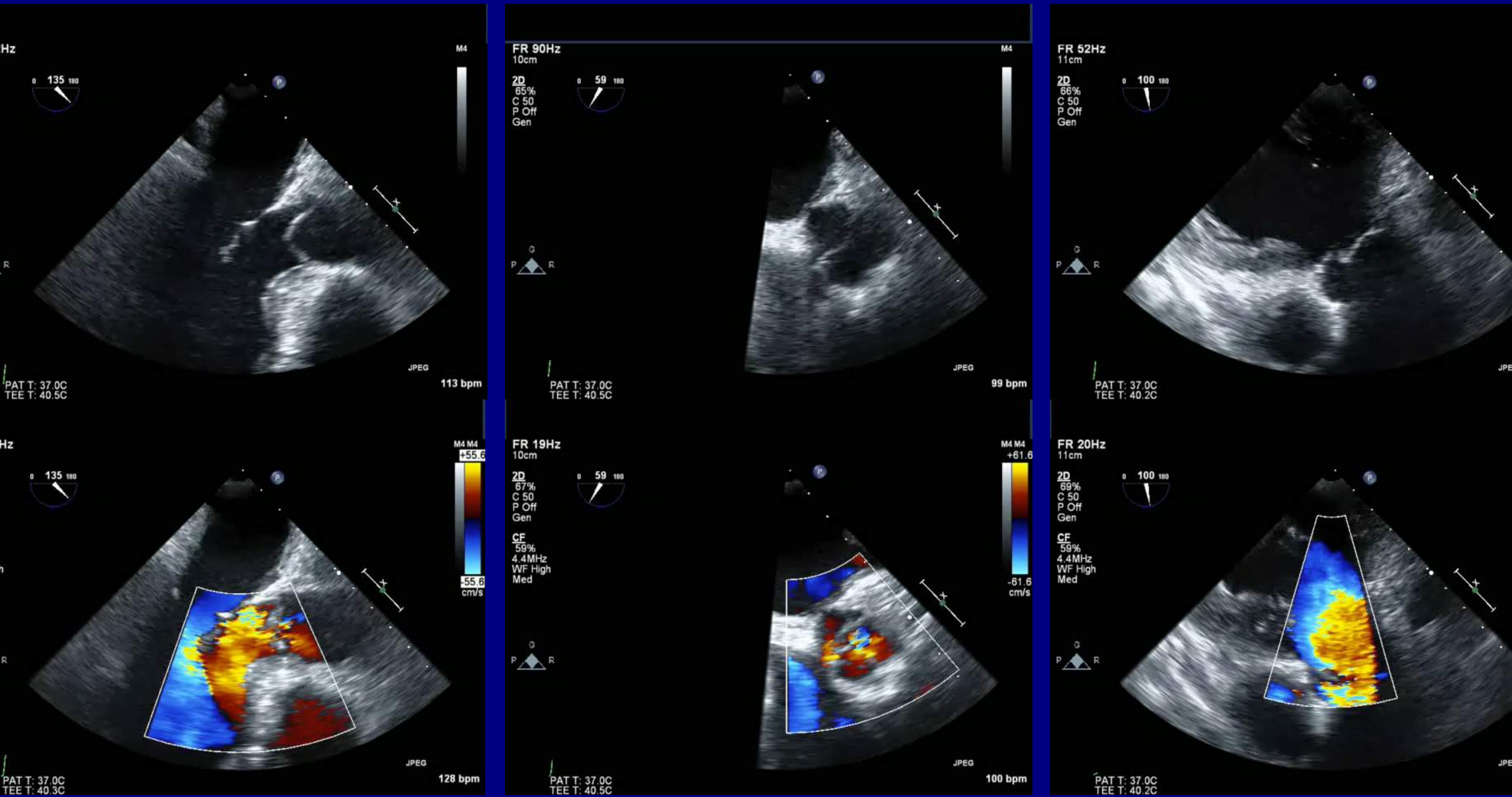
TYPE IC



"Annular" dilatation; Flail MV (Osteogenesis imperfecta)

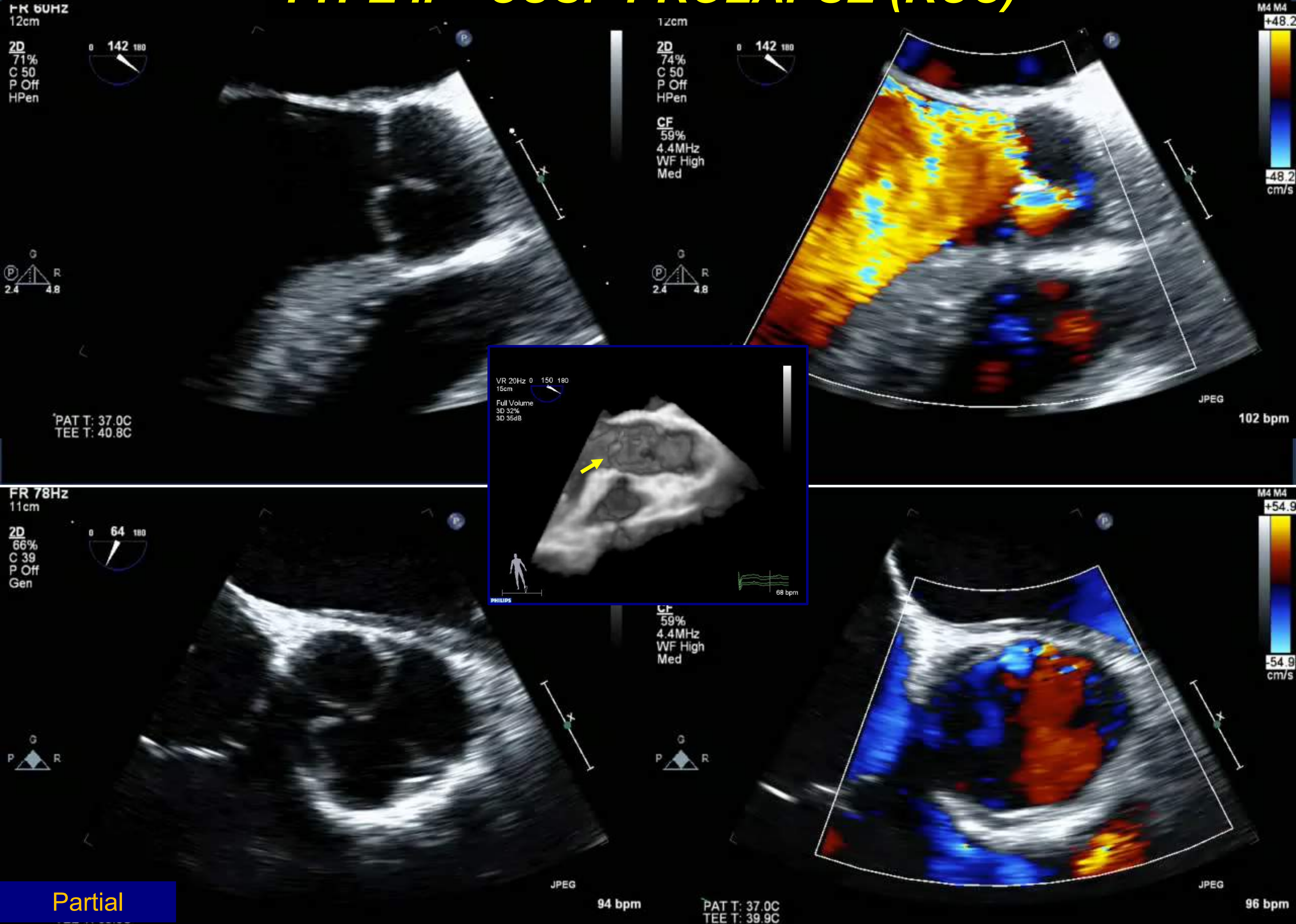


TYPE ID



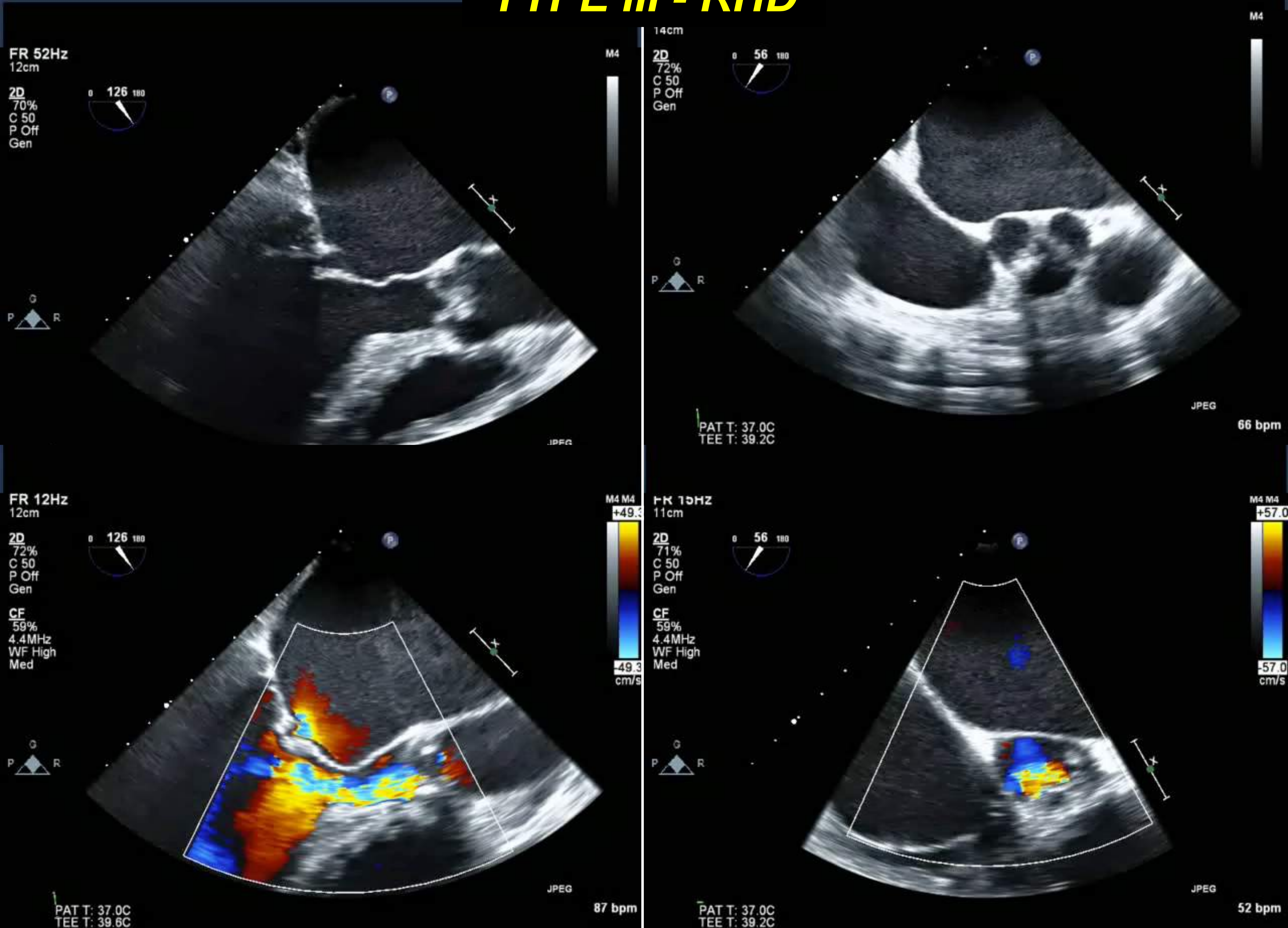
Perforated right coronary cusp

TYPE II – CUSP PROLAPSE (RCC)

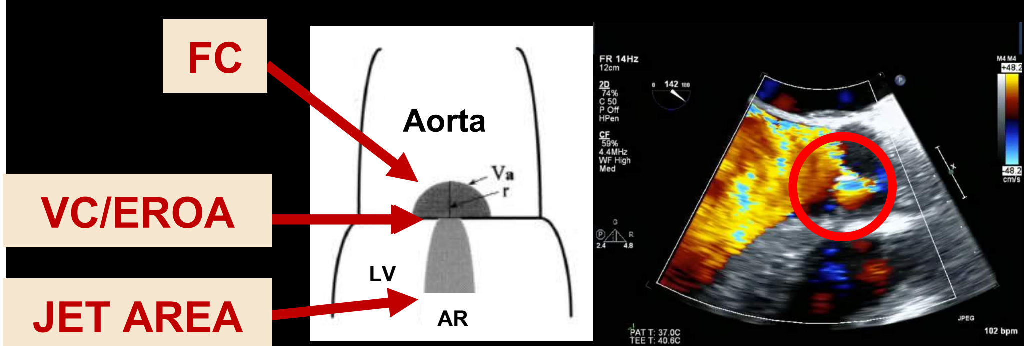
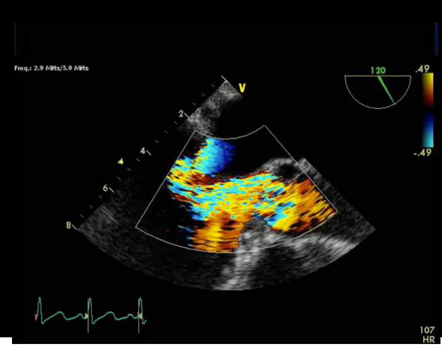


Partial

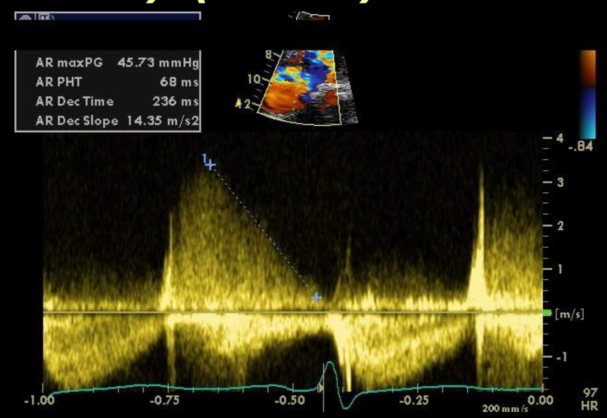
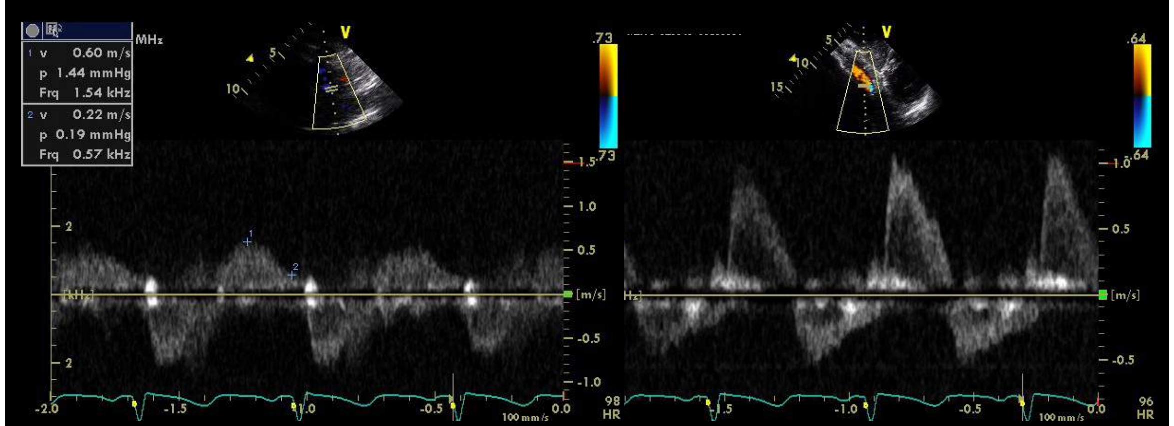
TYPE III - RHD


FR 52Hz
12cm
2D
70%
C 50
P Off
Gen
126
14cm
2D
72%
C 50
P Off
Gen
56
PAT T: 37.0C
TEE T: 39.2C
66 bpm
FR 12Hz
12cm
2D
72%
C 50
P Off
Gen
CF
59%
4.4MHz
WF High
Med
126
+49.3
-49.3
cm/s
PAT T: 37.0C
TEE T: 39.6C
87 bpm
FR 15Hz
11cm
2D
71%
C 50
P Off
Gen
CF
59%
4.4MHz
WF High
Med
56
+57.0
-57.0
cm/s
PAT T: 37.0C
TEE T: 39.2C
52 bpm
JPEG

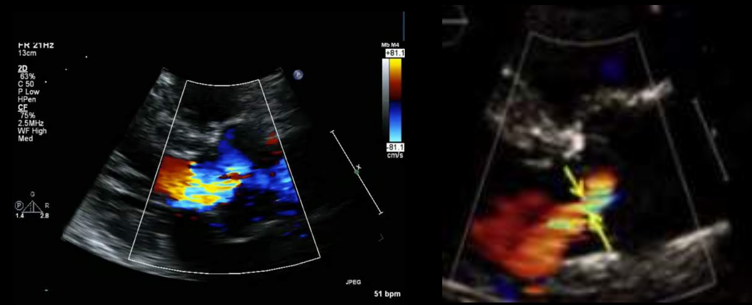
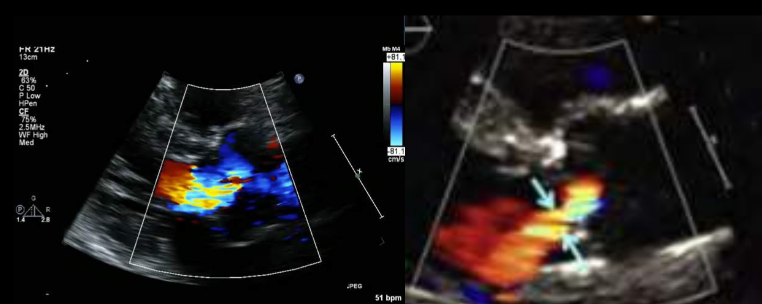
Grading Severity of Chronic Severe AR by Echo

Parameter	*Mild AR*	*Moderate AR*	*Severe AR*
• *Aortic leaflets* 	Normal or abnormal	Normal or abnormal	**Abnormal/flail or wide coaptation defect***
• *LV size*	Normal	Normal or dilated	**Usually dilated***
QUALITATIVE			
• *Flow convergence (CFD)* 	None or very small	Intermediate	**Large***
• *Jet width in LVOT (CFD)* 	Small in central jets	Intermediate	**Large in central jets; Variable in eccentric jets***

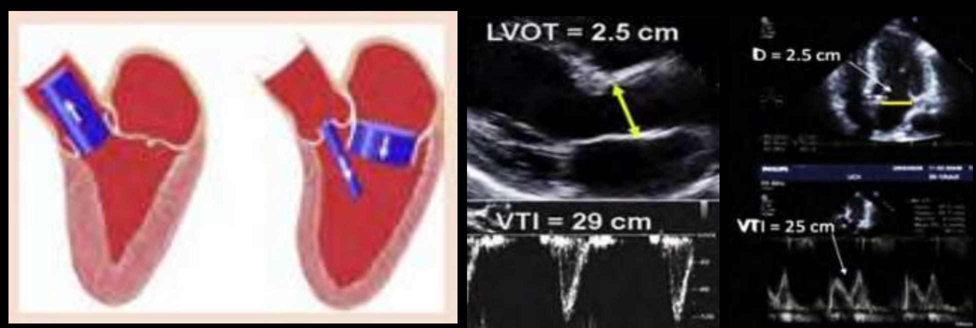
Grading Severity of Chronic Severe AR by Echo

Parameter	*Mild AR*	*Moderate AR*	*Severe AR*
QUALITATIVE Doppler			
• ***Jet density and deceleration rate (PHT msec) (CWD)*** 	Incomplete or faint >500msec	Dense 200-500msec	**Dense** **<200msec***
• ***Diastolic flow reversal in descending aorta (PWD)*** 	Brief, early diastolic reversal	Present in descending thoracic aorta (Holodiastolic)	**Present in abdominal aorta****

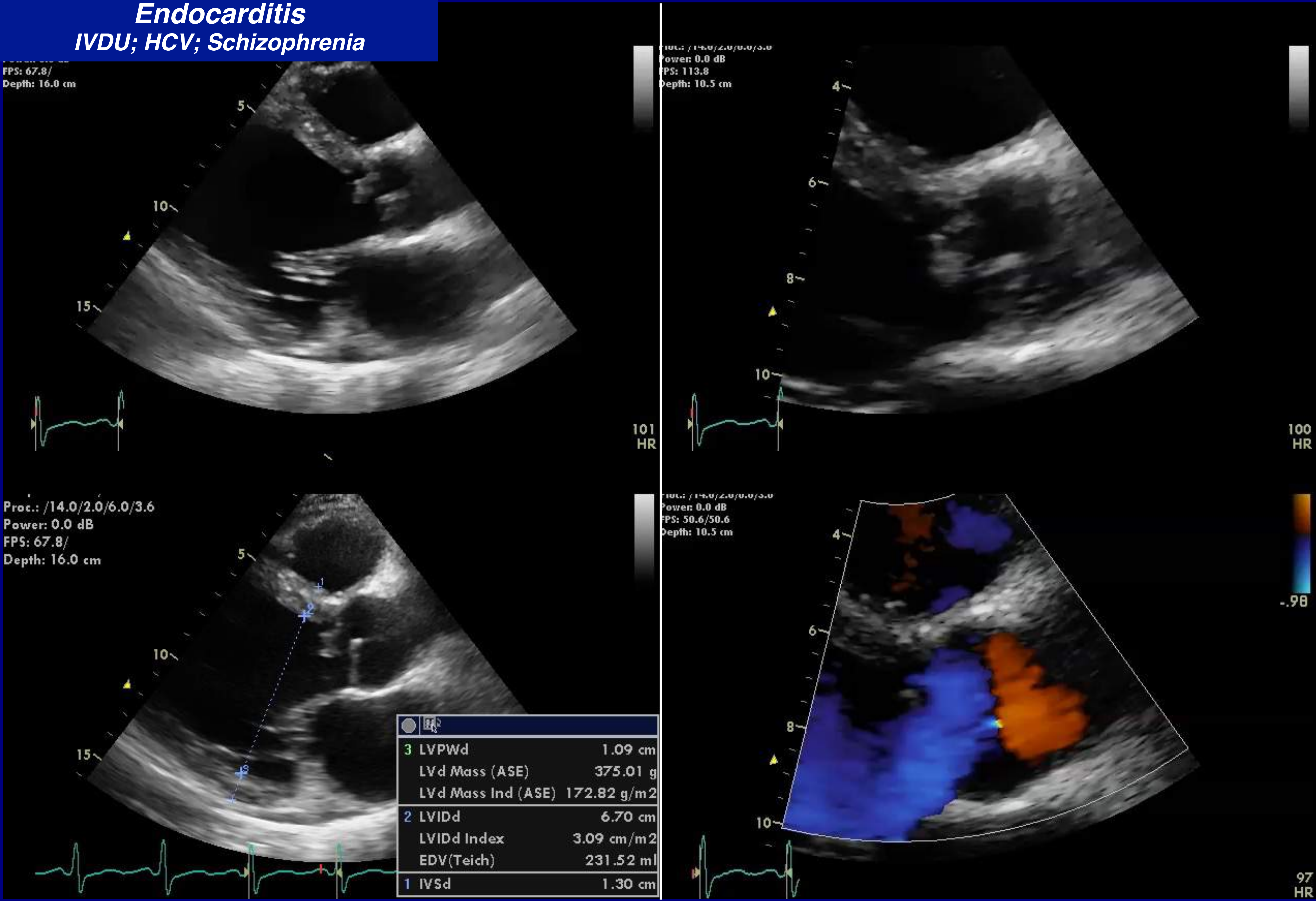
Grading Severity of Chronic Severe AR by Echo

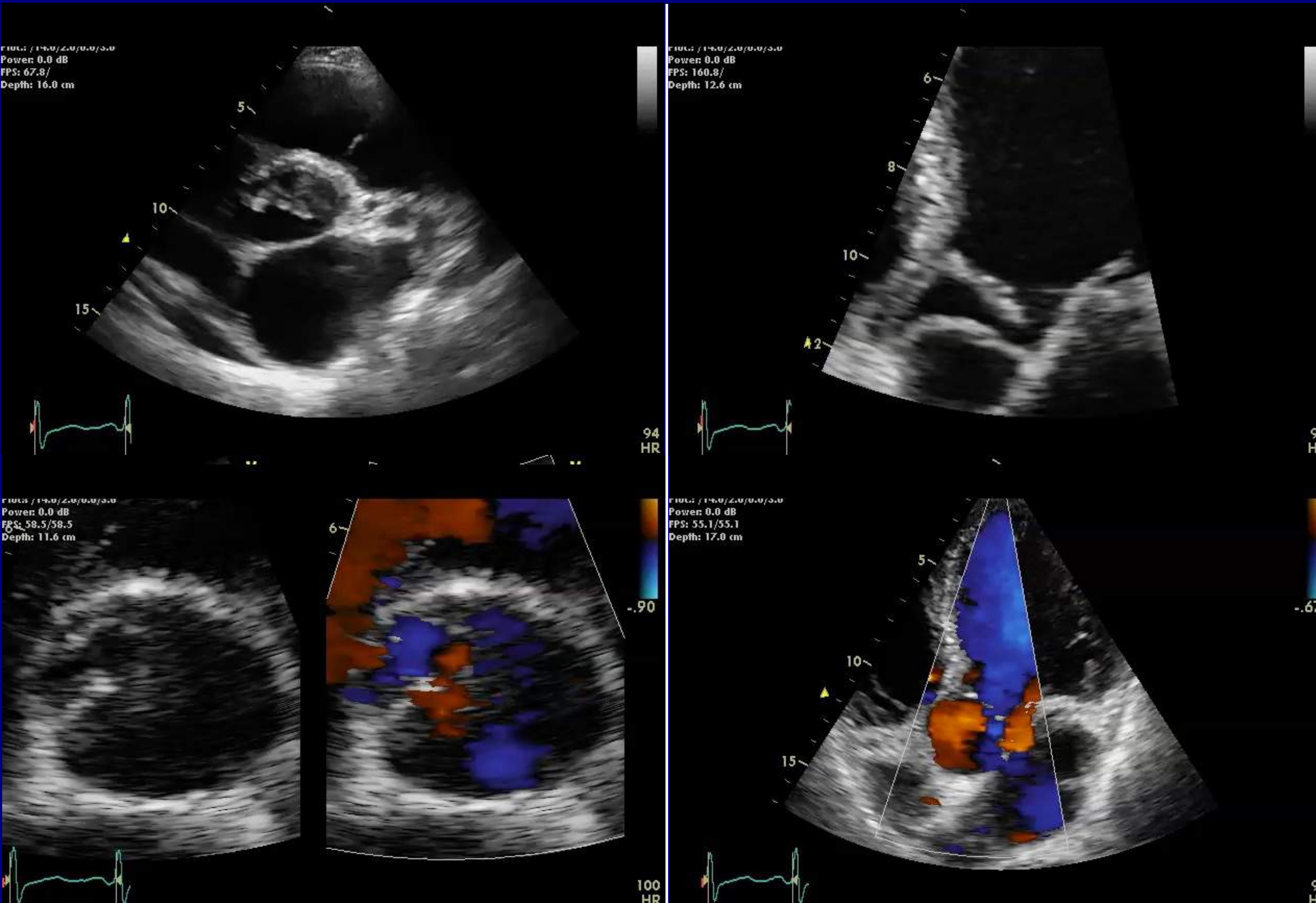
Parameter	Mild AR	Moderate AR	Severe AR
SEMIQUANTITATIVE Parameters			
• *Vena contracta width (cm)* 	<0.3cm	0.3-0.6cm	**>0.6cm***
• *Jet width/LVOT width for central jets (%)* 	<25%	24-45% 46-64%	**≥65%***
• *Jet CSA/LVOT CSA for central jets (%)* 	<5%	5-20% 21-59%	**≥60%**

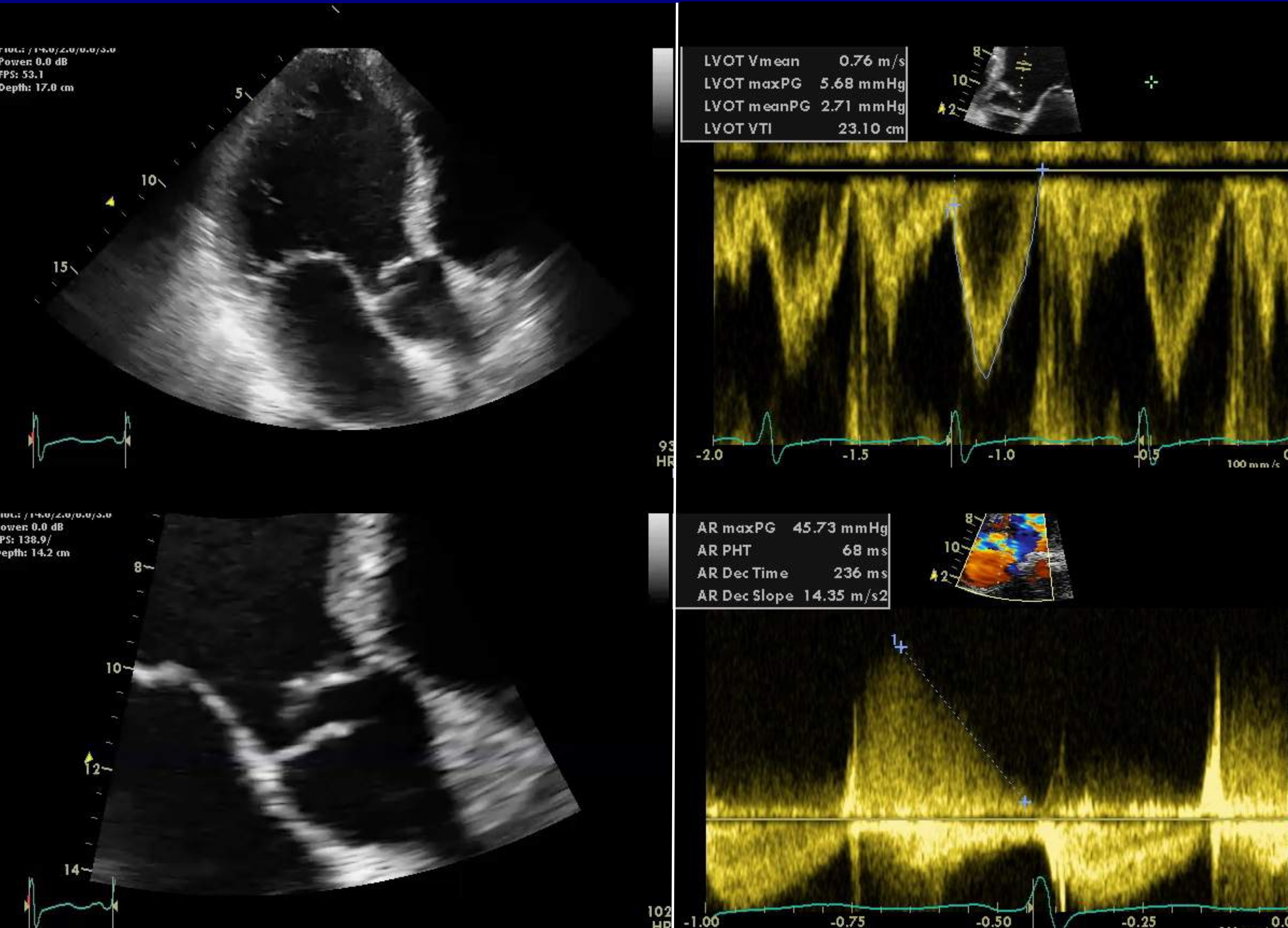
Grading Severity of Chronic Severe AR by Echo

Parameter	Mild AR	Moderate AR	Severe AR
QUANTITATIVE Parameters			
• *Regurgitant volume (RVol, mL/beat)* $RVol = SV_{RegValv} - SV_{CompValv}$ $Rvol = SV_{LVOT} - SV_{MV}$	<30mL	30 - 44mL 45 - 59mL	**≥60mL** **cMRI*
 			
• *Regurgitant fraction (RF, %)* $RF = RVol / SV_{RegValv}$	<30%	30 - 39% 40 - 49%	**≥50%** **cMRI*
• *EROA (cm²)* $EROA = 2\pi r^2 \times Vel_a / Vel_{AR}$ $Rvol\ (mL) = EROA \times VTI_{AR}$	$<0.10cm^2$	$0.10 - 0.19cm^2$ $0.20 - 0.29cm^2$	$\geq 0.30cm^2$
 			

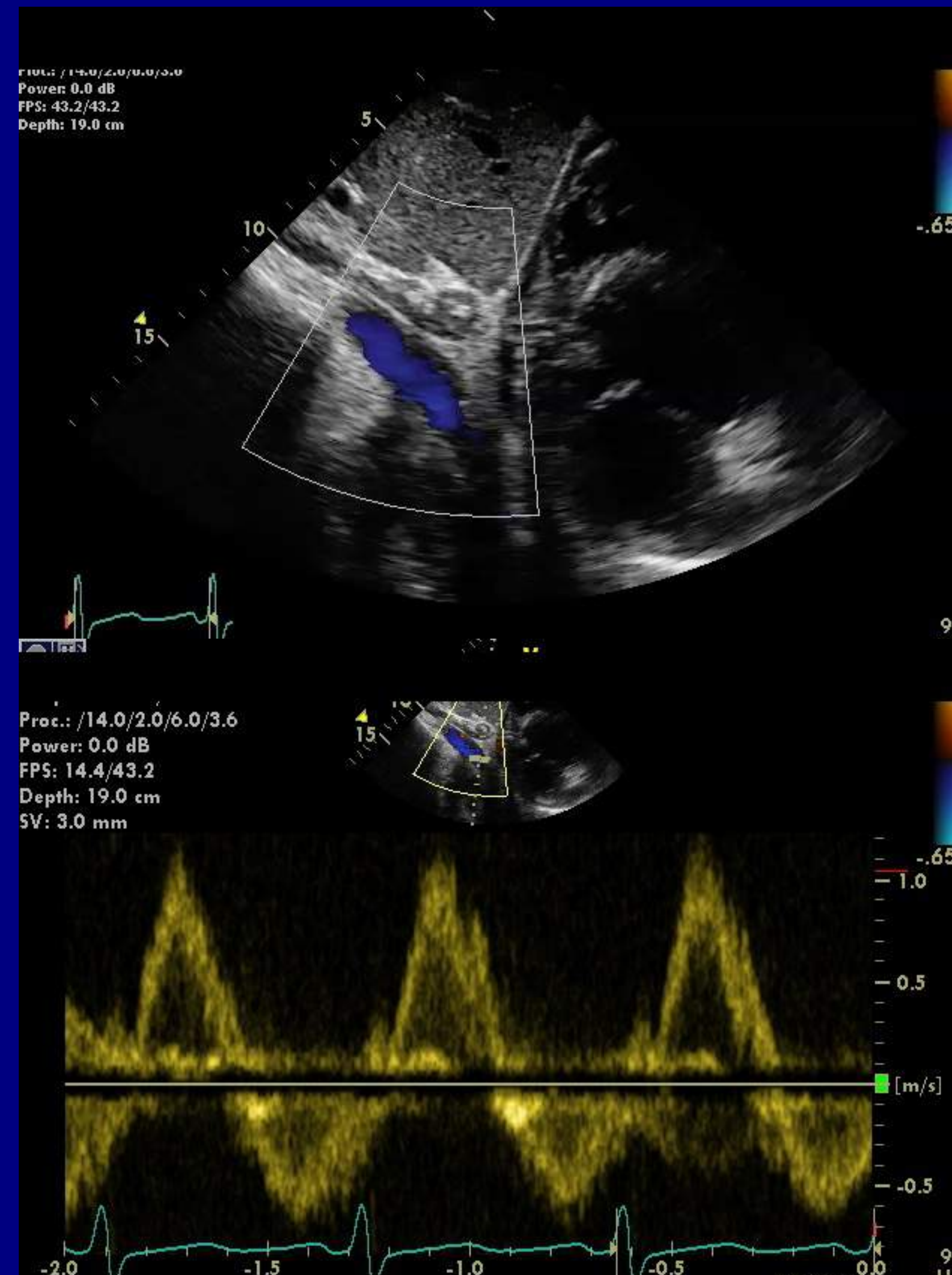
36yo male
Endocarditis
IVDU; HCV; Schizophrenia




Power: 0.0 dB
FPS: 67.8/
Depth: 16.0 cm
5
10
15
94
HR
Power: 0.0 dB
FPS: 160.8/
Depth: 12.6 cm
6
8
10
2
98
HR
Power: 0.0 dB
FPS: 58.5/58.5
Depth: 11.6 cm
6
-.90
100
HR
Power: 0.0 dB
FPS: 55.1/55.1
Depth: 17.0 cm
5
10
15
-.67
98
HR

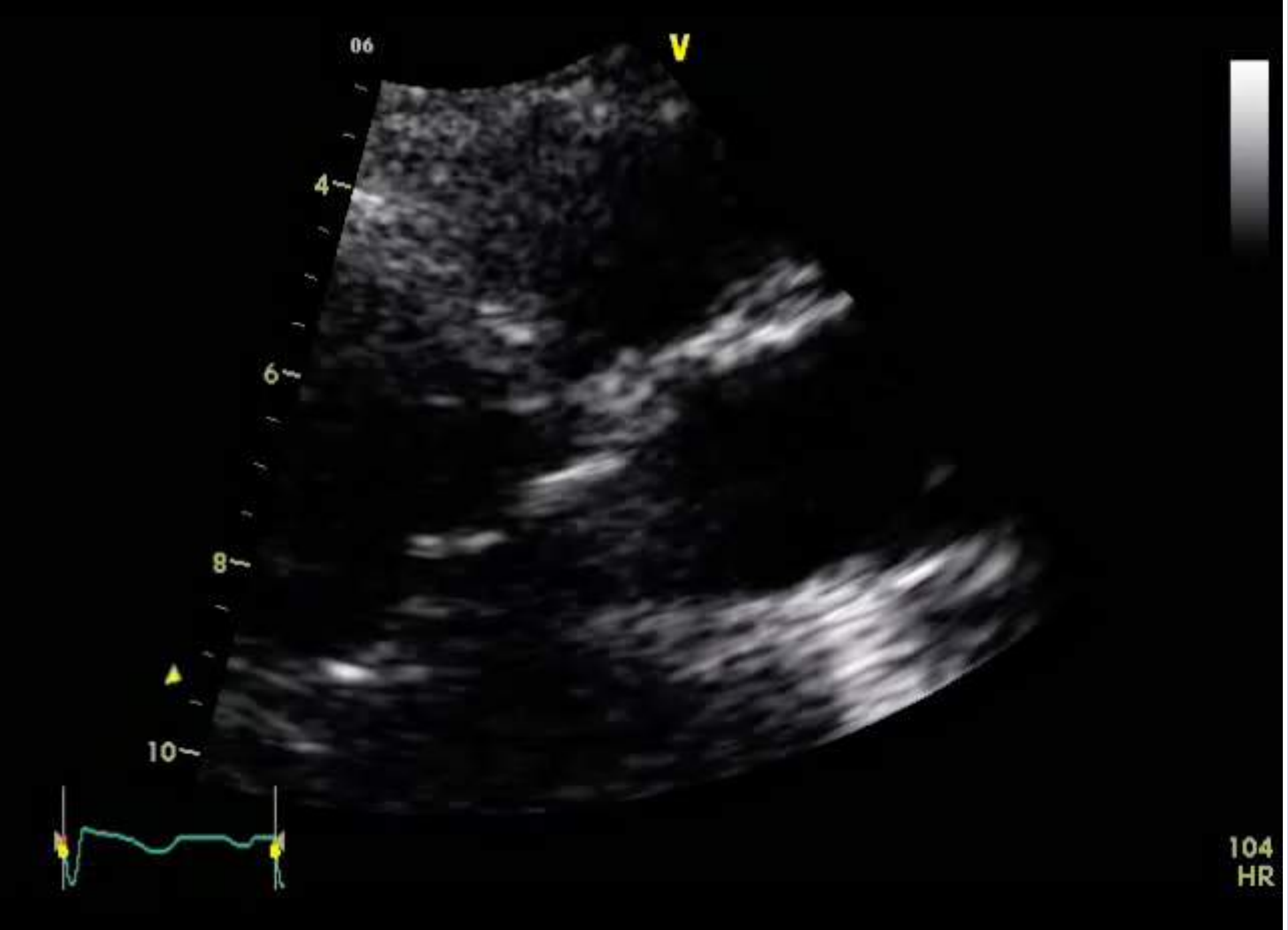


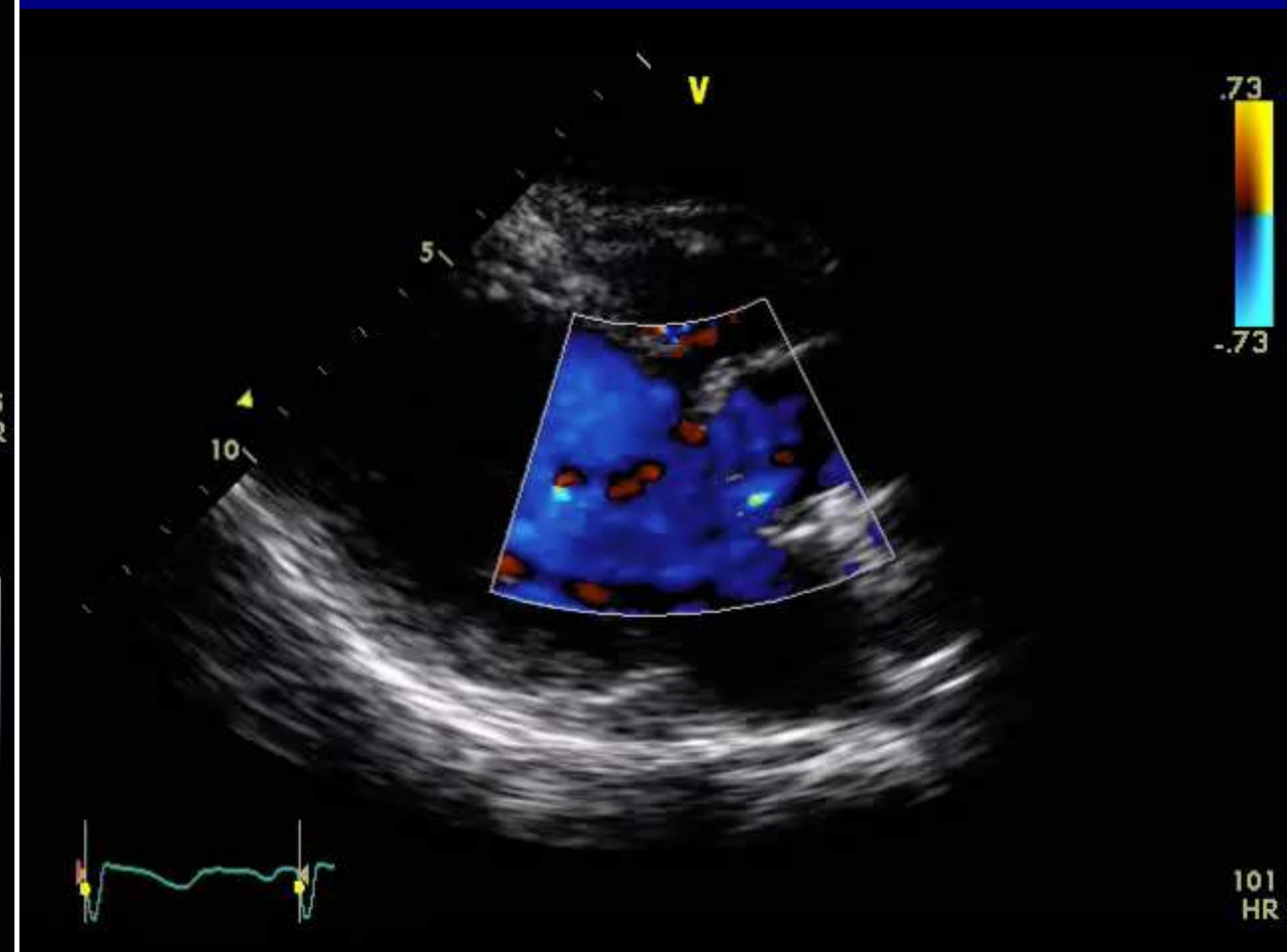
Power: 0.0 dB
FPS: 53.1
Depth: 17.0 cm
LVOT Vmean 0.76 m/s
LVOT maxPG 5.68 mmHg
LVOT meanPG 2.71 mmHg
LVOT VTI 23.10 cm
-2.0
-1.5
-1.0
-0.5
100 mm/s
FPS: 138.9/
Depth: 14.2 cm
AR maxPG 45.73 mmHg
AR PHT 68 ms
AR Dec Time 236 ms
AR Dec Slope 14.35 m/s2
-1.00
-0.75
-0.50
-0.25
0.00
200 mm/s

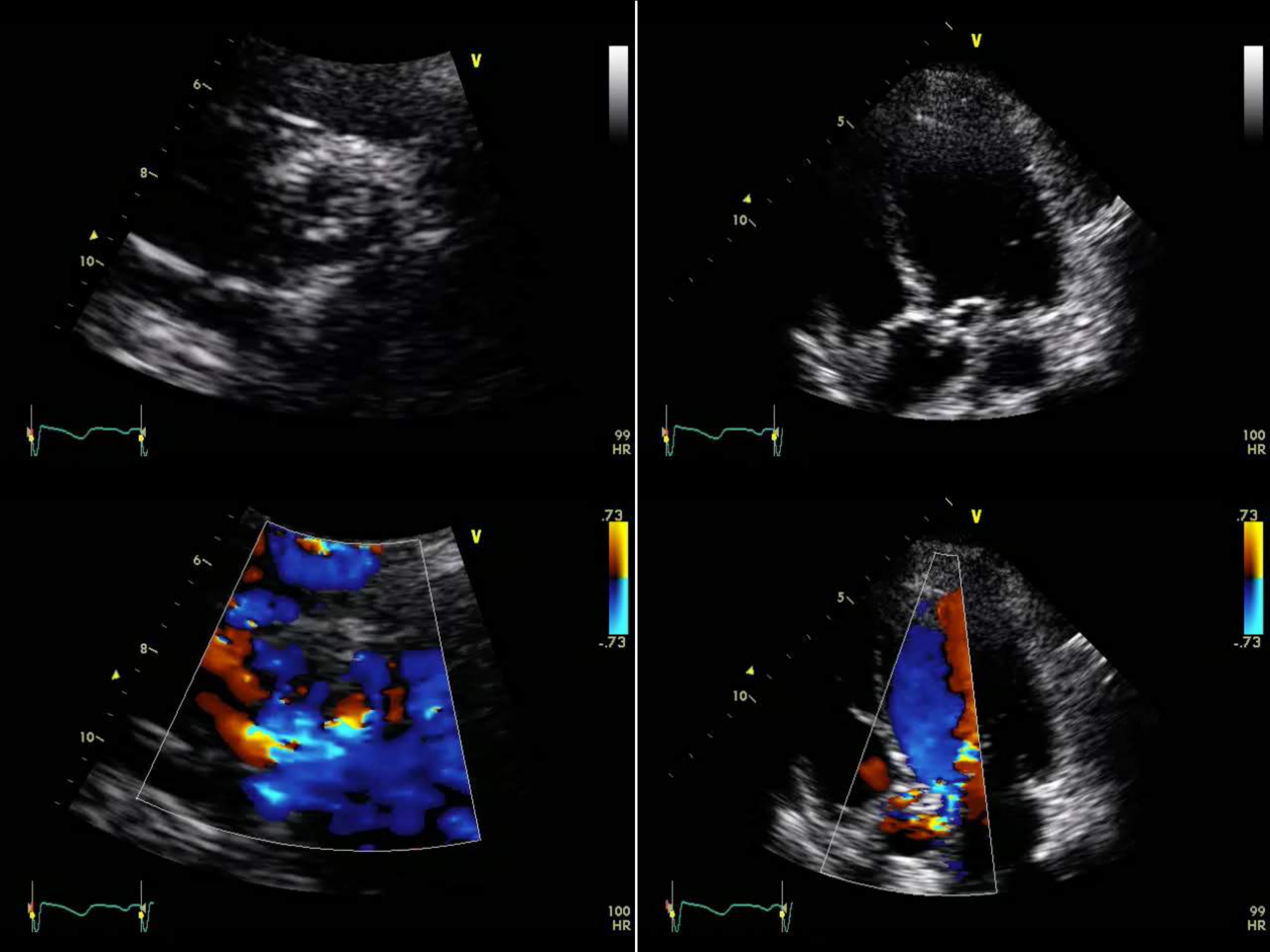

Power: 0.0 dB
FPS: 55.9/
Depth: 16.0 cm
96
HR
Power: 0.0 dB
FPS: 47.0/47.0
Depth: 16.0 cm
-.77
p 6.13 mmHg /3.6
Frq 3.22 kHz
Depth: 16.0 cm
SV: 2.4 mm
[m/s]
100 mm/s
94
HR

Power: 0.0 dB
FPS: 43.2/43.2
Depth: 19.0 cm
-.65
93
Proc.: /14.0/2.0/6.0/3.6
Power: 0.0 dB
FPS: 14.4/43.2
Depth: 19.0 cm
SV: 3.0 mm
[m/s]
100 mm/s
94
HR

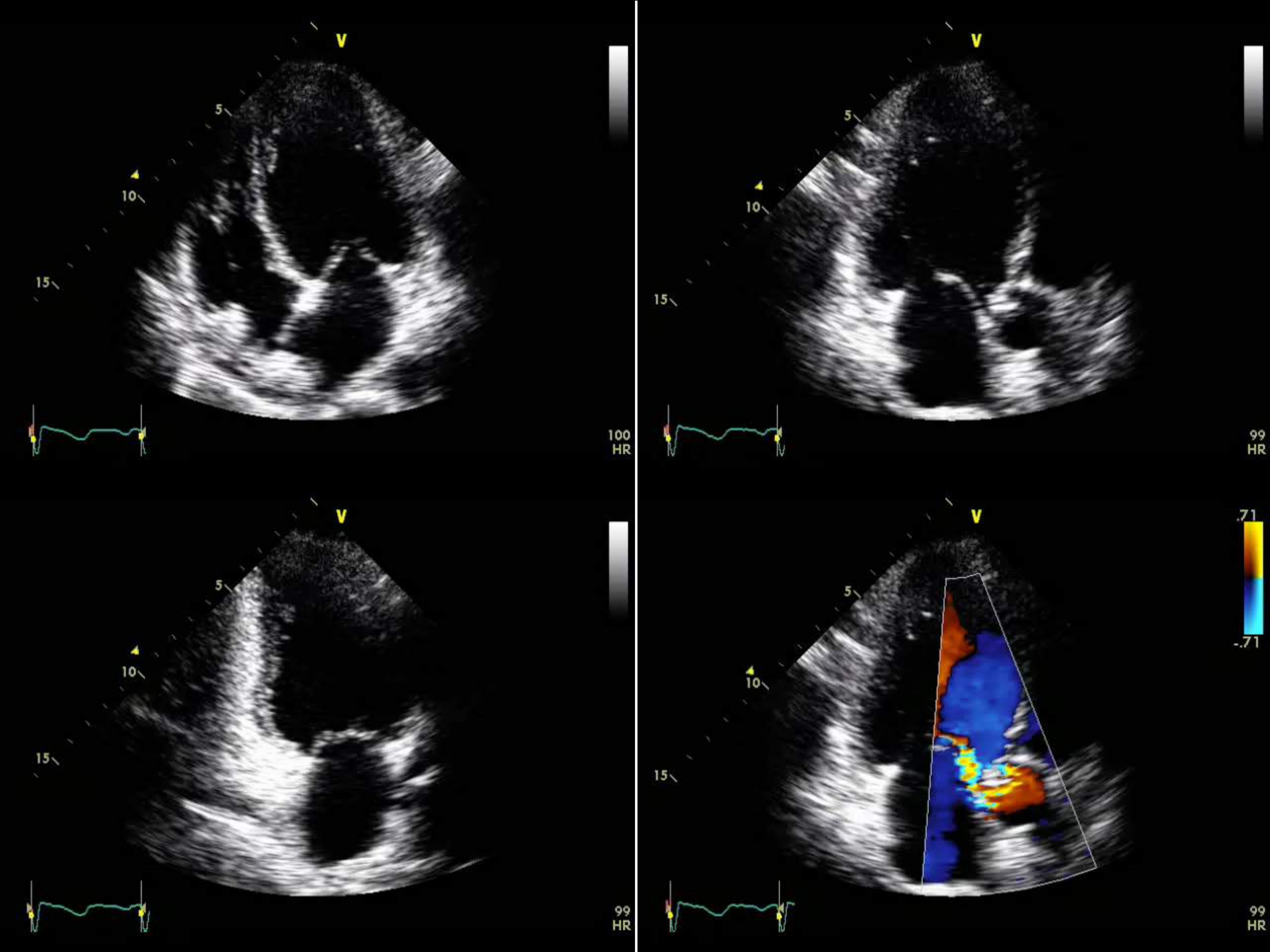
Acute Severe AR

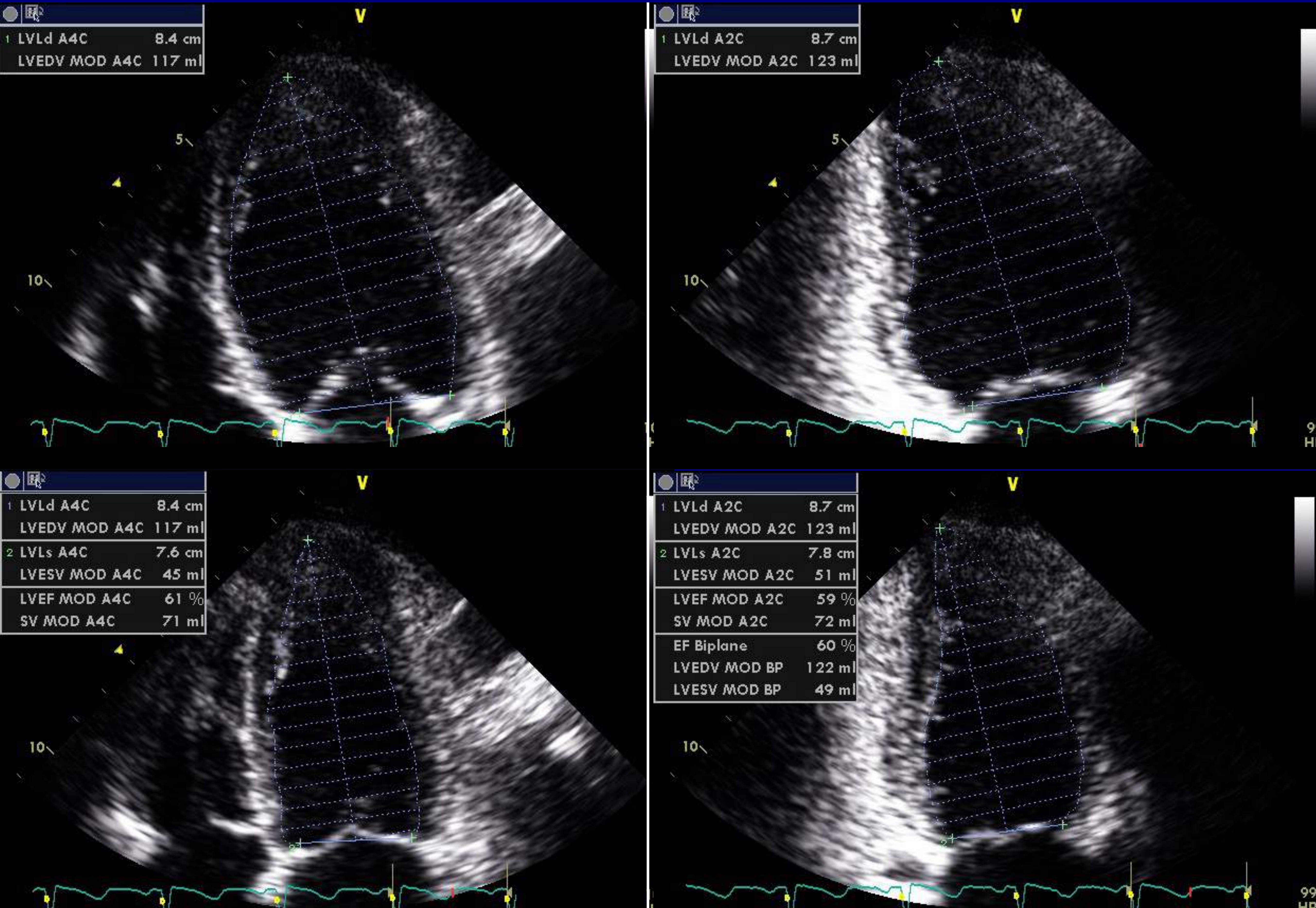
59 yo female
Indication for TTE:
Aortic valve endocarditis + NSTEMI



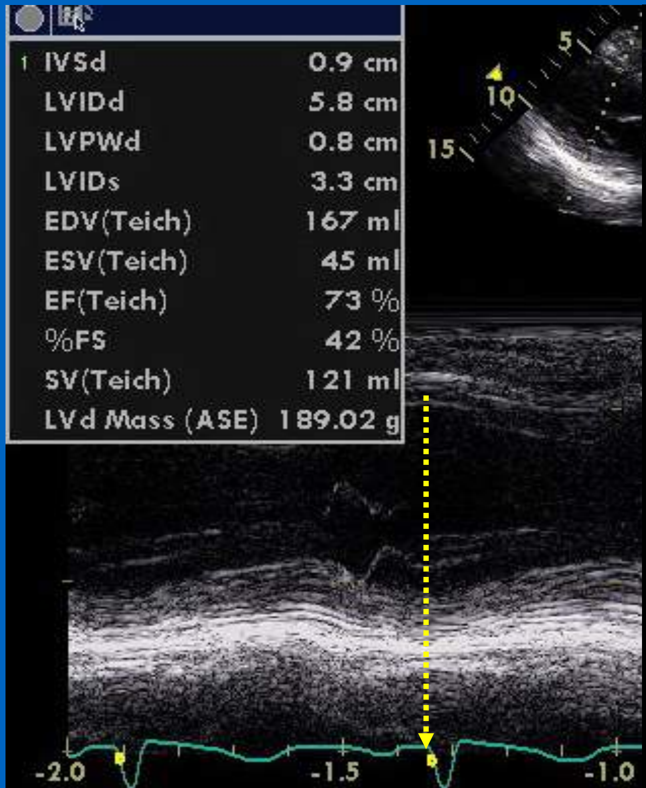


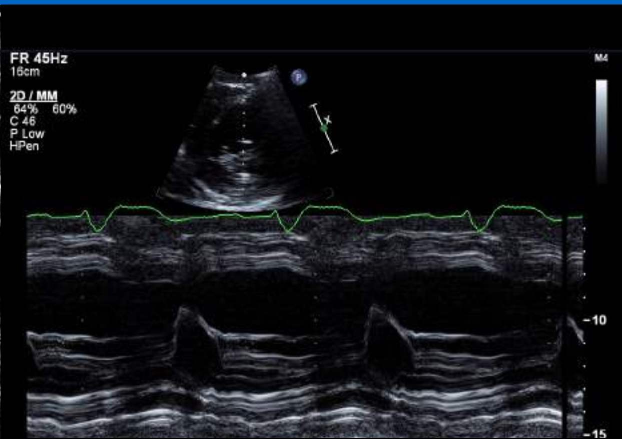

V
6
8
10
99
HR
V
5
10
100
HR
V
.73
-.73
6
8
10
100
HR
V
.73
-.73
5
10
99
HR


V
5
10
15
100
HR
V
5
10
15
99
HR
V
5
10
15
99
HR
V
.71
5
10
-.71
15
99
HR



LVLd A4C 8.4 cm
LVEDV MOD A4C 117 ml
LVLd A2C 8.7 cm
LVEDV MOD A2C 123 ml
99 HR
LVLd A4C 8.4 cm
LVEDV MOD A4C 117 ml
LVLs A4C 7.6 cm
LVESV MOD A4C 45 ml
LVEF MOD A4C 61 %
SV MOD A4C 71 ml
LVLd A2C 8.7 cm
LVEDV MOD A2C 123 ml
LVLs A2C 7.8 cm
LVESV MOD A2C 51 ml
LVEF MOD A2C 59 %
SV MOD A2C 72 ml
EF Biplane 60 %
LVEDV MOD BP 122 ml
LVESV MOD BP 49 ml
99 HR



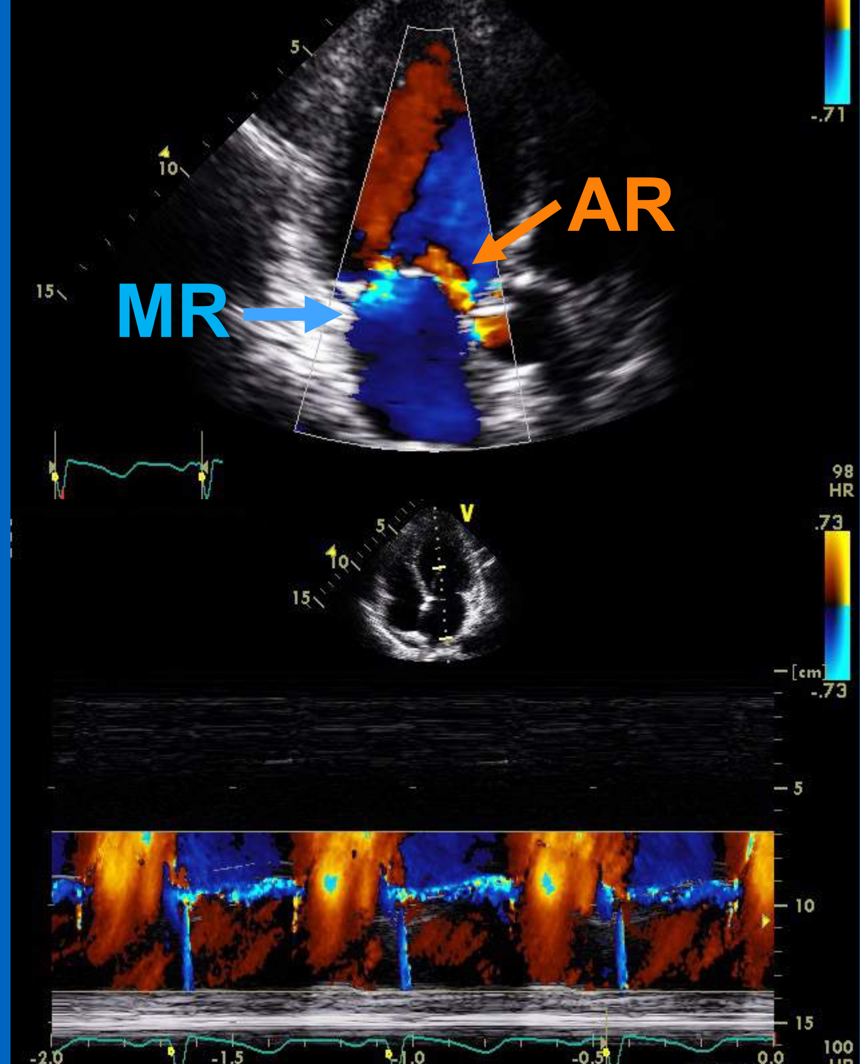


Premature MV closure

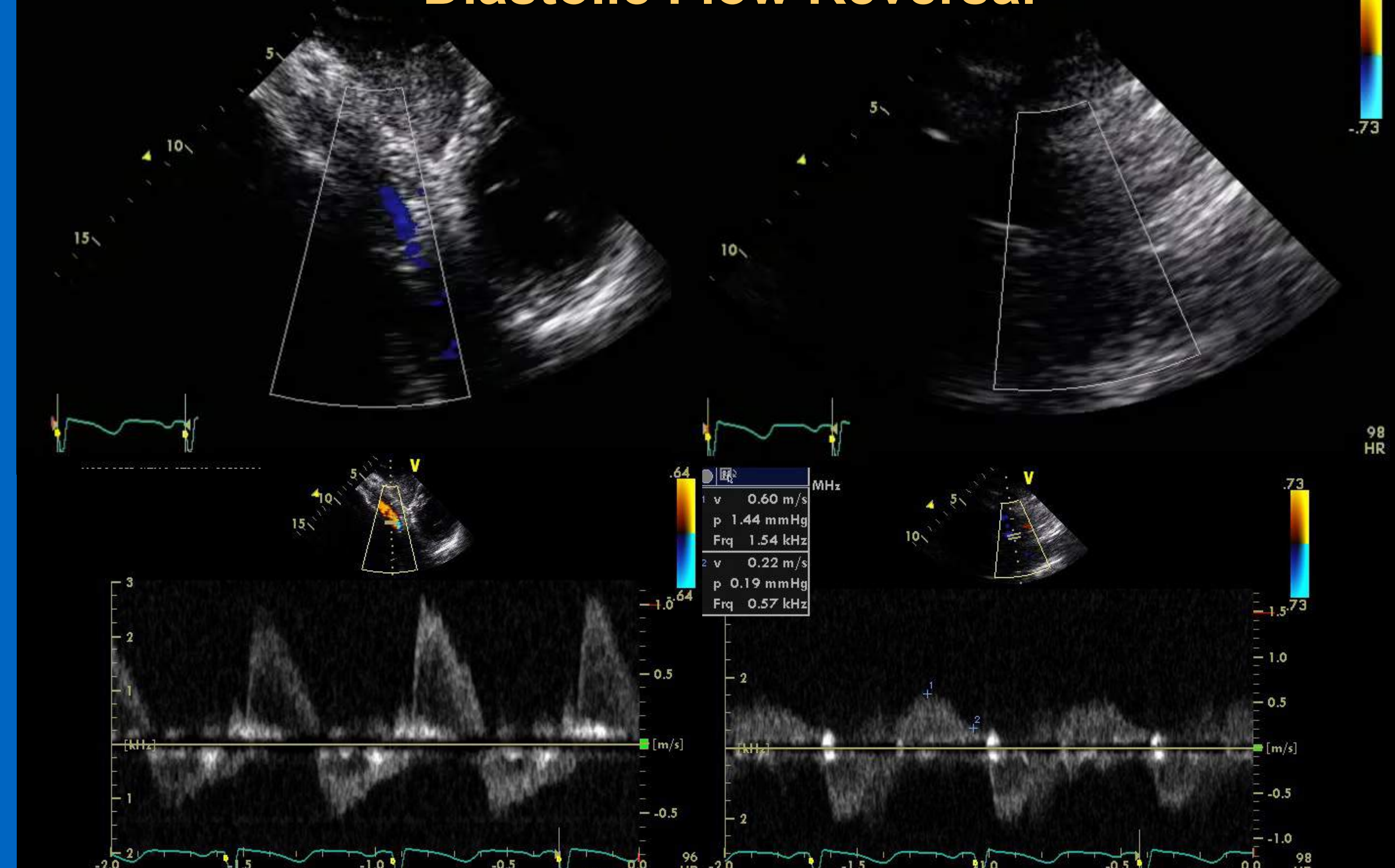
1. Due to acute increase in LVDP
2. Normal MV closure occurs after onset of LV contraction (~40msec after onset of QRS)
3. Sp & Sn sign of acute severe AR

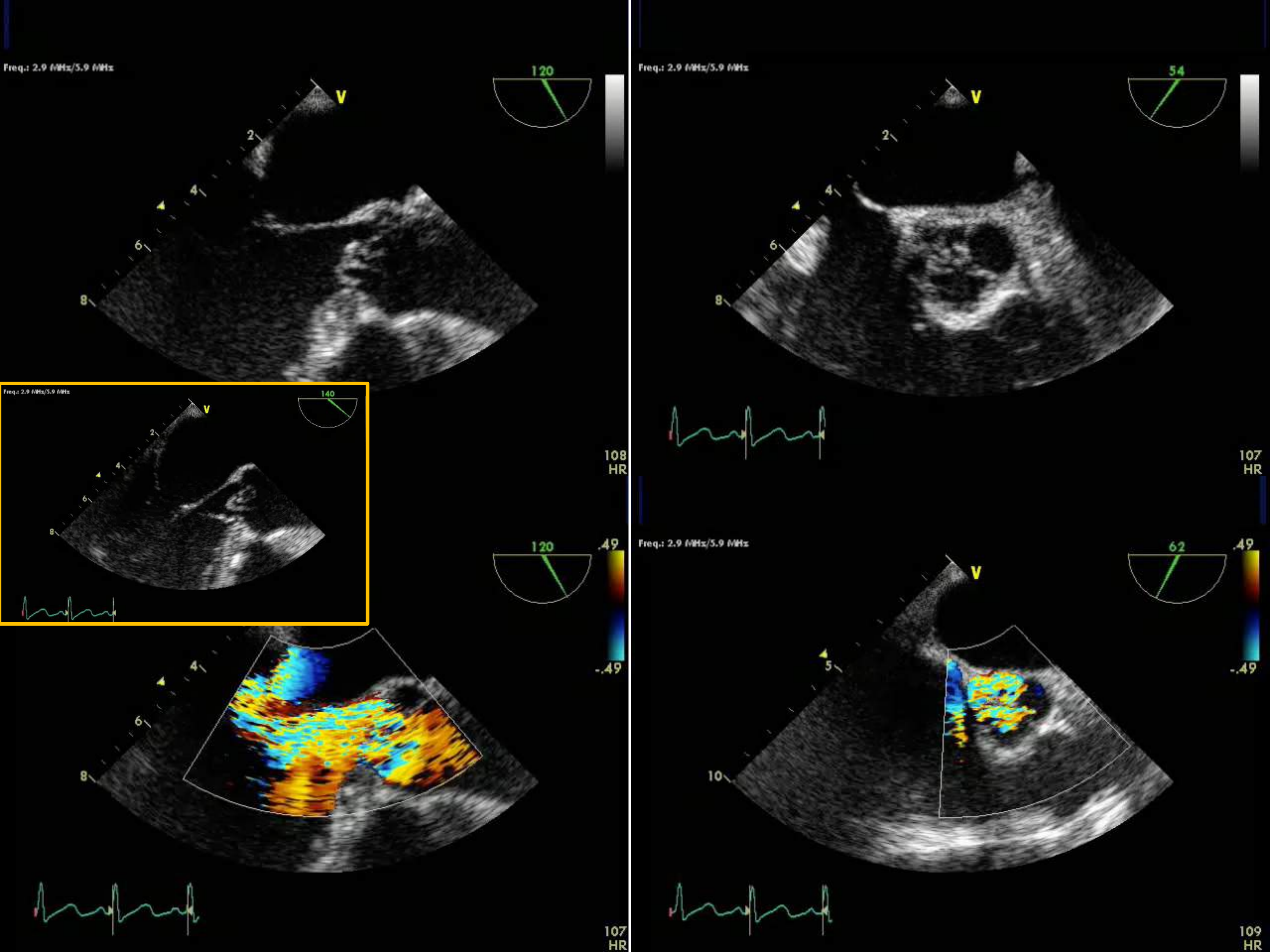
1. **Increased LVOT VTI (Stroke volume)**
2. **Raised left-sided filling pressures**
3. **Short AR PHT**

Diastolic MR

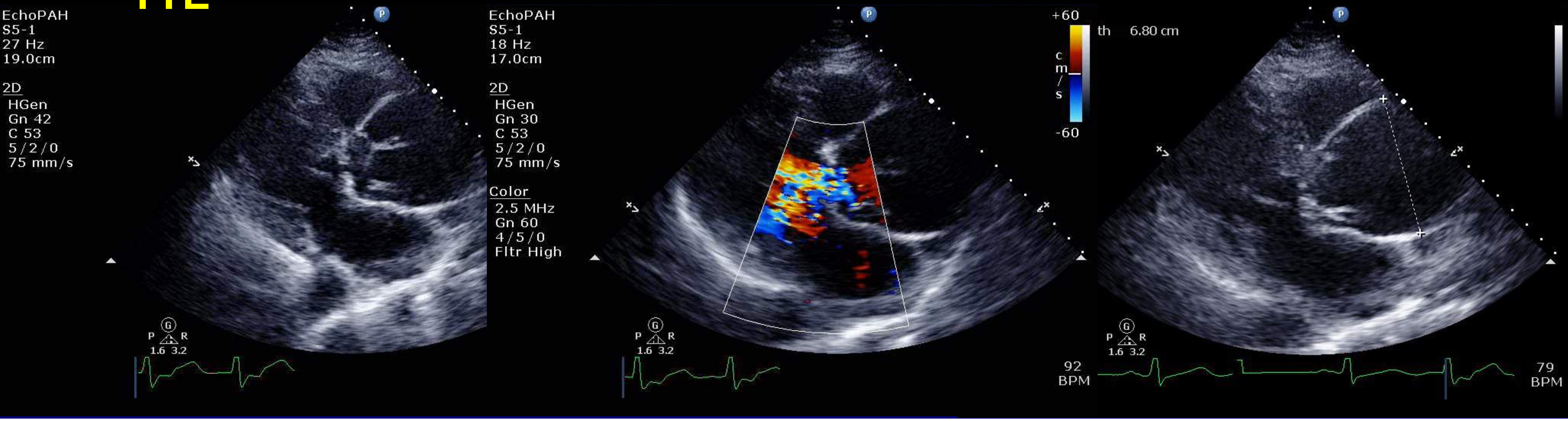


Diastolic Flow Reversal

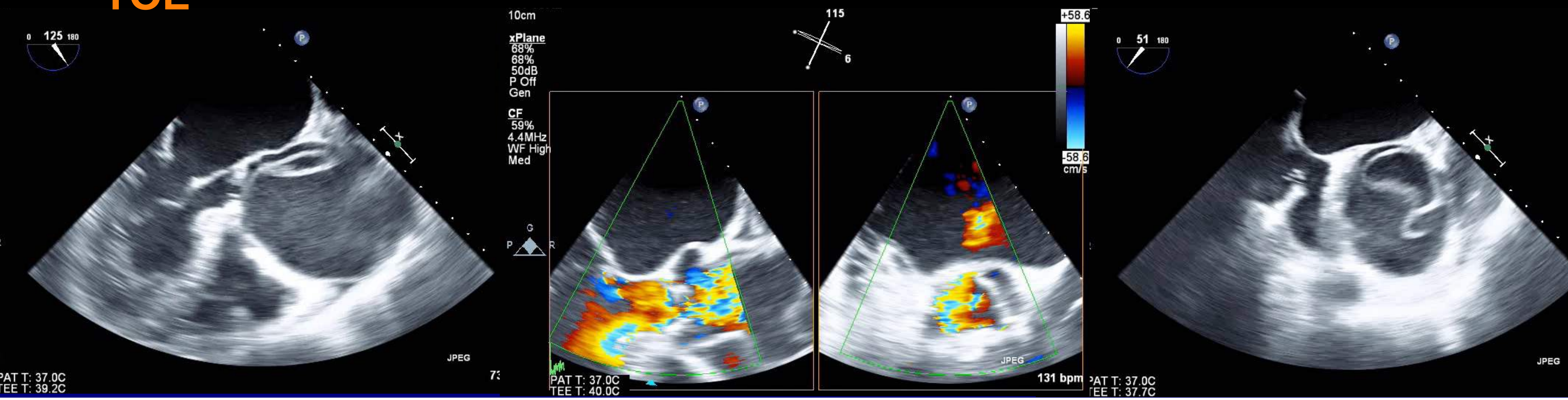



Freq.: 2.9 MHz/5.9 MHz
V
120
108
HR
Freq.: 2.9 MHz/5.9 MHz
V
140
Freq.: 2.9 MHz/5.9 MHz
V
54
107
HR
120
.49
-.49
107
HR
Freq.: 2.9 MHz/5.9 MHz
V
62
.49
-.49
109
HR

TTE



TOE



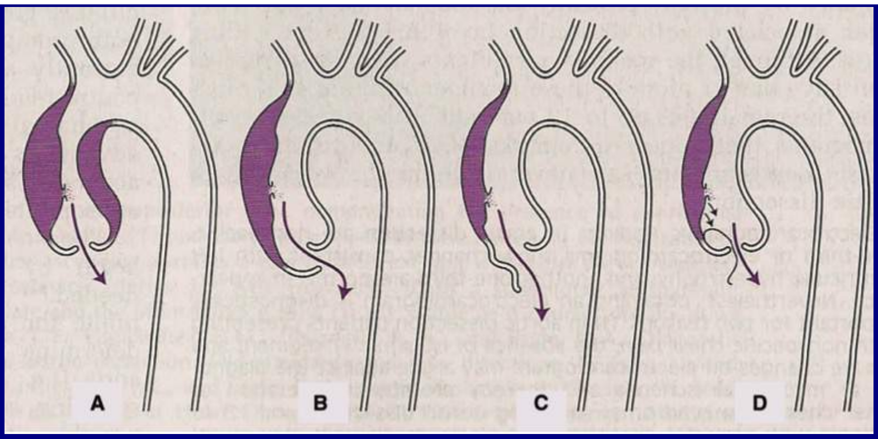
Type A Dissection:

Aortic root/annular dilatation

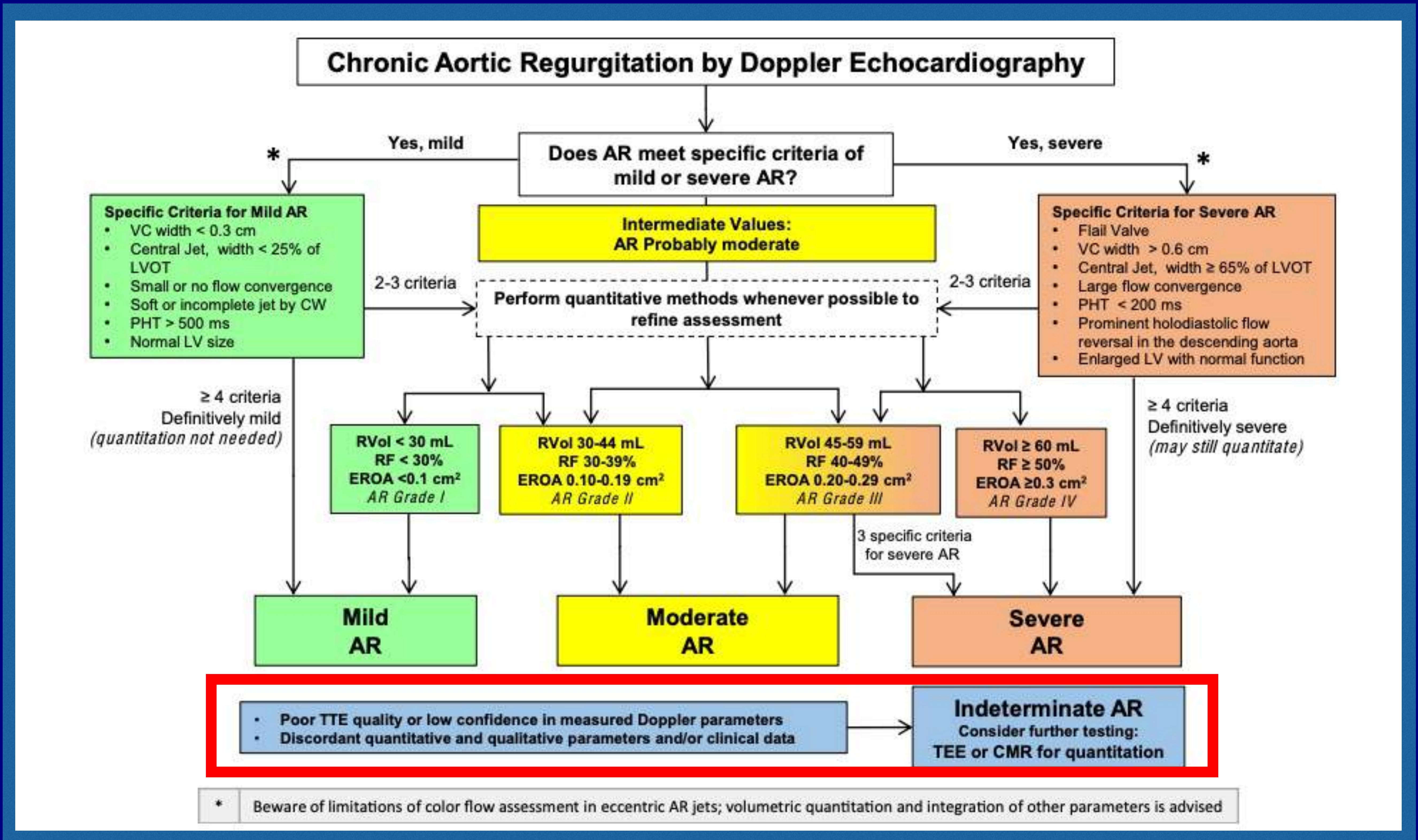
Asymmetrical cusp coaptation due to pressure from false lumen

Flail aortic cusp secondary to annular disruption

Prolapse of intimal flap through the aortic valve



Hamirani YS et al. Acute aortic regurgitation. Circulation 2012;126:1121-1126.



Zoghbi WA, et al. Recommendations for noninvasive evaluation of native valvular regurgitation. JASE 2017;30:303-371.

Surgical Aortic Valve Replacements (SAVR)

Prosthetic Valves (Surgical)

Table 1 Types of prosthetic heart valves

- Biological
  - Stented
    - Porcine bioprosthesis
    - Pericardial bioprosthesis
  - Stentless
    - Porcine bioprosthesis
    - Pericardial bioprosthesis
    - Aortic homograft
    - Pulmonary autograft (Ross procedure)
  - Sutureless
  - Transcatheter
- Mechanical
  - Bileaflet
  - Single tilting disk
  - Caged ball

Table 2 Designs and models of biological replacement heart valve

Stented porcine replacement valve
- Hancock standard and Hancock II
- Medtronic Mosaic[a]
- Carpentier-Edwards standard and supra-annular
- St Jude Medical Biocor, Bioimplant, Epic
- AorTech Aspire
- Labcor
- Carbomedics Synergy

Stentless valve Porcine
- St Jude Medical Toronto[a]
- Medtronic Freestyle
- Cryolife-O'Brien[a]
- Cryolife-Ross Stentless porcine pulmonary
- Edwards Prima Plus
- AorTech Aspire
- St Jude Biocor
- Labcor
- St Jude Quattro stentless mitral
- Shelhigh Skeletorized Super-Stentless aortic porcine and pulmonic
- Medtronic-Venpro Contegra pulmonary valve conduit

Stented pericardial replacement valve
- Carpentier-Edwards Perimount
- Carpentier Edwards Magna
- Mitroflow Synergy
- St Jude Biocor pericardia
- St Jude Trifecta
- Labcor pericardial
- Sorin Pericarbon MORE[a]

Stentless pericardial
- Sorin Pericarbon
- 3F-SAVR
- Freedom Solo

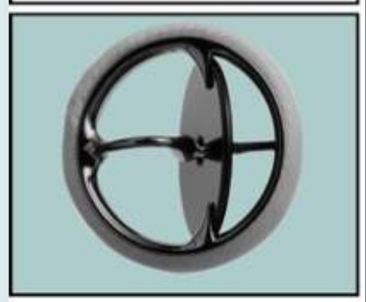
Sutureless
- Perceval S (Sorin)
- Edwards Intuity (Edwards Lifesciences)
- 3F Enable (ATS Medical)
- Trilogy (Arbor Surgical Technologies)

Table 3 Designs and models of mechanical replacement heart valve

Bileaflet mechanical replacement valves
- St Jude Medical: standard, HP, Masters, and Regent
- Carbomedics: standard, reduced cuff, Optiform, Orbis, and supra-annular (Top Hat) Carboseal includes a woven aortic graft
- Edwards Tekna
- Sorin Bicarbon
- Edwards Mira
- ATS
- On-X
- Medtronic Advantage
- Jyros

Tilting disk replacement valves
- Bjork-Shiley monostrut[a]
- Sorin Monoleaflet Allcarbon
- Medtronic-Hall
- Omnicarbon
- Ultracor

Caged ball
- Starr-Edwards
- Smeloff-Cutter



- Zoghbi WA, et al. Recommendations for evaluation of prosthetic valves with echocardiography and Doppler ultrasound. JASE 2009;22:975-1014.
- Lancellotti P, et al. Recommendations for the imaging assessment of prosthetic heart valves. Eur Heart J 2016.

Complications Post-Valve Replacement Surgery

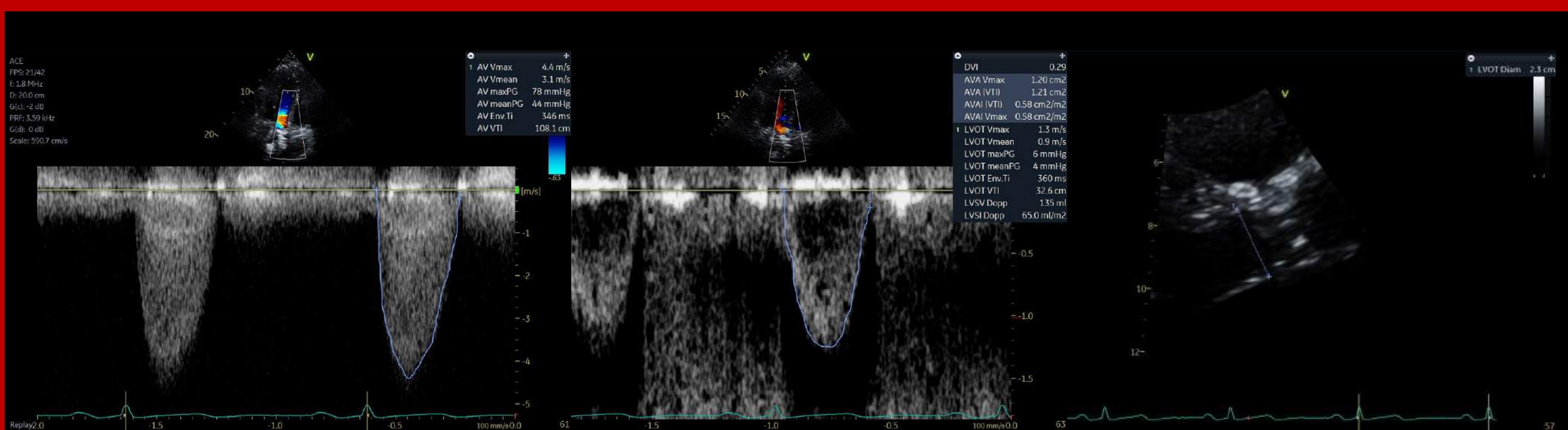
Complication	Definition	Examples or notes
Structural valve deterioration	Deterioration or dysfunction of the operated valve caused by changes intrinsic to the valve	(1) Mechanical valve—wear, fracture, poppet escape (2) Biological valve—calcification, leaflet tear, stent creep (3) Both—disruption of components of a prosthetic valve
Non-structural dysfunction	Any abnormality not intrinsic to the valve that results in stenosis or regurgitation of the valve or haemolysis	(1) Entrapment by pannus, tissue, or suture (2) Paravalvular leak (3) Inappropriate sizing or positioning (4) Residual leak or obstruction after valve implantation (5) Clinically important intravascular haemolysis (6) Dilatation of aorta or aortic annulus causing aortic regurgitation (for stentless valves)
Valve thrombosis	Any thrombosis not caused by infection that occludes part of the blood flow path, interferes with valve function, or is sufficiently large to warrant treatment	
Embolism	An embolic event that occurs in the absence of infection after the immediate perioperative period	(1) Stroke (>72 h neurological deficit) or non-specific symptoms with brain imaging demonstrating an acute ischaemic event (2) TIA (fully reversible symptoms of short duration with no abnormality on brain imaging) (3) Non-cerebral embolic event (not perioperative myocardial infarct)
Bleeding event	Any episode of major internal or external bleeding that causes death, hospitalization, permanent injury, or blood transfusion	Exclude bleeding associated with major trauma or an operation. Include major unexpected bleeding associated with minor trauma.
Endocarditis	Proved infection of the replacement heart valve	Proof by: (1) Reoperation with evidence of abscess or other local complication (2) Autopsy evidence of abscess, pus, or vegetation (3) Duke criteria positive

Lancellotti P, et al. Recommendations for the imaging assessment of prosthetic heart valves. Eur Heart J 2016.

Comprehensive Assessment of Prosthetic Aortic Valve Function	
	Parameters
Clinical information	• Date of valve replacement • Type and size of prosthesis • Patient height, weight, BSA • Symptoms, BP, HR
2D imaging	• Motion of cusps, leaflets or occluders • Calcification or abnormal echodensities on the prosthesis components • Valve sewing ring integrity and motion ("Rocking")

Comprehensive Assessment of Prosthetic Valve Function

	Parameters
Doppler assessment	**Spectral Doppler** • Peak velocity • Peak/mean gradients • DVI (VTI ratio aka DSI or DPI) • EOA (AVA) • Flow dynamics (Acceleration time; Ejection time) **Colour Doppler – Aortic Regurgitation** • Physiologic vs Pathologic • Intravalvular vs Paravalvular



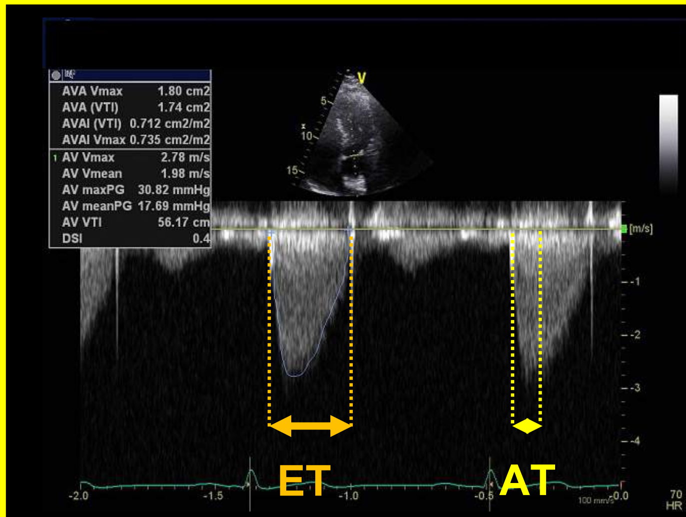
$$\Delta P = P1 - P2 = 4(V_2^2 - V_1^2)$$

$$\Delta P = 4(V_2^2)$$

$$DVI = \frac{\text{peak } V_{LVOT}}{\text{peak } V_{PrV}} \quad \text{or} \quad \frac{VTI_{LVOT}}{VTI_{PrV}}$$

$$EOA = CSA \times VTI_{LVOT}/VTI_{PrV}$$
$$= 0.785 \times (D_{LVOT})^2 \times VTI_{LVOT}/VTI_{PrV}$$

$$EOA = \frac{\text{Stroke volume}}{VTI_{PrV}}$$



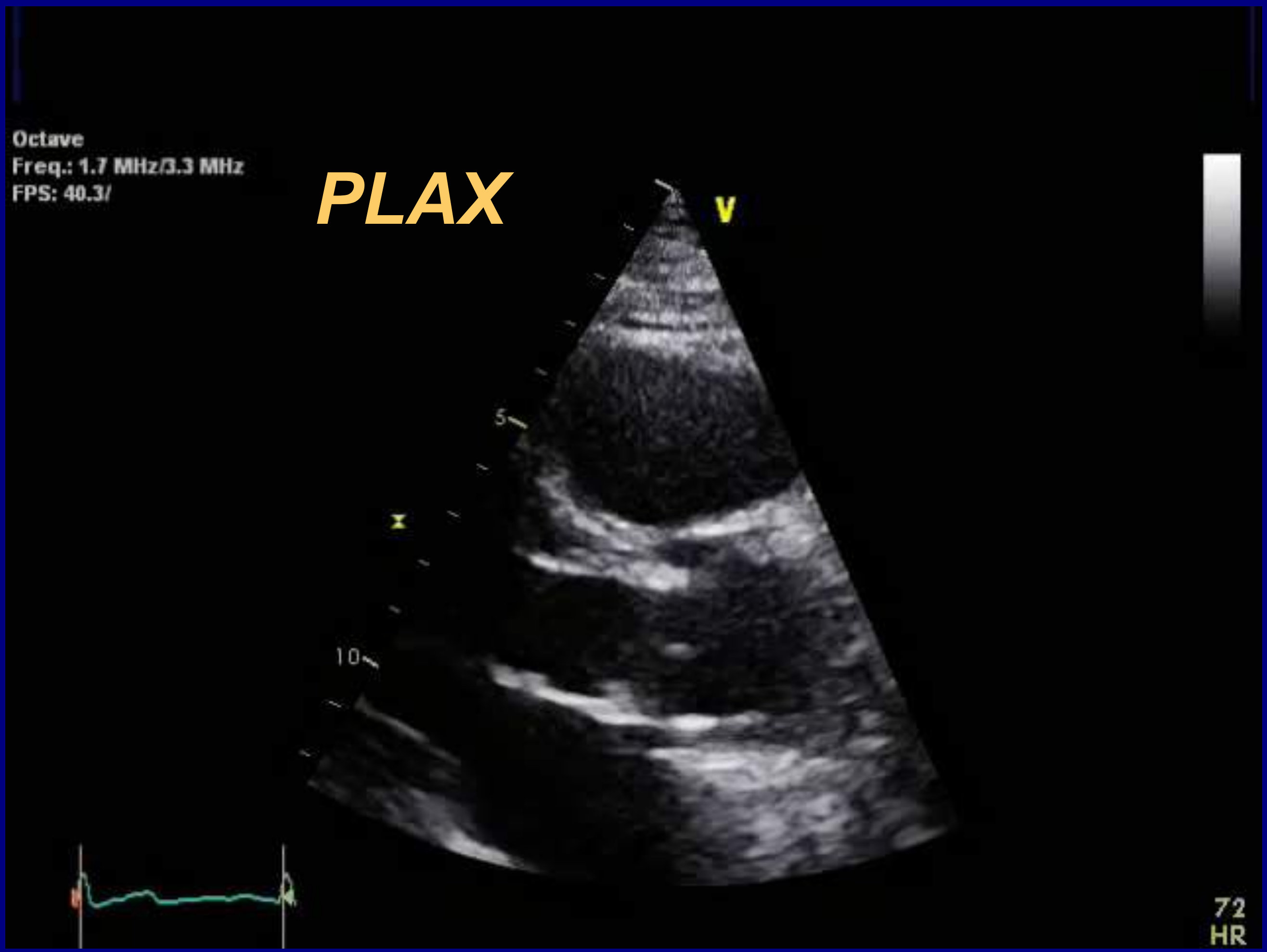
AT <80msec

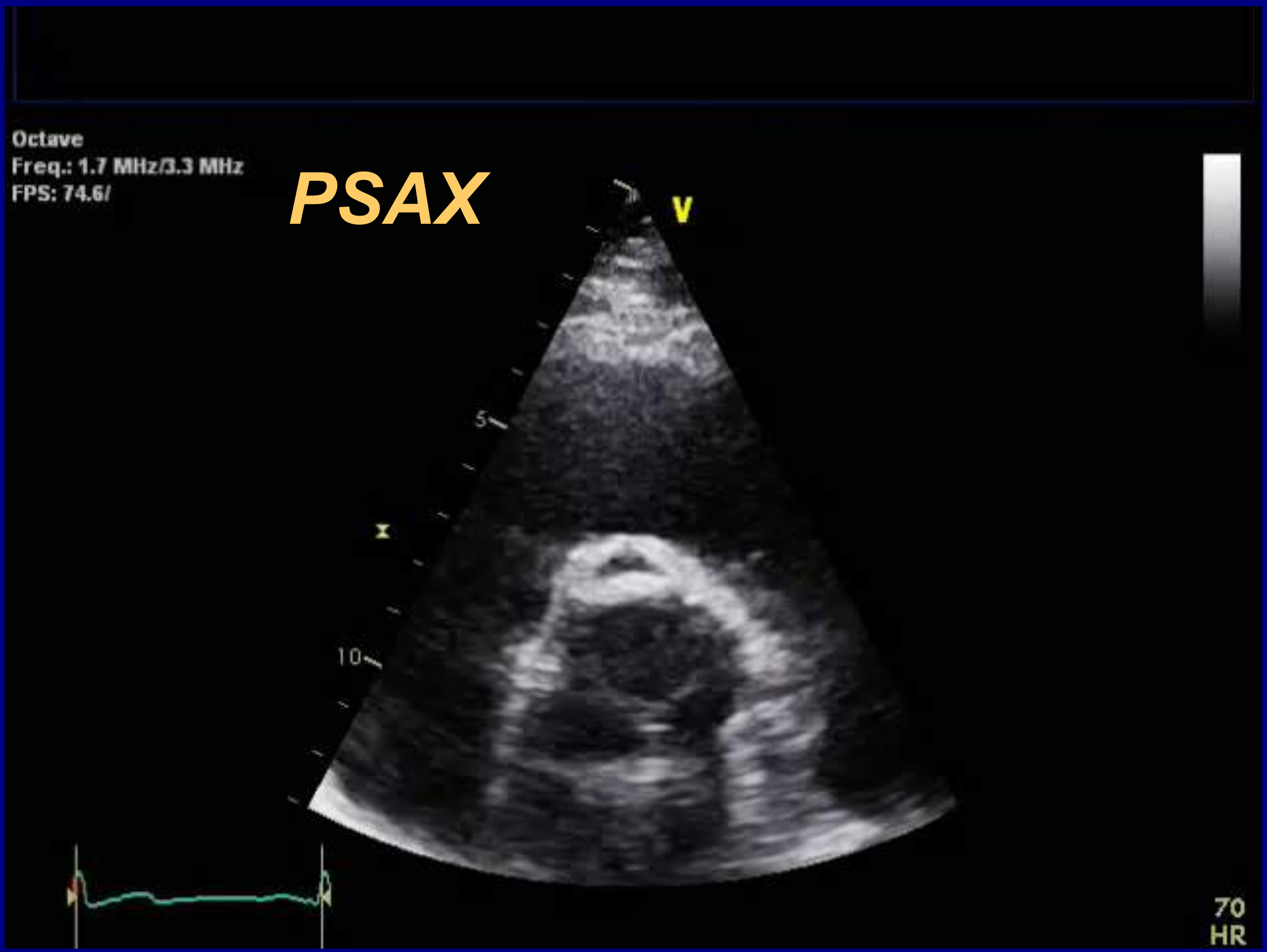
AT : ET ratio <0.35

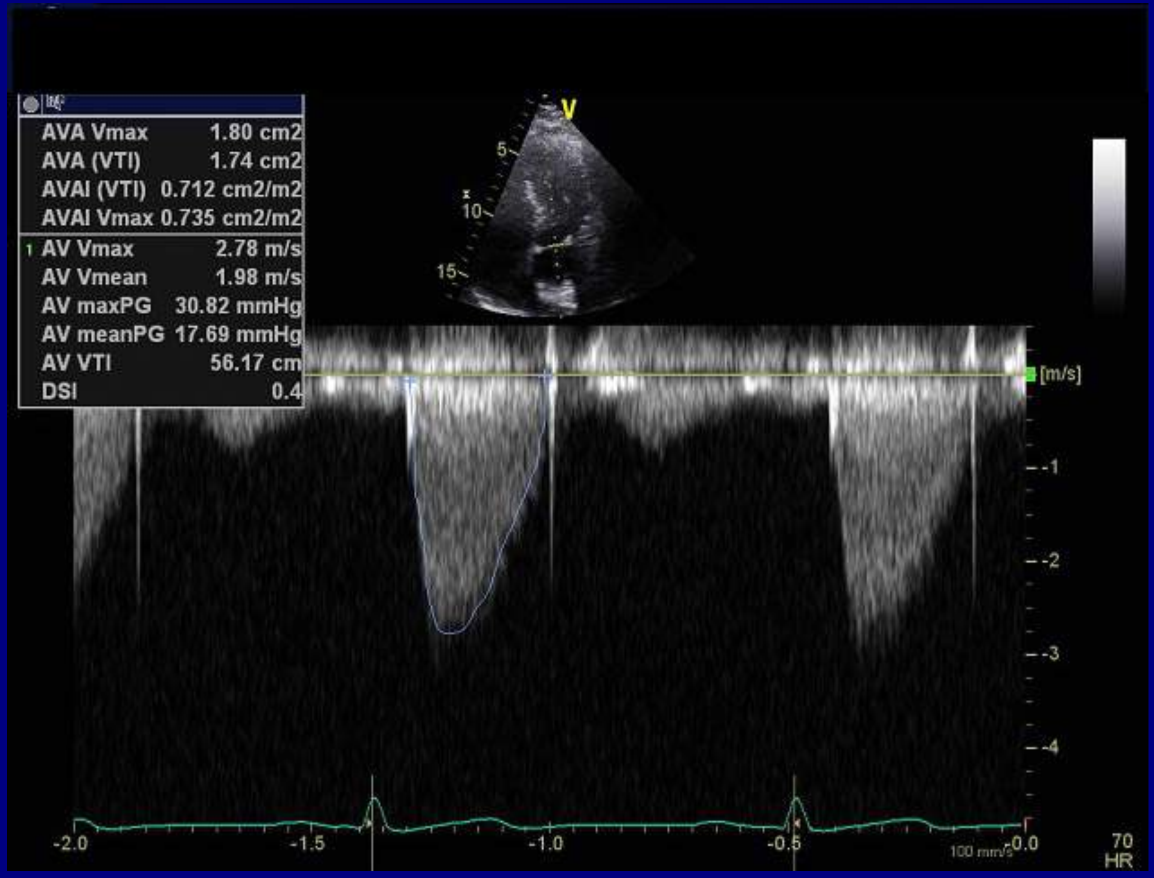
Comprehensive Assessment of Prosthetic Valve Function

	Parameters
Other imaging data	• LV/RV size, function, hypertrophy • LA/RA size • Co-existent valvular disease • {RVSP} PASP
Previous post-op echo assessments	• Comparison with baseline parameters if suspected prosthetic valvular dysfunction

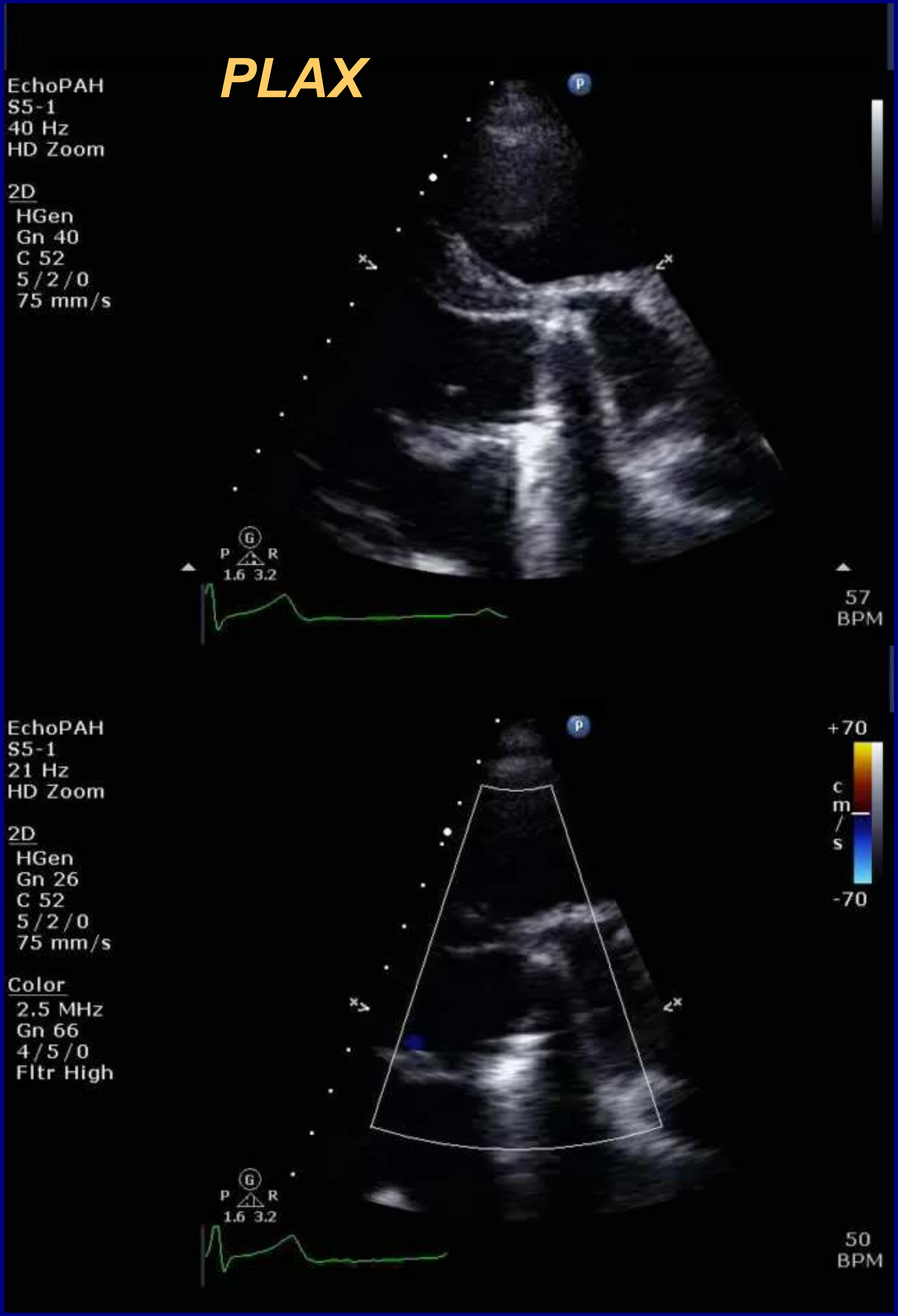
Echo Appearance of SAVRs - Bioprosthetic

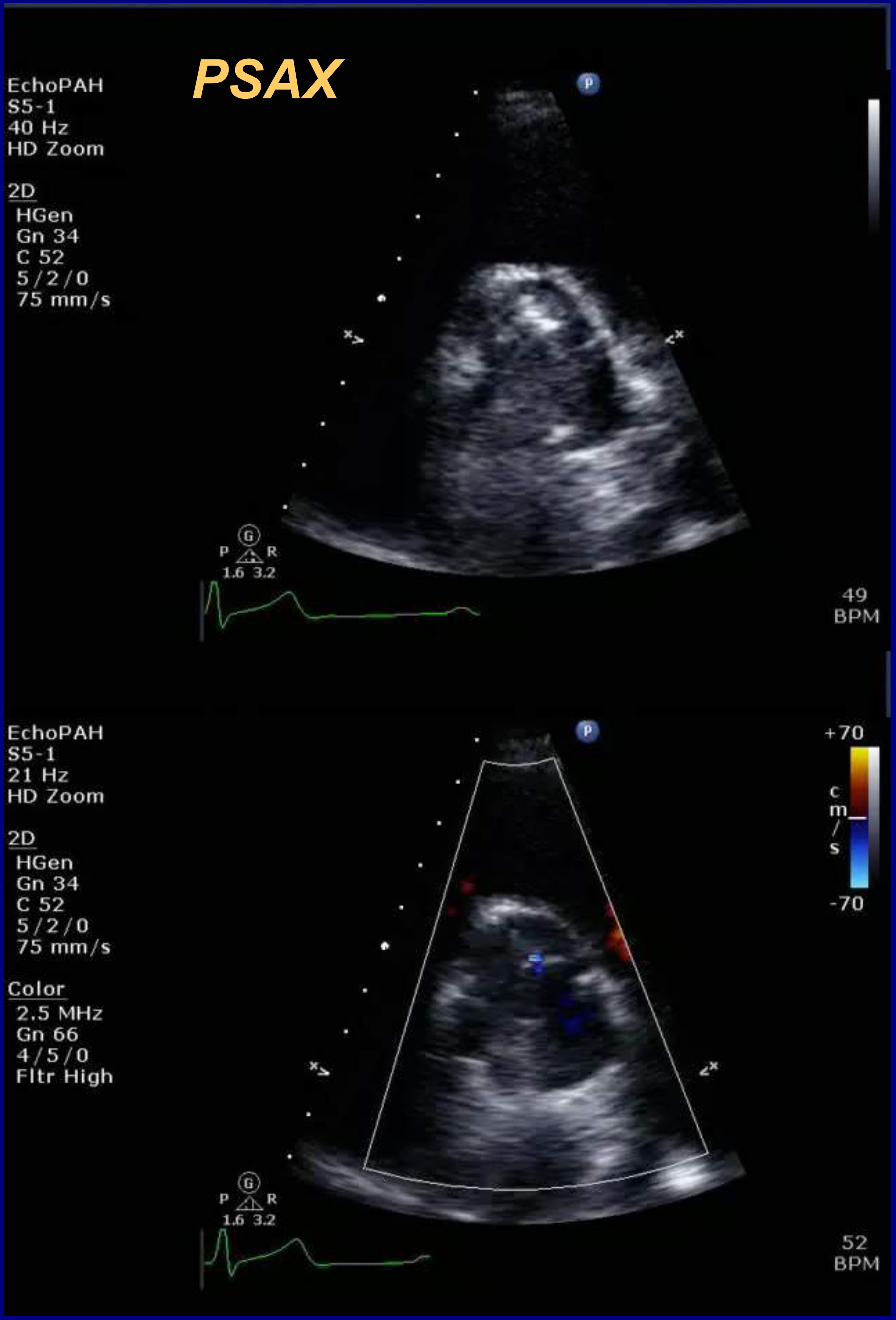




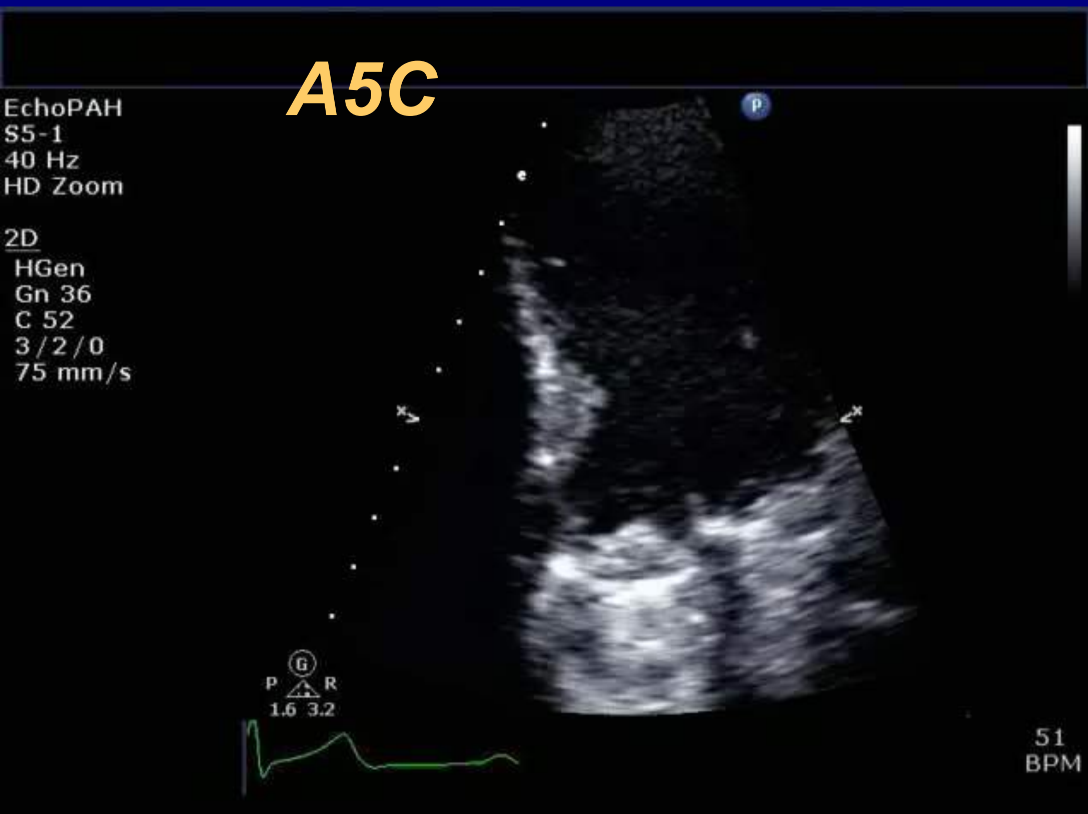


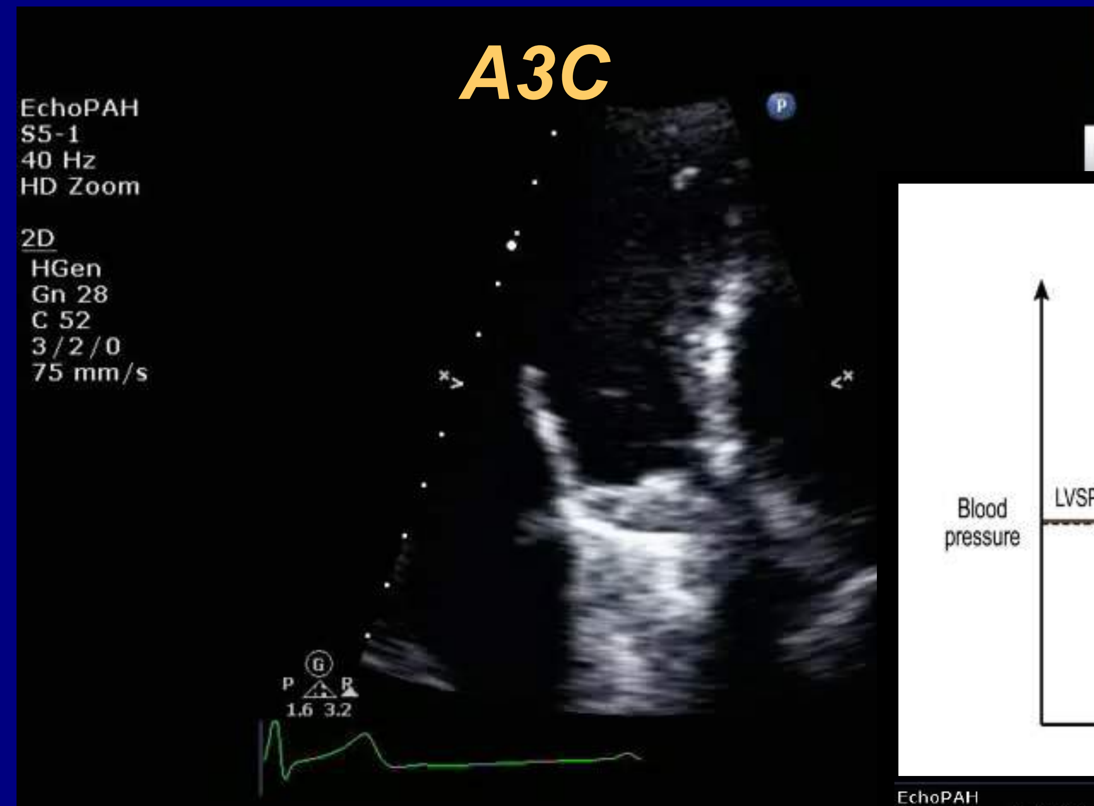
Echo Appearance of SAVRs – Mechanical (1)

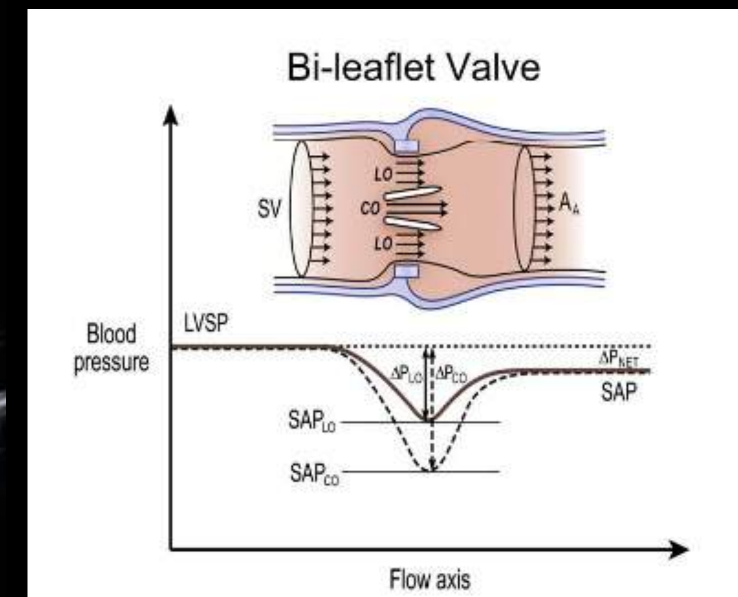


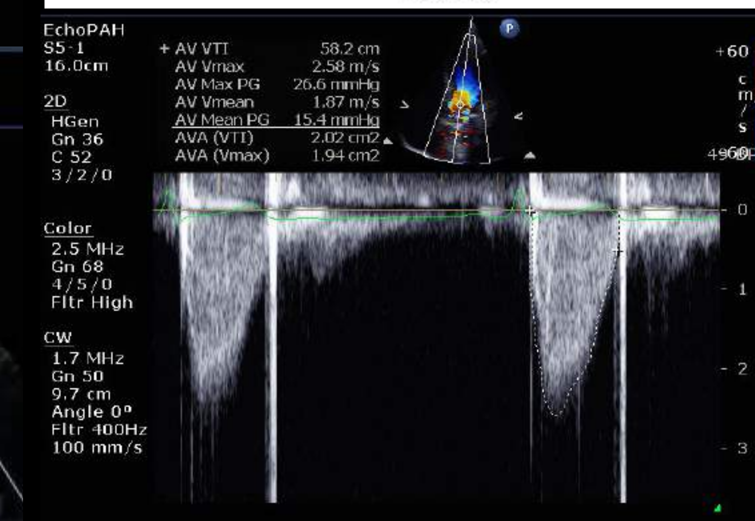


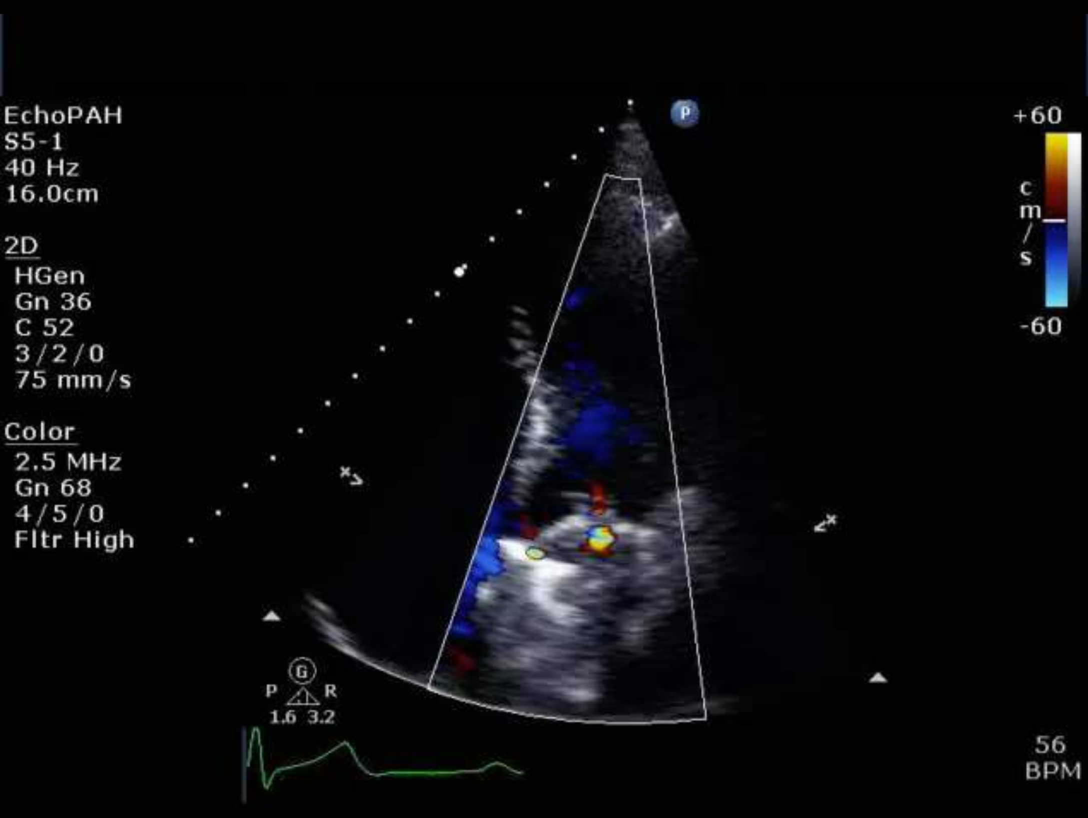
Echo Appearance of AVRs – Mechanical (2)

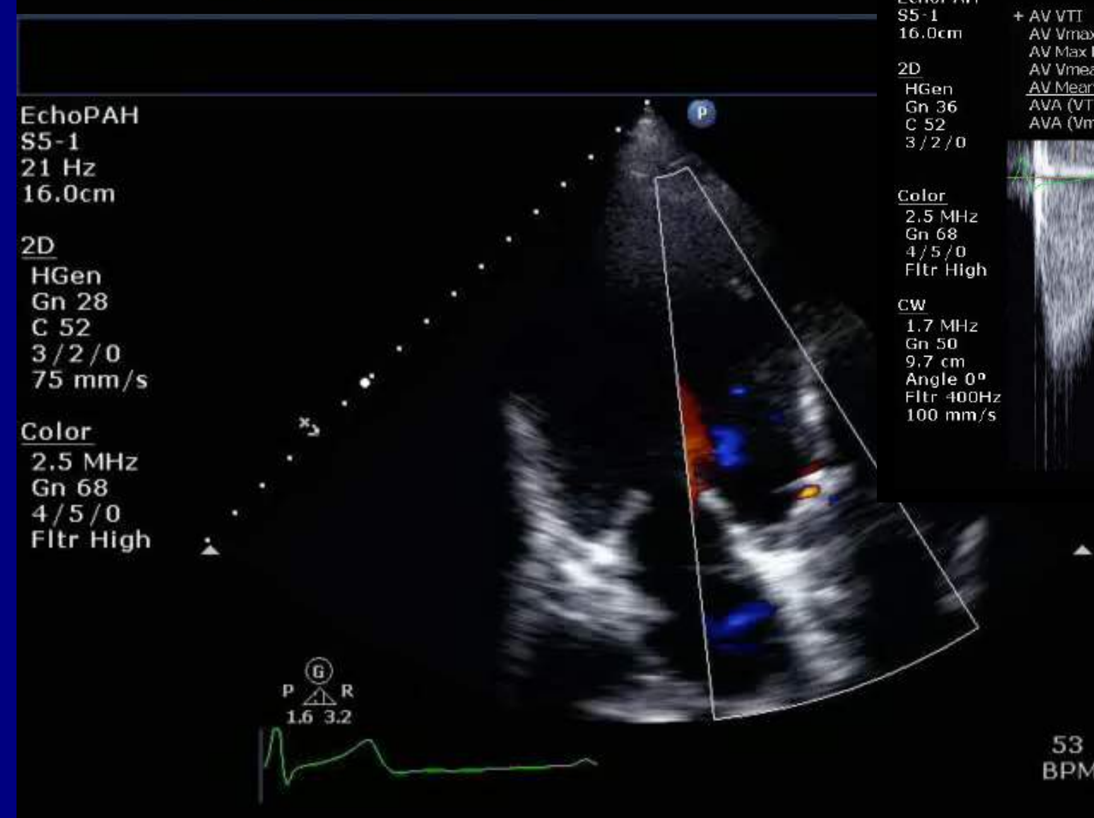




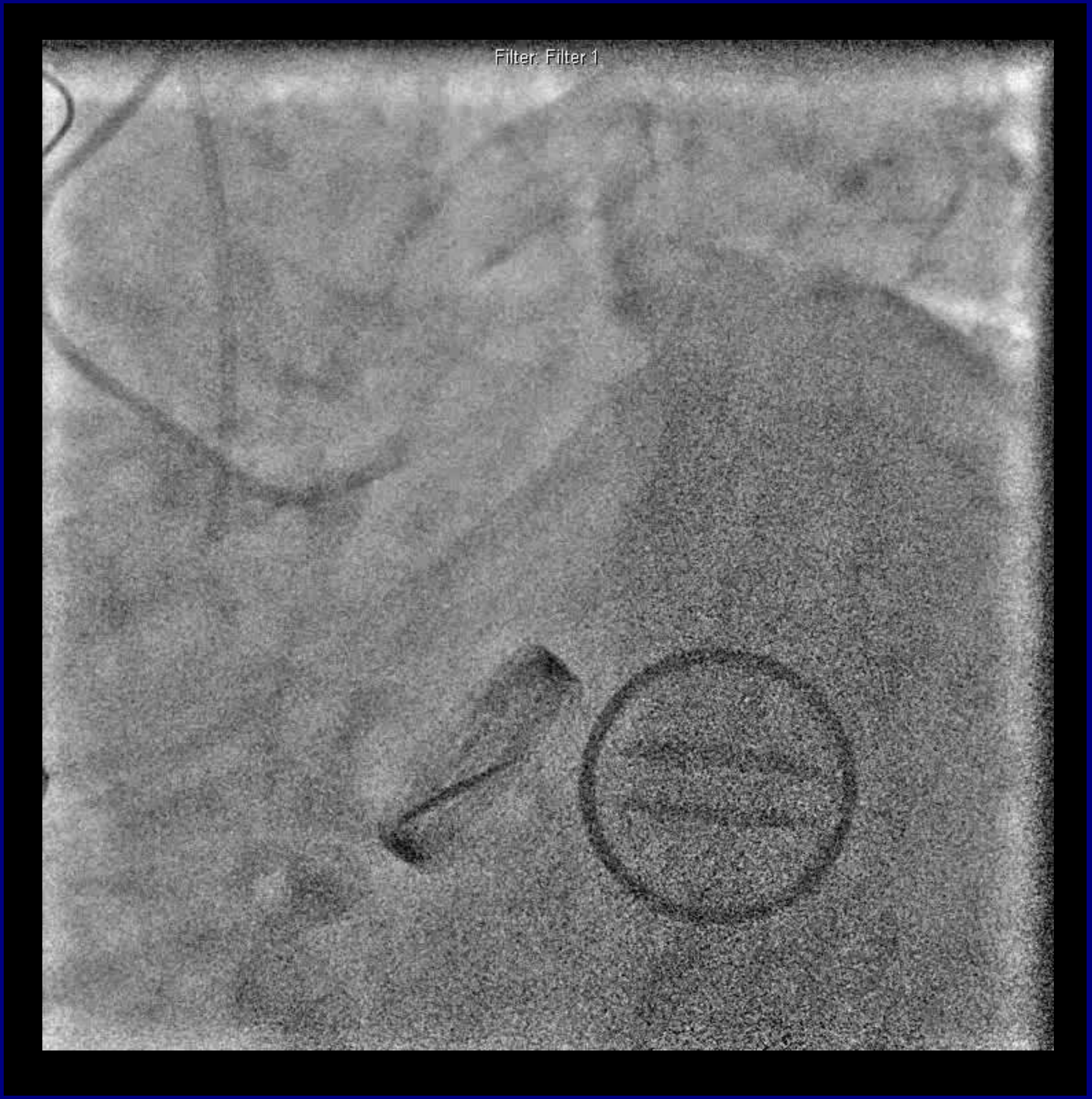






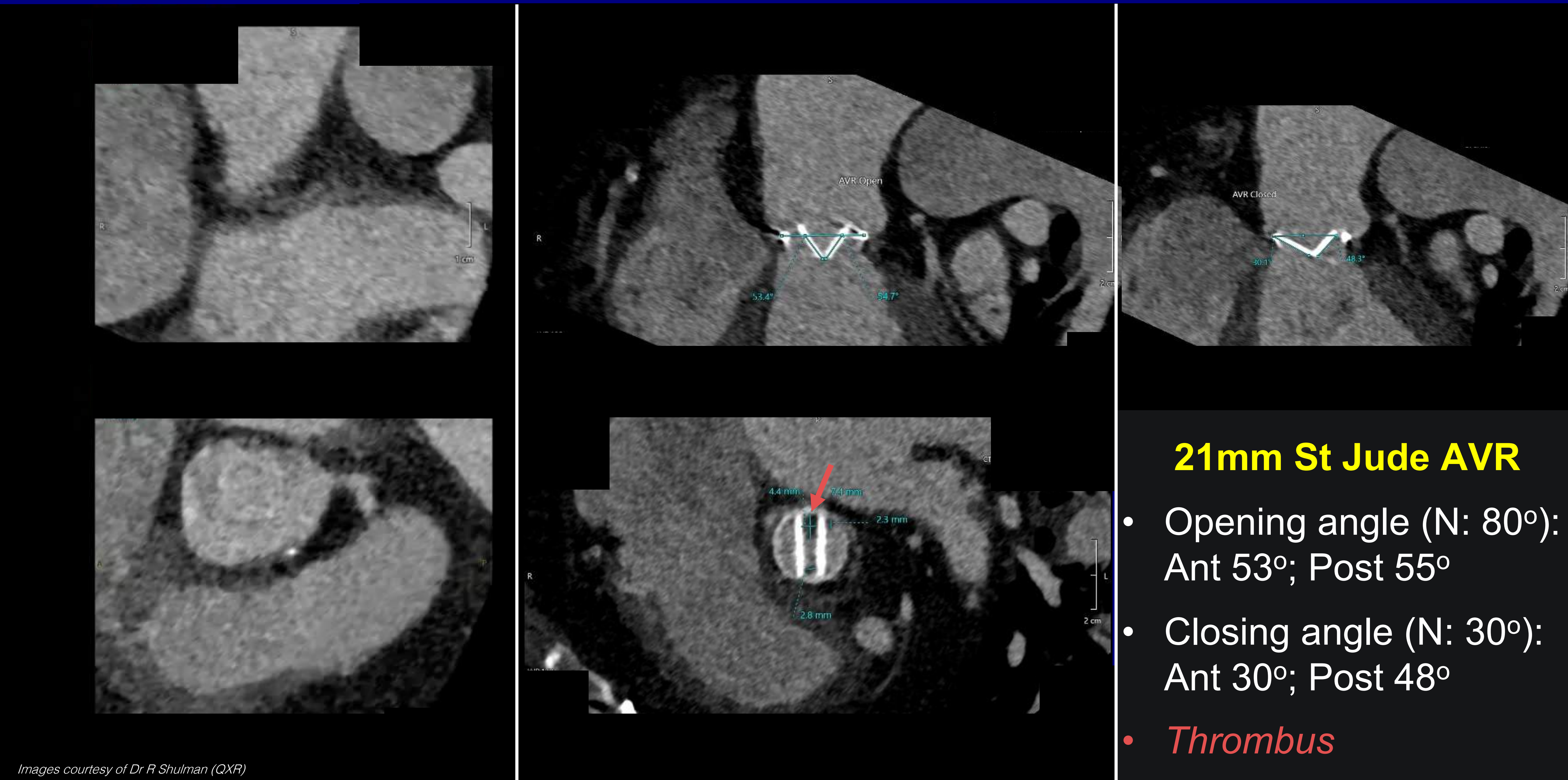


Cinefluoroscopy



- Indicated in abnormally increased gradients
- Occluder mobility, valvular ring motion
- Rocking = Extensive (40%) valve dehiscence

Cardiac CT (4D)



Images courtesy of Dr R Shulman (QXR)

21mm St Jude AVR

- Opening angle (N: 80°): Ant 53°; Post 55°
- Closing angle (N: 30°): Ant 30°; Post 48°
- *Thrombus*

- Alternative to fluoroscopy for opening/closing angles
- Valvular mobility, integrity, and paravalvular pathology
- Bioprosthetic leaflet thickening, calcification or thrombus; AVA by planimetry
- Thrombus vs pannus on mechanical valves

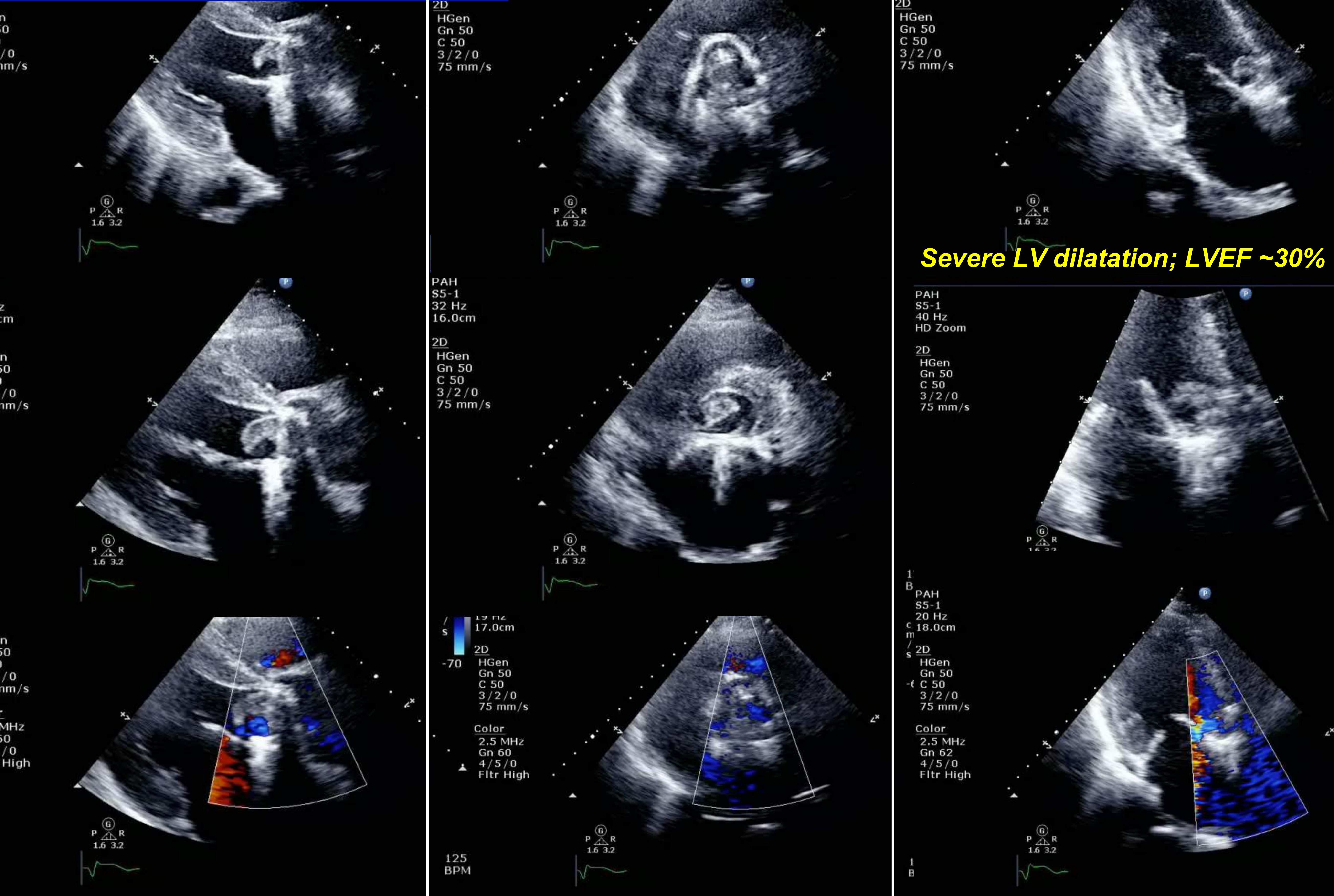
Aortic Prosthetic Valve Obstruction

	Normal	Possible Obstruction	Significant Obstruction
QUALITATIVE			
• *Valve structure/motion*	Normal	Often abnormal	Abnormal
• *CW Doppler envelope*	Triangular; Earl peak	Triangular to intermediate	Rounded; Symmetrical
SEMI-QUANTITATIVE			
• *Acceleration time (AT)*	<80msec	80-100msec	>100msec
• *AT : Ejection time (ET) ratio*	<0.32	0.32-0.37	>0.37
QUANTITATIVE			
• *Peak vel.*	<3.0m/sec	3.0 - 3.9m/sec	≥4.0m/sec
• *Mean gradient*	<20mmHg	20 - 34mmHg	≥35mmHg
• *Increase in mean gradient during f/up*	<10mmHg	10 - 19mmHg	≥20mmHg
• *EOA*	>1.1cm^2	0.8 – 1.1cm^2	<0.8cm^2
• Measured EOA vs normal (reference) value	Reference +/-1SD	<Reference - 1SD	<Reference - 2SD
• Reference EOA – measured EOA	<0.25cm^2	0.25 – 0.35cm^2	>0.35cm^2
• *DVI*	≥0.35	0.25 – 0.34	<0.25

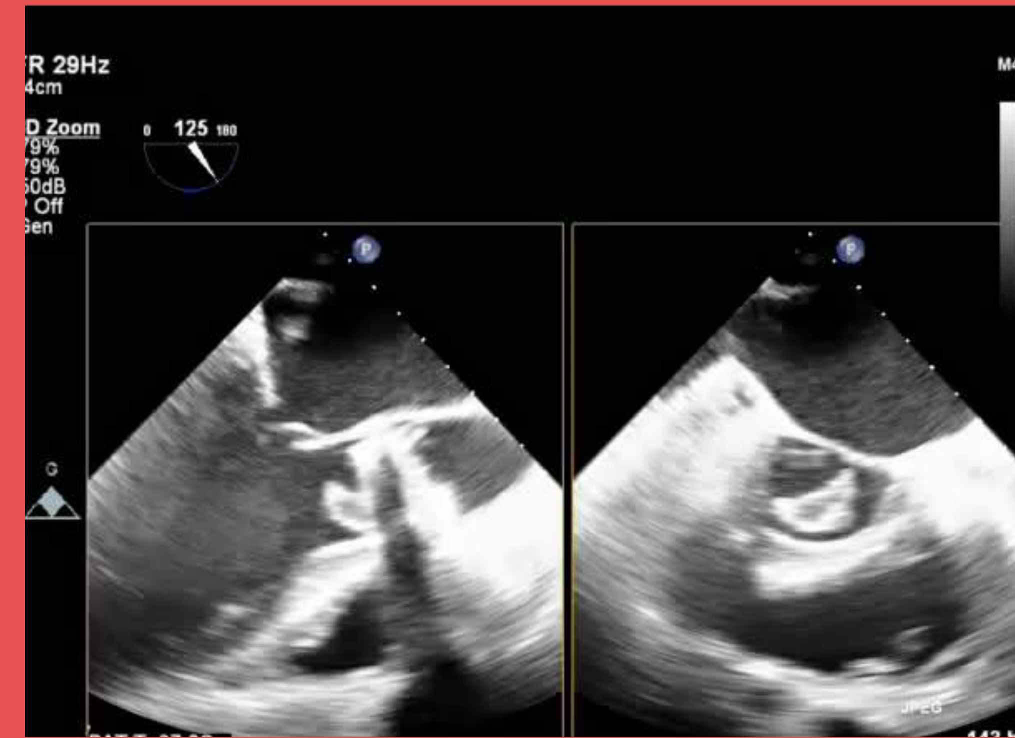
22yo female

Chest pain; Hypotension; Shocked

AVR; Subtherapeutic INR (Non-compliant)




Thrombus

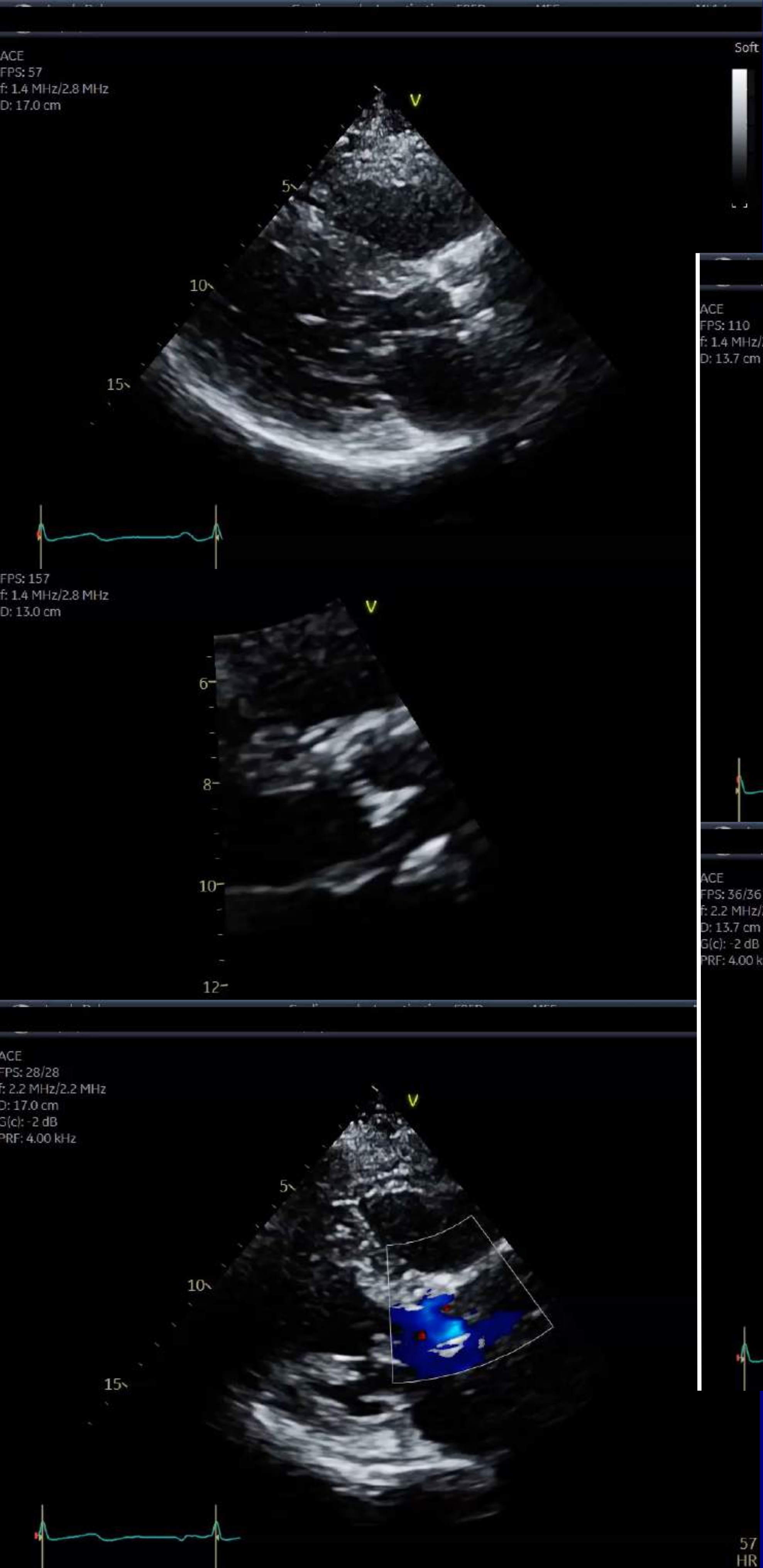

D Zoom
125
JPEG


25mm Magna Ease
PAT T: 37.0C
TEE T: 39.7C
JPEG
JPEG

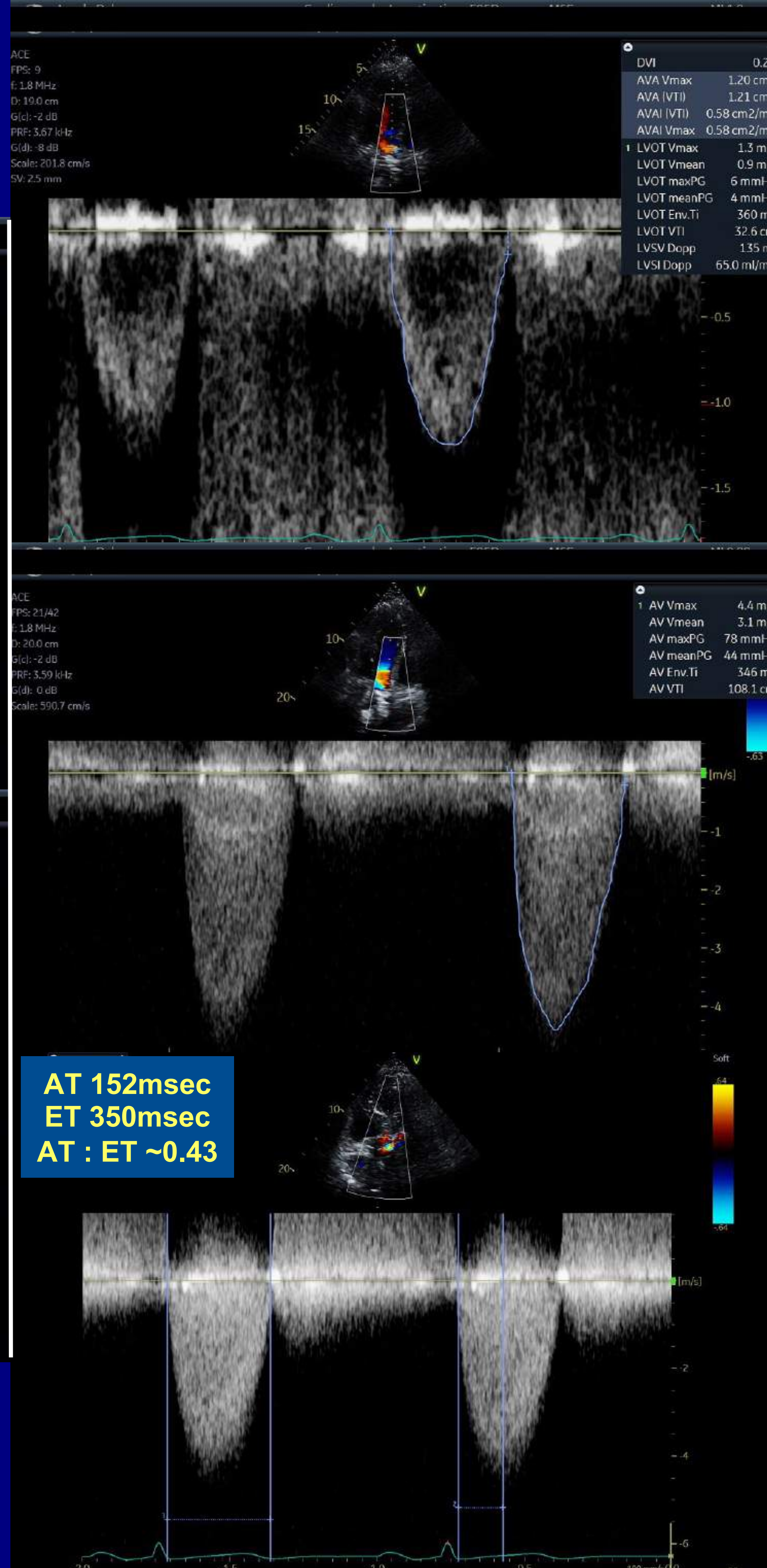
58yo male

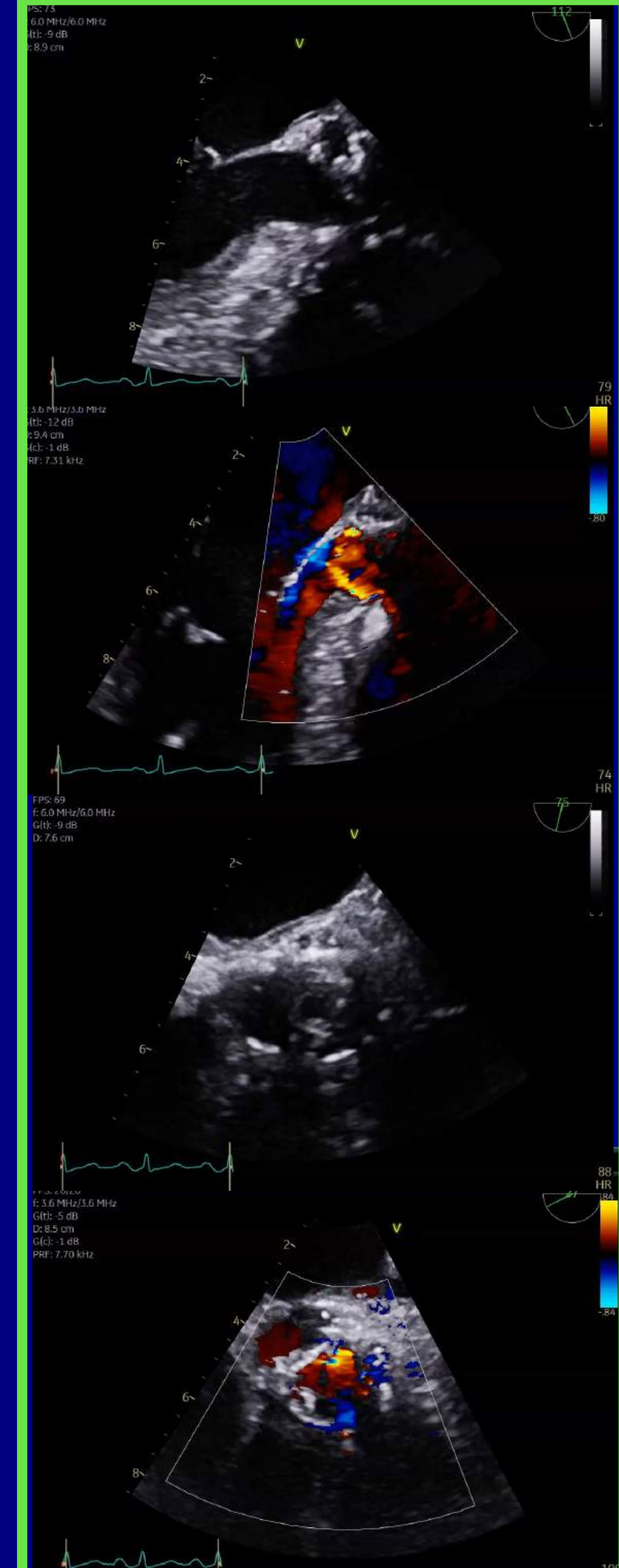
23mm Trifecta BioAVR (Implanted 2017)

Increasing gradients on serial TTEs



Structural Valve Dysfunction (SVD)



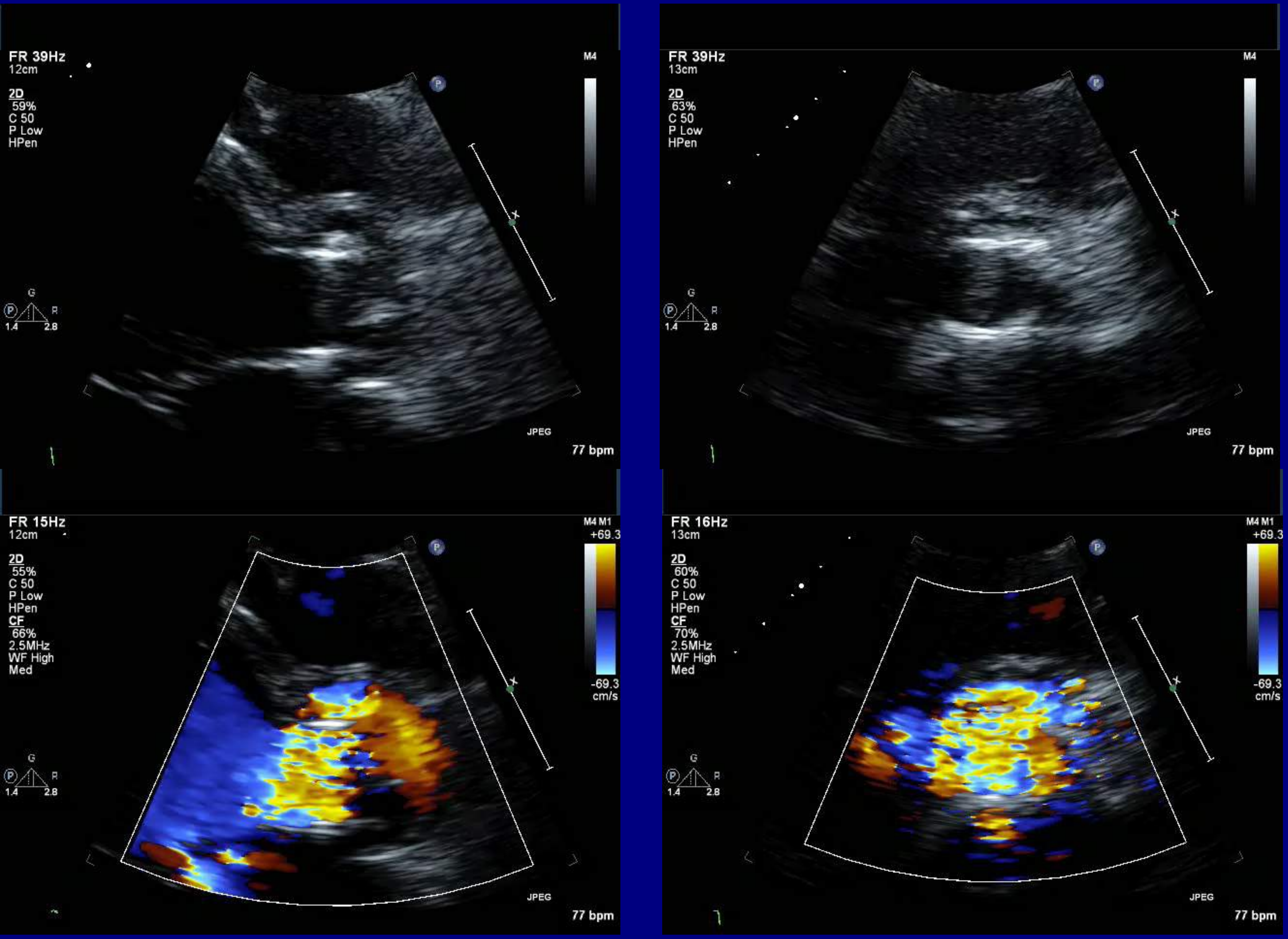


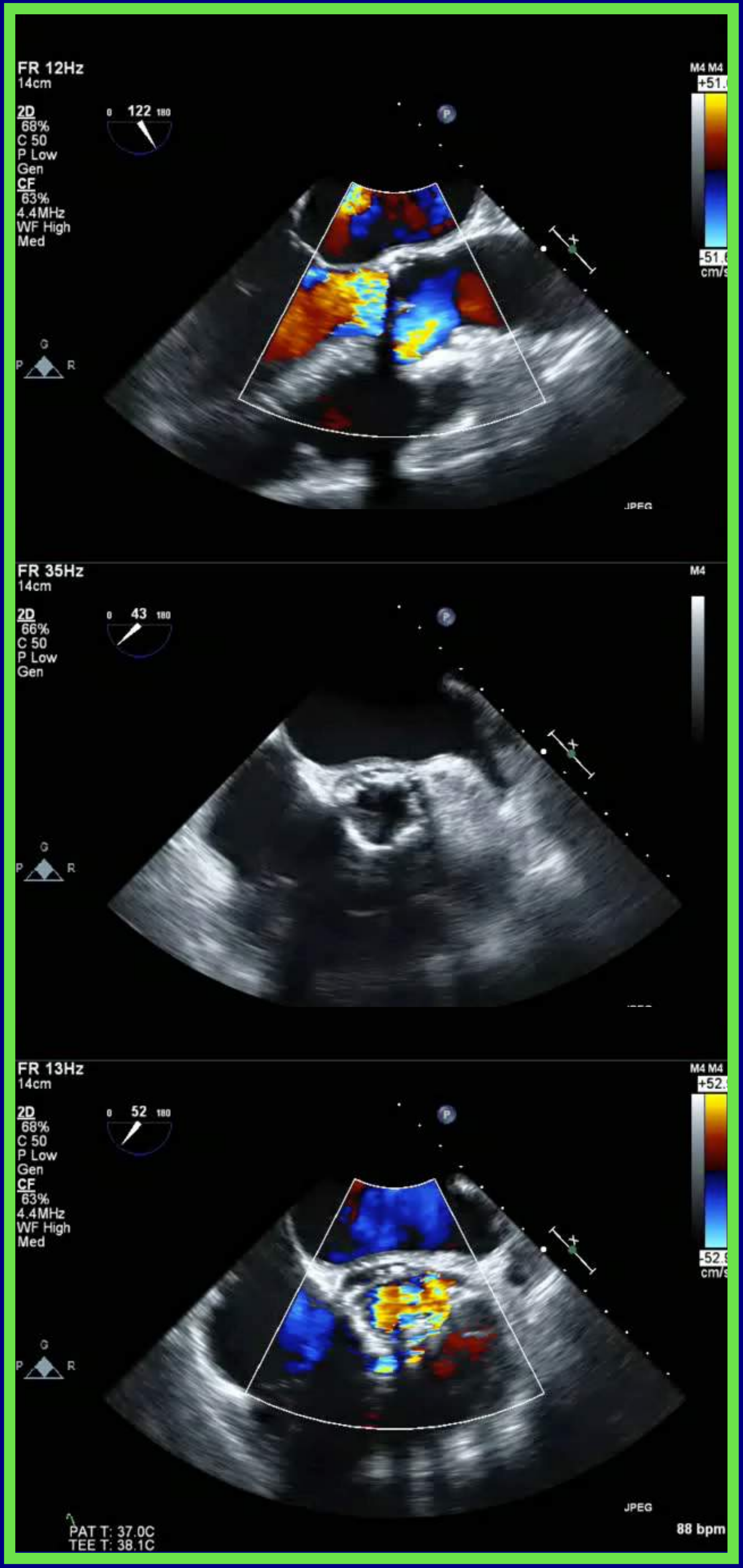
Severe BioAVR Stenosis & Mild-moderate AR

Aortic Prosthetic Valve Regurgitation

	Mild	Moderate	Severe
QUALITATIVE			
• *Valve structure/motion*	Usually normal	Usually abnormal	Abnormal
• *AR jet width (Central AR)*	Small (<25%)	Intermediate	>65% LVOT width
• *AR CW signal density*	Incomplete; Faint	Dense	Dense
• *Diastolic flow reversal in descending aorta*	Brief; Early diastole	Descending thoracic aorta; Holodiastolic	Abdominal aorta
• *LV size*	Normal	Normal/Mildly dilated	Dilated
SEMI-QUANTITATIVE			
• *Pressure half-time*	>500msec	200-500msec	<200msec
• *Circumferential extent of PARAVALVULAR AR*	<10%	10-29%	≥30%
• Vena contracta	<0.3cm	0.3 - 0.6cm	>0.6cm
QUANTITATIVE			
• EROA	$<0.10cm^2$	$0.10 - 0.29cm^2$	≥0.30cm2
• RVolume	<30mL	30 - 59mL	≥60mL
• RFraction	<30%	30 - 50%	>50%

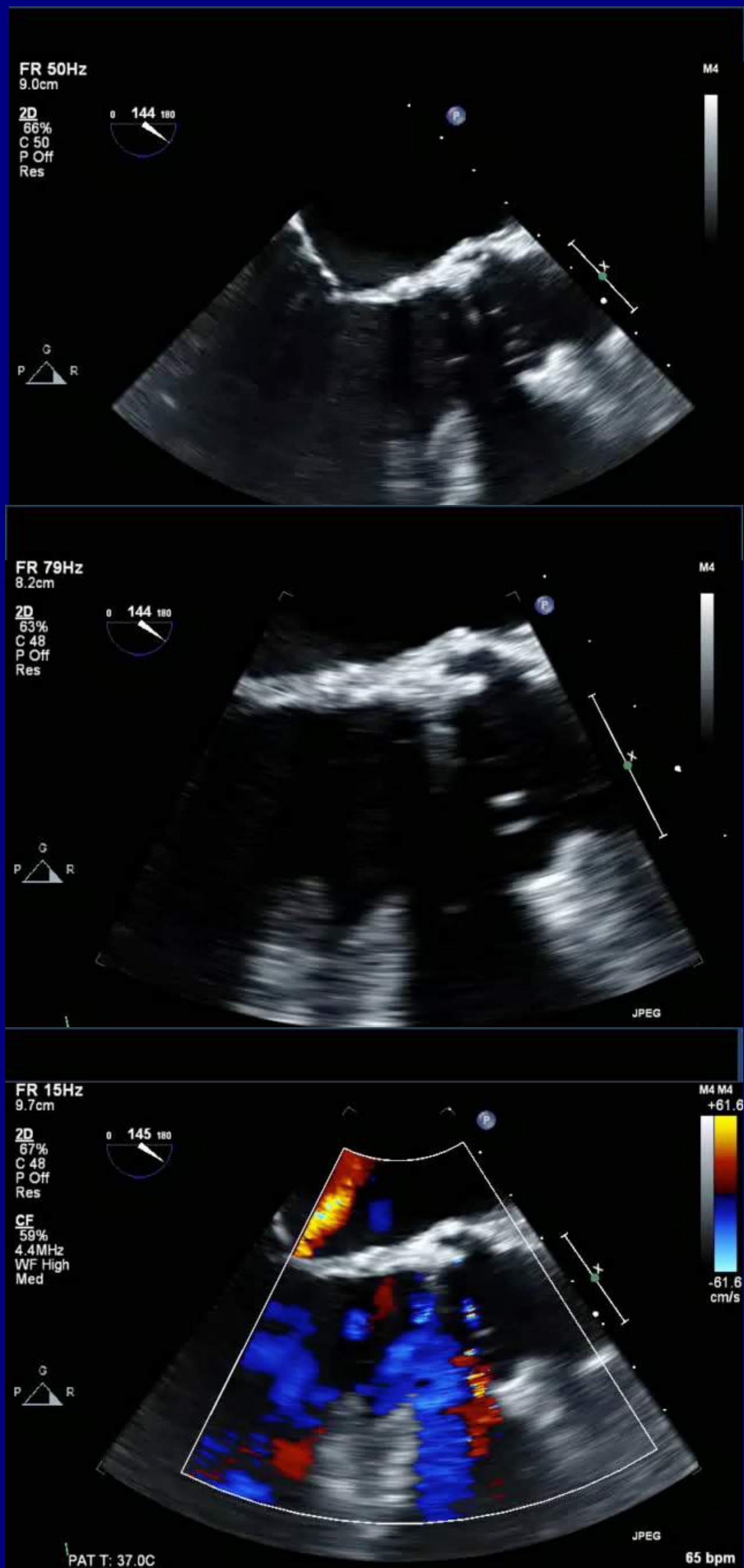
Bioprosthetic AVR – Paravalvular AR



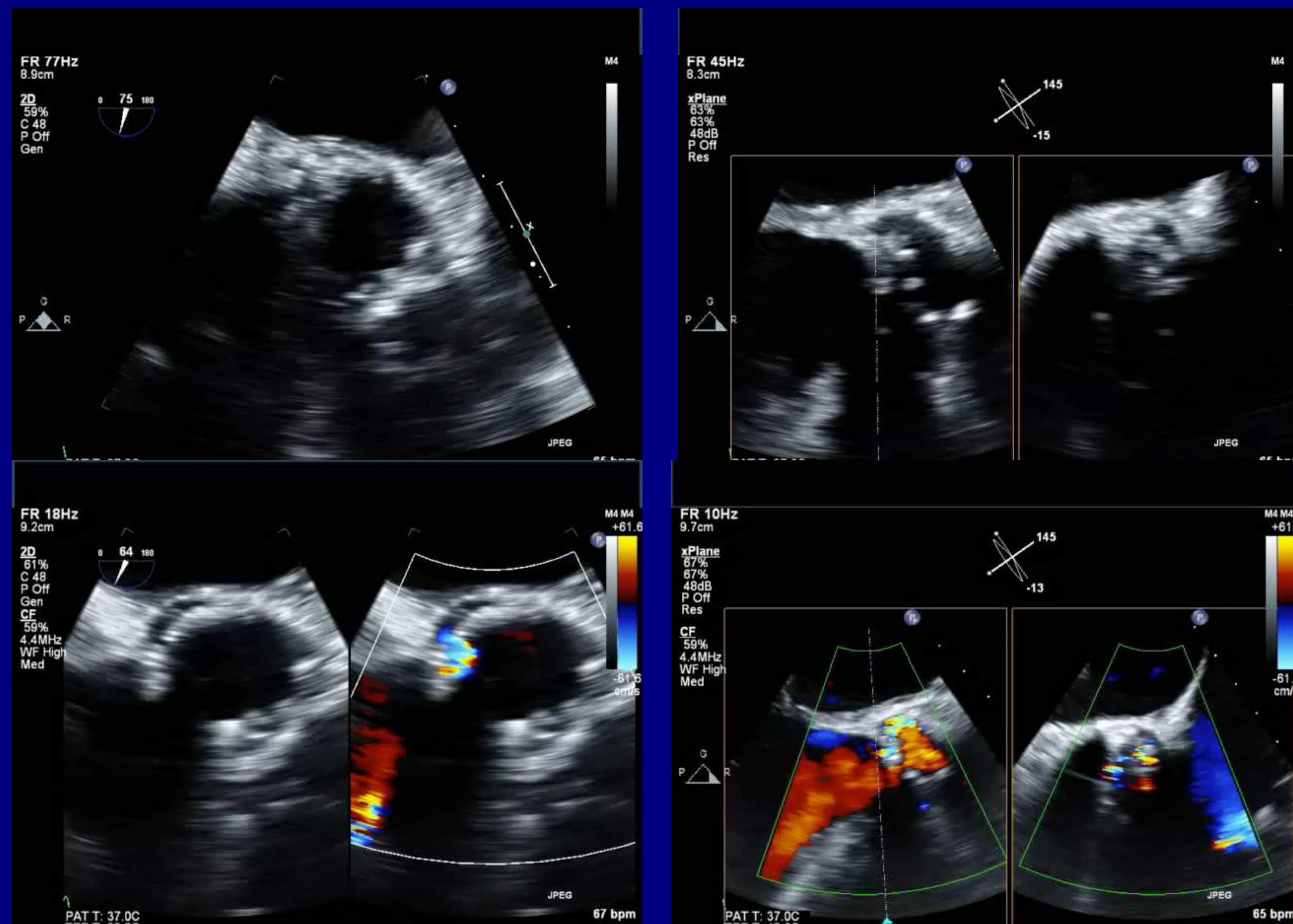


Severe anterior paravalvular AR

Mechanical AVR – Paravalvular AR

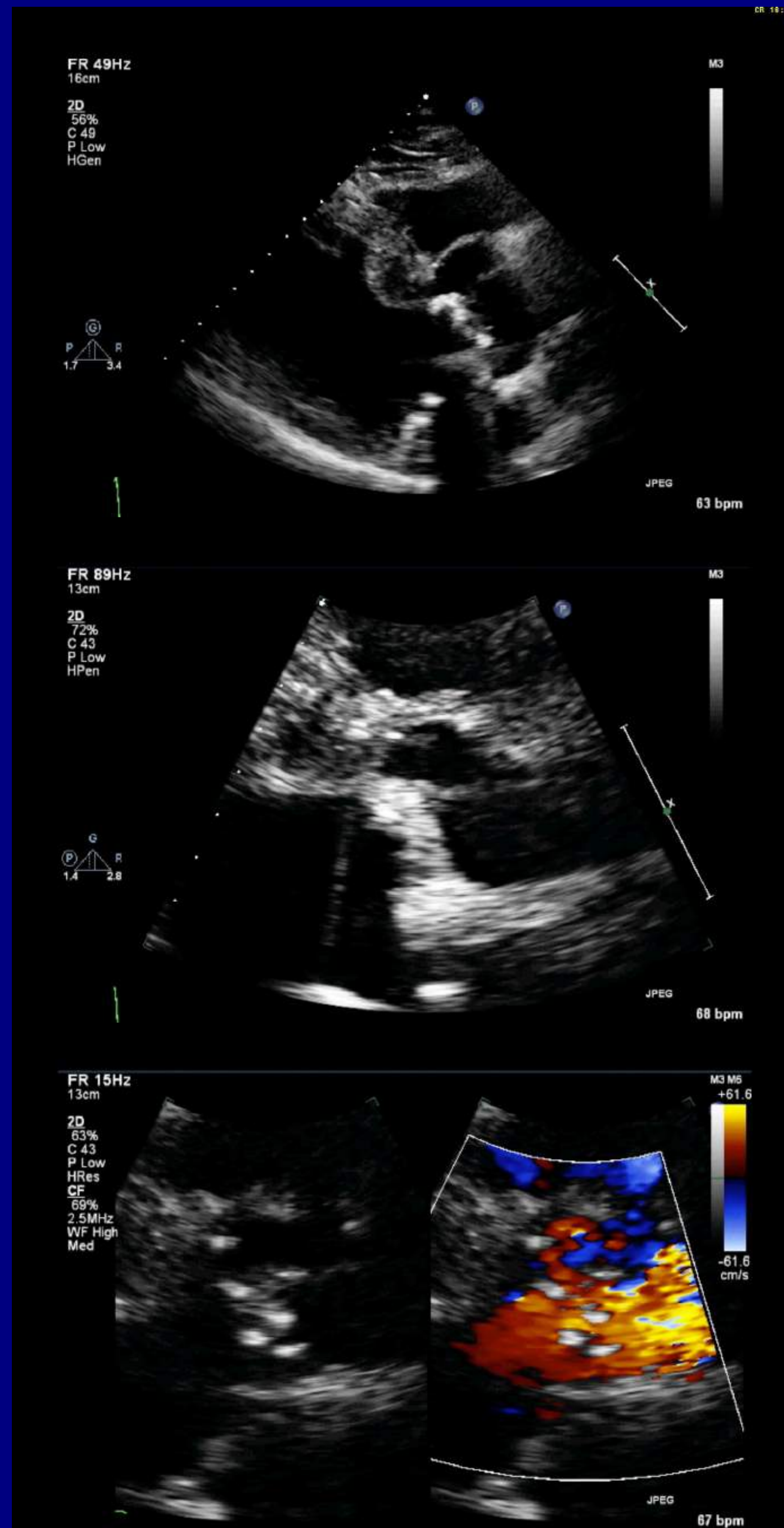


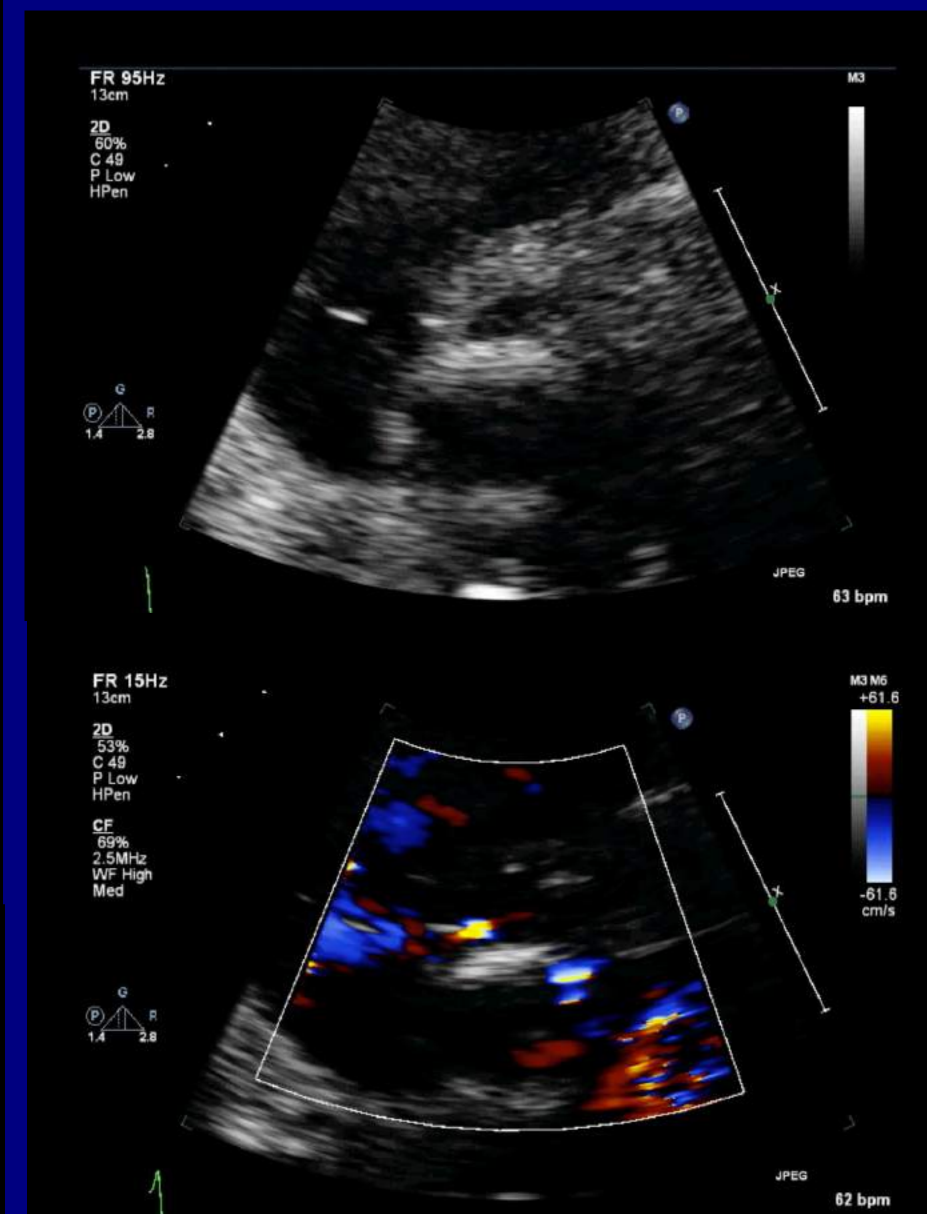
21mm SJM

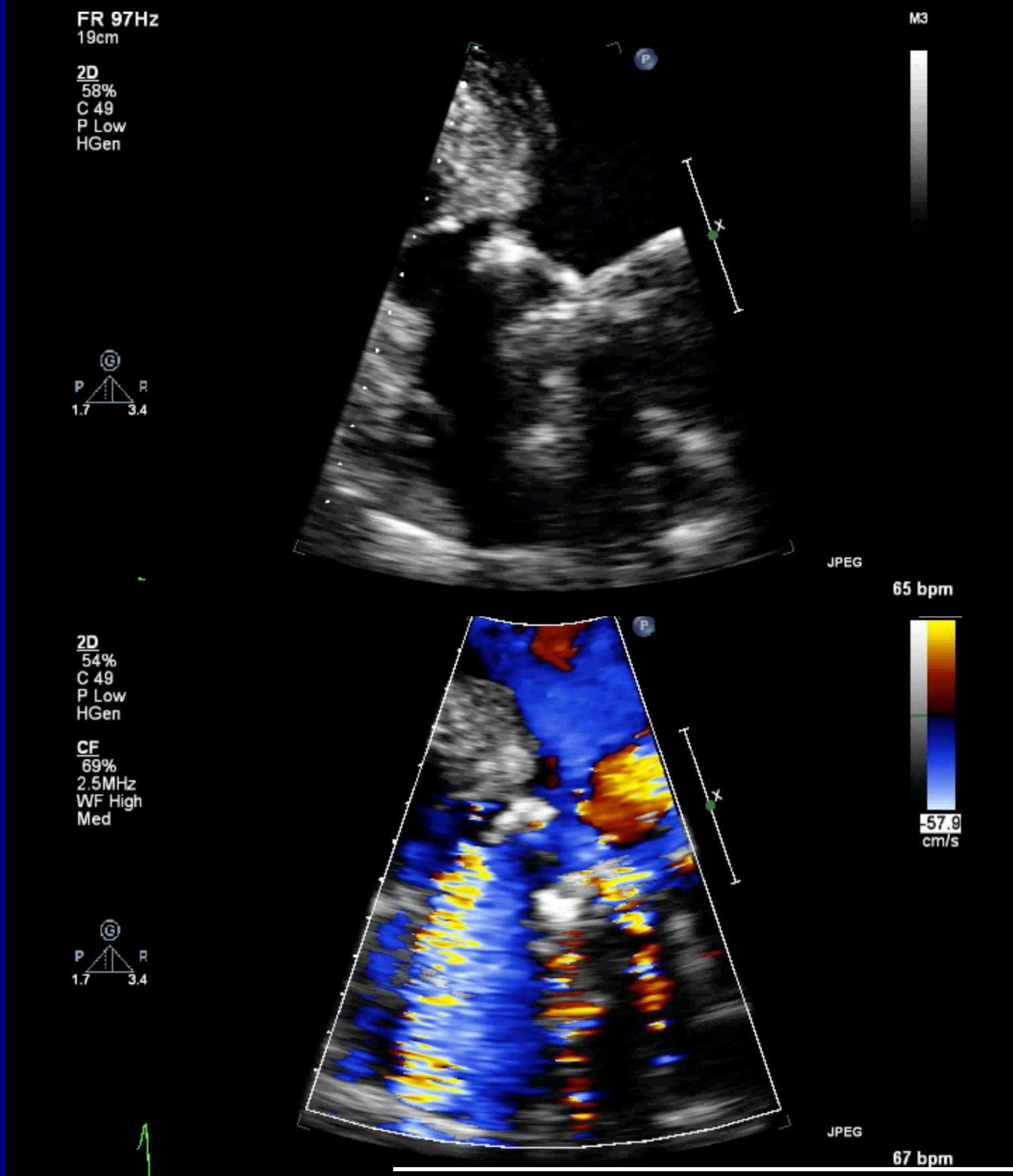
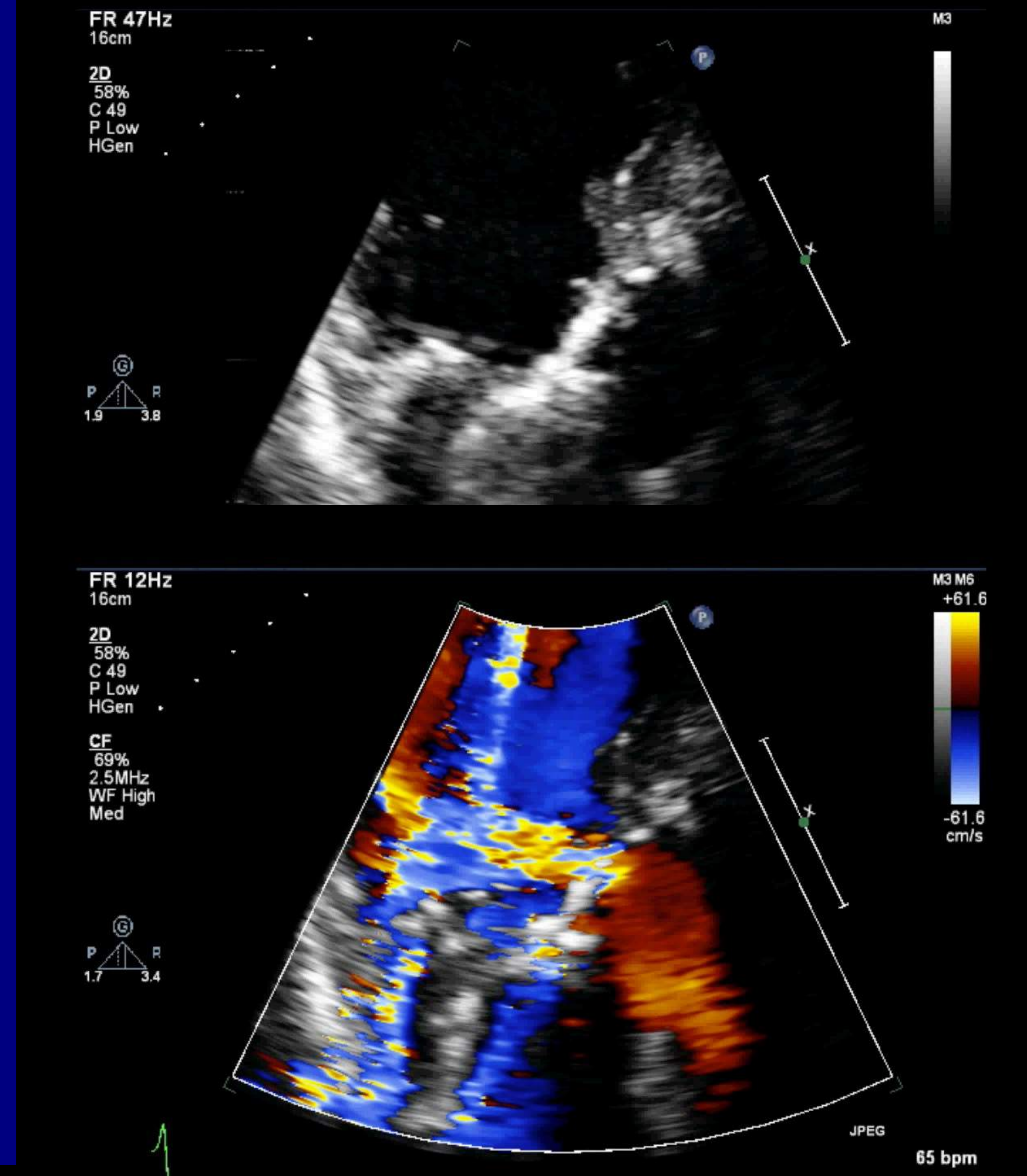
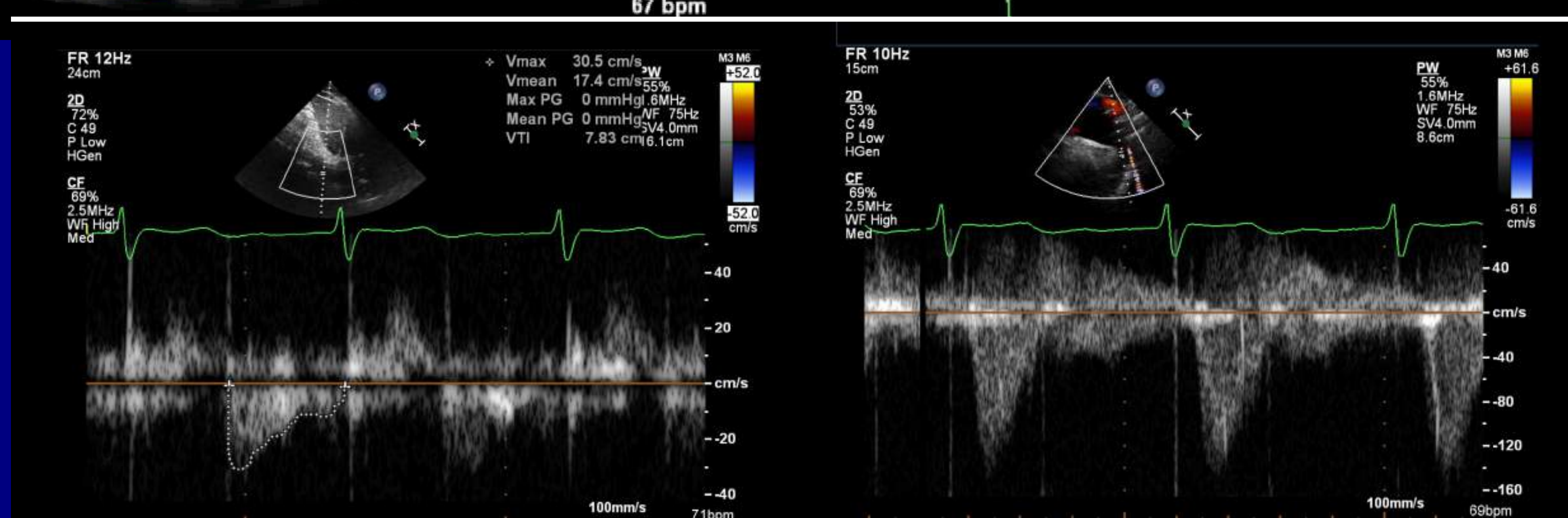


Mild-moderate posteromedial paravalvular AR

“Rocking” AVR and Severe Paravalvular AR





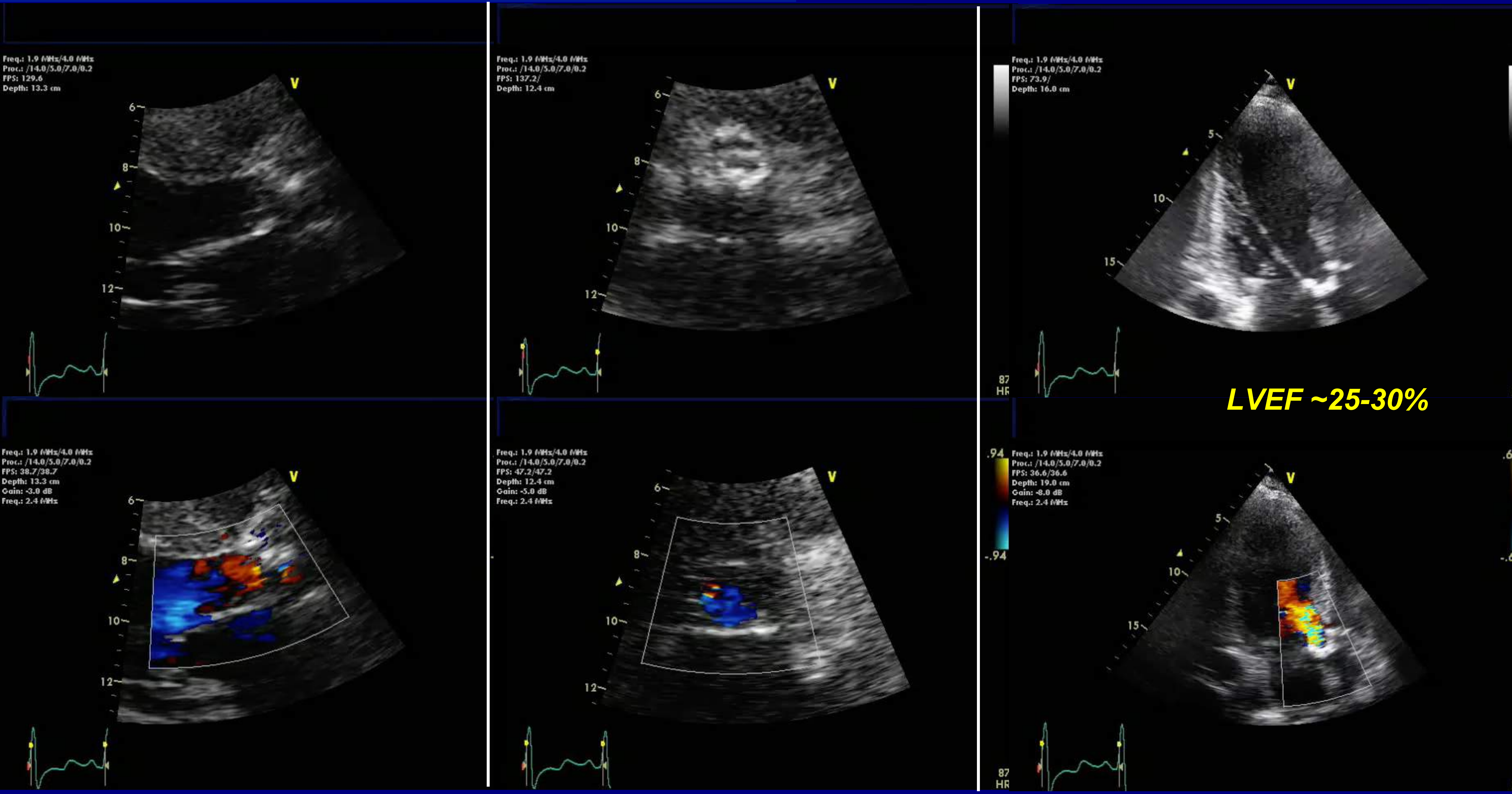

FR 97Hz
19cm
2D
58%
C 49
P Low
HGen
M3
1.7 3.4
JPEG
65 bpm
2D
54%
C 49
P Low
HGen
CF
69%
2.5MHz
WF High
Med
-57.9
cm/s
JPEG
67 bpm

FR 47Hz
16cm
2D
58%
C 49
P Low
HGen
M3
1.9 3.8
FR 12Hz
16cm
2D
58%
C 49
P Low
HGen
CF
69%
2.5MHz
WF High
Med
M3 M6
+61.6
-61.6
cm/s
1.7 3.4
JPEG
65 bpm

FR 12Hz
24cm
2D
72%
C 49
P Low
HGen
CF
69%
2.5MHz
WF High
Med
Vmax 30.5 cm/s
Vmean 17.4 cm/s
Max PG 0 mmHg
Mean PG 0 mmHg
VTI 7.83 cm
+52.0
-52.0
cm/s
40
20
cm/s
-20
-40
100mm/s
FR 10Hz
15cm
2D
53%
C 49
P Low
HGen
CF
69%
2.5MHz
WF High
Med
PW
55%
1.6MHz
WF 75Hz
SV4.0mm
8.6cm
M3 M6
+61.6
-61.6
cm/s
40
cm/s
-40
-80
-120
-160
100mm/s
69bpm

58yo female

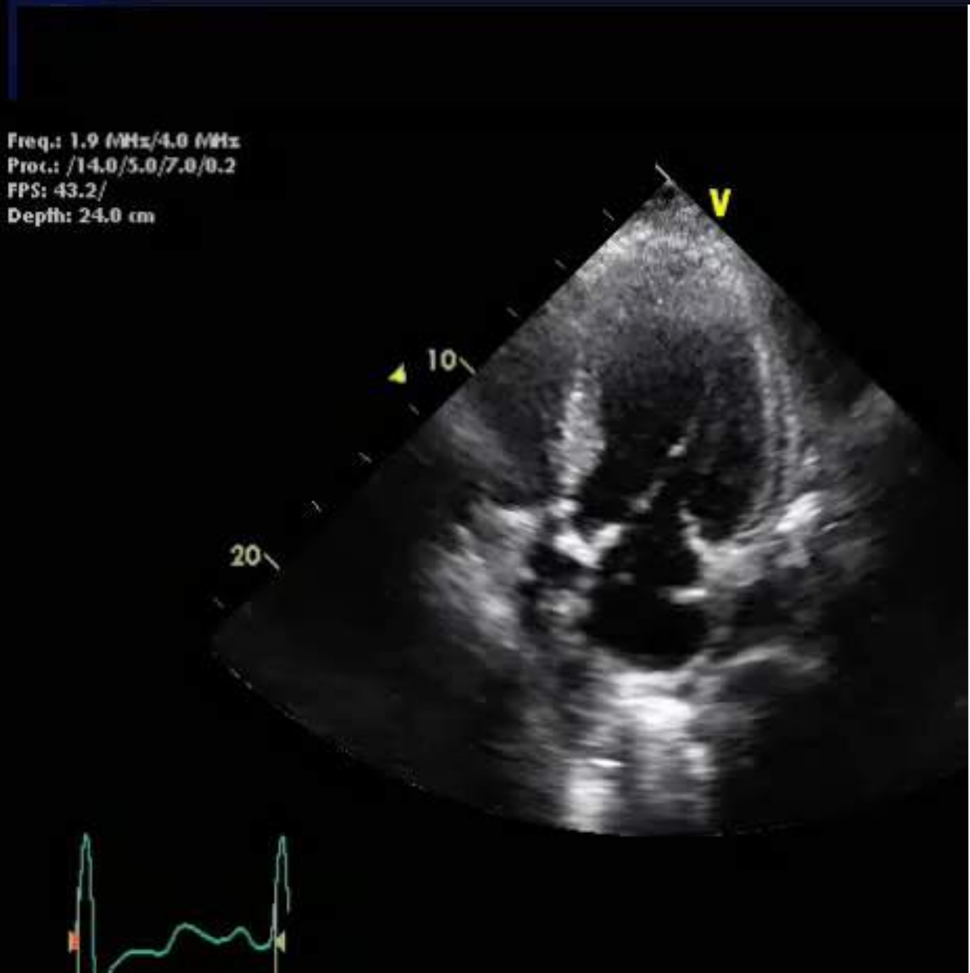
Worsening SOB and LVF

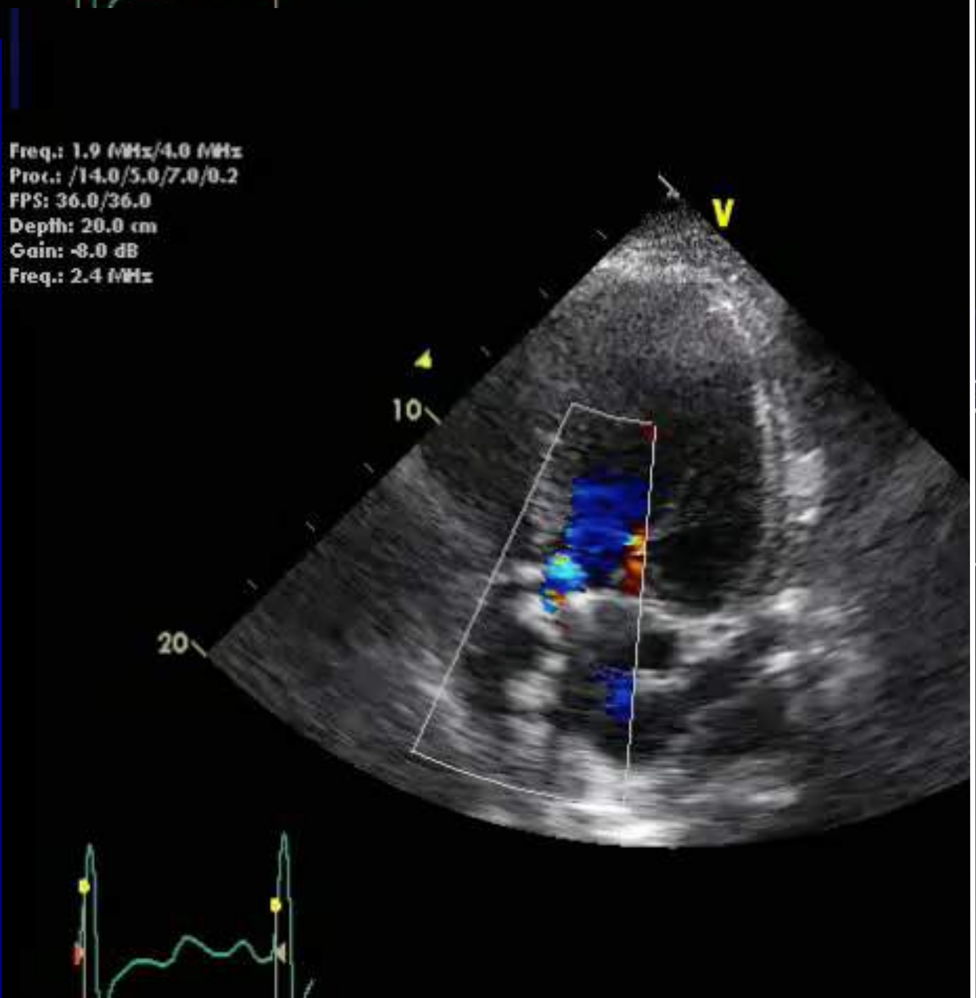
21mm Magna Ease AVR (2009) for IE

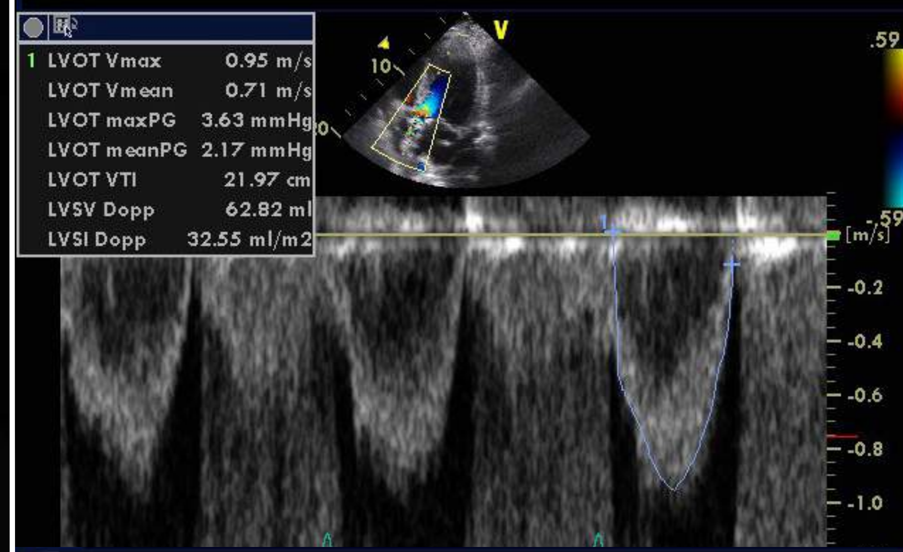
B/G: IVDU, HCV, Wegener's; BSA 1.82m^2

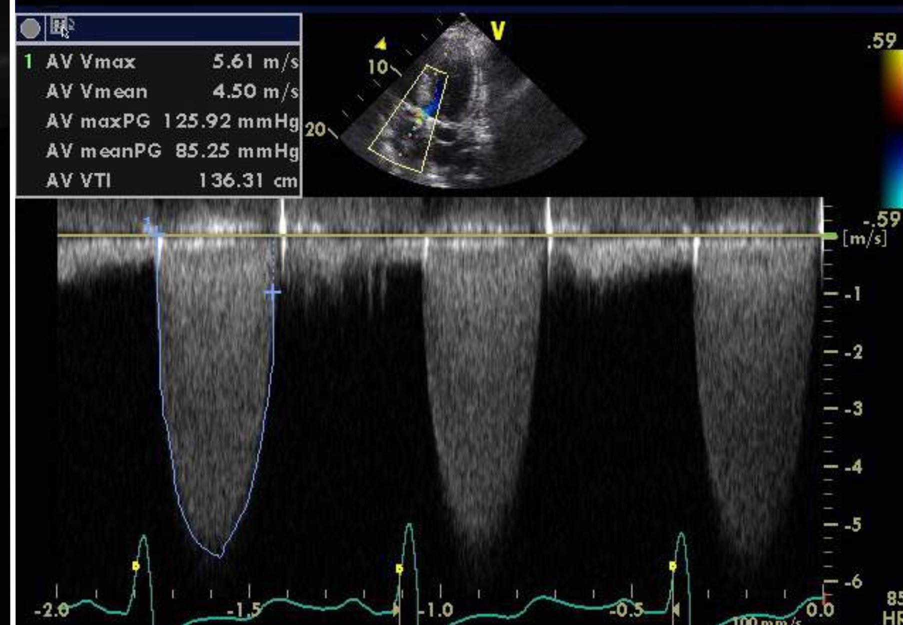


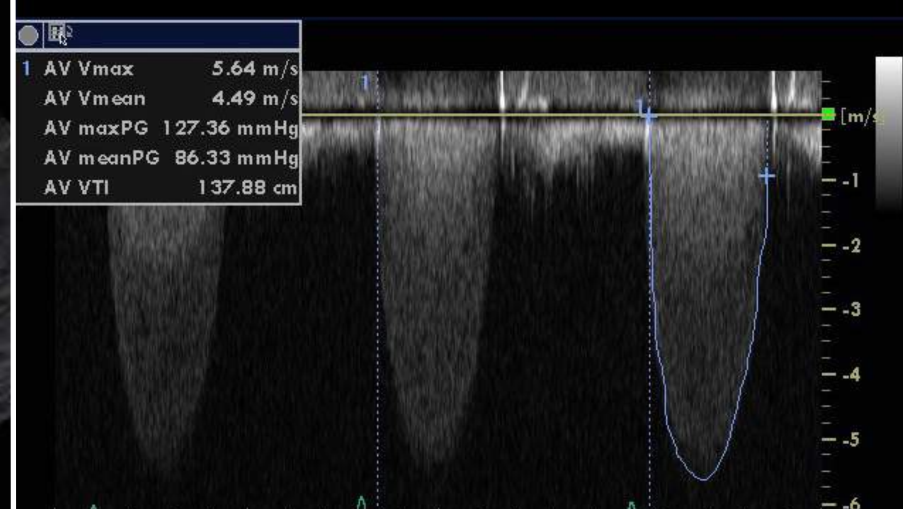
TTE 2014





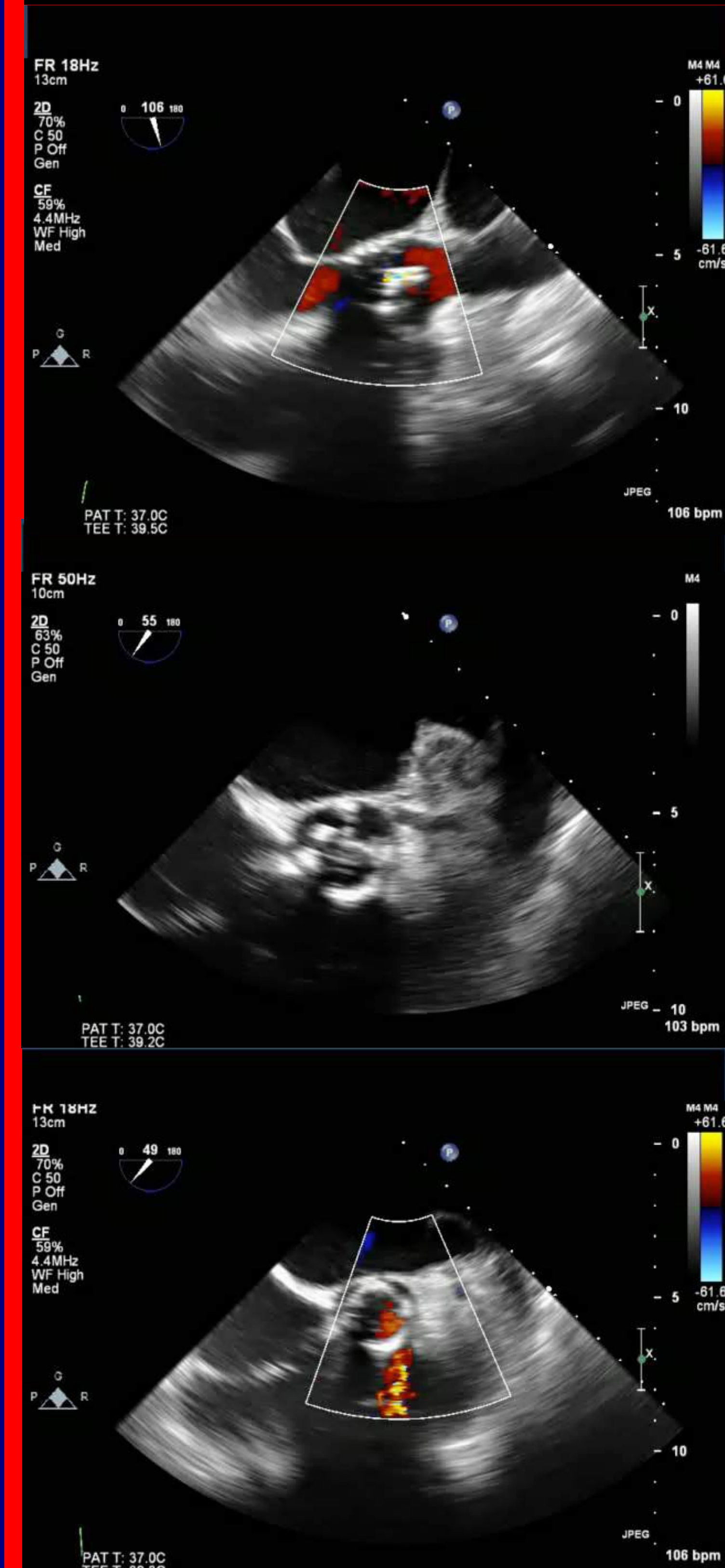




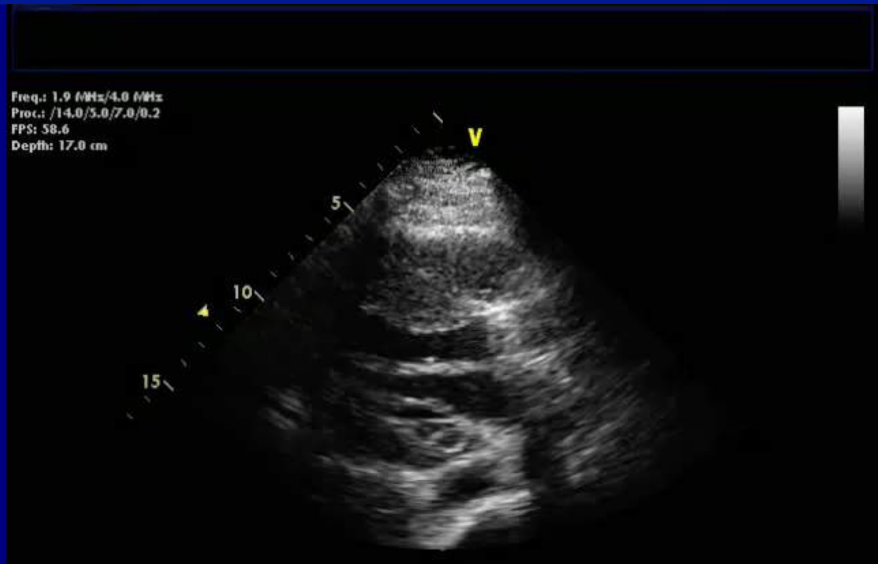


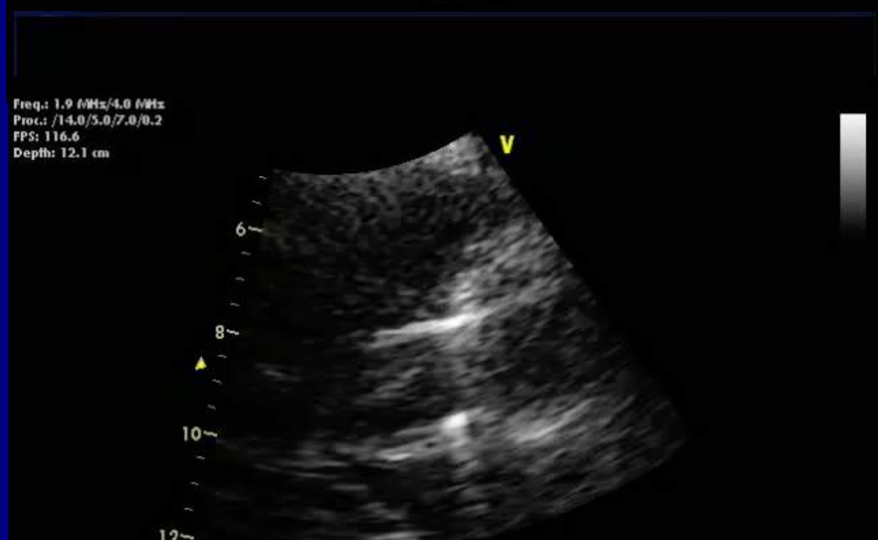
Pressure recovered PG/MG 109/72mmHg
DPI 0.16; EOA 0.6cm^2
AT 126msec; AT 318msec (AT : ET ~0.40)

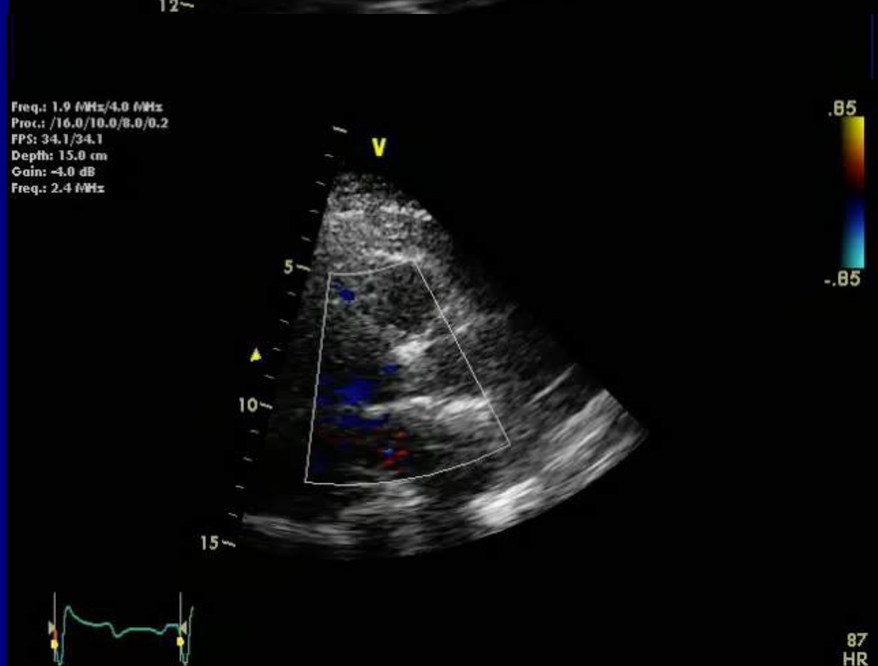
Intra-op TEE

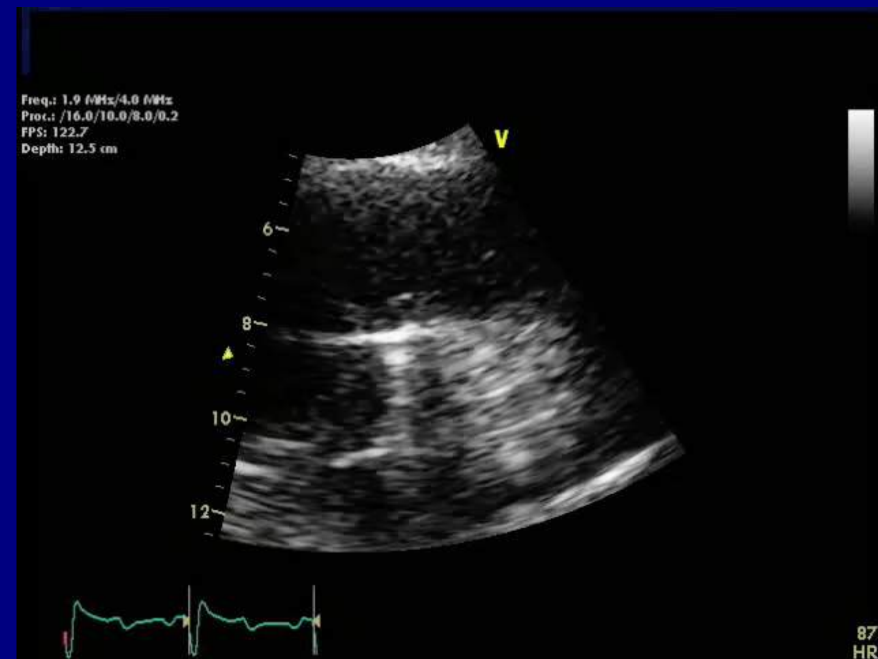


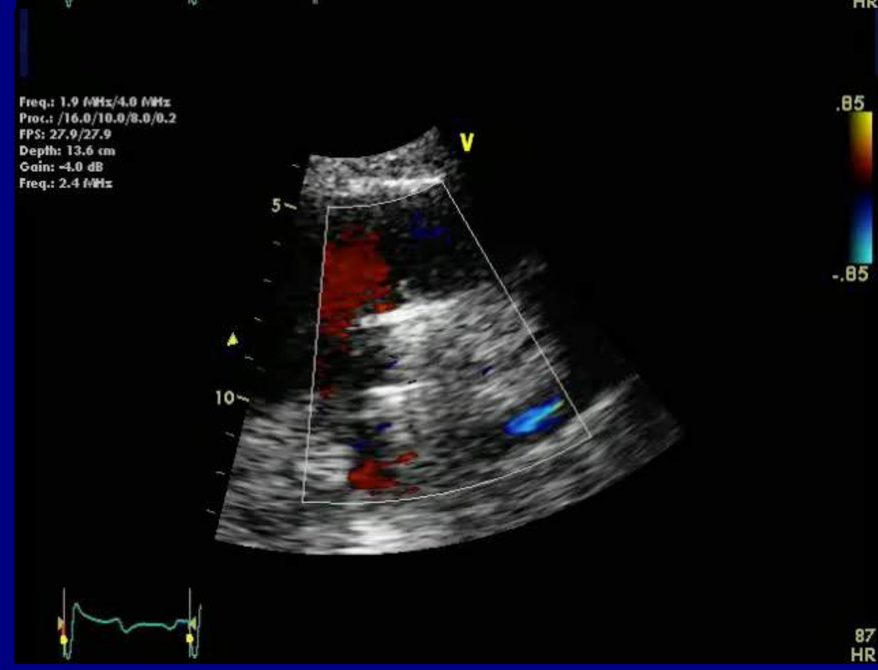
Day 10 post re-do AVR (21mm St Jude Medical Regent)

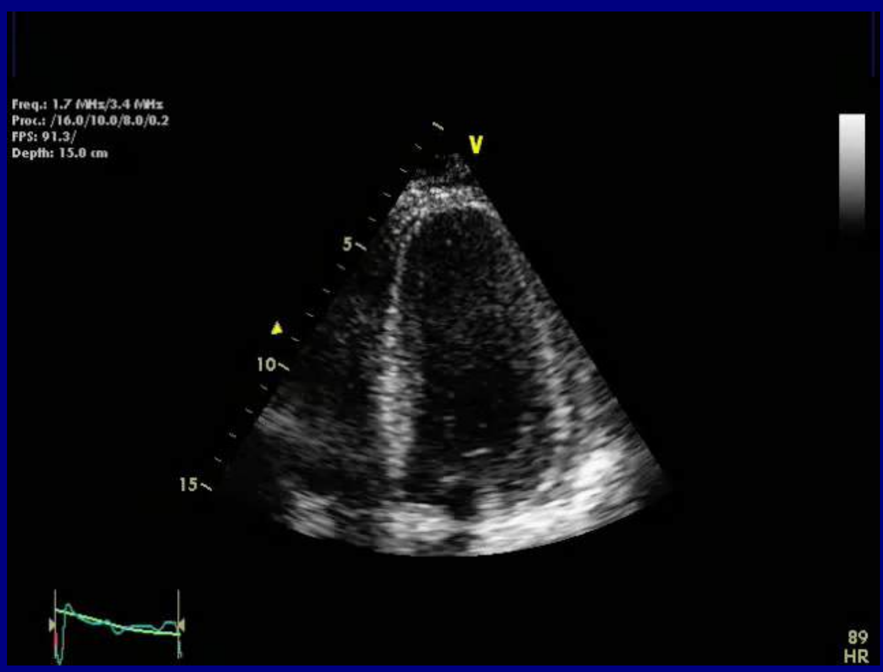




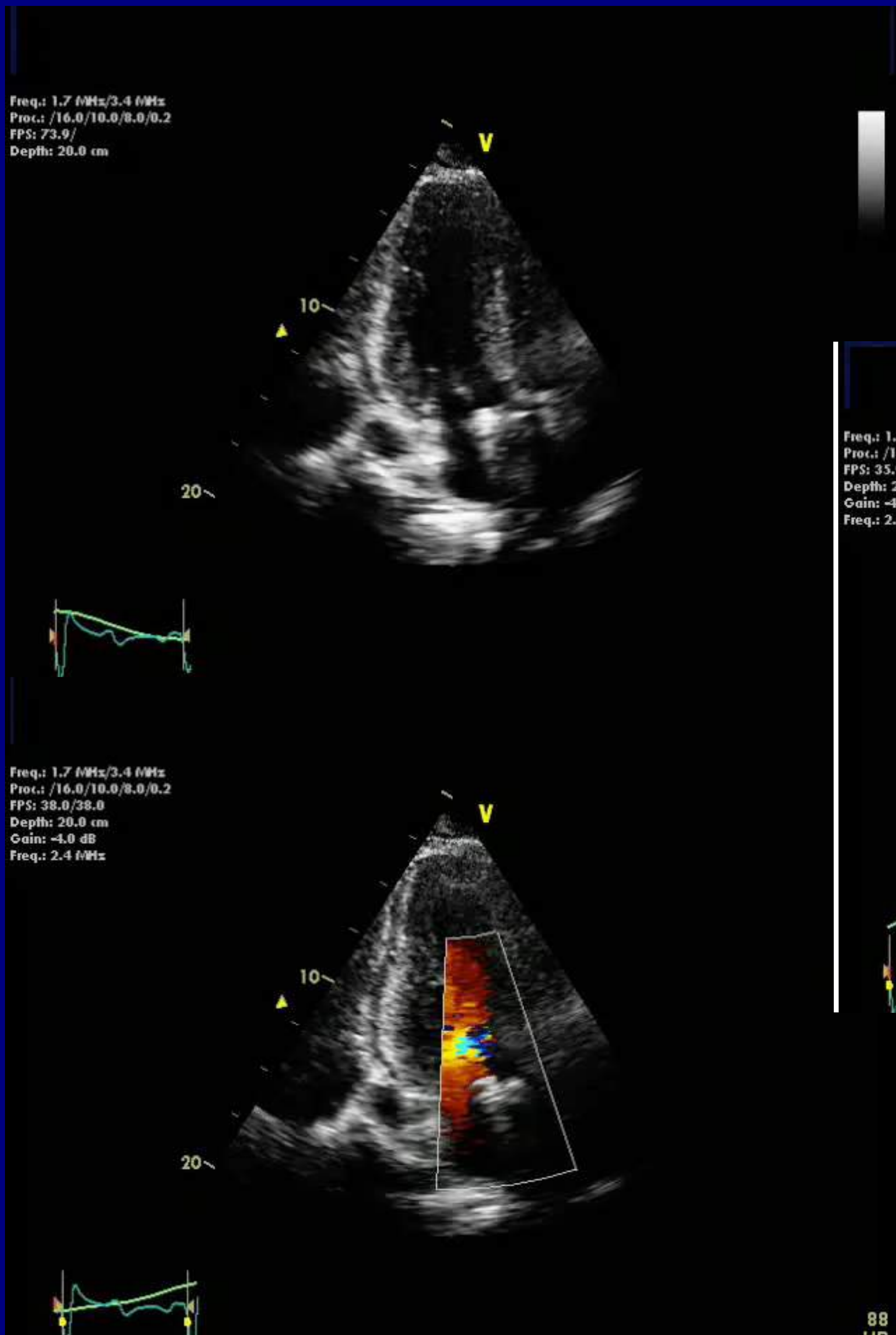


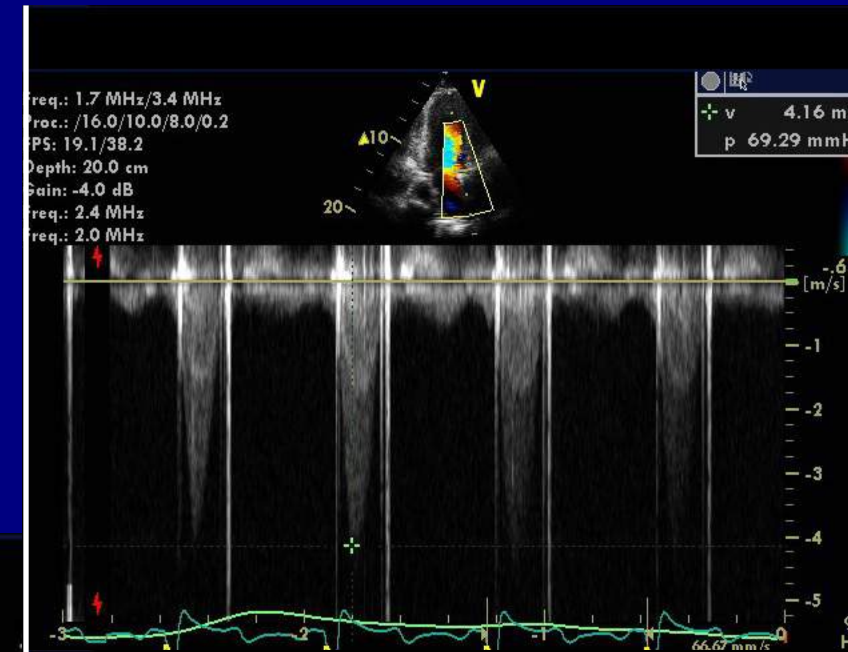


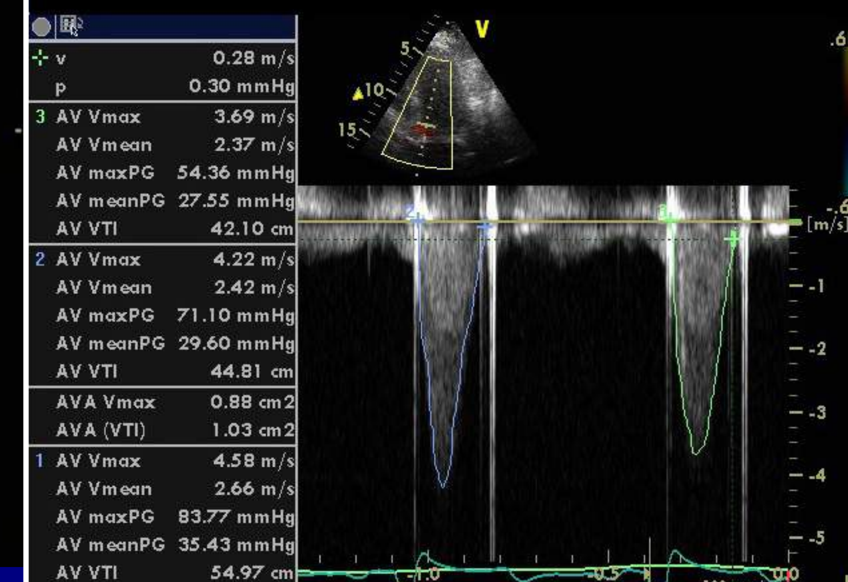




LVEF >60%







NORMAL RANGES (ST JUDE MEDICAL REGENT 21MM)

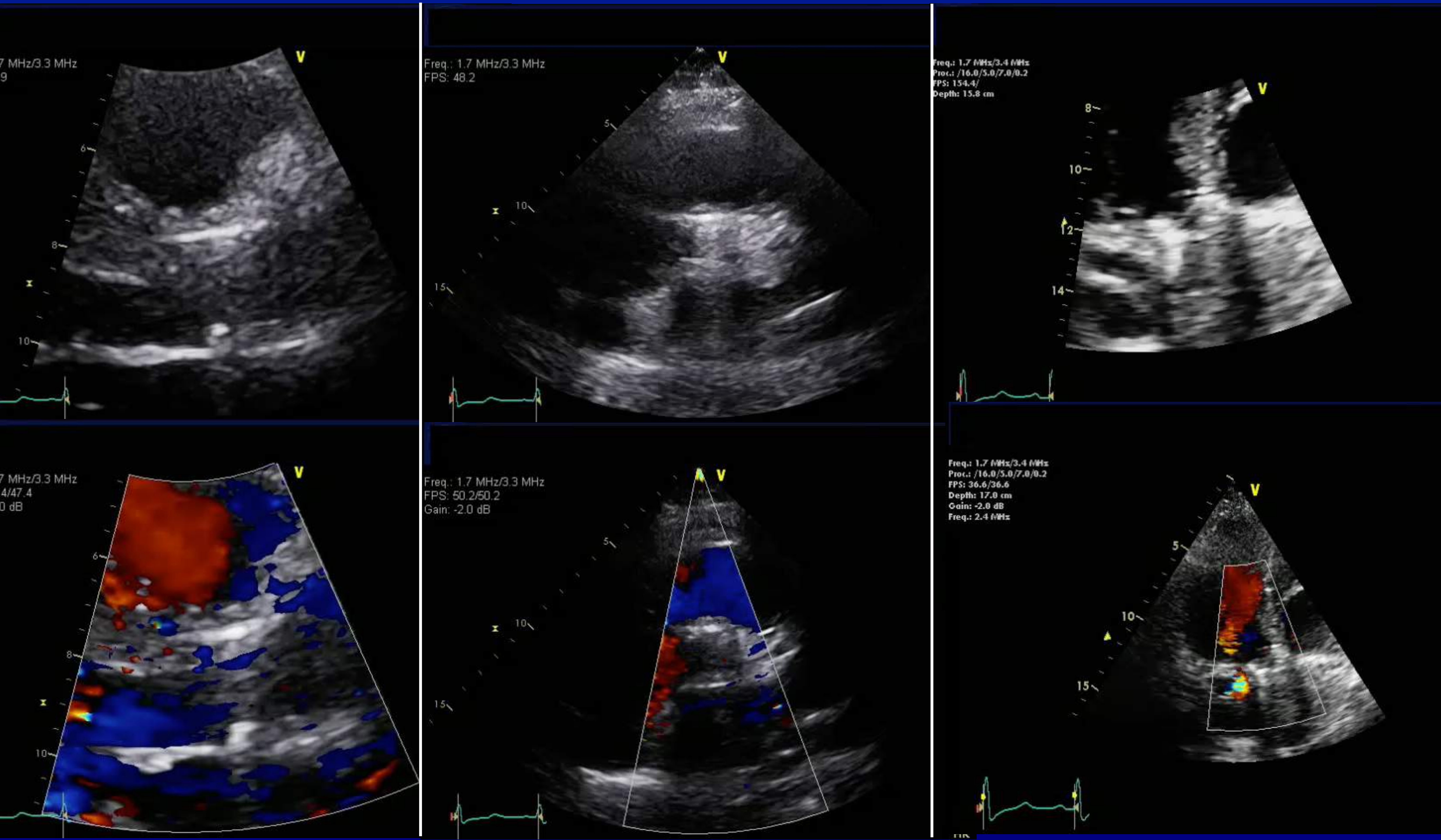
Peak gradient: 15.6+/-9.4mmHg

Mean gradient: 8.0+/-4.8mmHg

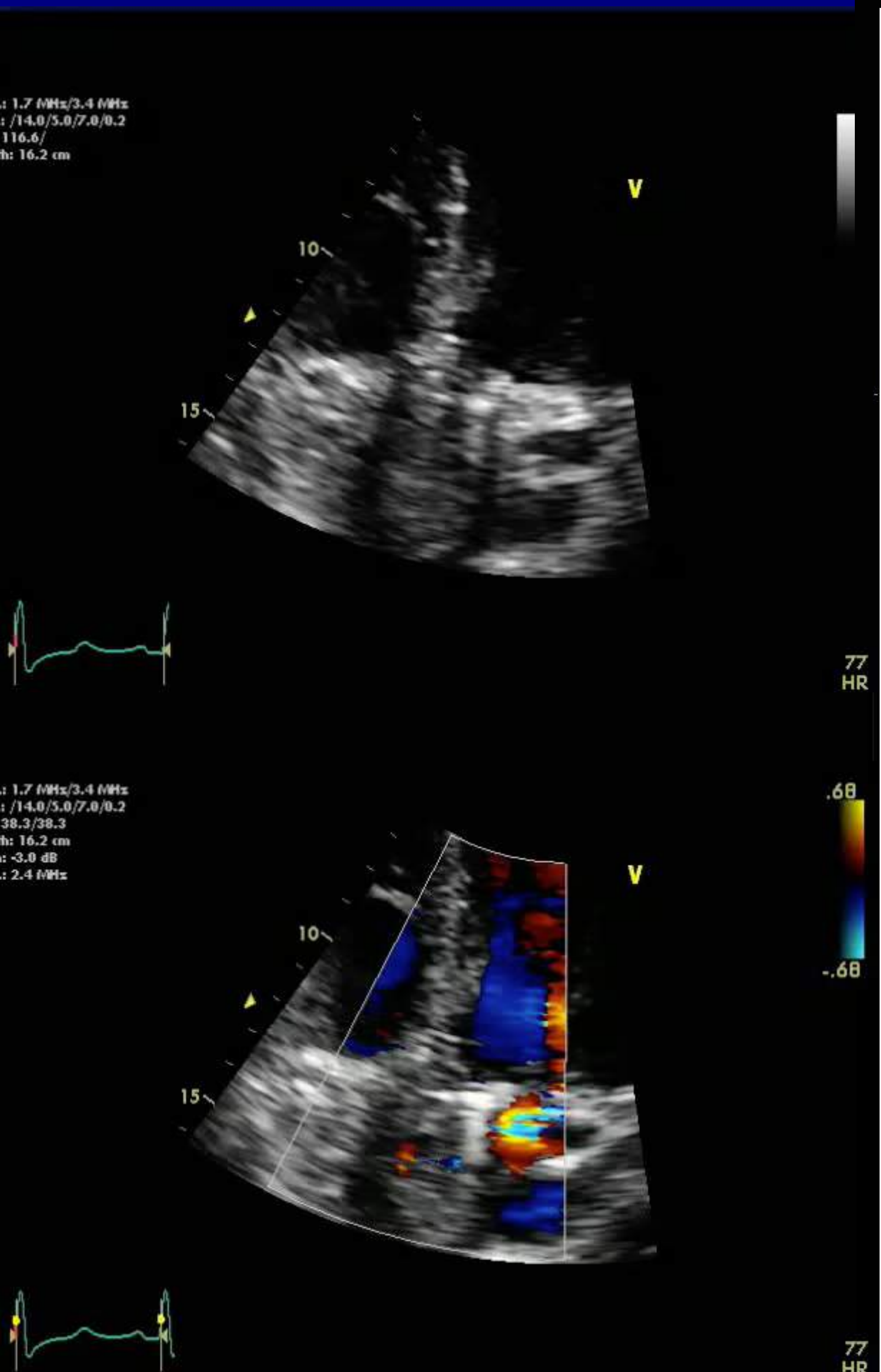
EOA: 2.0+/-0.7cm^2

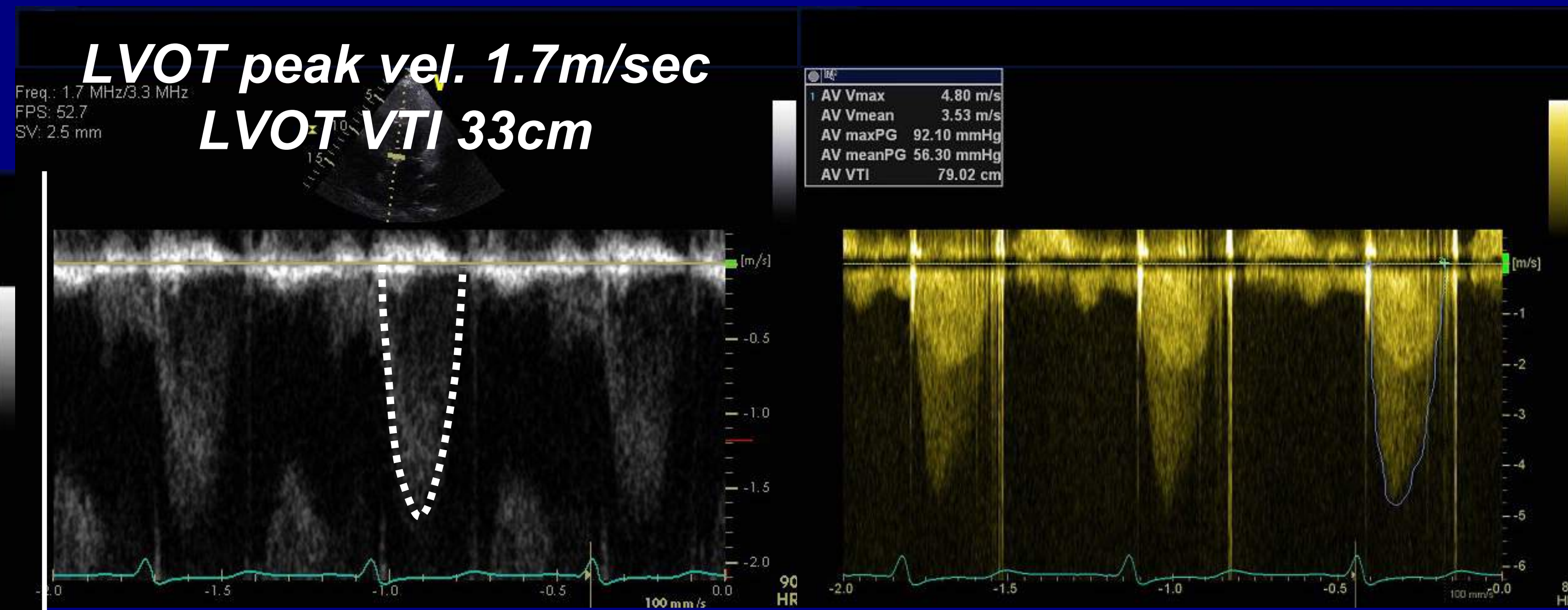
8 weeks post re-do AVR (21mm St Jude Medical Regent)

Re-admission with ongoing SOB and "fluid overload"



LVOT diameter 2.1cm; Sinotubular junction diameter 2.8cm; BSA 1.82m²



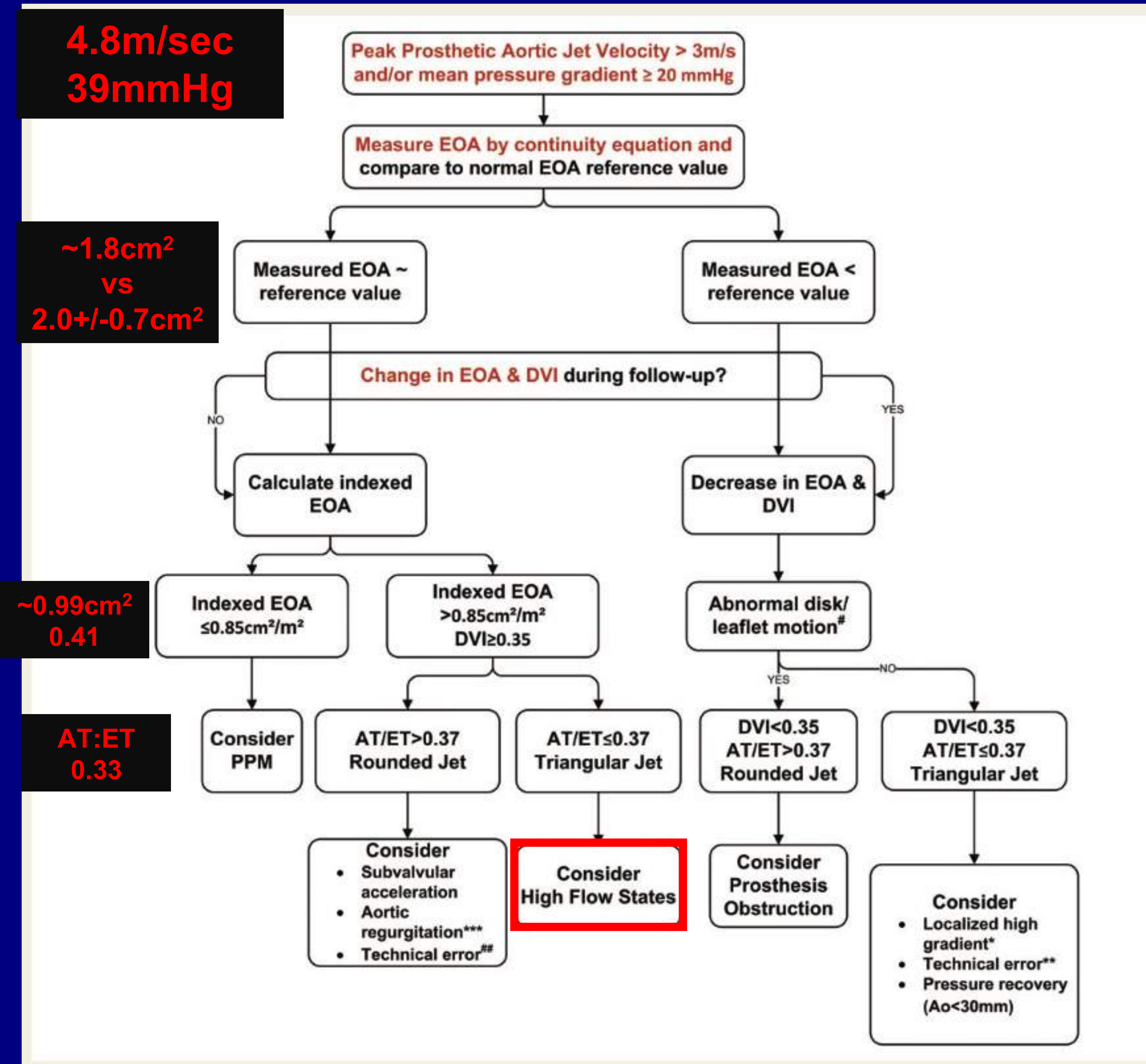


TTE REPORT:

1. Normal LV size and LVEF >60%
2. Normal RV size and systolic function
3. Well-seated mechanical AVR; Trivial intravalvular AR
   - Peak vel. 4.8m/sec; PG/MG 94/56mmHg; DSI 0.41; EOA 1.4cm^2
   - Pressure recovered: PG/MG 61/39mmHg, EOA 1.8cm^2 (~0.99cm^2/m^2)
   - AT 79msec; ET 239msec; AT : ET 0.33
4. RVSP 35mmHg

NOT prosthetic AVR stenosis
DDx – PPM or high flow state

High Transvalvular Aortic Prosthetic Gradients



RHC 18.11.2014:

- RA: a wave 17, v wave 17, mean 12
- RV: 44/20
- PA: 35/13, mean 23
- PCWP: a wave 21, v wave 29, mean 19
- Transpulmonary gradient: 4
- Ao: 90/39, mean 57
- SVR 3.9WU
- PVR 0.3WU
- ***CO (Thermo): 11.7L/min***

Conclusion:

1. Borderline mean PA pressure with very low transpulmonary gradient (4mmHg), **significantly high cardiac output**, markedly reduced PVR
2. Findings likely supportive of **hepatopulmonary syndrome with known liver cirrhosis secondary to HCV**

Patient-Prosthesis Mismatch

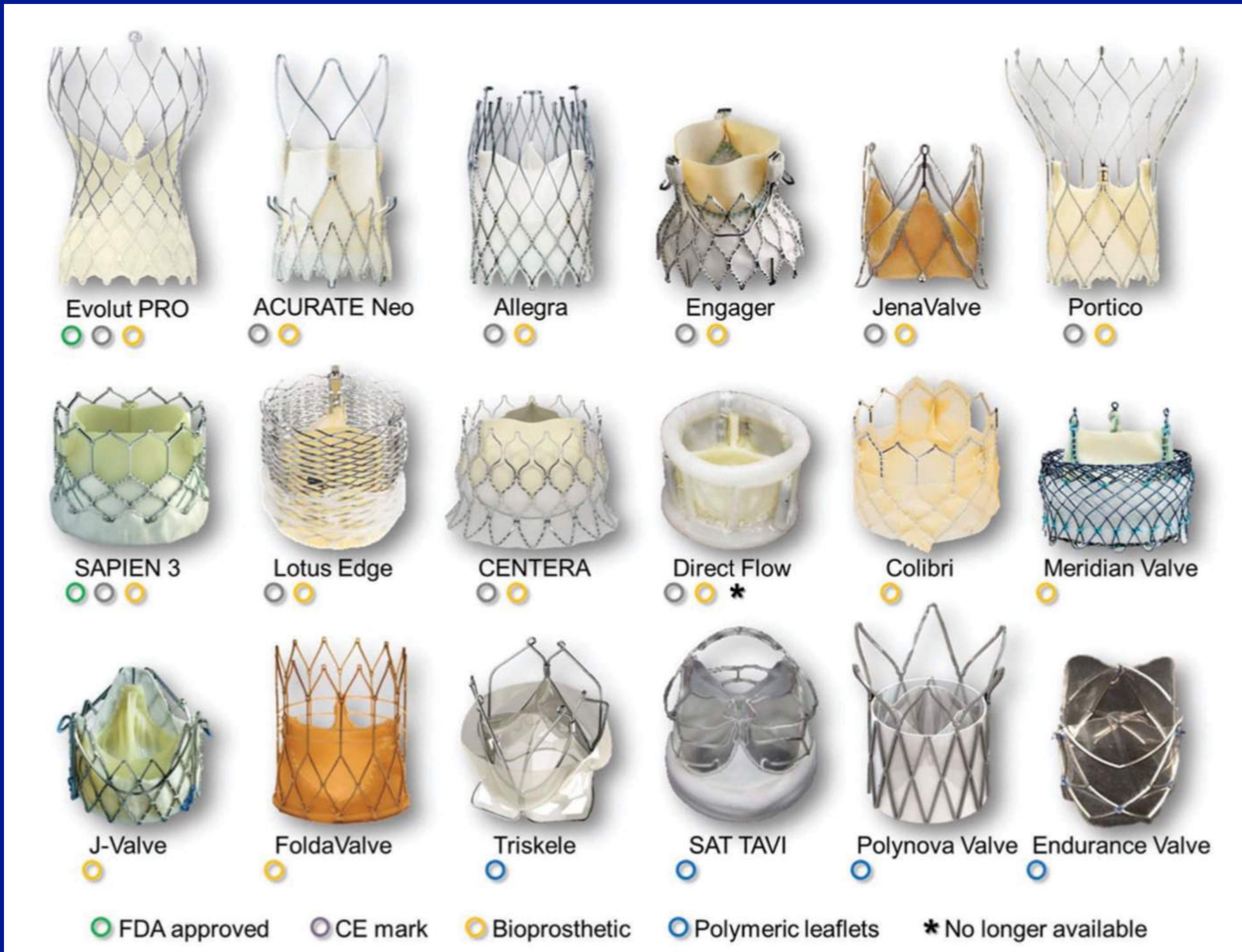
- EOA of a normally functioning prosthesis is too small in relation to the patient's body size and cardiac output requirements, resulting in abnormally high post-operative gradients

Imaging criteria for PPM			
AVR	**Mild PPM**	**Moderate PPM**	**Severe PPM**
Indexed EOA (Projected or measured) • *BMI <30kg/m²* • *BMI ≥30kg/m²*	$>0.85 cm^2/m^2$ $>0.70 cm^2/m^2$	$0.66\text{-}0.85 cm^2/m^2$ $0.56\text{-}0.70 cm^2/m^2$	$\leq 0.65 cm^2/m^2$ $\leq 0.55 cm^2/m^2$
Measured EOA vs normal reference value	Reference +/- 1SD	Reference +/- 1SD	Reference +/- 1SD
Difference (Reference EOA – measured EOA)	$<0.25 cm^2$	$<0.25 cm^2$	$<0.25 cm^2$
Valve structure and motion	Normal	Normal	Normal

- Worse functional class, exercise capacity, QOL, increased cardiac events and lower survival
- Worse hemodynamics, slower/incomplete regression of LVH, pulmonary hypertension
- Faster degeneration of bioprosthetic AVRs

Transcatheter Aortic Valve Replacements (TAVR)

"Buffet" of THVs



Key requirements:

Low thrombogenicity

Hydrodynamics

Hemocompatibility

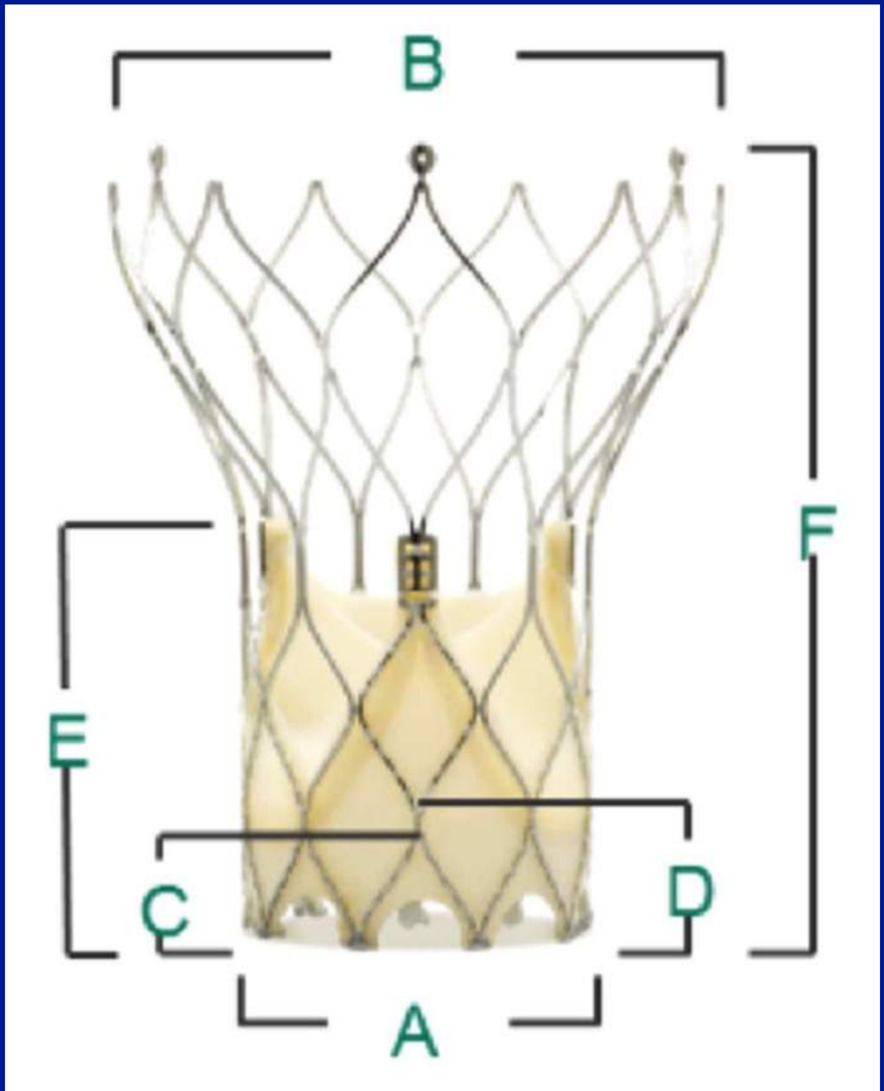
Durability

Low calcification susceptibility

Crimping and deployment stability

Rotman OM, et al. Principles of TAVR valve design, modelling and testing. *Expert Review of Medical Devices 2018;15:771-791.*

Portico (Abbott)



Portico THV:

1. *Nitinol self-expanding frame*
2. *Bovine pericardial leaflets*
3. *Porcine pericardial sealing cuff*

Table 1. Portico Valve Dimensions (mm)

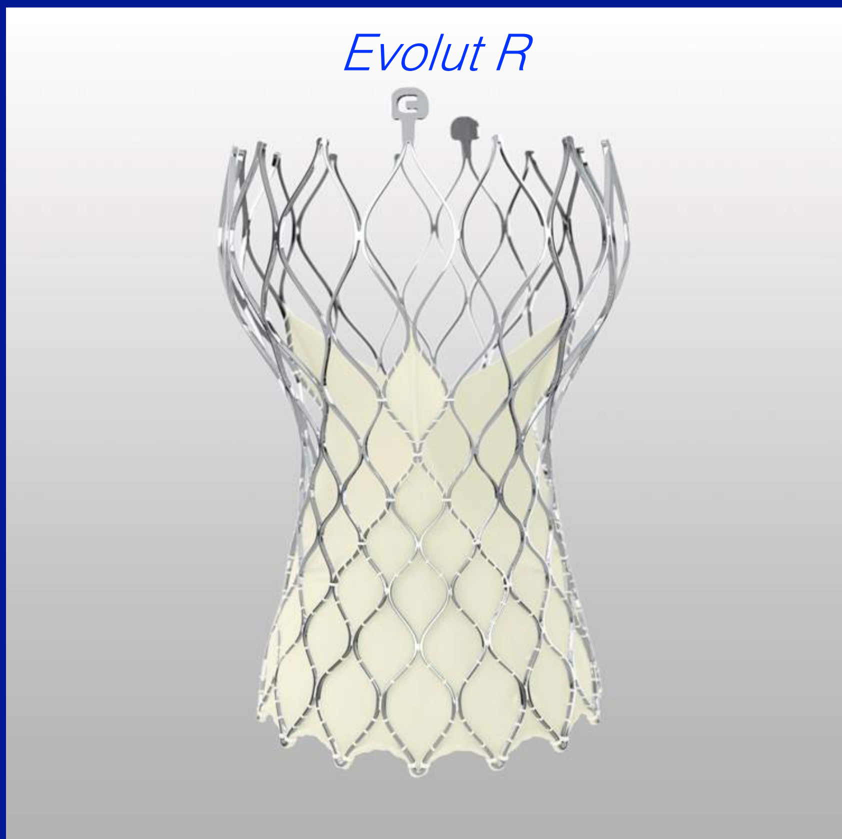
Valve Size	A	B	C	D	E	F
23	23	39	7	9	26	50
25	25	41	7	9	28	53
27	27	42	8	10	28	49
29	29	44	8	10	29	50

Table 2. Portico Valve Sizing

Valve Size (mm)	Annulus Range (mm)	Area (mm^2)	Perimeter (mm)	Ascending Aorta Diameter (mm)	Sinus of Valsalva Width (mm)	Sinus of Valsalva Height (mm)	Landing Zone (mm)	Vascular Access Diameter (mm)
23	19–21	277–346	60–66	26–36	≥27	≥15	1–9	≥6
25	21–23	338–415	66–73	28–38	≥27	≥15	1–9	≥6
27	23–25	405–491	72–79	30–40	≥29	≥15	1–10	≥6.5
29	25–27	479–573	79–85	32–42	≥31	≥15	1–10	≥6.5

Sondergaard L, et al. One-year Outcomes With a Self-Expanding, Repositionable Transcatheter Heart Valve in Severe Aortic Stenosis Patients: PORTICO-I. JACC 2018.
Tzikas A, et al. Transcatheter Aortic Valve Replacement Using the Portico System: 10 Things to Remember. J Interven Cardiol 2016;29:523-529.
Wilson AB, et al. Transcatheter aortic valve replacement with the St Jude Medical Portico Valve - First in human experience. J Am Coll Cardiol 2012;60:581-586 .

Evolut R and Pro (Medtronic)

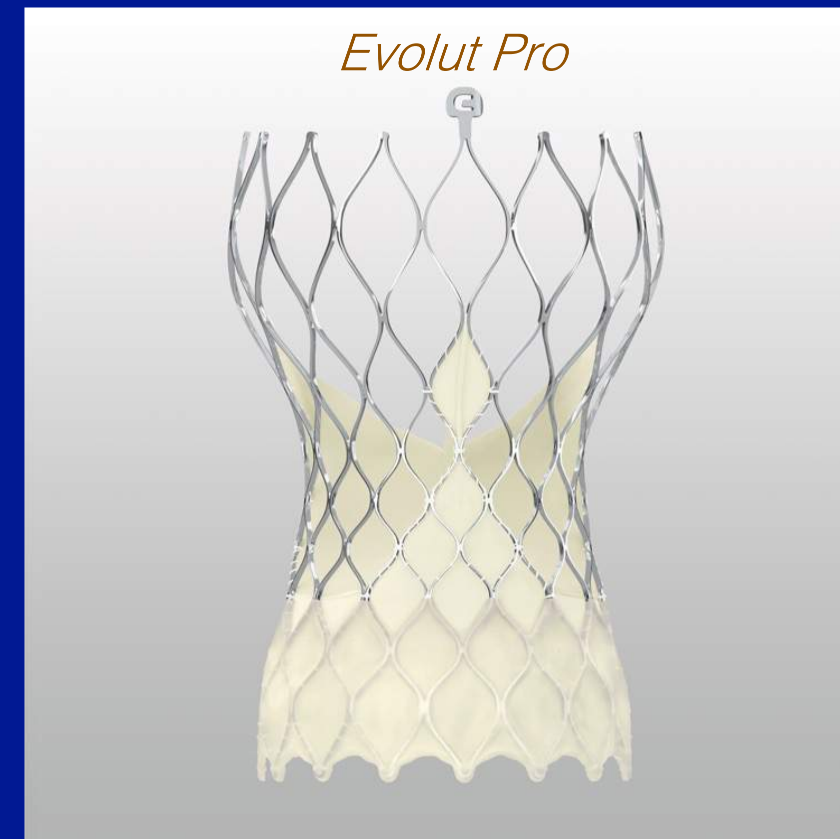


Evolut R System:

1. *Nitinol self-expanding frame*
2. *Porcine pericardial leaflets*
3. *Supra-annular leaflet position*
4. *34mm option*

Evolut Pro System:

1. *External porcine pericardial tissue wrap*
2. *Range 23-29mm*
3. *2-4mm but <6mm below native annulus*



Valve Size Selection	Evolut™ PRO Bioprosthesis			Evolut™ R Bioprosthesis
				
Size	23 mm	26 mm	29 mm	34 mm
Annulus Diameter (A)	17*/18-20 mm	20-23 mm	23-26 mm	26-30 mm
Annulus Perimeter†	53.4*/56.5-62.8 mm	62.8-72.3 mm	72.3-81.7 mm	81.7-94.2 mm
Sinus of Valsalva Diameter (Mean) (B)	≥25 mm	≥27 mm	≥29 mm	≥31 mm
Sinus of Valsalva Height (Mean) (C)	≥15 mm	≥15 mm	≥15 mm	≥16 mm

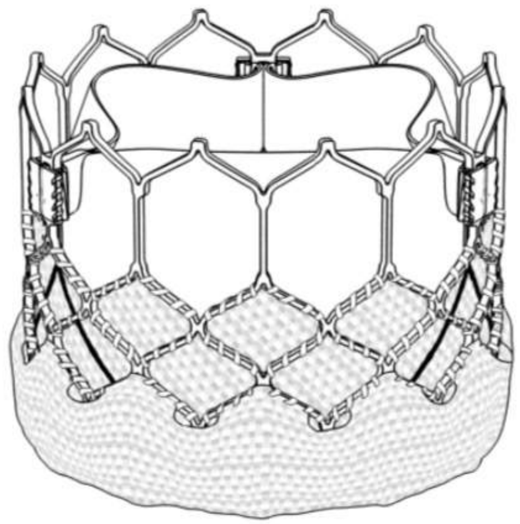
*Measurement for TAV-in-SAV only. | †Annulus Perimeter = Annulus Diameter x π
NOTE: Evolut PRO valve size selection is identical to Evolut™ R valve size selection criteria

Medtronic.com

Mahtta D, et al. From CoreValve to Evolut Pro: Reviewing the Journey of Self-Expanding Transcatheter Aortic Valves. Cardiol There 2017;6:183-192.

Hellhammer K, et al. The Latest Evolution of the Medtronic CoreValve System in the Era of Transcatheter Aortic Valve Replacement. JACC Cardiol Intv 2018;11:2314-2322

Sapien 3 (Edwards Lifesciences)



Valve Size	Height	Crimped
20 mm	15.5 mm	*21mm*
23 mm	18 mm	*24.5mm*
26 mm	20 mm	*27mm*
29 mm	22.5 mm	*31mm*

Edwards SAPIEN 3 THV:

1. *Cobalt-chromium alloy frame*
2. *Bovine pericardial leaflets*
3. *Polyethylene terephthalate (PET) inner (1/2) and outer skirts (1/3)*
4. *Shortens on deployment from LV side (Crimped: Aortic edge covers native leaflets & below STJ); Final depth 1-2mm below native annulus*

Transesophageal Echocardiogram (TEE*)	Native Annulus Area (mm^2)	Area-derived diameter (mm)	THV Size
16-19 mm	273-345	18.6-21.0	20 mm
18-22 mm	338-430	20.7-23.4	23 mm
21-25 mm	430-546	23.4-26.4	26 mm
24-28 mm	540-683	26.2-29.5	29 mm

edwards.com

*Shivaraju A, et al. Transcatheter Aortic and Mitral Valve-in-Valve Implantation Using the Edwards Sapien 3 Heart Valve. JAHA 2018**

Different Echocardiographic Appearances

Portico

Evolut R

Sapien 3

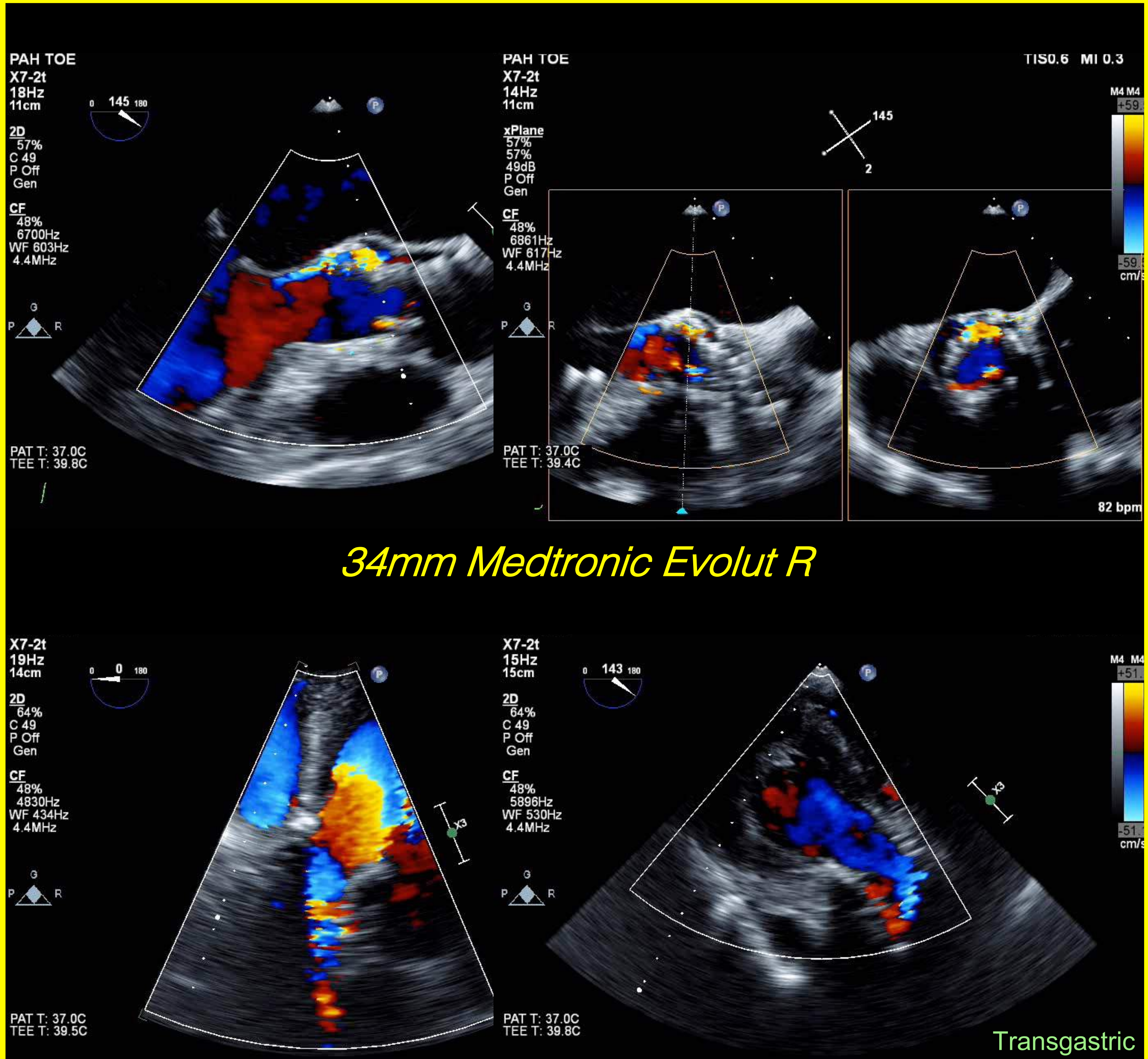
Post-deployment:

- Assessment of implanted THV
  - Stent position
  - Circular configuration or shape
  - Leaflet movement
  - Hemodynamic assessment

- *Assessment of AR*
  - *Intravalvular*
  - *Paravalvular*

- *Check LV*
  - *Systolic function*
  - *RWMAs ≈ Occluded coronary artery*
- *Check RV, MV, TV, RVSP*
- *Exclude aortic complication, perforation, pericardial effusion*

Intra-procedural TOE



Mild-moderate posterior PARAVALVULAR AR
Trivial-mild INTRAVALVULAR AR

1. Jayasuriya C, et al. Transcatheter aortic valve implantation in aortic stenosis: the role of echocardiography. J Am Soc Echocardiogr 2011;24:15-27.
2. Zamorano JL, et al. EAE/ASE recommendations for the use of echocardiography in new transcatheter interventions for vavlular heart disease. J Am Soc Echocardiogr 2011;24:937-965.
3. Moss RR, et al. Role of echocardiography in percutaneous aortic valve implantation. J Am Coll Cardiol Img 2008;1:15-24.
4. Hahn R, et al. Recommendations for Comprehensive Intraprocedural Echocardiographic Imaging During TAVR. J Am Coll Cardiol Img 2015;8:261-287

Post-TAVR AR

Intravalvular (Central) AR:

Rx:
Post-dilatation
Valve-in-valve

- Guidewire-related
- Oversized prosthesis (Suboptimal stent expansion, impaired cusp mobility)
- Improper valve deployment or over-expansion
- Overhanging leaflet material prolapsing into the prosthesis
    - *Interfering with diastolic flow pattern and THV leaflet coaptation*
- Damage during THV pre-implantation preparation/crimping

Paravalvular leaks:

Rx:
Post-dilation
Valve-in-valve
Device (plug) closure

- Undersized prosthesis
- Inadequate prosthesis inflation & under-expansion
- Elliptical annulus geometry
- Asymmetric calcification of the native aortic valve
    - *Calcific deposits preventing sealing within the annulus*
- Low ("supra-skirt" PAR) or high implantation ("infra-skirt" PAR)

Zoghbi W et al. Guidelines for the evaluation of valvular regurgitation after percutaneous valve repair or replacement. J Am Soc Echocardiogr 2019
Otto C, et al. 2017 ACC Expert Consensus Decision Pathway for Transcatheter Aortic Valve Replacement in the Management of Adults With Aortic Stenosis. JACC 2017;69:1313-1346.
Sinning JM, et al. Evaluation and management of paravalvular aortic regurgitation after transcatheter aortic valve replacement. J Am Coll Cardiol 2013;62:11-20.

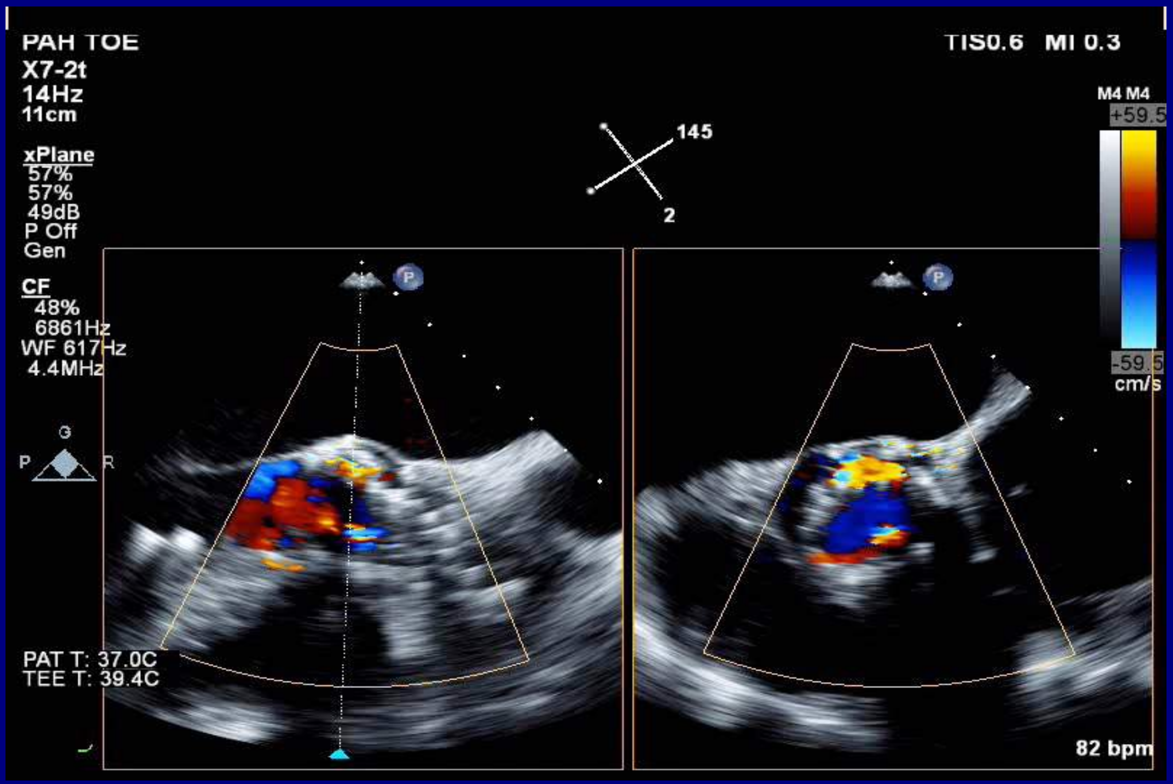
Assessment of Paravalvular AR

- Multi-window and multi-parametric (**Integrative**) approach
  - Identify **location** (*native commissures*), **size**, and **mechanism** of the AR
    - *POST-DILATATION considered if:*
      - *Clear mal-apposition (“free space”) of the THV stent with native structures*
      - *Non-circular or irregular shape of the valve implying under-expansion*

- *CFD assessment on:*
  - LAX and SAX views; Trans-gastric views
    - *Acoustic shadowing of anterior jets on TOE and posterior jets on TTE*
  - *Small paravalvular jets may regress over 10-15minutes*
    - *Progressive nitinol frame expansion*
  - *Atypical jets: Multiple, eccentric, irregular, confined along the LVOT*

Hahn R, et al. Recommendations for Comprehensive Intraprocedural Echocardiographic Imaging During TAVR. J Am Coll Cardiol Img 2015;8:261-287
Hahn R, et al. Echocardiographic imaging of procedural complications during self-expandable transcatheter aortic valve replacement. J Am Coll Cardiol Img 2015;8:319-336.
Pibarot P, et al. Assessment of paravalvular regurgitation following TAVR - A proposal of unifying grading scheme. J Am Coll Cardiol Img 2015;8:340-360.

Assessment of Paravalvular AR

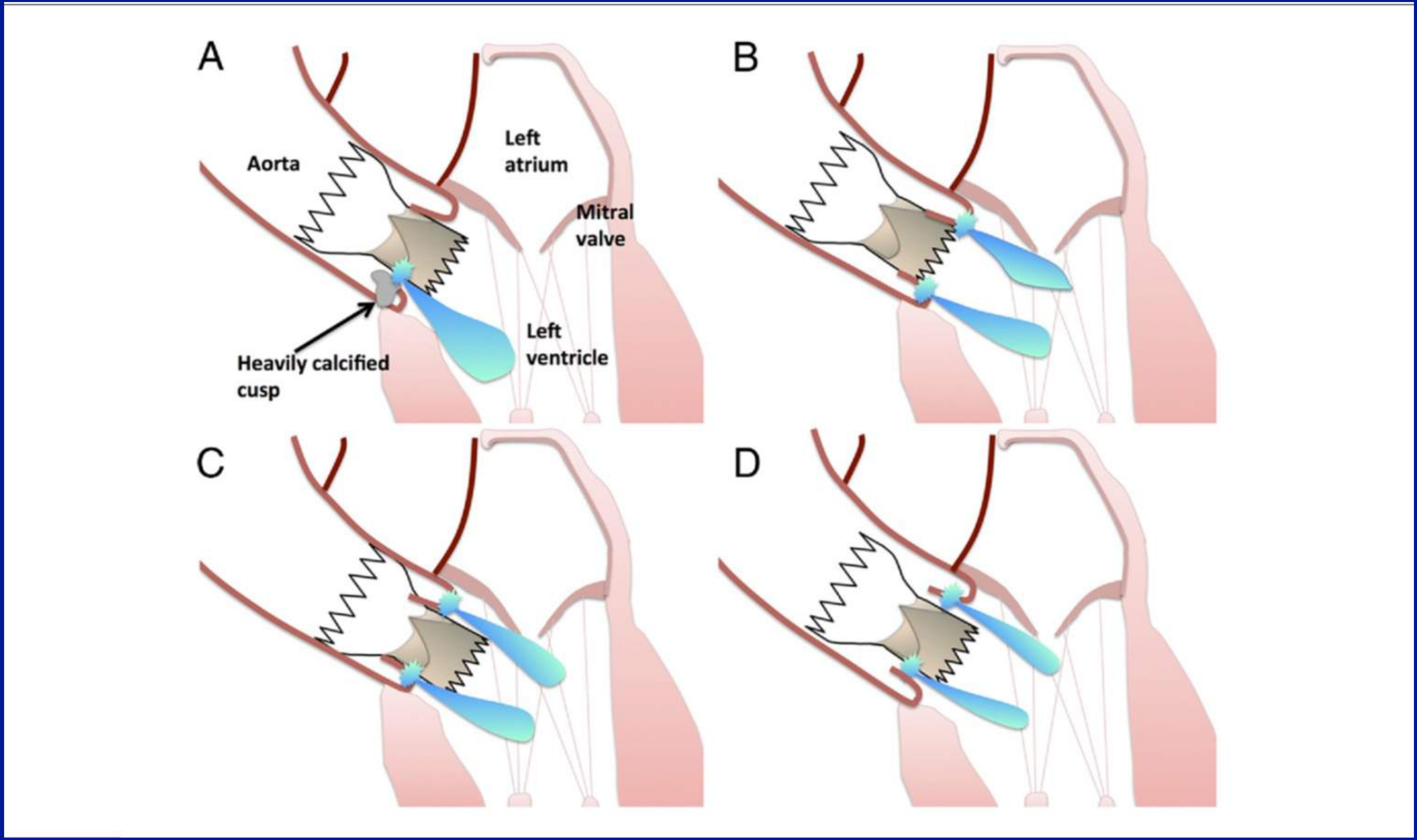


- *Severity based on:*
    - Total circumferential extent of the jet(s)**
    - Width of jet(s) at their ***origin*** **(Vena contracta width >6mm specific for severe AR)**
    - Number of jets
    - Path of the jet(s) visible along the stent
    - Presence of proximal flow convergence
        - 3D EROA

Jet length or area should NOT be used to grade severity, but rather to confirm the presence and location of AR

Hahn R, et al. Recommendations for Comprehensive Intraprocedural Echocardiographic Imaging During TAVR. J Am Coll Cardiol Img 2015;8:261-287
Hahn R, et al. Echocardiographic imaging of procedural complications during self-expandable transcatheter aortic valve replacement. J Am Coll Cardiol Img 2015;8:319-336.
Pibarot P, et al. Assessment of paravalvular regurgitation following TAVR - A proposal of unifying grading scheme. J Am Coll Cardiol Img 2015;8:340-360.

Assessment of Paravalvular AR



Mechanisms of paravalvular AR post-TAVR:

A - THV stent frame underexpansion

(Ca^{2+} in native cusp/annulus; Non-circular stent shape; "Space or gaps" between stent and native annulus)

B - Too high

C - Too low

D - Annulus-prosthesis size mismatch

Sinning JM, et al. Evaluation and management of paravalvular aortic regurgitation after transcatheter aortic valve replacement. J Am Coll Cardiol 2013;62:11-20.

Assessment of Paravalvular AR (Echo)

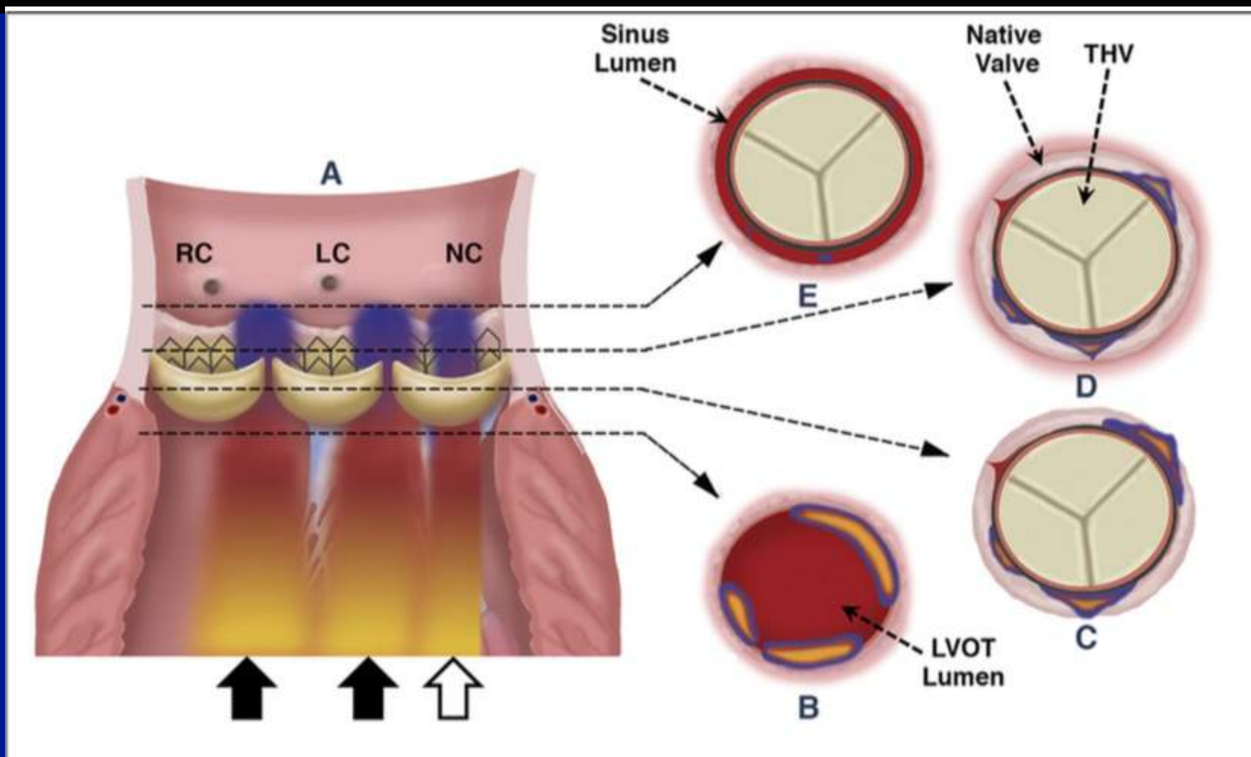
Circumferential extent of the paravalvular AR jet on the SAX view

Recommended for semi-quantitative assessment

$$\frac{\text{No. of minutes occupied by the AR jet}}{\text{60 minutes}}$$

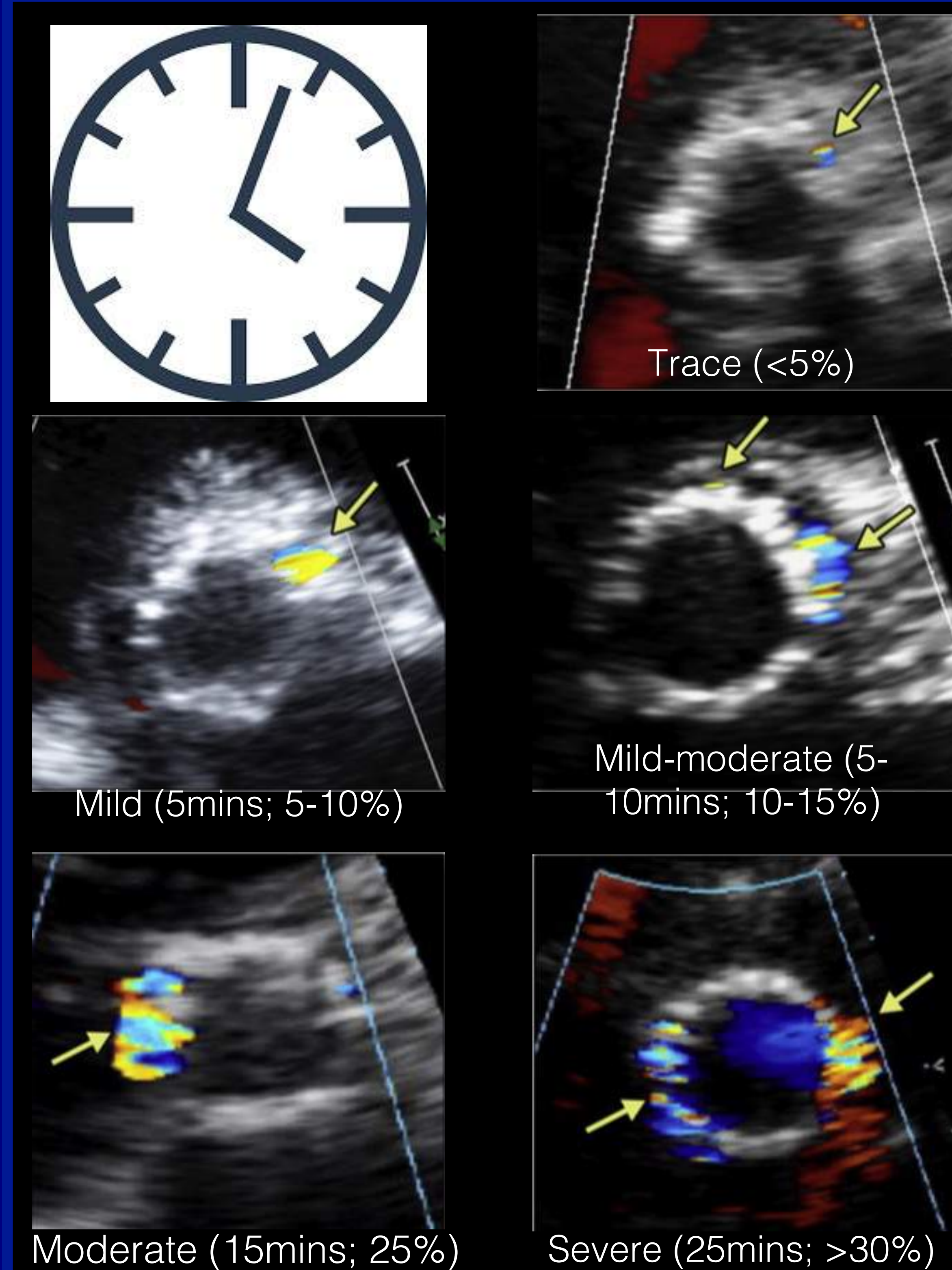
VARC2:

<10% suggests mild, 10-29% suggests moderate, >30% suggests severe



Size of the AR jet is dependent on the SAX scan plane of imaging:

- *Too "high" = Underestimation*
- *Too "low" = Overestimation due to "splaying" downstream from the VC*
- *Ideal = Just below THV stent/skirt within the LVOT* {Smallest VC}



Abdelghani M, et al. Echocardiographic and angiographic assessment of paravalvular regurgitation after TAVI: optimising inter-technique reproducibility. Eur Heart J 2016;852-860.

Sinning JM, et al. Evaluation and management of paravalvular aortic regurgitation after transcatheter aortic valve replacement. J Am Coll Cardiol 2013;62:11-20.

Pibarot P, et al. Assessment of paravalvular regurgitation following TAVR - A proposal of unifying grading scheme. J Am Coll Cardiol Img 2015;8:340-360.

Kappetein AP, H et al. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document. J Am Coll Cardiol 2012;60:1438–54.

Assessment of AR (Invasive Hemodynamic Ax)

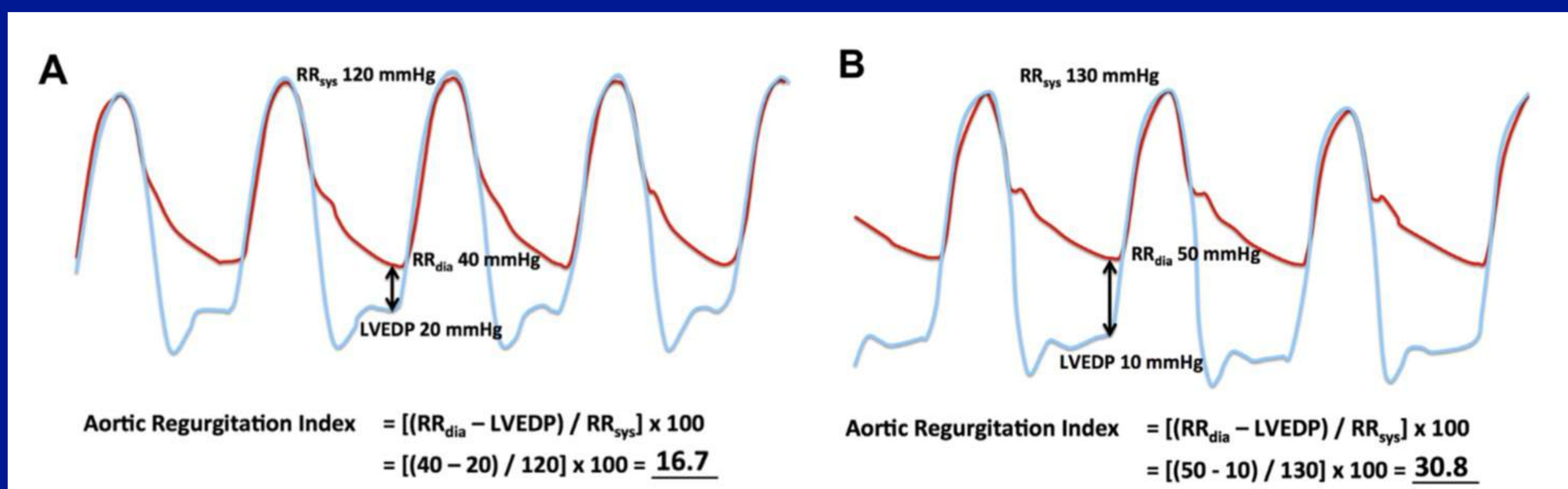
AR Index = [(DBP - LVEDP) / SBP] x 100

*__*Cutoff value <25%__* predictive of increased 1-year mortality after TAVR

NPV 95-100% for >Mild AR (When complements angio or echo Ax of paravalvular AR severity)

False +ves {*i.e. <25% but no significant AR*}:

Abnormal LV/Ao compliance {High LVEDP, increased aortic stiffness; (AR PHT*)}



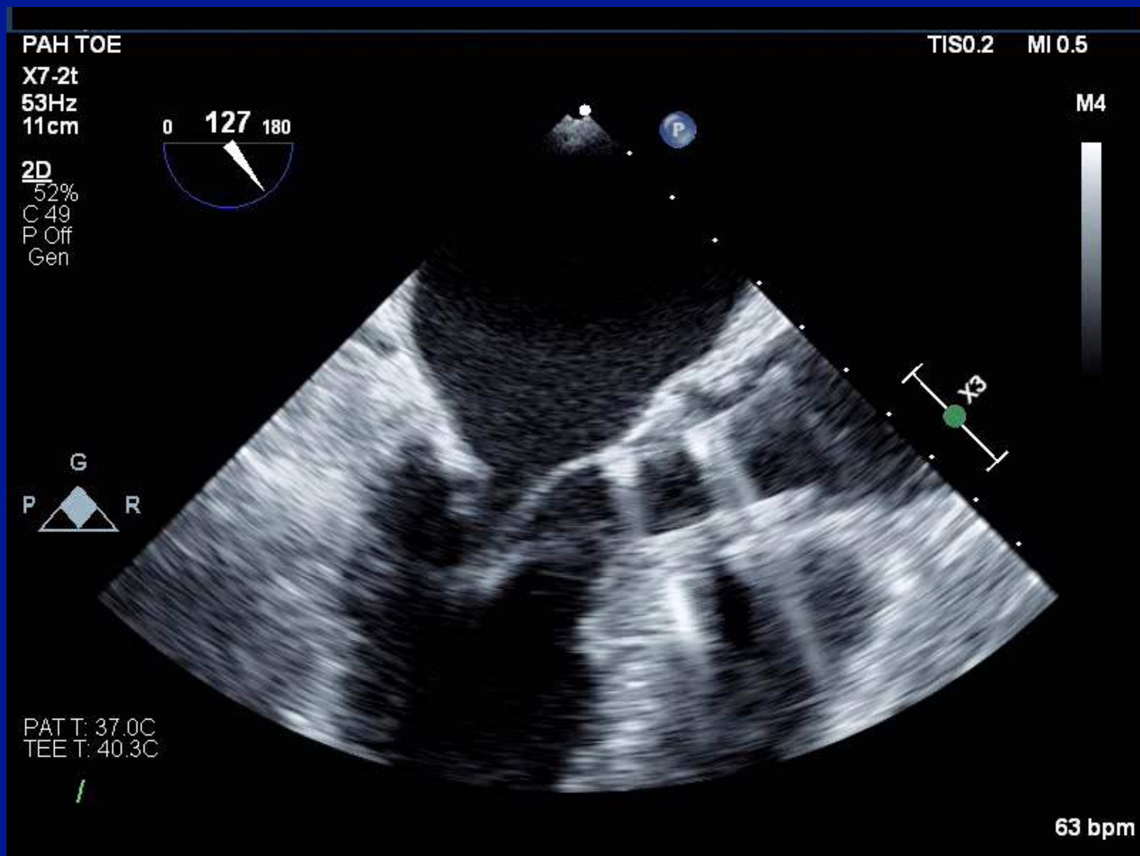
Moderate AR *Trivial AR*

** ~10 minutes after THV deployment [Avoid confounding by increased LVEDP post-rapid pacing and BAV]*

** HR 60-80bpm [Higher HR -> Shortened diastole -> Increased DBP -> False -ve ARI {>25}]*

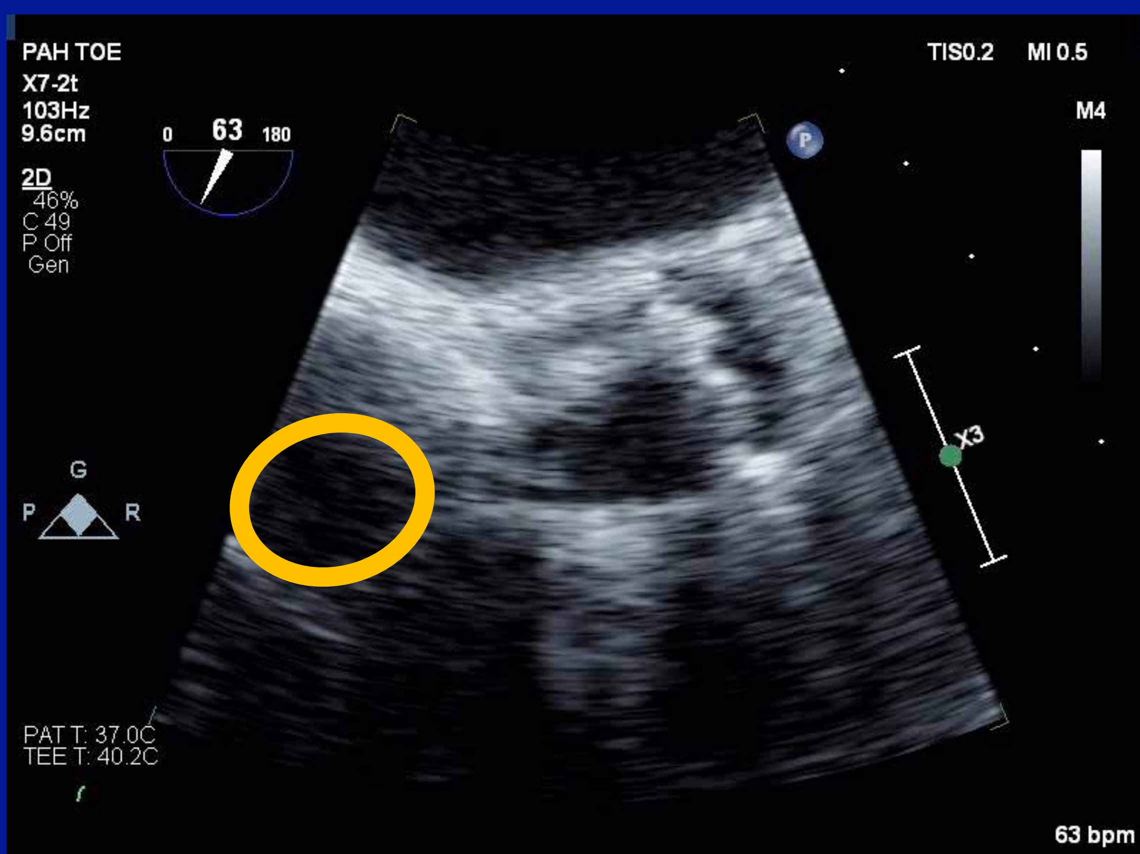
Zoghbi W et al. Guidelines for the evaluation of valvular regurgitation after percutaneous valve repair or replacement. J Am Soc Echocardiogr 2019
Abdelghani M, et al. Echocardiographic and angiographic assessment of paravalvular regurgitation after TAVI: optimising inter-technicue reproducibility. Eur Heart J 2016;852-860.
Sinning JM, et al. Aortic regurgitation index defines severity of peri-prosthetic regurgitation and predicts outcome in patients after transcatheter aortic valve implantation. J Am Coll Cradle 2012;59:1134–41.
Sinning JM, et al. Evaluation and management of paravalvular aortic regurgitation after transcatheter aortic valve replacement. J Am Coll Cardiol 2013;62:11-20.
Pibarot P, et al. Assessment of paravalvular regurgitation following TAVR - A proposal of unifying grading scheme. J Am Coll Cardiol Img 2015;8:340-360.

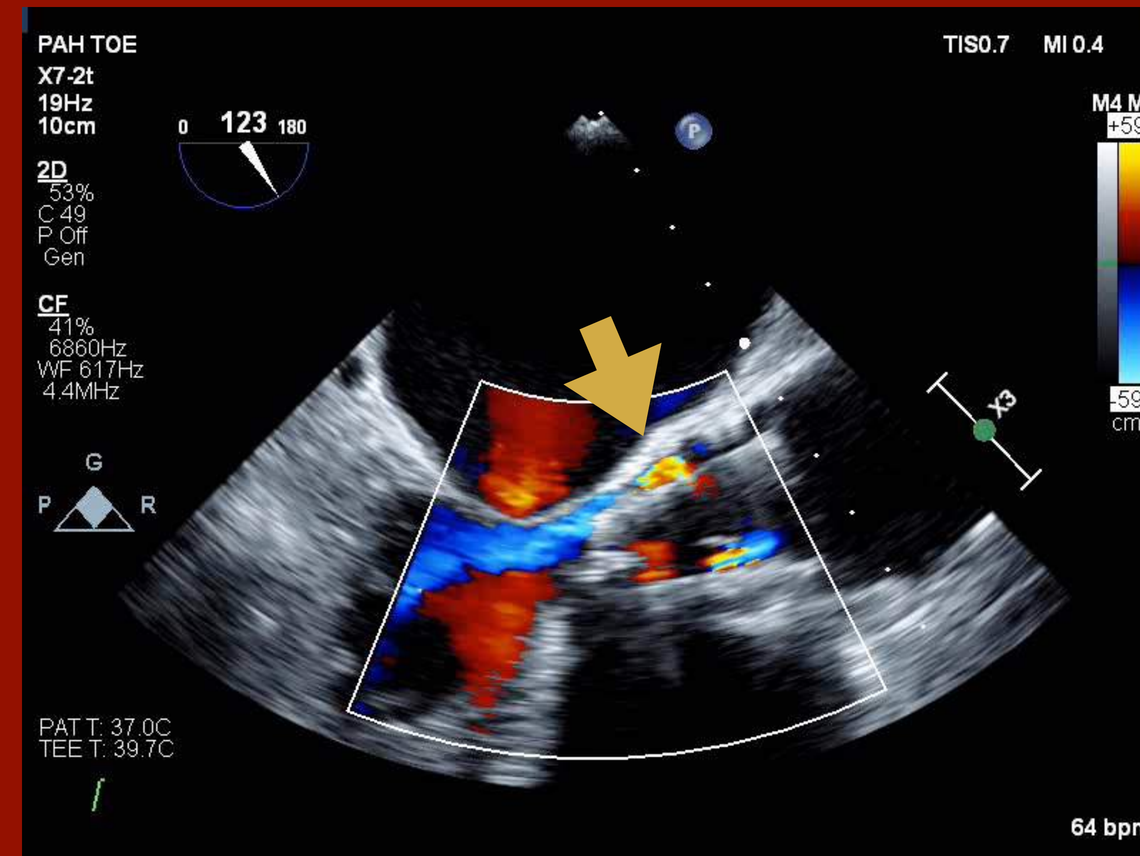
Intra-procedural TOE (88yo F; 27mm Portico)



"Oval" appearance

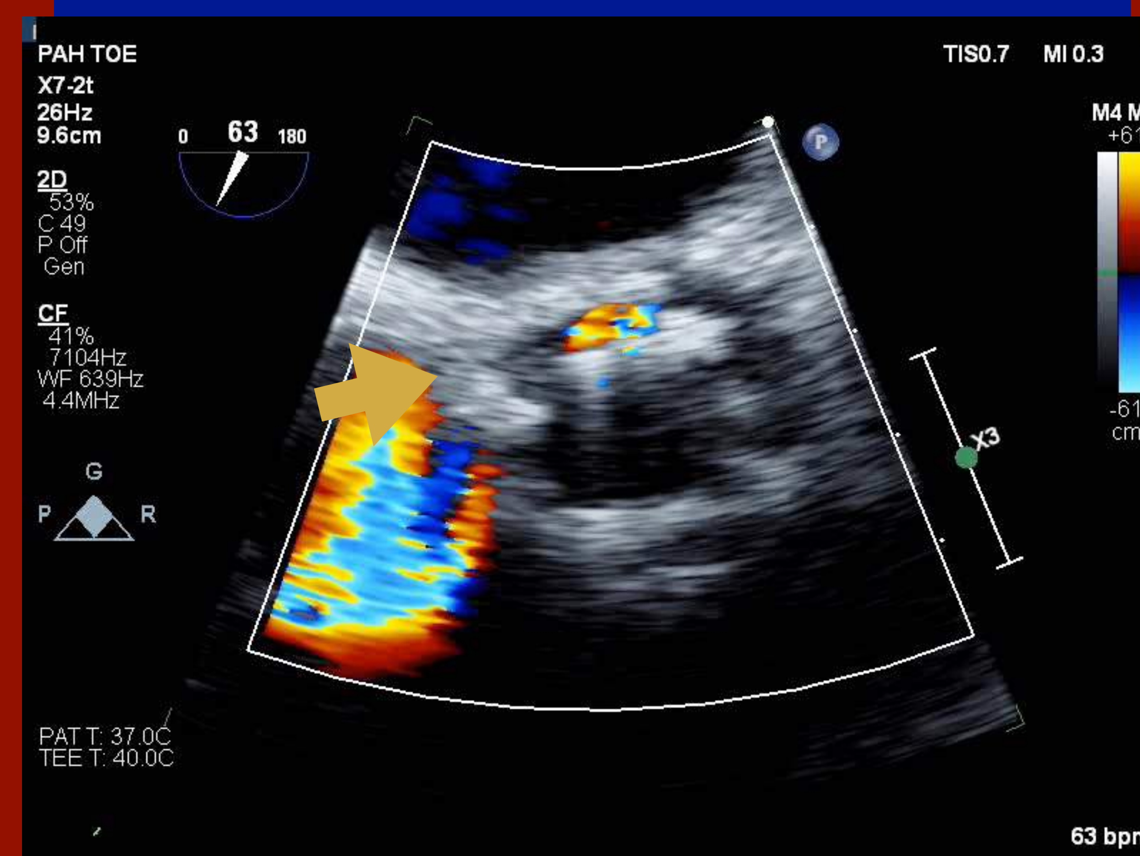
Posterior malapposition *(Native leaflet Ca^{2+})*



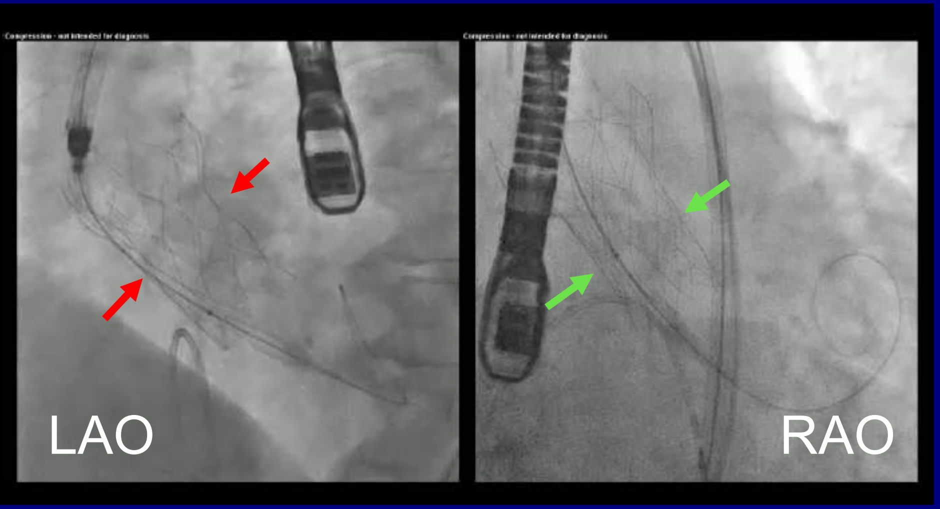


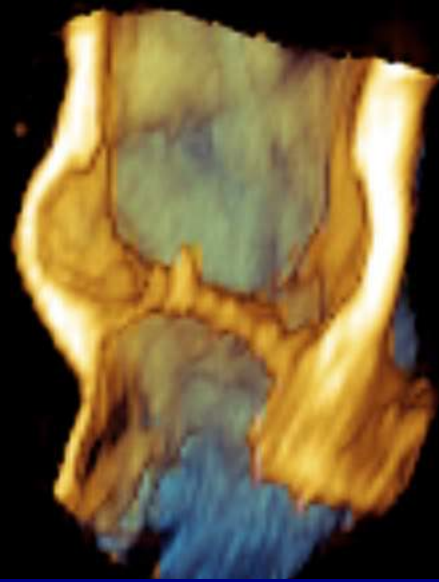
Moderate posterior paravalvular AR

Mild anterior intravalvular AR



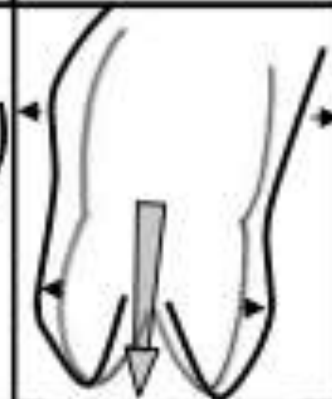
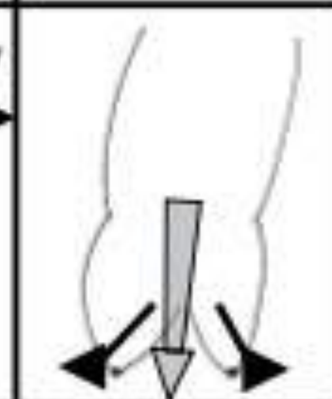
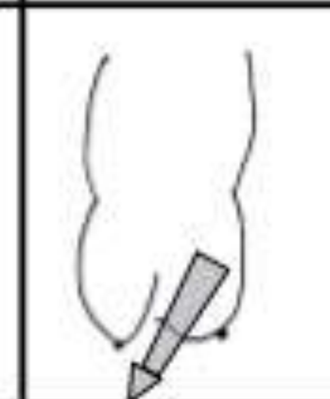
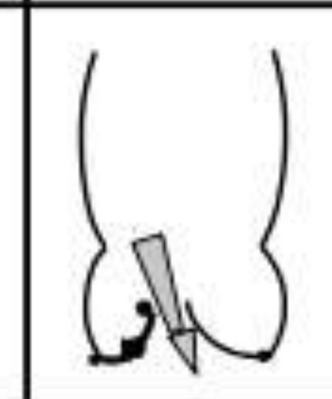
Intra-procedural TOE





Aortic Valve Repair

Repair-Oriented Functional Classification of AR

AI Class	Type I Normal cusp motion with FAA dilatation or cusp perforation				Type II Cusp Prolapse	Type III Cusp Restriction
	Ia	Ib	Ic	Id		
Mechanism						
Repair Techniques (Primary)	STJ remodeling *Ascending aortic graft*	Aortic Valve sparing: *Reimplantation or Remodeling with SCA*	SCA	Patch Repair *Autologous or bovine pericardium*	Prolapse Repair *Plication* *Triangular resection* *Free margin Resuspension* *Patch*	Leaflet Repair *Shaving* *Decalcificatio* *Patch*
(Secondary)	SCA		STJ Annuloplasty	SCA	SCA	SCA

Functional aortic annulus (Ia–Ic) — **Aortic leaflets** (Id–III)

Ia-c: Functional aortic annulus (AscAo+STJ; SOVA+STJ; VAJ); Id: Cusp perforation {Normal FAA}

II: Prolapse (Excessive cusp tissue or commissural disruption)

III: Leaflet restriction (BAV, degenerative, rheumatic)

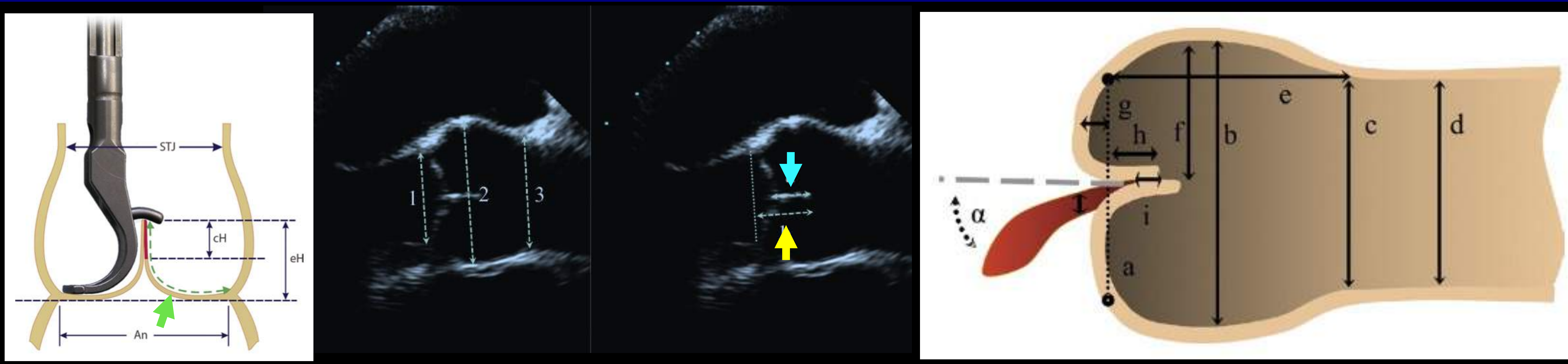
Single or multiple lesions

Boodhwani M, et al. Repair-oriented classification of aortic insufficiency: Impact on surgical techniques and clinical outcomes. J Thorac Cardiovasc Surg 2009;137:286-294.

Pre-Repair Assessment (TOE)

1. Aortic cusps (Number, thickening, calcification, coaptation, fenestrations, “heights”)
2. AR (Mechanism, direction, *severity)
3. Aortic root measurements

- Annulus measurement – Prosthesis sizing (Undersizing may cause cusp prolapse and induce AR) +/- need for SCA to stabilize the proximal FAA and increase leaflet coaptation surface



Geometric Ht (Leaflet length): Tri≥7mm, Bi≥20mm
Coaptation Height: ≥4-5mm
Effective Height: 9-10mm

1. H.J. Schafers, et al. A new approach to the assessment of aortic cusp geometry, Journal of Thoracic and Cardiovascular Surgery 2006;132:436–438.
2. Vojack J, et al. Aortic valve repair and valve sparing procedures. Cor Et Vasa 2017;59:e77-e84.
3. Vanoverschelde J, et al. The role of echocardiography in aortic valve repair. Ann Cardiothorac Surg 2013;2:65-72.
4. le Polain de Waroux JB, et al. Mechanisms of recurrent aortic regurgitation after aortic valve repair. Predictive value of intra-operative transesophageal echocardiography. JACC Cardiovasc Imaging 2009;2:931–9
5. Van Dyck MJ, et al. Transesophageal echocardiographic evaluation during aortic valve repair surgery. Anesth Analg 2010;111:59-70.
6. Berrebi A, et al. Systematic echocardiographic assessment of aortic regurgitation – what should the surgeon know for aortic valve repair. Ann Cardiothorac Surg 2019;8:331-341.

Post-Repair Assessment

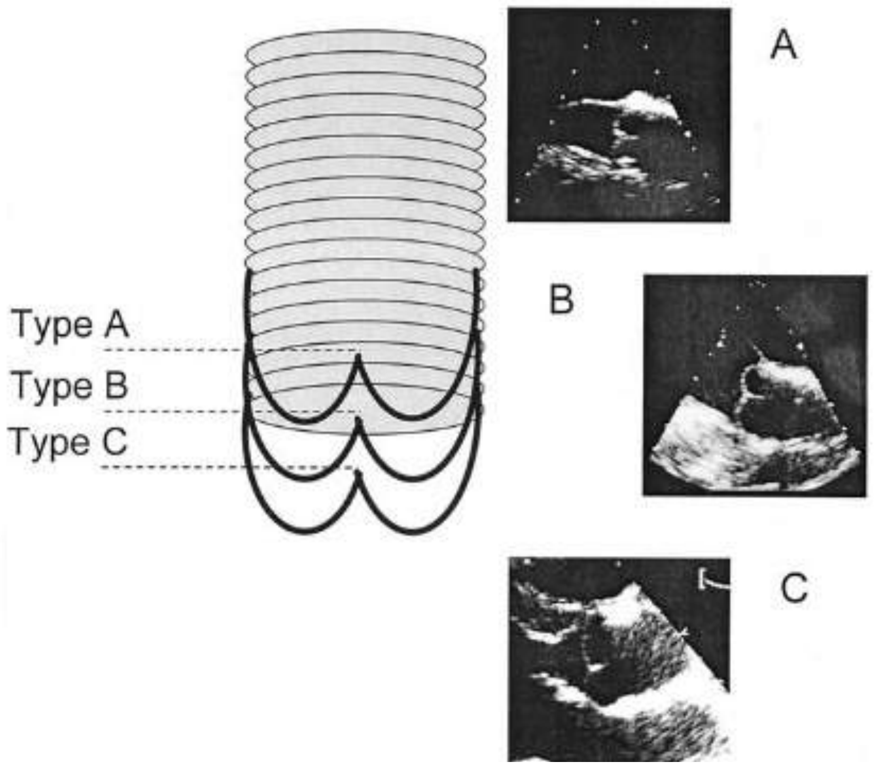
Satisfactory repair (Recurrence of AR):

1. **Level of aortic cusp coaptation**
   - *Above aortic annulus* (Lower end higher than VAJ, upper end towards mid-height of SOV)
   - Effective height ≥9mm
   - *No residual or new prolapse*
2. **Presence of residual AR (*None or <trivial central*)**
3. **Coaptation length (*≥4mm*)**

Additional assessment:

1. **Aortic annulus <25mm*
2. RWMAs (Coronary artery injury)
3. Peak/mean AV gradients (Unsatisfactory if >30/15(10) mmHg; Risk of AS and need for repeat surgery)

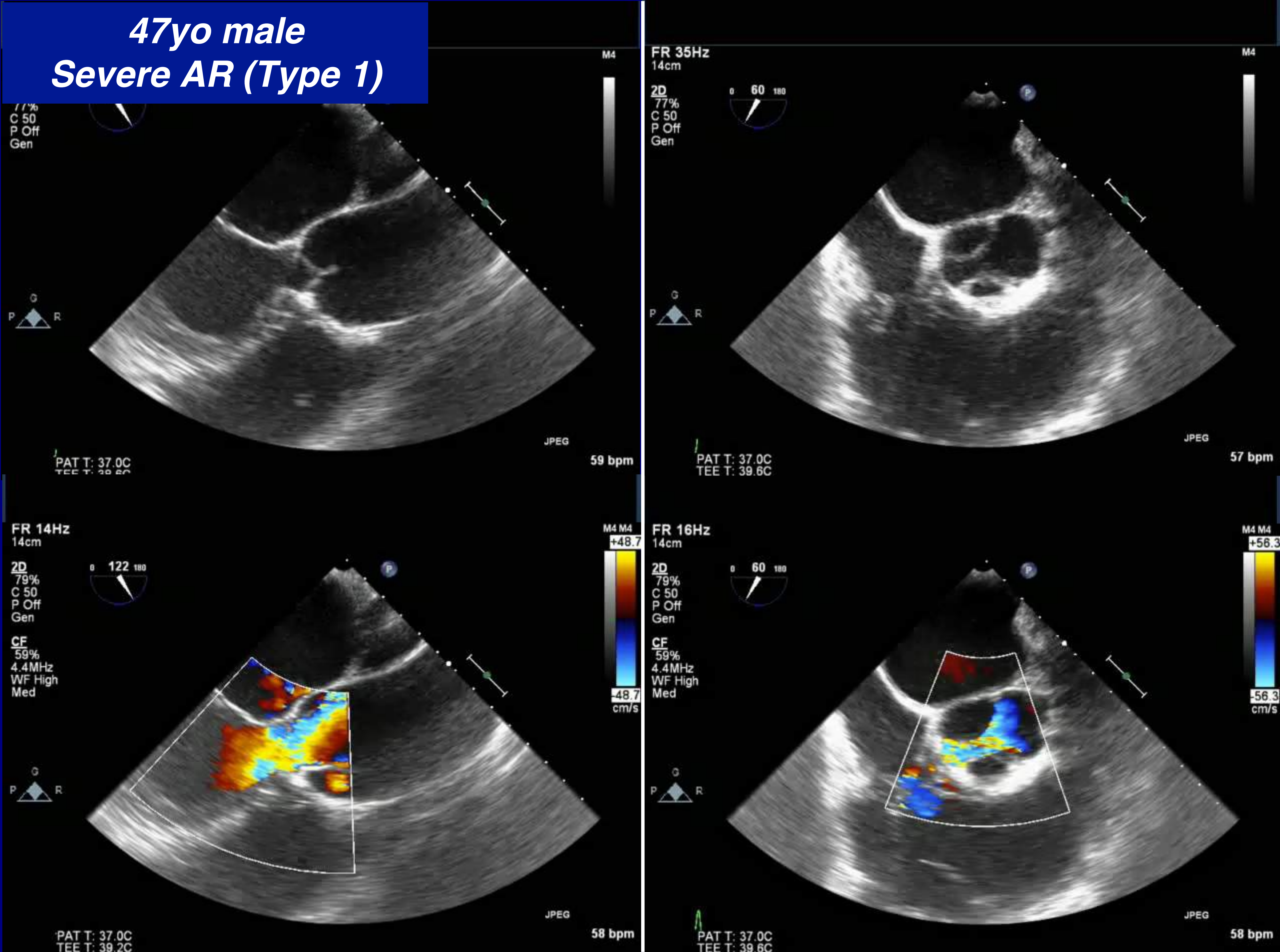
AV Re-implantation

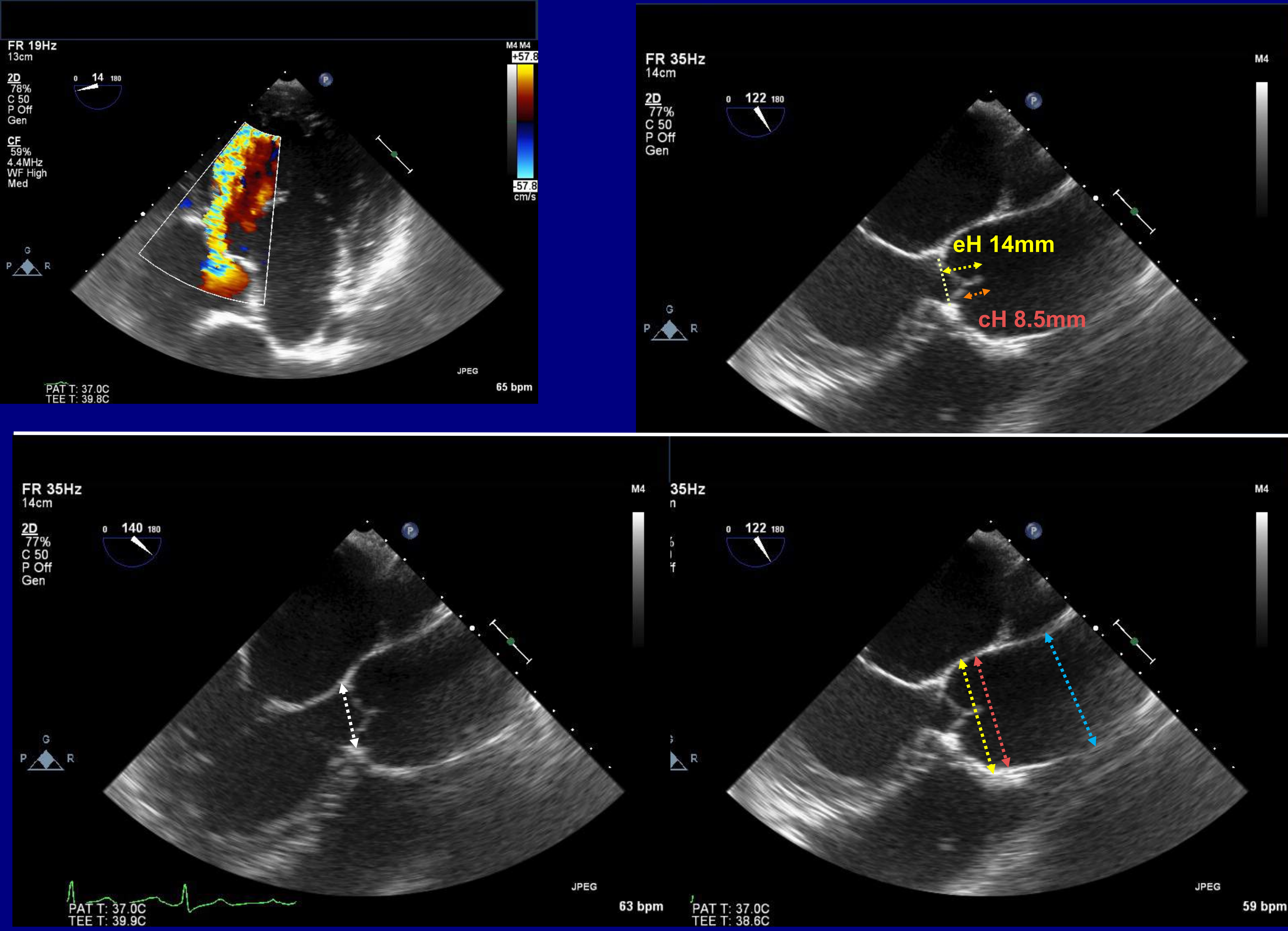


A: Coaptation ≥2mm within the prosthesis
B: Close to lower border of the Dacron graft
C: Coaptation ≥2mm below the prosthesis

1. Pethig K, et al. Aortic valve reimplantation in ascending aortic aneurysm: risk factors for erly valve failure. Ann Thorac Surg 2002;73:29-33.
2. le Polain de Waroux JB, et al. Mechanisms of recurrent aortic regurgitation after aortic valve repair. Predictive value of intra-operative transesophageal echocardiography. JACC Cardiovasc Imaging 2009;2:931–939.
3. Van Dyck MJ, et al. Transesophageal echocardiographic evaluation during aortic valve repair surgery. Anesth Analg 2010;111:59-70.
4. Berrebi A, et al. Systematic echocardiographic assessment of aortic regurgitation – what should the surgeon know for aortic valve repair. Ann Cardiothorac Surg 2019;8:331-341.

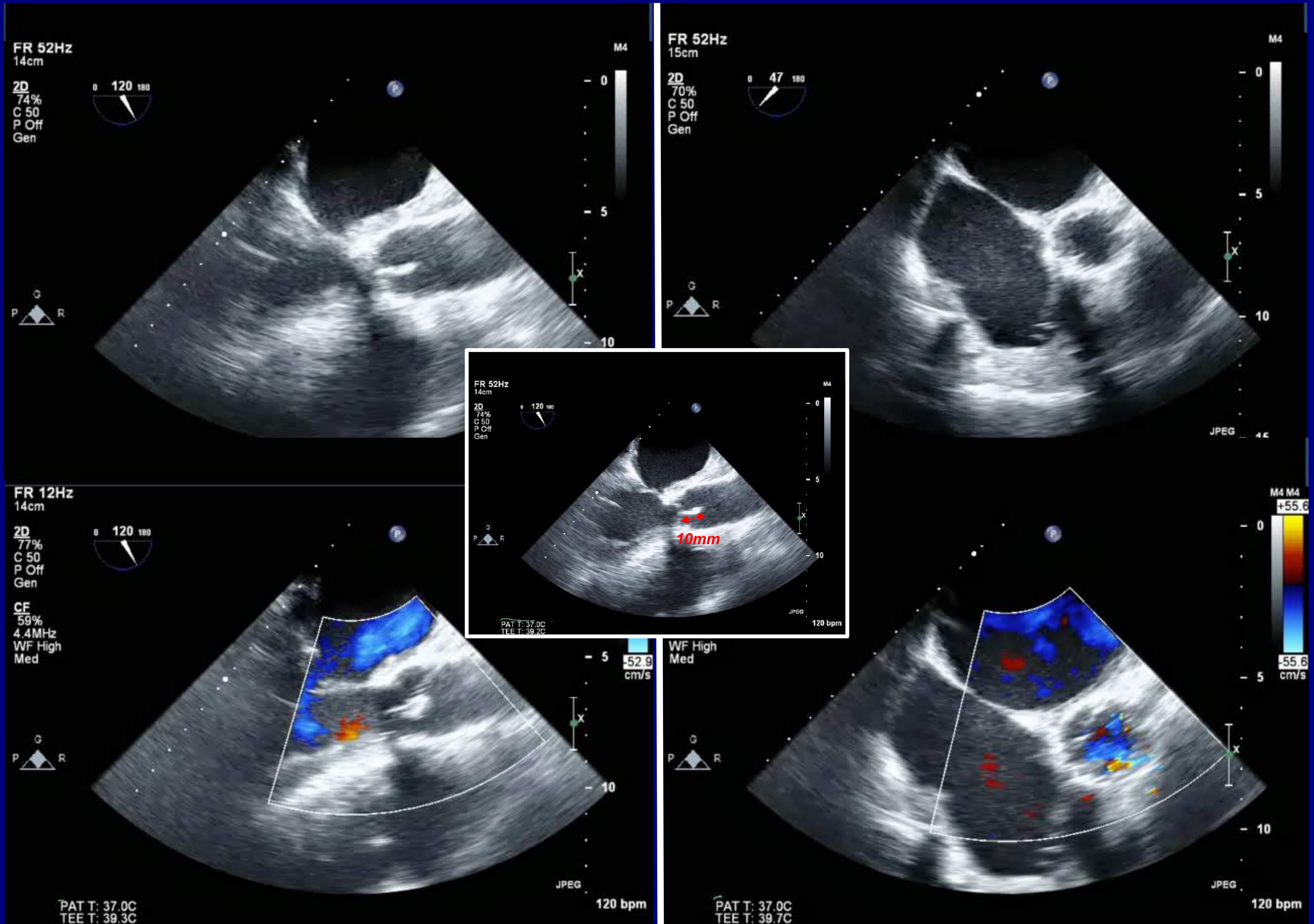
47yo male
Severe AR (Type 1)



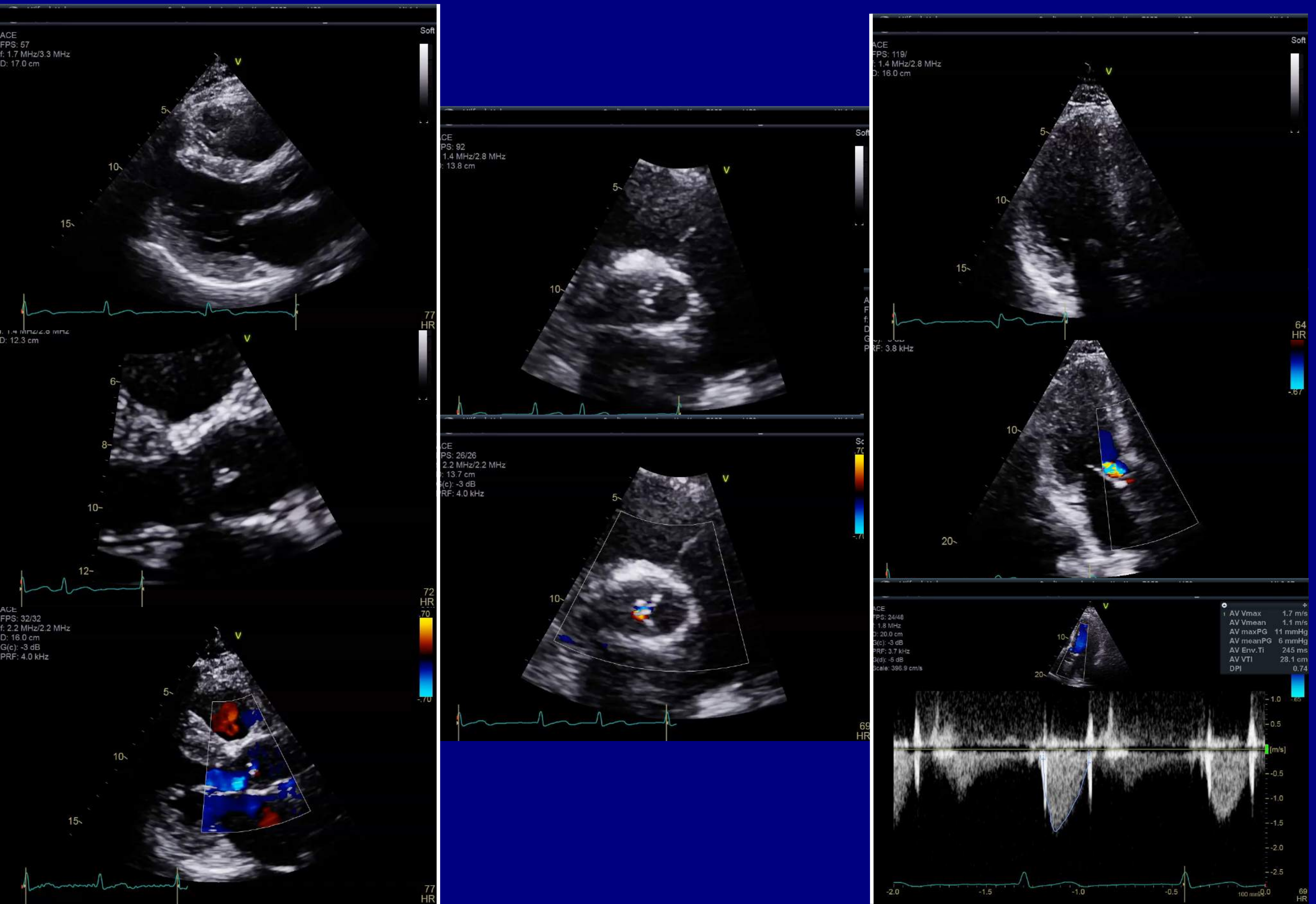


Annulus: 2.3cm; Trans-sinus 4.5cm; STJ 4.5cm; AscAo 4.7cm

Intra-op TOE Post-Repair



TTE 12.2020 (8yrs Post-AV Repair)



Take Home Messages

1. Do not judge severity of a lesion based on a single parameter
2. Beware discrepant parameters in assessment of AS
    - *Measurement errors*
    - *LFLG syndromes (True vs Pseudosevere)*
3. Beware severe acute regurgitant lesions (Clinical assessment + supportive echocardiographic findings)
4. Additional diagnostic benefit of other imaging modalities
    - *CT - AV Ca^{2+} in AS; Mechanical AVRs*
    - *cMRI - RVolume/RFraction in AR*

Questions?

Thank You