Quantitative and Semiquantitative Echocardiography

PERIOPERATIVE POCUS MODULE 6:
TRANSESOPHAGEAL ECHOCARDIOGRAPHY ASSESSMENTS

Objectives

- List five semi-quantitative assessments using advanced TEE
- Describe chamber assessment using TEE
- Discuss methods of assessing biventricular function using advanced TEE
- Identify measurements used to assess valve area, gradients and regurgitant volumes

Essential Quantitative Assessments

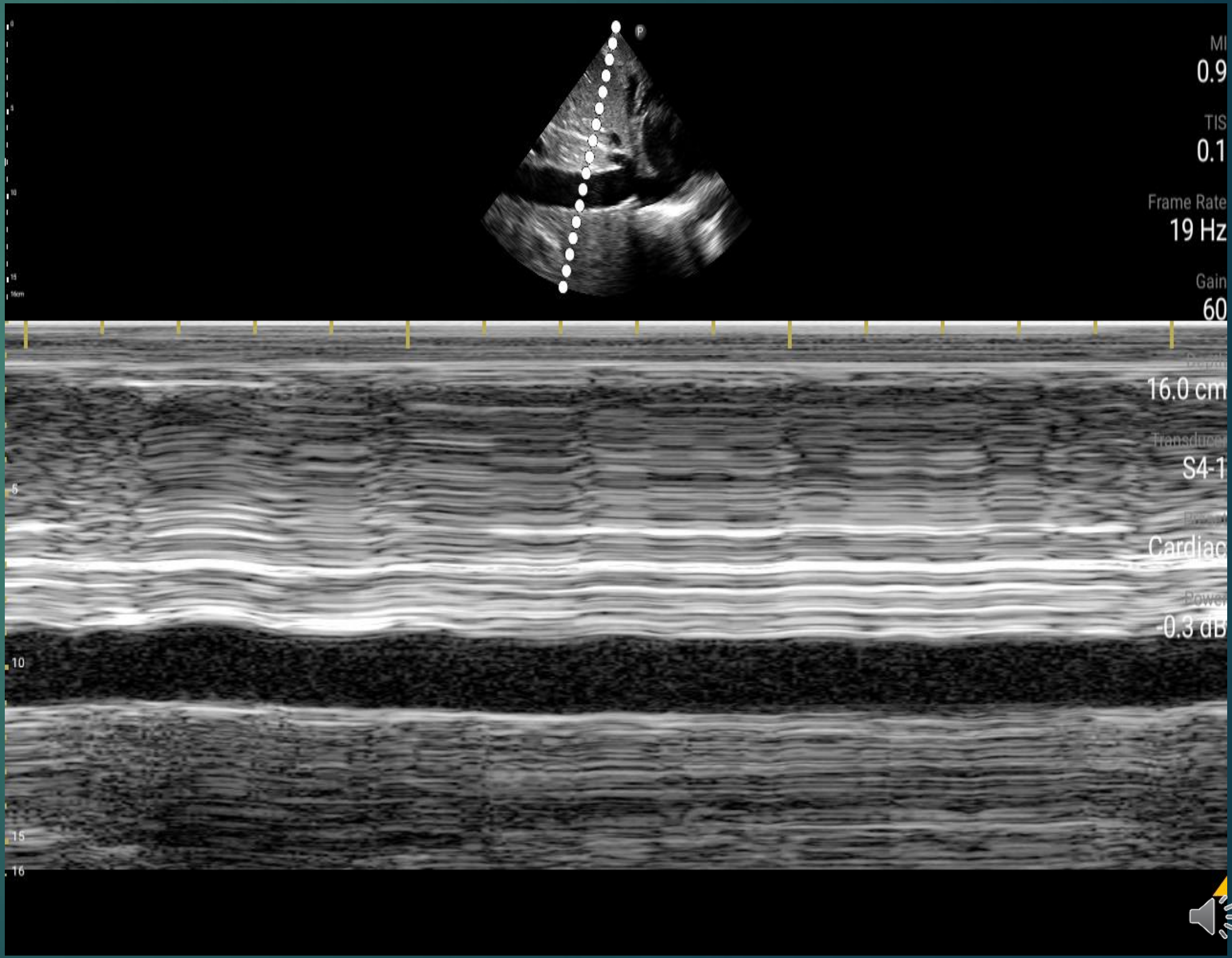
1. Abnormal chamber sizes (LA, LV, RV)
2. Ejection Fraction
3. Pulmonary Artery Systolic Pressure
4. Mitral valve area and gradient
5. Aortic valve area and gradient
6. Mitral valve regurgitation
7. Aortic valve regurgitation
8. Aorta and aortic valve annulus dimensions
9. E/A ratio (diastology)
10. Tricuspid Annular Plane Systolic Excursion (TAPSE)

Measuring and Imaging Techniques

- Calipers
- Area Tool
- M-Mode
- Color flow mapping with Doppler
  - Use of color box and position
  - Manipulation of Nyquist limit
- Pulse Wave Doppler
- Continuous Wave Doppler
  - Velocity
  - Velocity Time Integral
  - Pressure Half-Time

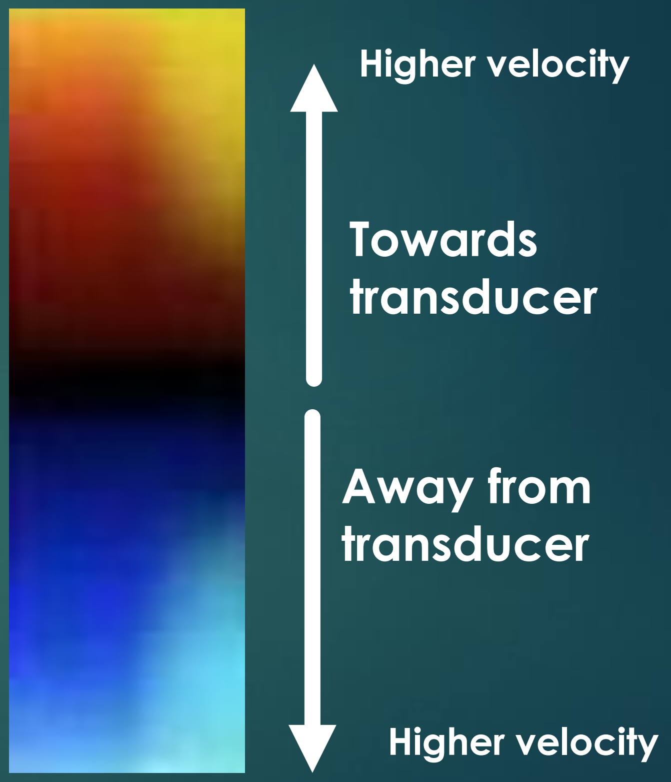
M-Mode as a TEE Imaging Technique

- Waves are transmitted as a single beam
- Only a limited area is scanned as only tissues which come into this narrow beam are displayed
- Amplitude of returning waves are displayed in shades of brightness
- Valve tissue and myocardium are gray and white, blood is black
- Color doppler may be applied to display velocity and direction of blood flow



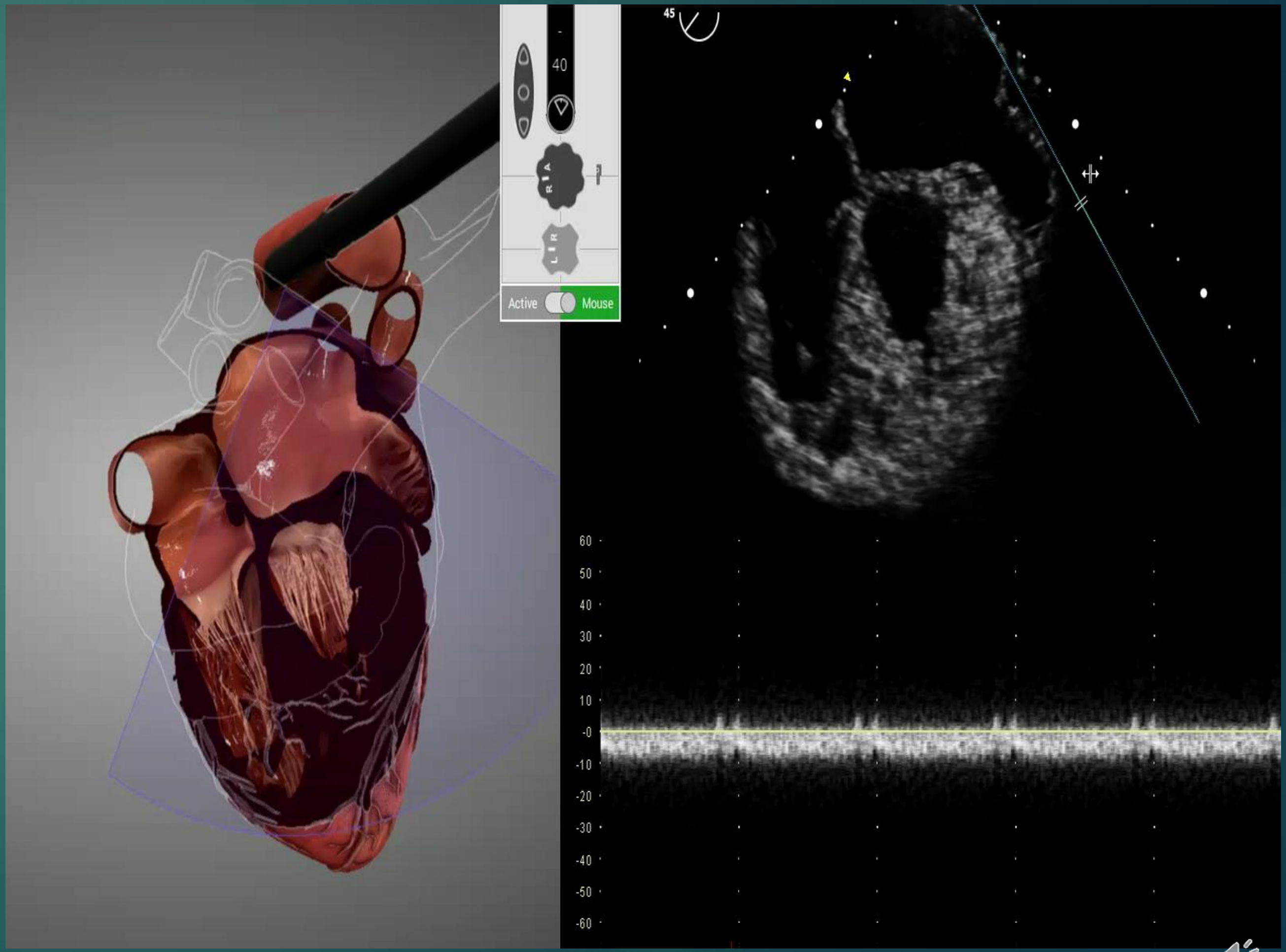
The Doppler Principle

- When a sound wave is reflected from a moving object, the frequency of the wave will be different from the emitted wave
- This frequency is called the Doppler principle
- The magnitude and direction of the frequency shift are related to the velocity and direction of the moving target
- In this manner blood flow velocity and direction may be determined ("BART")



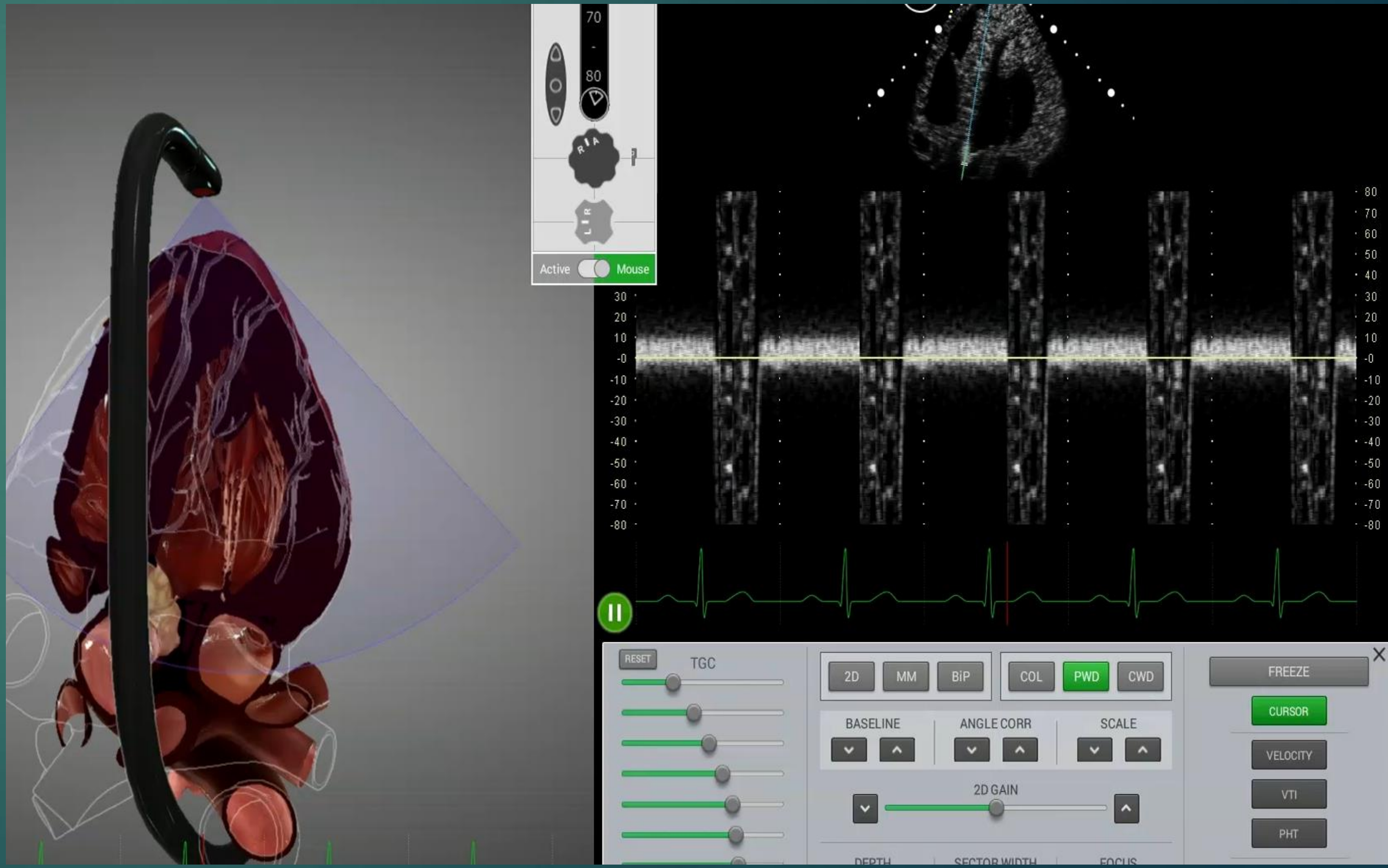
Pulsed Wave (PW) Doppler

- A single crystal sends and receives ultrasound signals then analyzes for frequency shifts
- A cursor is placed on a region on a 2-D image and velocity and direction of blood flow may be determined
- Allows flow direction and velocity in a small region (e.g., atrial appendage) to be measured
- Higher velocities (> 1 m/s) create aliasing and erroneous data (e.g., aortic stenosis)



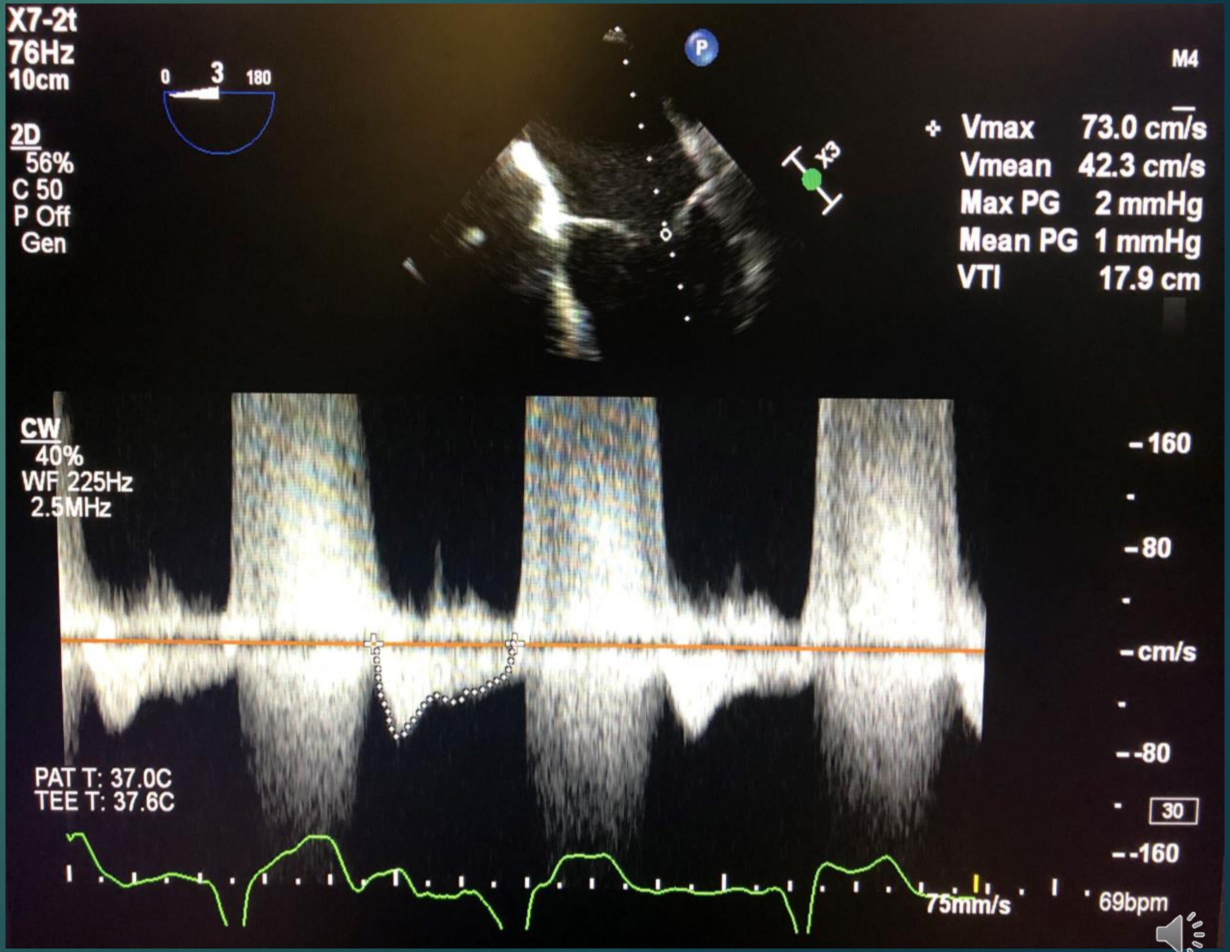
Continuous Wave (CW) Doppler

- Continuous wave doppler uses continuous sampling instead of discrete pulses of ultrasound waves
  - Waves are being continuously emitted by multiple transducers
  - Region in which flow is measured cannot be precisely located
- Higher velocities are more accurately measured (e.g., aortic stenosis)



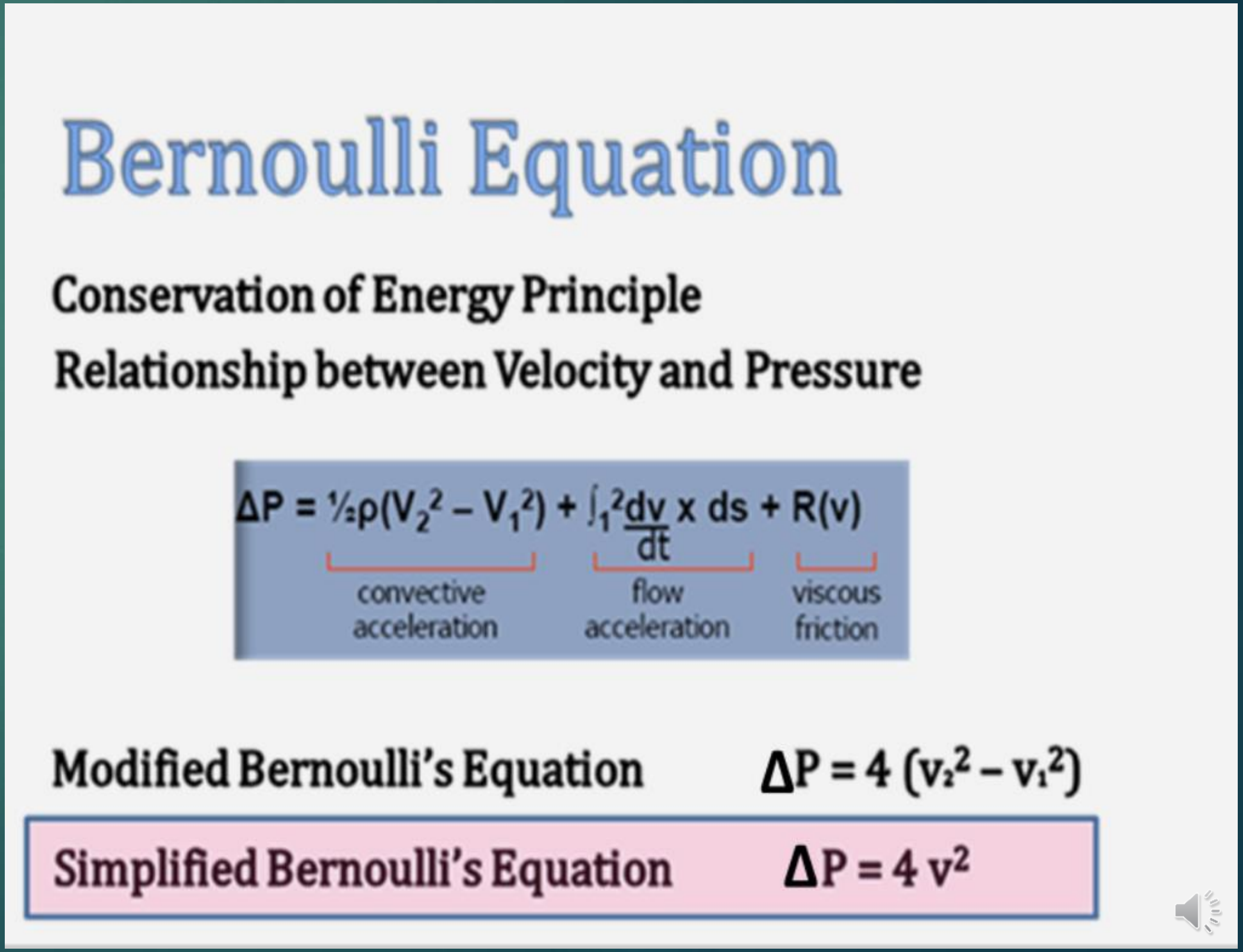
Equations and Calculations

- TEE may be used to estimate flows, gradients and valve areas
- Direction and velocity of flow may be qualitatively and quantitatively assessed using continuous and pulse wave Doppler
- Intravascular pressures and chamber dimensions may be measured to assess pathology



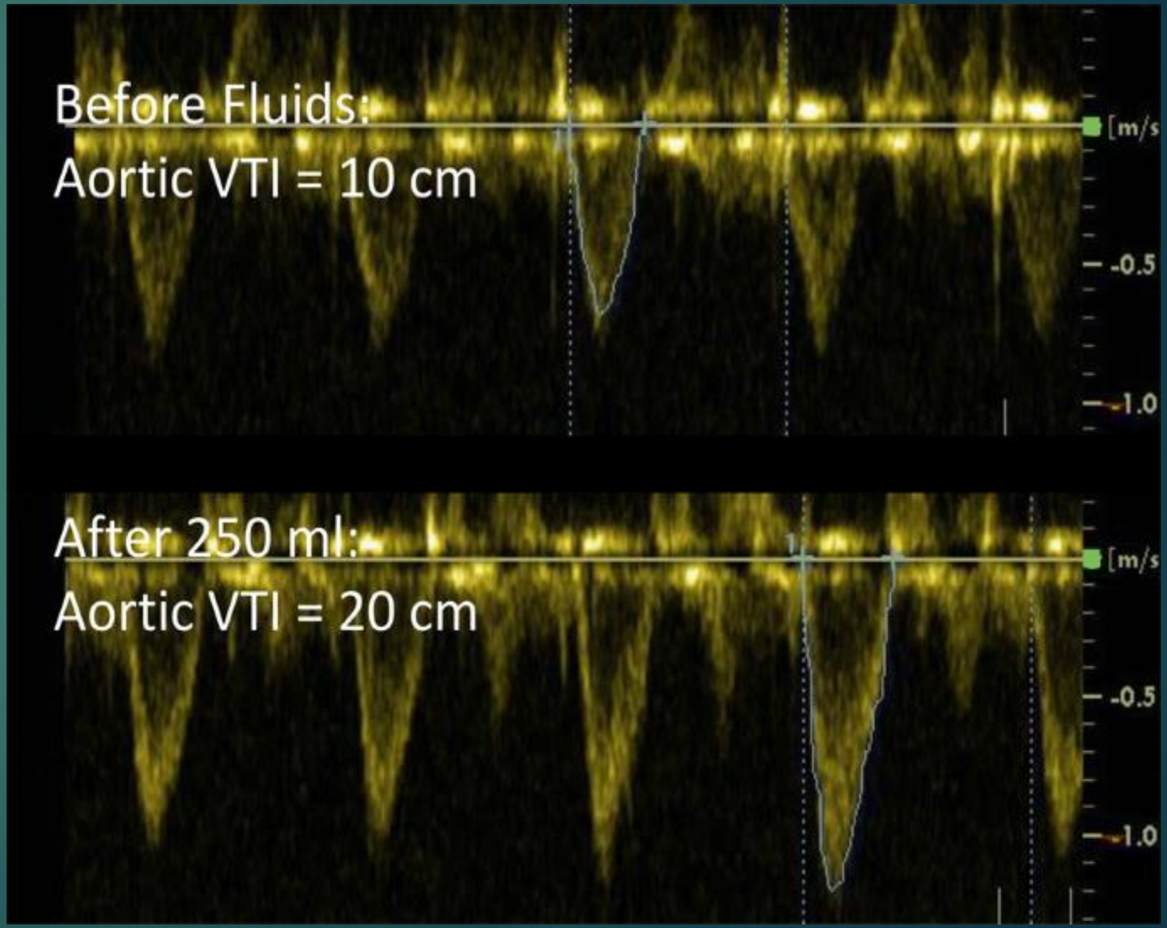
Simplified Bernoulli Equation

- If a volume of fluid is moving from higher to lower pressure, then the volume is accelerating in relationship to the pressure difference
- Used to estimate pressures and gradients across an orifice
  - Native aortic valve
  - Prosthetic aortic valve
  - Native mitral valve
  - Mitral valve repair/prosthesis



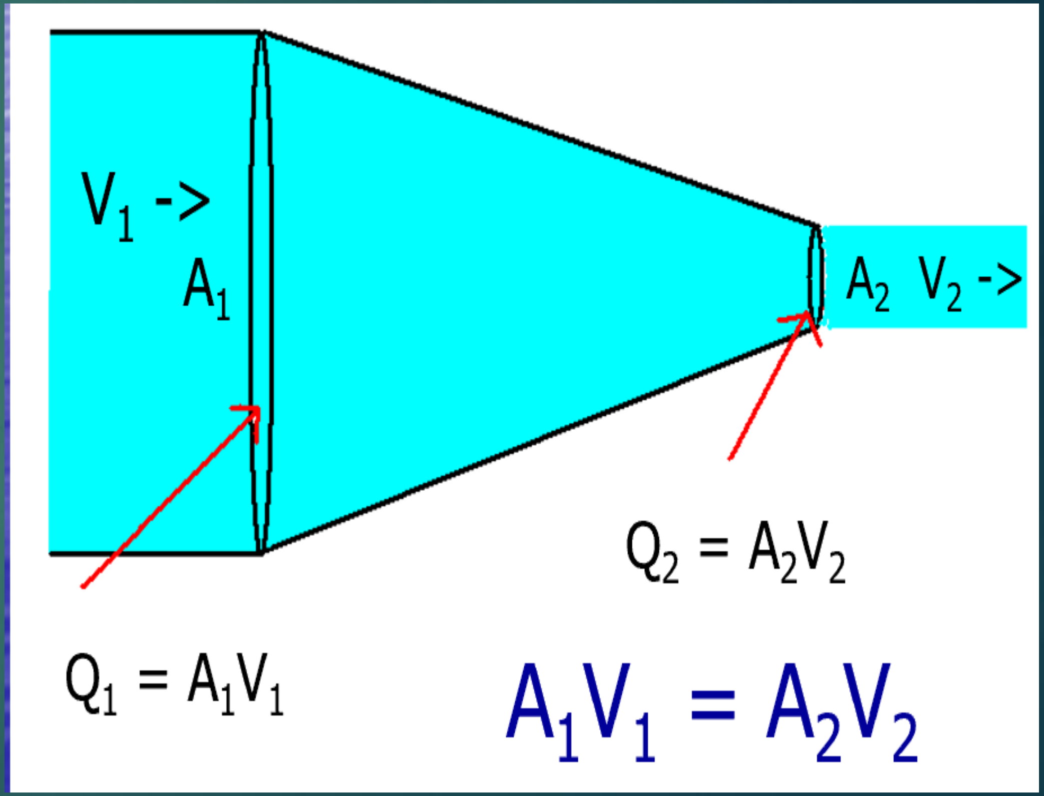
Velocity Time Integral (VTI)

- Flow towards and away from the transducer is plotted as velocity
  - *Pulse wave* Doppler measures flow in a specific sample
  - *Continuous wave* Doppler measures all flow along a line
- Velocity may be plotted over time (VTI) to estimate flow in a structure or chamber (SV=CSA x VTI)
- In this manner flow in a specific region is estimated



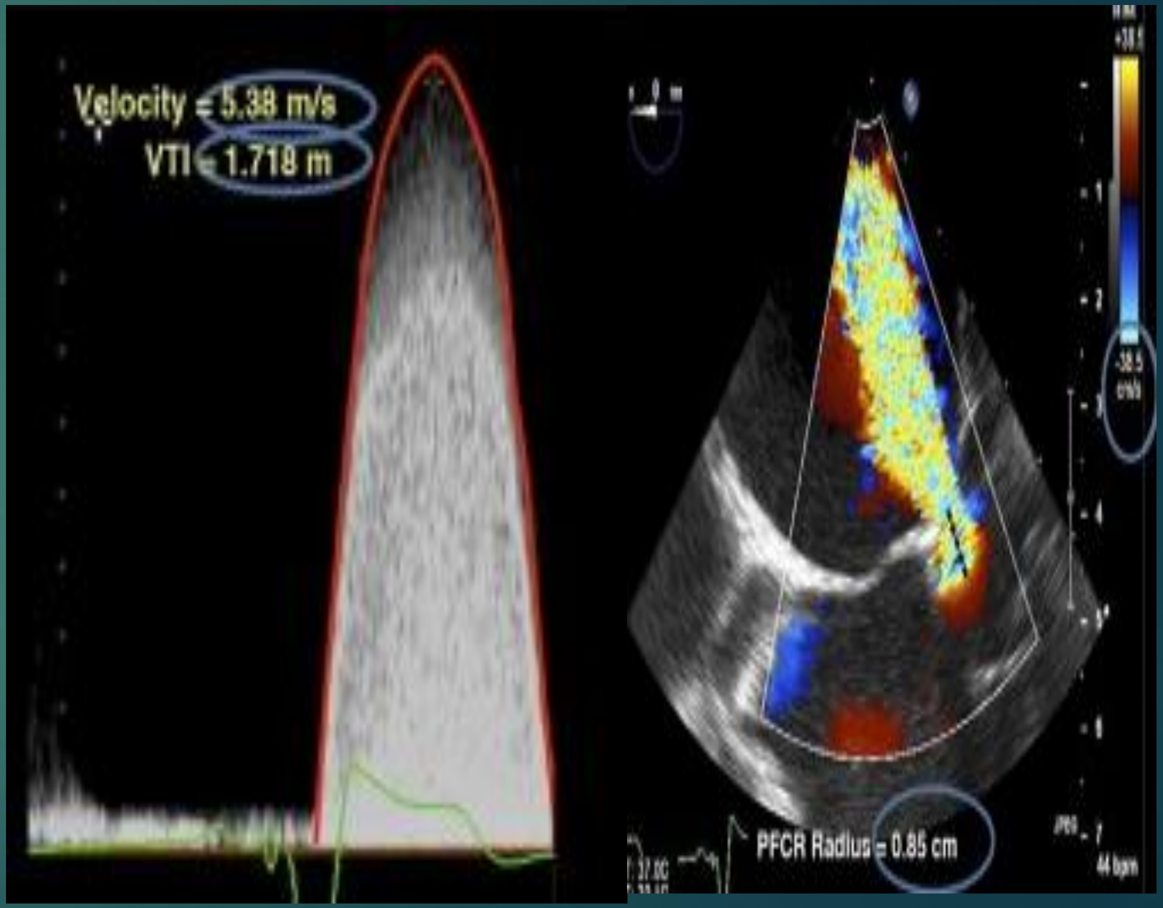
Continuity Equation

- Because liquids are not compressible, flow into an area must equal flow out of an area
- By applying the continuity equation, the flow must be greater in the more narrow area
- Used to calculate areas, specifically valve areas
- Area=A; Velocity=V
- $A_1V_1=A_2V_2$
- $A_2=A_1xV_1/V_2$



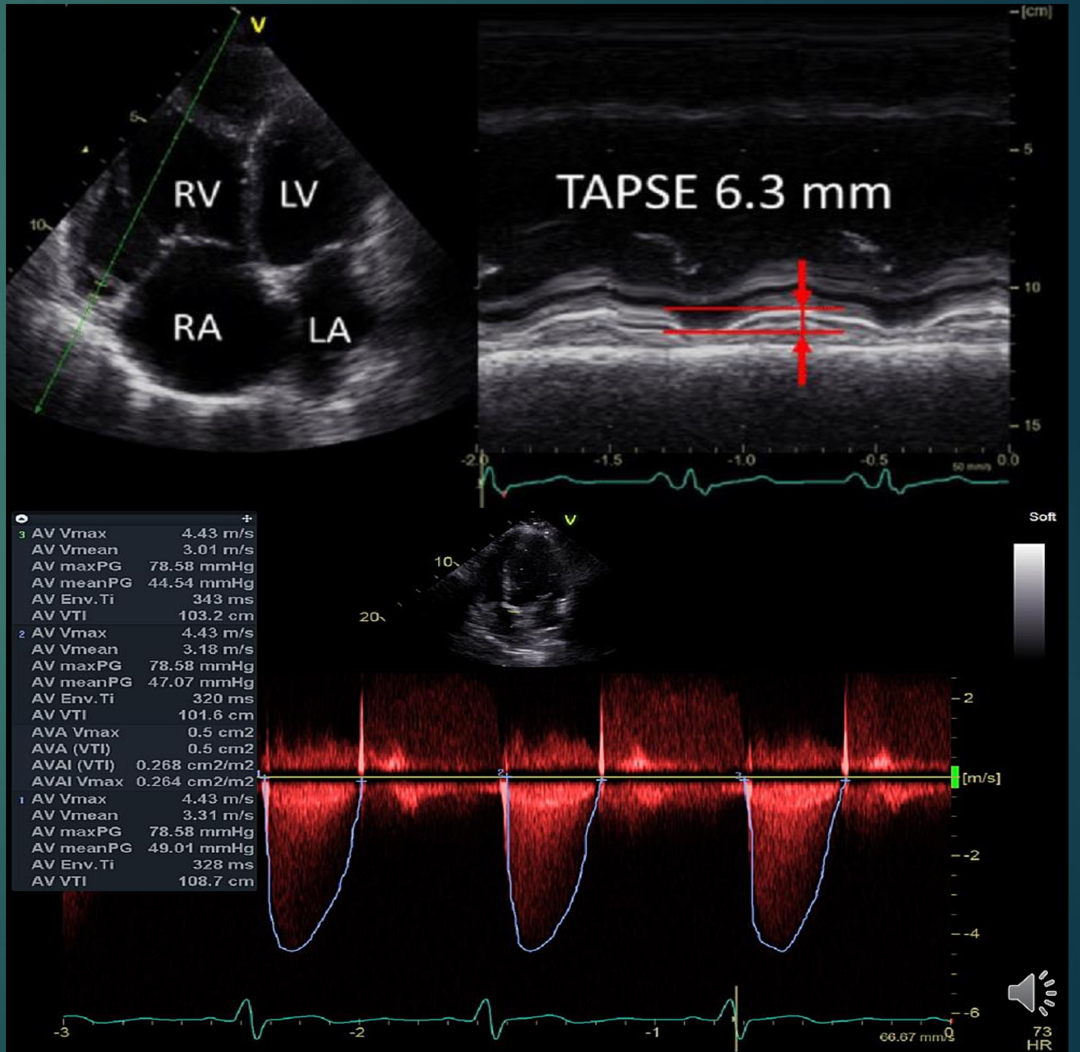
Proximal Isovelocity Surface Area (PISA)

- Used to quantify the severity of valvular regurgitation
- PISA assumes that as blood flows towards a regurgitant valve the flow comes together and accelerates
- Color flow Doppler (by adjusting Nyquist limit, V_n) may be used to identify the region of increasing velocity and its absolute velocity (V_O)
- Flow=Velocity x Area such that regurgitant orifice area (ROA) is calculated by:
- $ROA=2\pi r^2 V_n/V_o$
- Regurgitant Volume=VTI_{regurg} x (ROA)



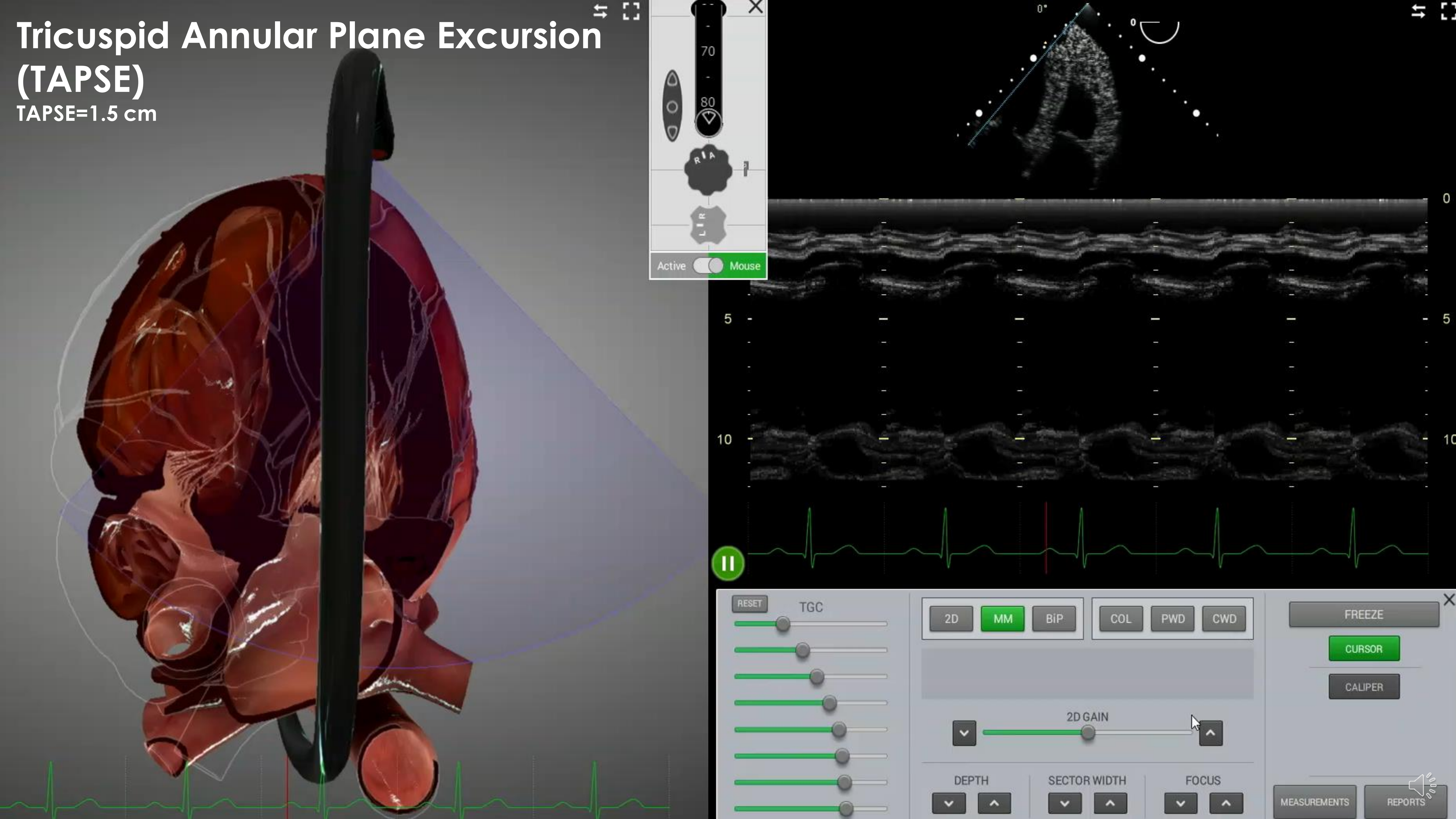
Basic Principles of Semiquantitative Echocardiography

- Basic principles of assessing cardiac chamber size and intracardiac flows are similar to TTE
  - TTE was used for initial assessments
  - Optimal views for TEE are not established
  - Doppler alignment more difficult with TEE
- General anesthesia changes chamber sizes, volumes and pressures



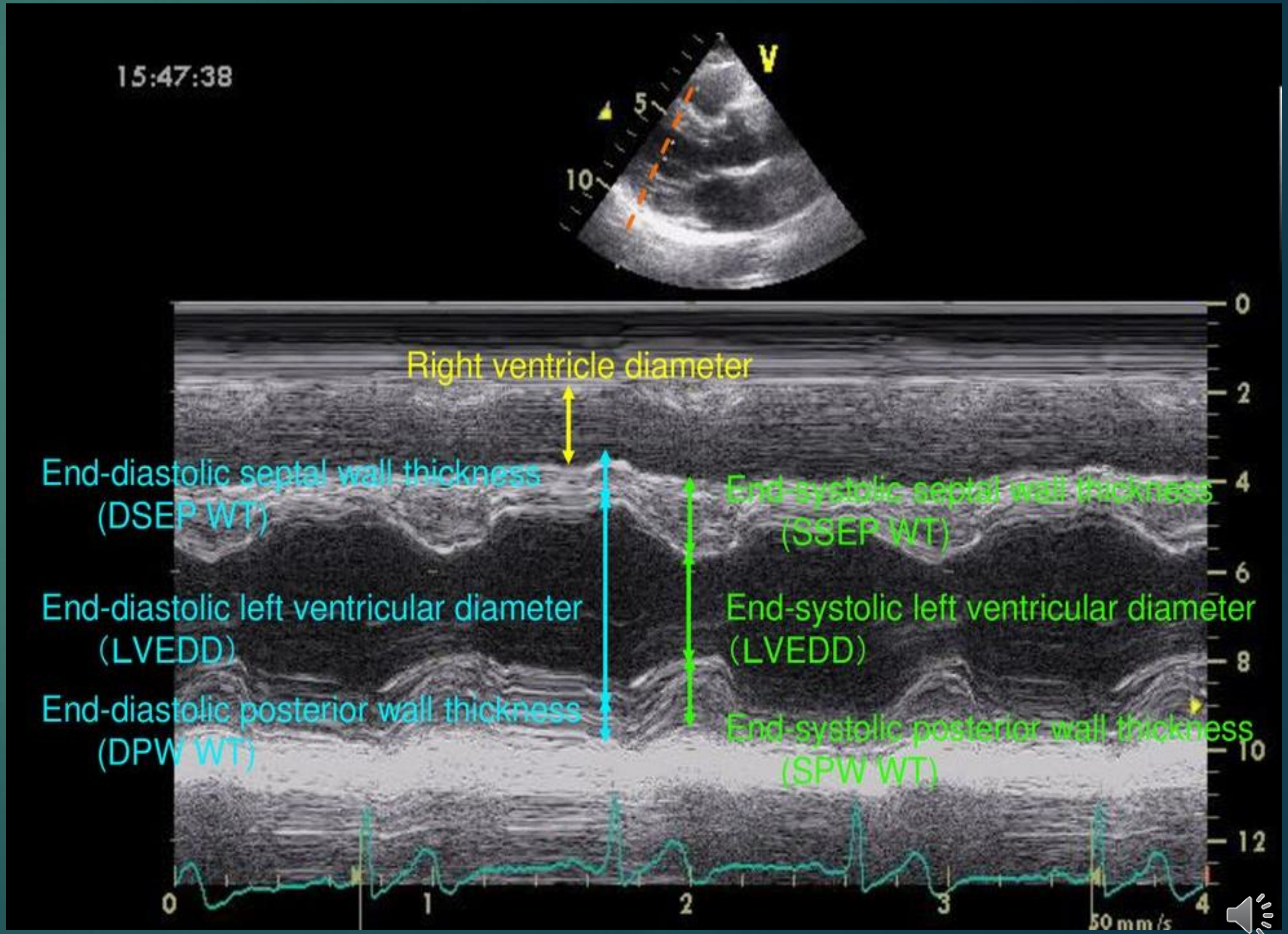
Tricuspid Annular Plane Excursion (TAPSE)

TAPSE=1.5 cm



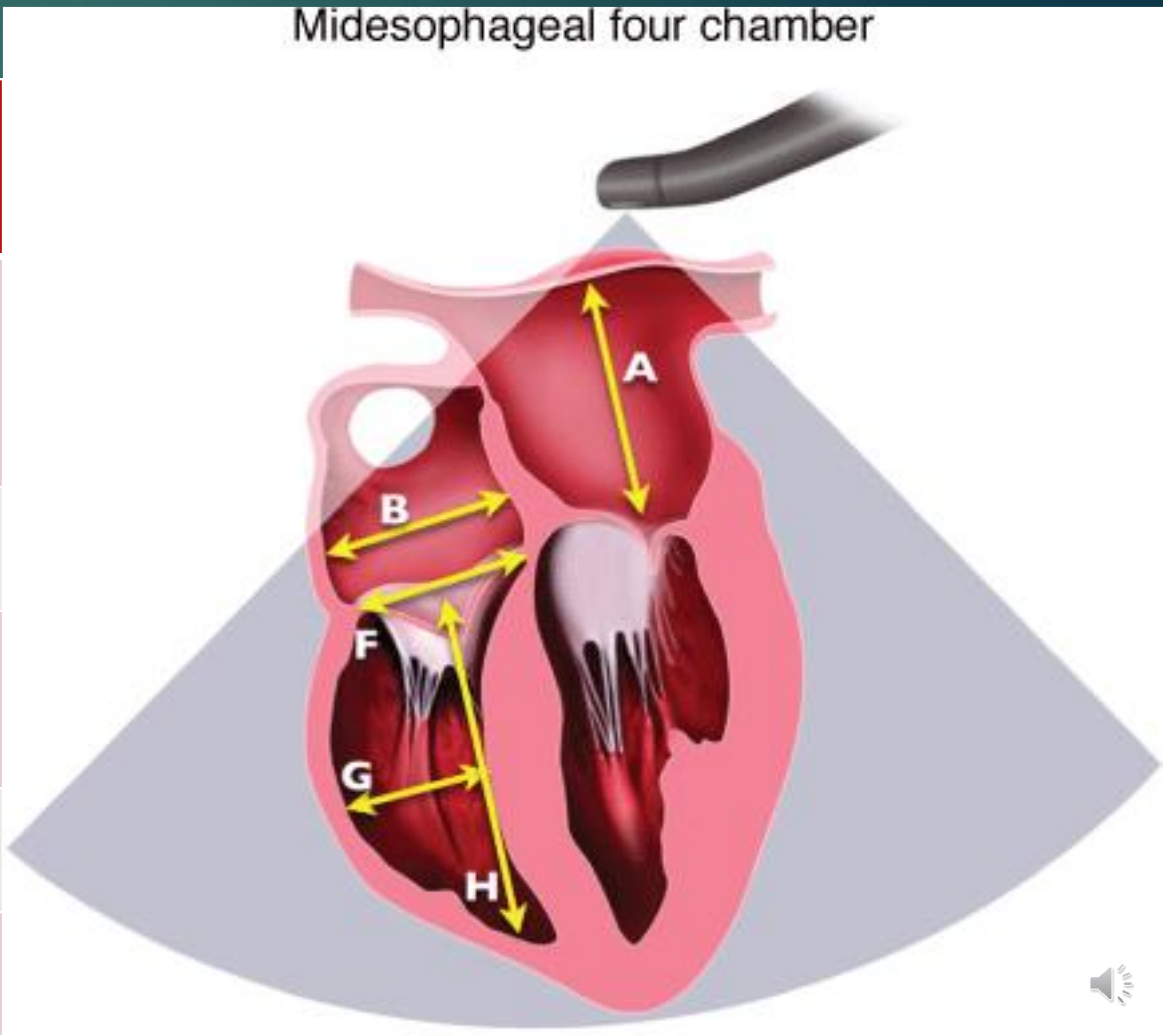
Measurement of Cardiac Chamber and Wall Dimensions

- Qualitative assessment of chamber size, function and flow is almost immediate
- Measurement of chamber sizes reveal ventricular function, valve pathology, cardiac defects and other pathology
- Chamber wall dimensions reveal pathology as well



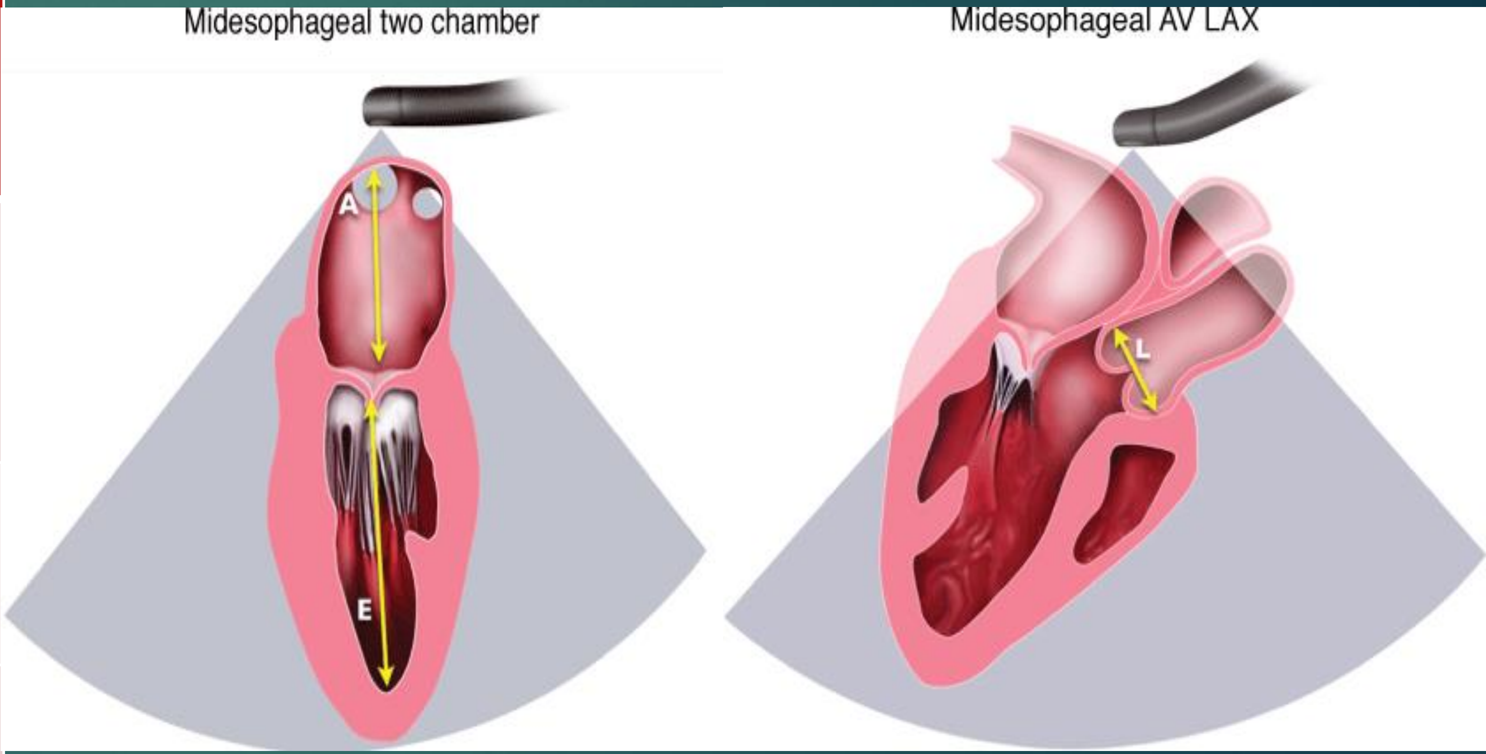
Normal Chamber Dimensions: ME 4 Chamber

Structure	Measurement	Dimension (cm)
Left Atrium (unreliable)	Diameter (A)	2.7-4.0
Right Atrium	Minor Axis (B)	2.9-4.5
Right Ventricle	Basal Diameter (F)	2.0-2.8
	Mid Diameter (G)	2.7-3.3
	Length (H)	7.1-7.9



Normal Chamber Dimensions: ME 2 Chamber and ME AV LAX

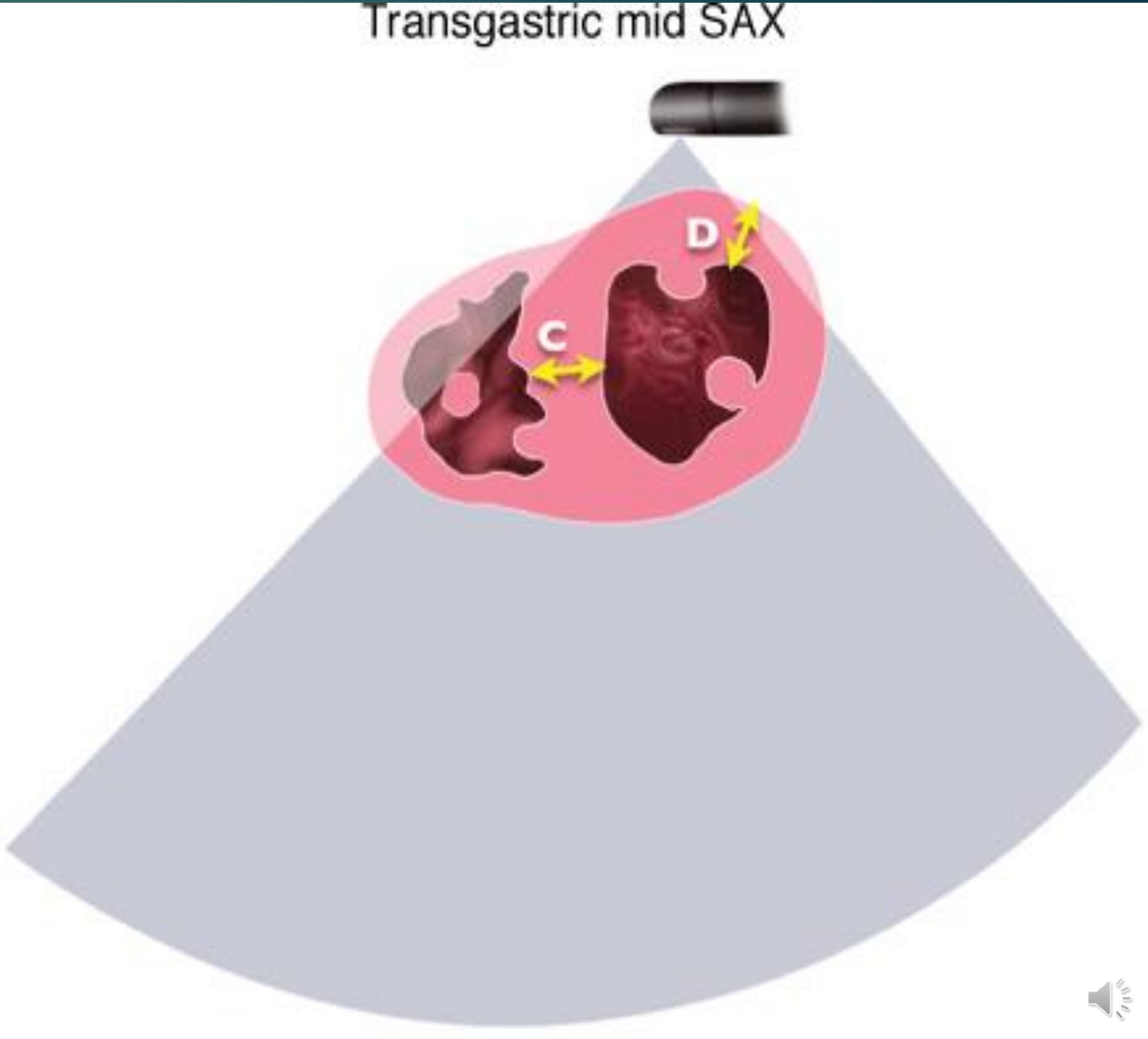
Structure	Measurement	Dimension (cm)
Left Atrium (unreliable)	Diameter (A)	2.7-4.0
Left Ventricle	Diameter (E)	3.9-5.9
Aortic Root	Sinus of Valsalva (L)	2.6-4.0



Lang RM, Badanp LP, Mor-Avi B et al. Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr*, 2015, 28:1-39

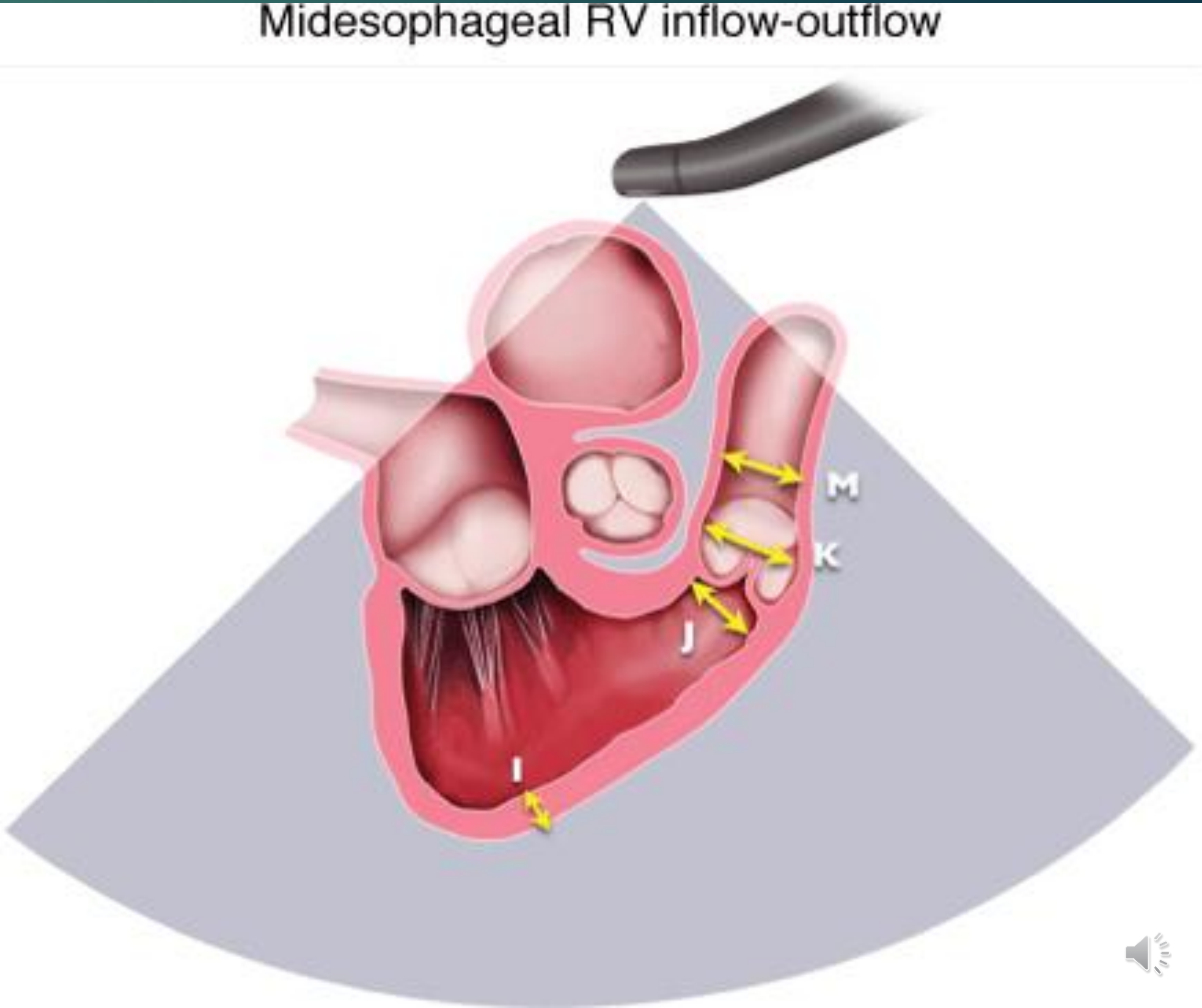
Normal Chamber Dimensions: TG MP SAX

Structure	Measurement	Dimension (cm)
Left Ventricle	Wall Thickness (septal)(C)	0.6-1.0
	Wall Thickness (inferolateral)(D)	0.6-1.0



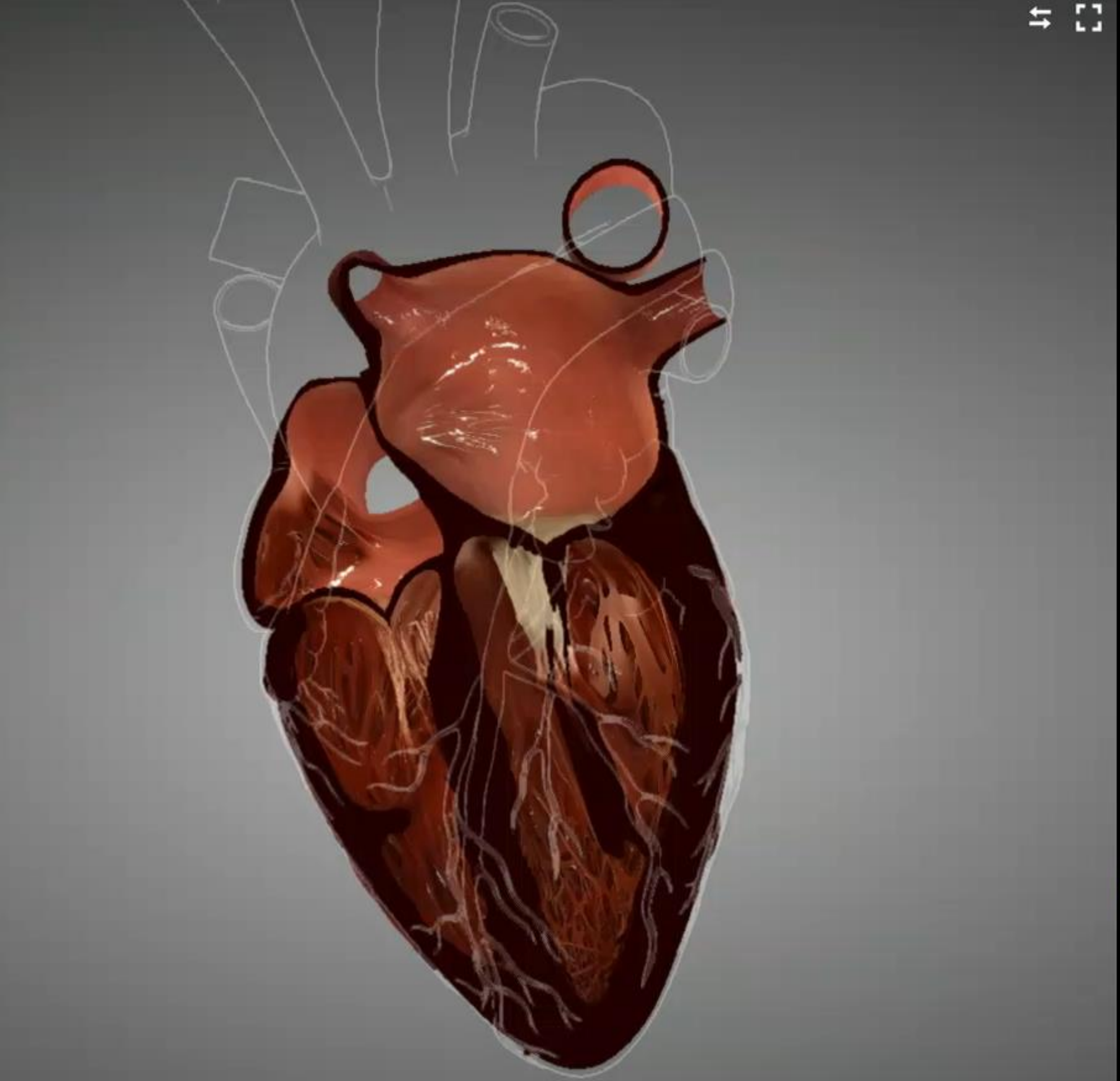
Normal Chamber Dimensions

Structure	Measurement	Dimension (cm)
Right Ventricle	Wall Thickness (I)	<0.5
Right Ventricular OF	RVOT Diameter (below PV)(J)	2.5-2.9
	RVOT Diameter (above PV)(K)	1.7-2.3
Pulmonary Artery	Diameter (M)	1.5-2.1

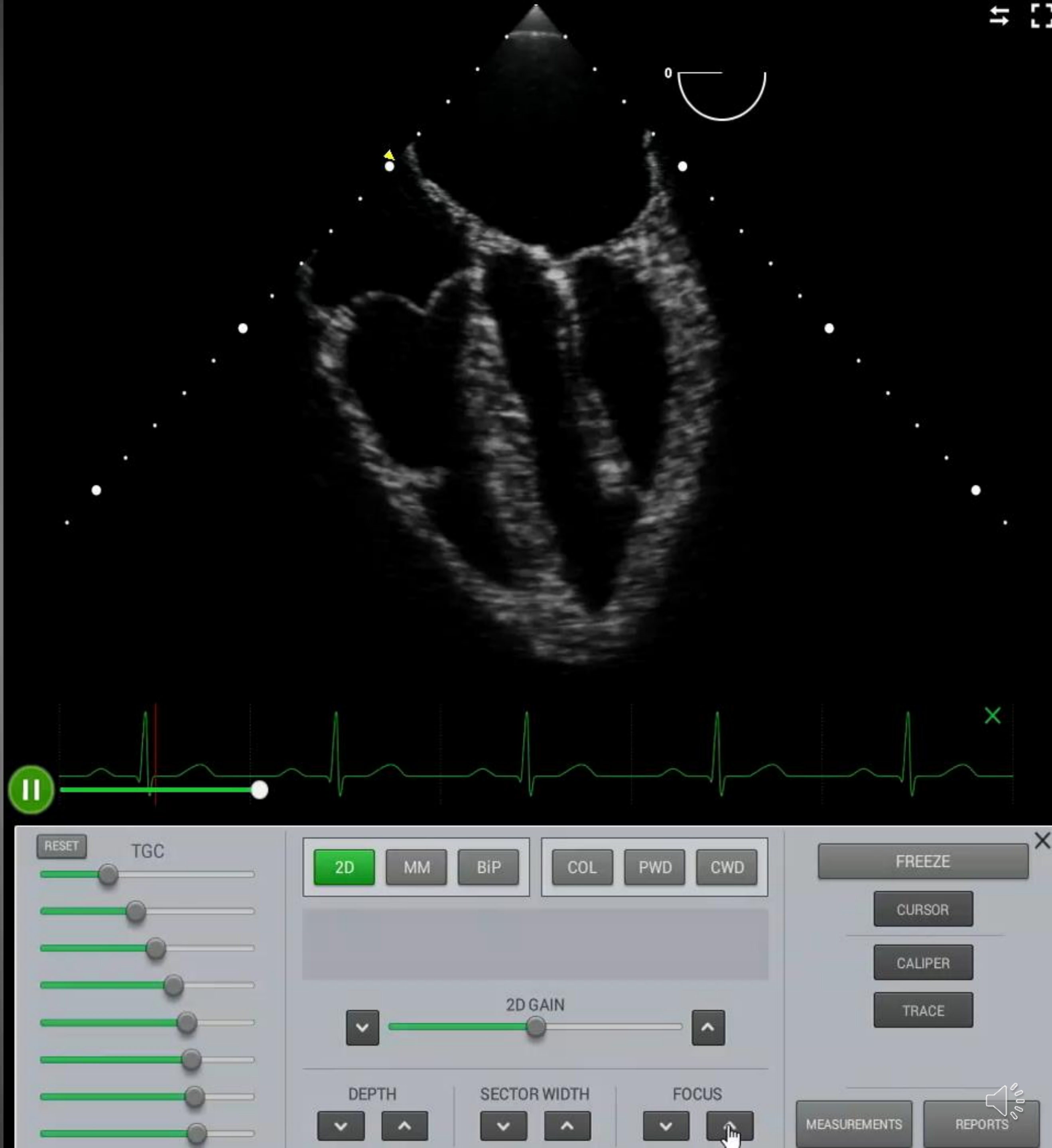


Normal Chamber Dimensions

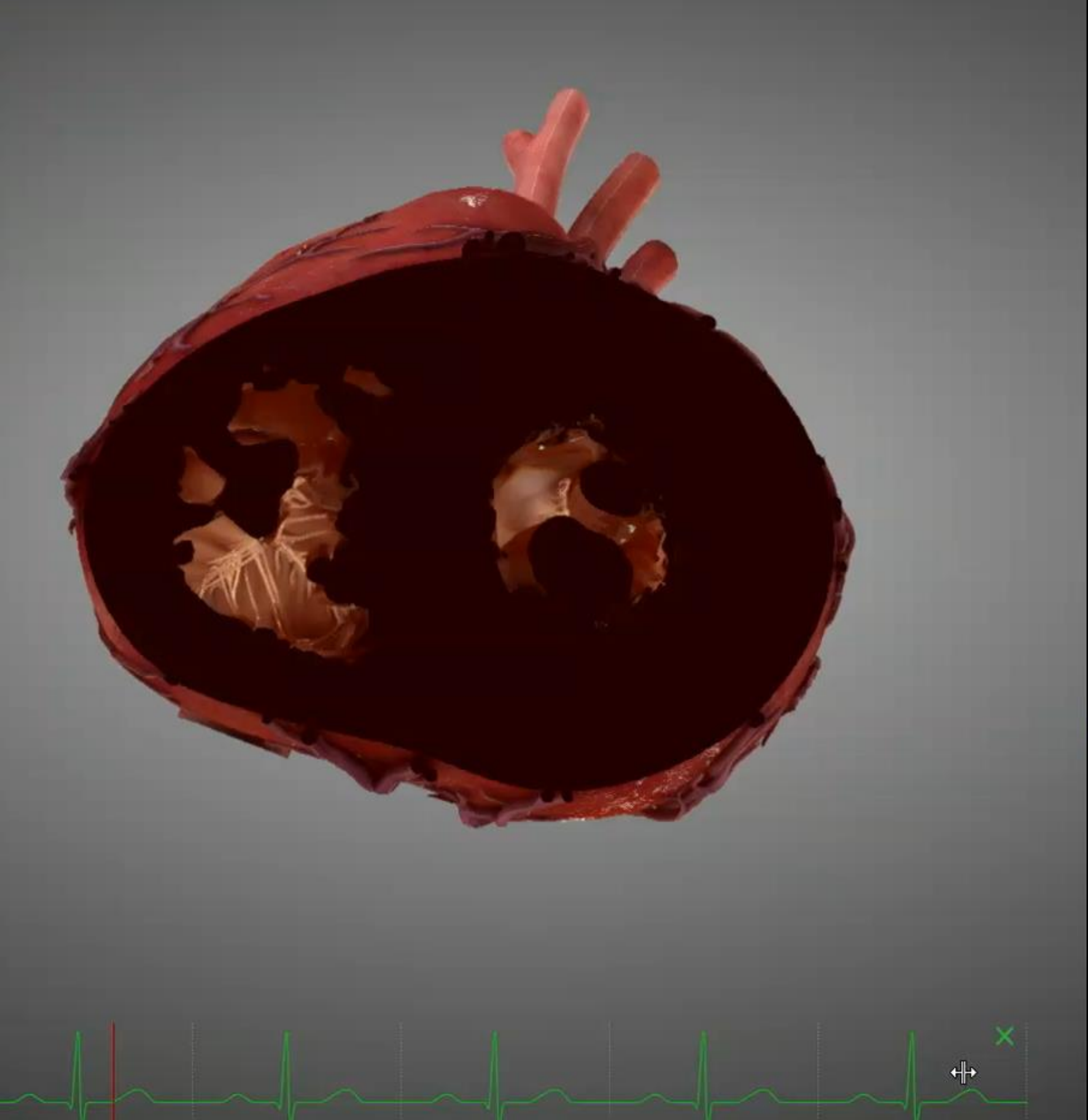
Structure		Measurement	View	Dimension (cm)
Chambers	Left Atrium (unreliable)	**Diameter**	ME4C or ME2C	**2.7-4.0**
	Right Atrium	Minor Axis	ME4C	2.9-4.5
	Left Ventricle	**Wall Thickness (septal)**	TGmidSAX	**0.6-1.0**
		Wall Thickness (inferolateral)	TGmidSAX	0.6-1.0
		Diameter	ME2C or TG2C	**3.9-5.9**
	Right Ventricle	Basal Diameter	ME4C	2.0-2.8
		Mid Diameter	ME4C	**2.7-3.3**
		Length	ME4C	7.1-7.9
		Wall Thickness	ME4C or RVIFOF	<0.5
Tracts/Vessels	Right Ventricular OF	RVOT Diameter (below PV)	ME AV SAX or RVIFOF	2.5-2.9
		RVOT Diameter (above PV)	ME AV SAX or RVIFOF	1.7-2.3
	Aortic Root	**STJ, Proximal Ascending Aorta, Sinus of Valsalva**	ME AV LAX	**2.6-4.0**
	Pulmonary Artery	Diameter	RVIFOF	1.5-2.1
	Inferior Vena Cava	Diameter	ME4C (modified)	1.2-1.7

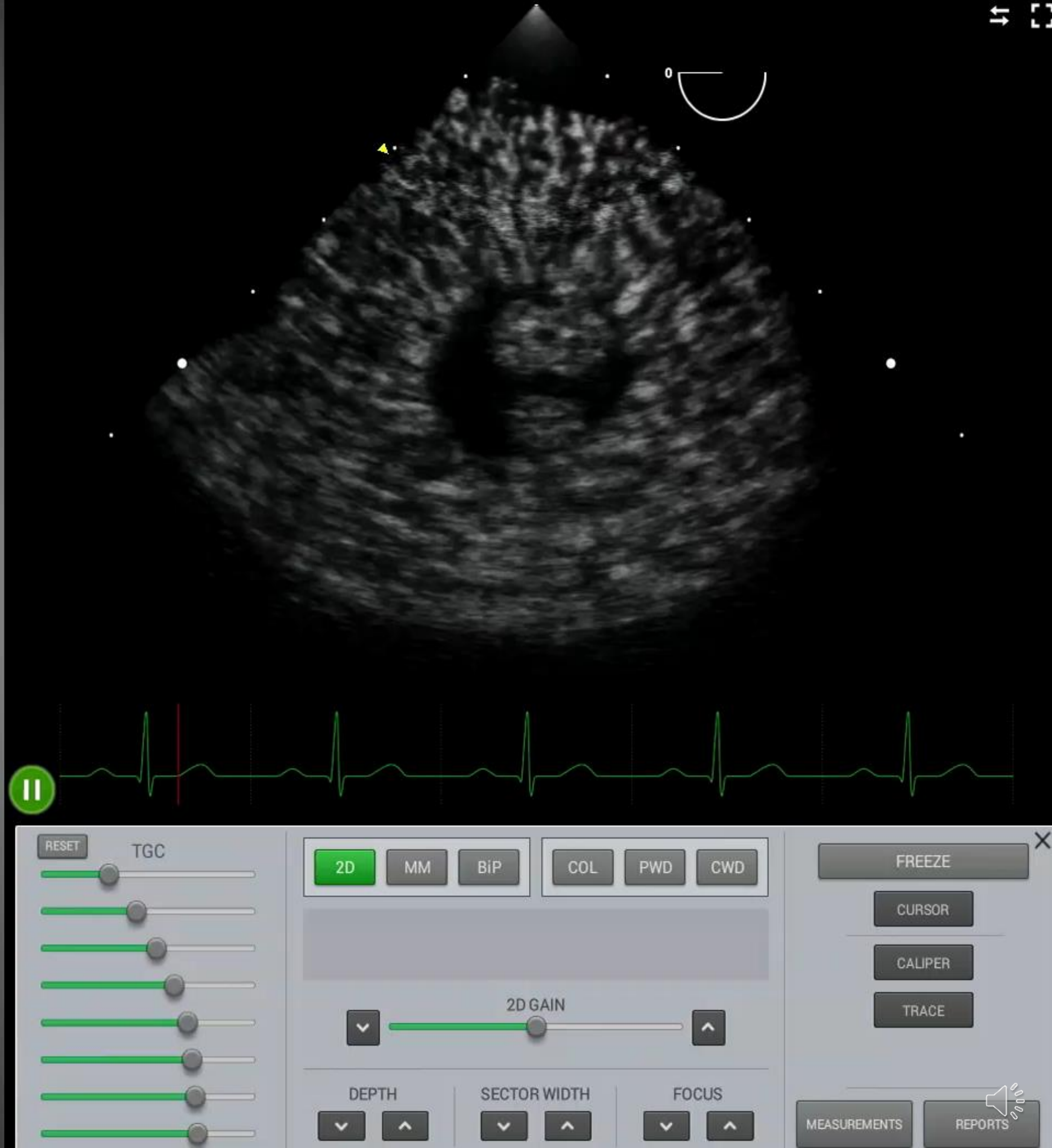


Left Atrial Dimensions

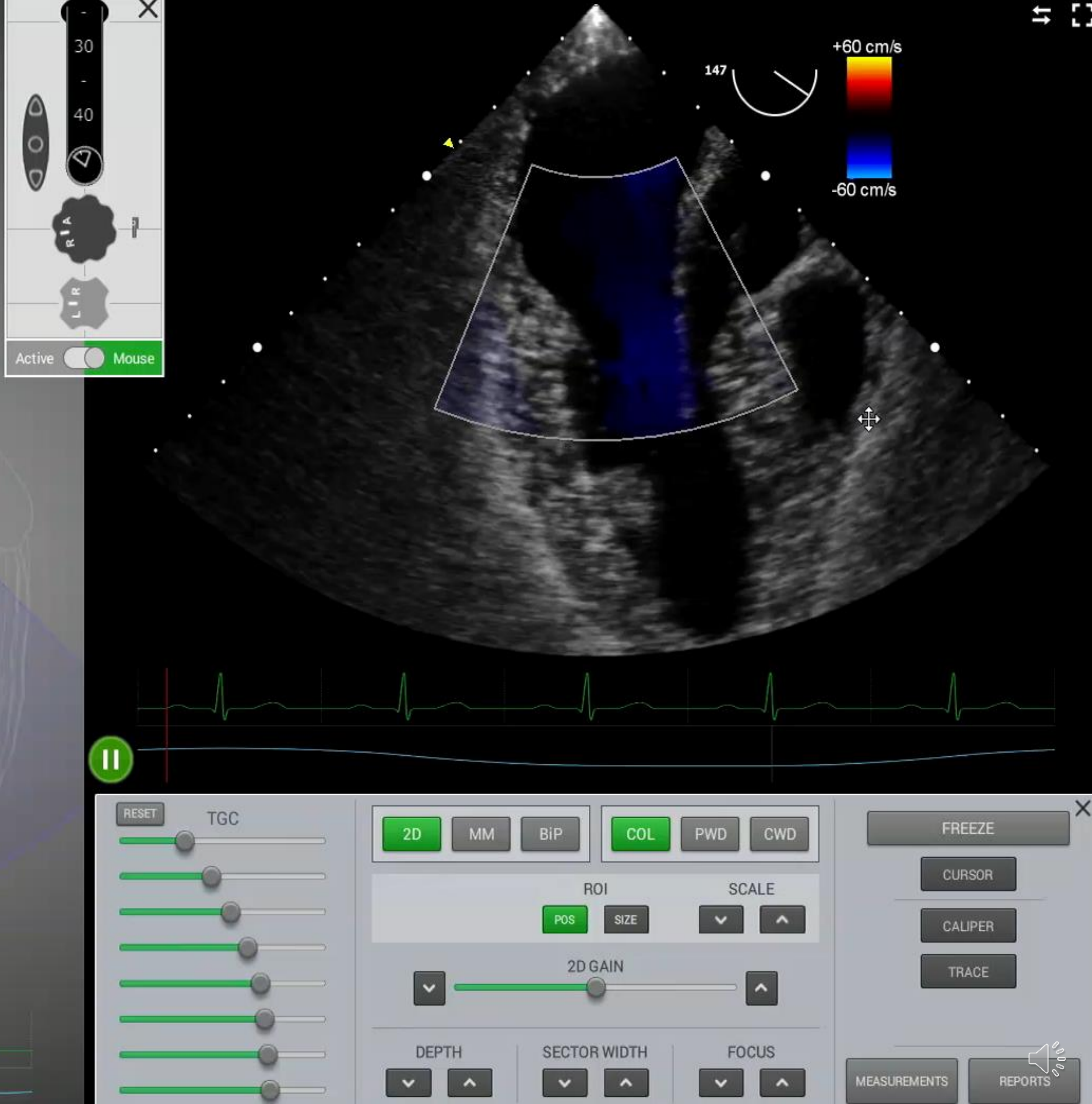


Left Ventricular Wall Thickness

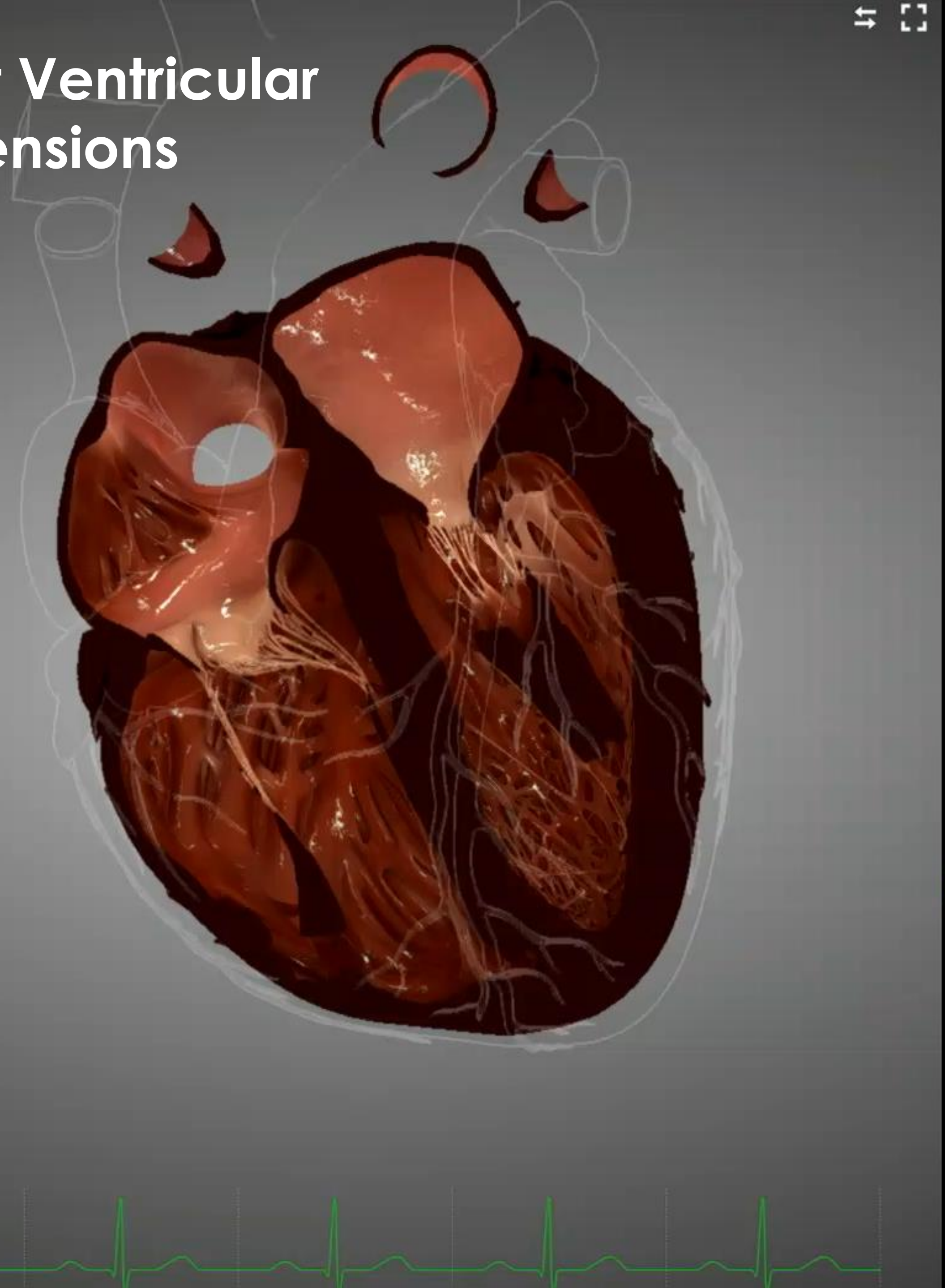


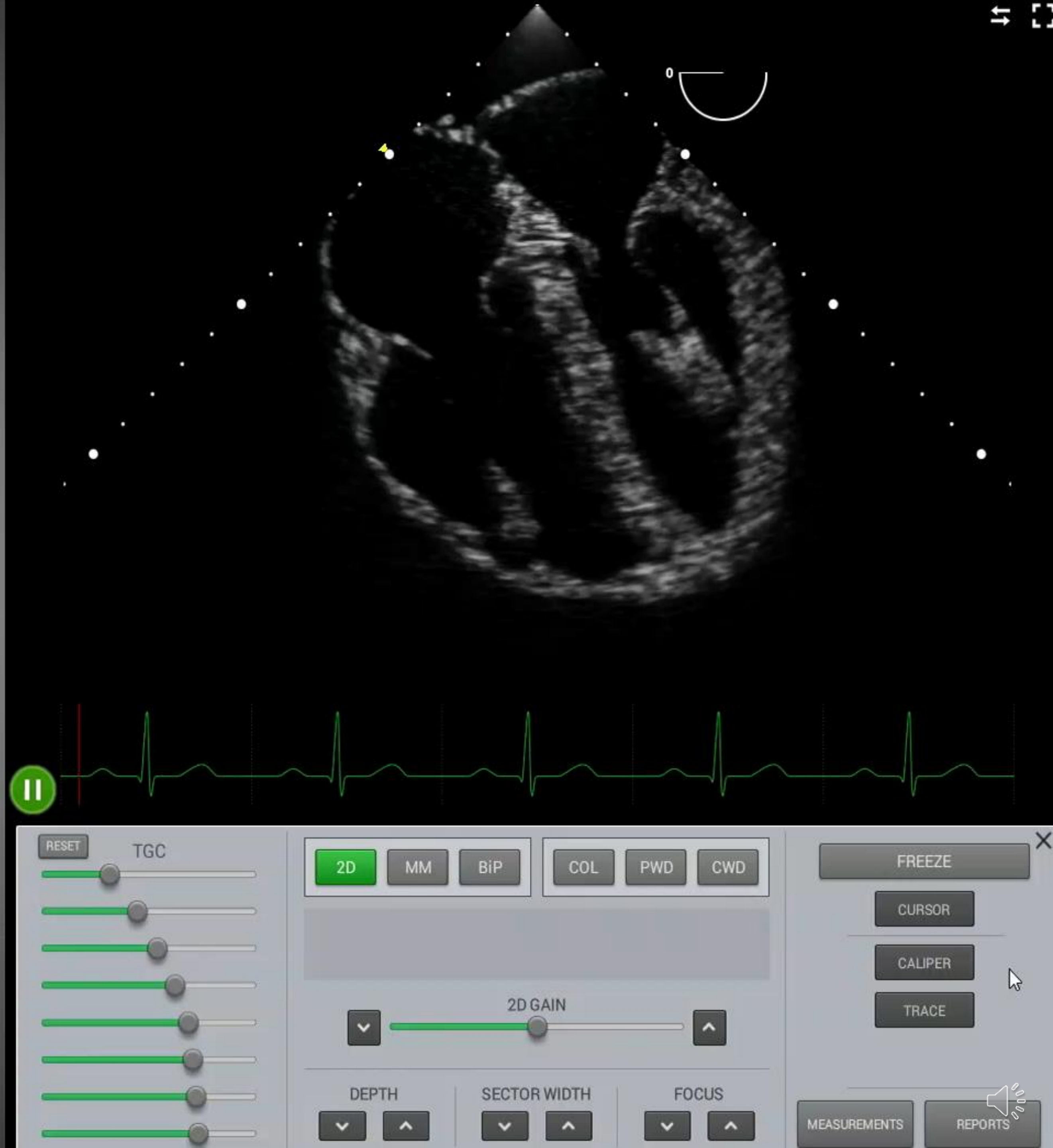


Septal Wall Thickness



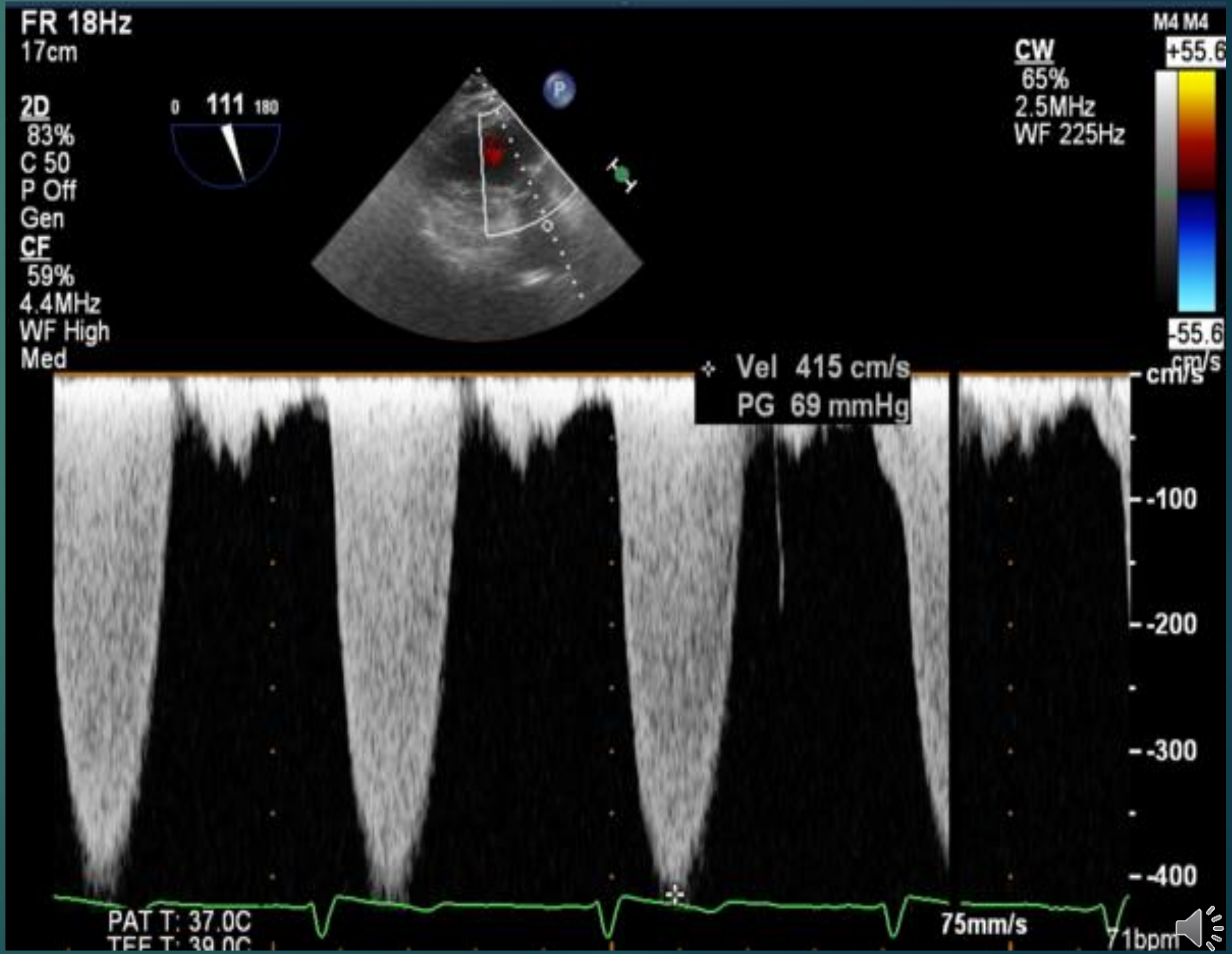
Right Ventricular Dimensions





Use of Doppler to Plot Velocity and Velocity Over Time

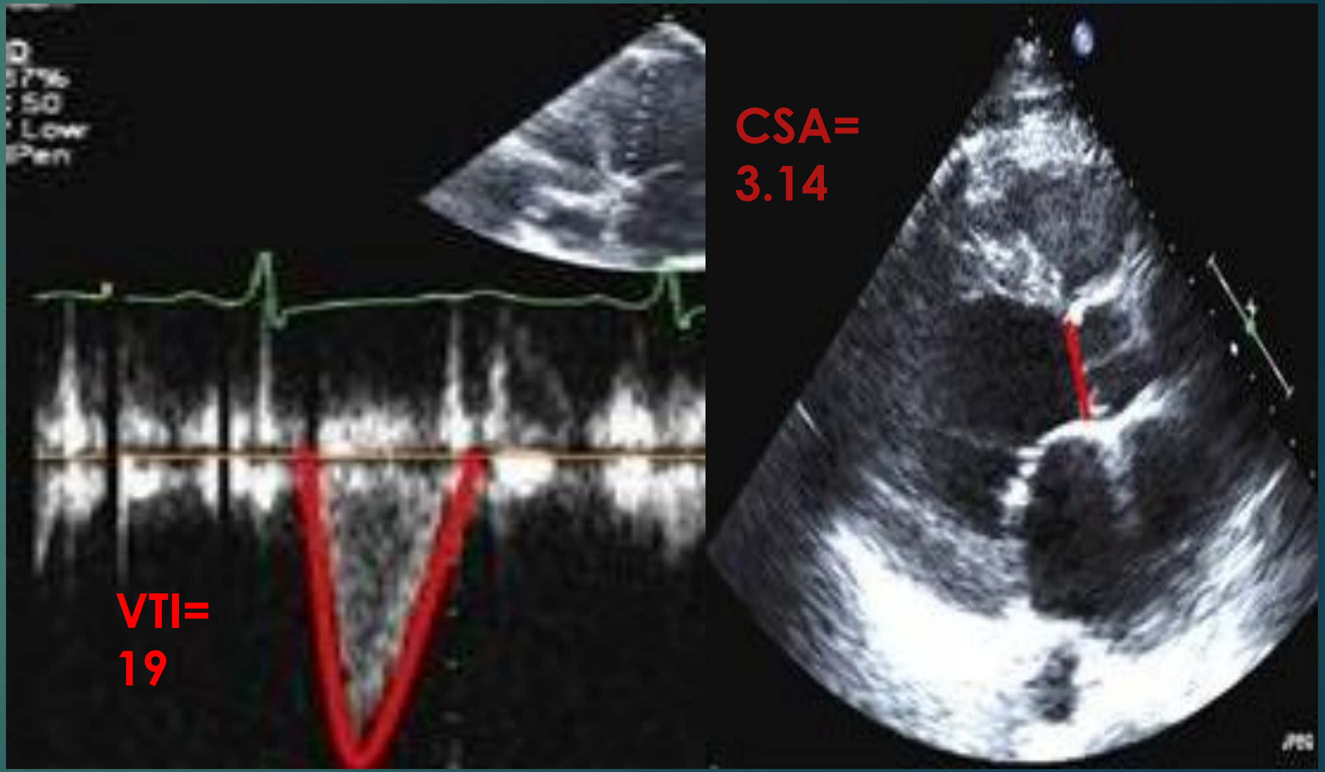
- Flow towards and away from the transducer is plotted as velocity
  - *Pulse wave* Doppler measures flow in a specific sample
  - *Continuous wave* Doppler measures all flow along a line
- Velocity is used to calculate gradients and regurgitant flow
- Velocity may be plotted over time (VTI) to calculate cardiac output and PASP



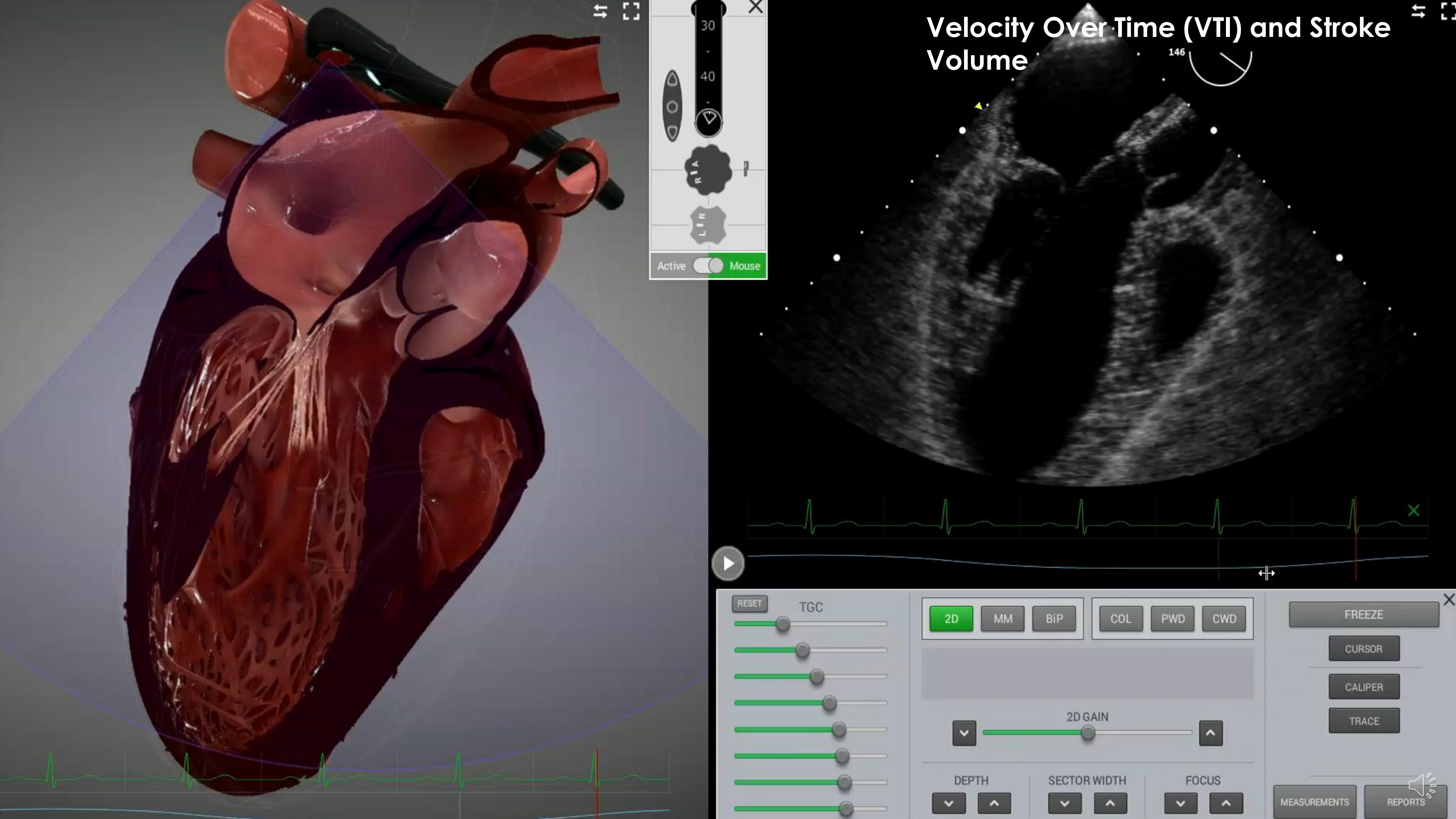
Velocity and
Velocity Over Time (VTI)

Measurement of Intracardiac Flows

- Doppler allows estimation of intracardiac flows including pulmonary artery and cardiac output
- Flow can be measured over time by measuring VTI and CSA
- VTI is measured with CW doppler
- Cross sectional area is measured by (diameter^2 x 0.785)
- SV=VTI x CSA=57 ml

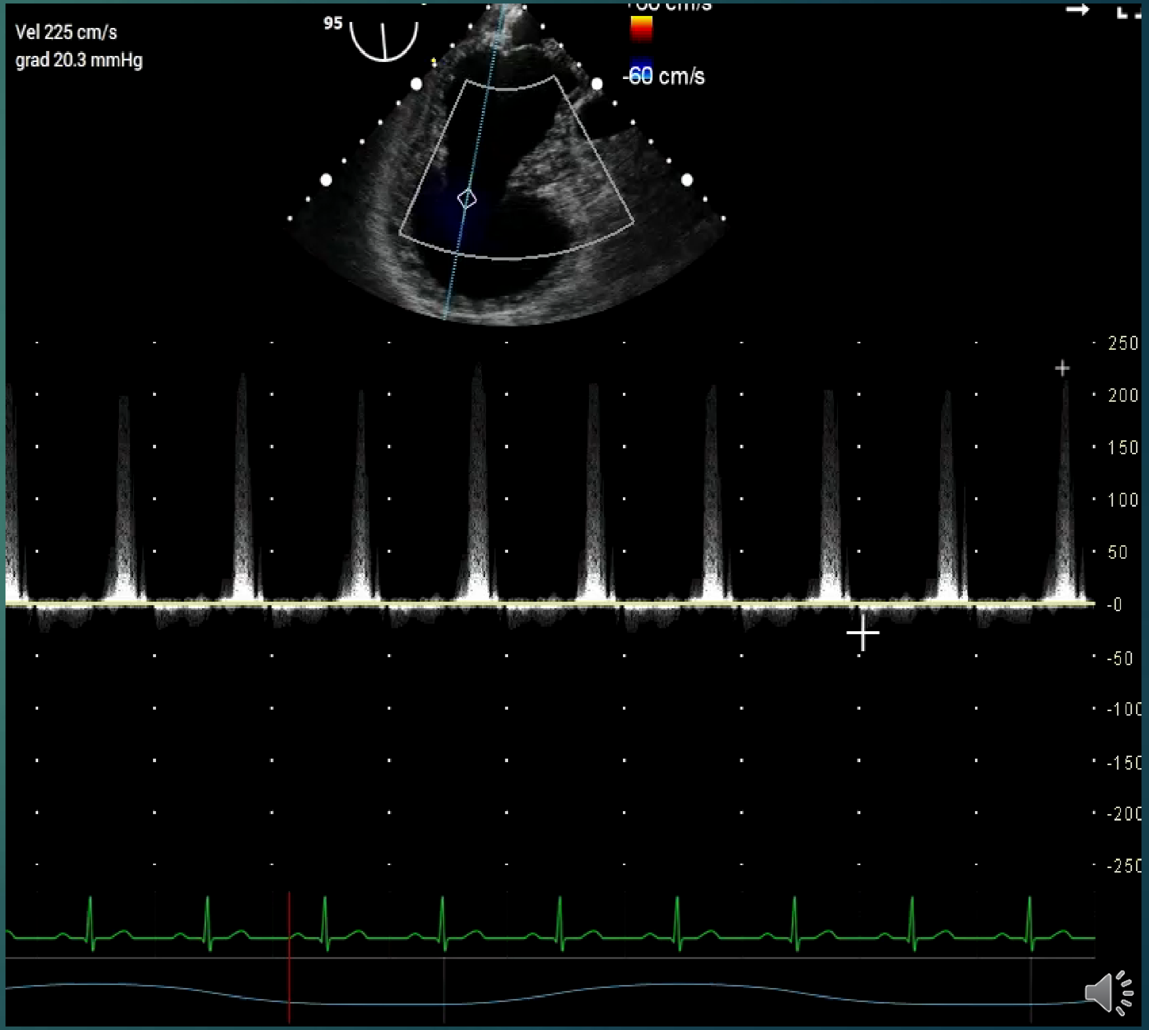


Velocity Over Time (VTI) and Stroke Volume



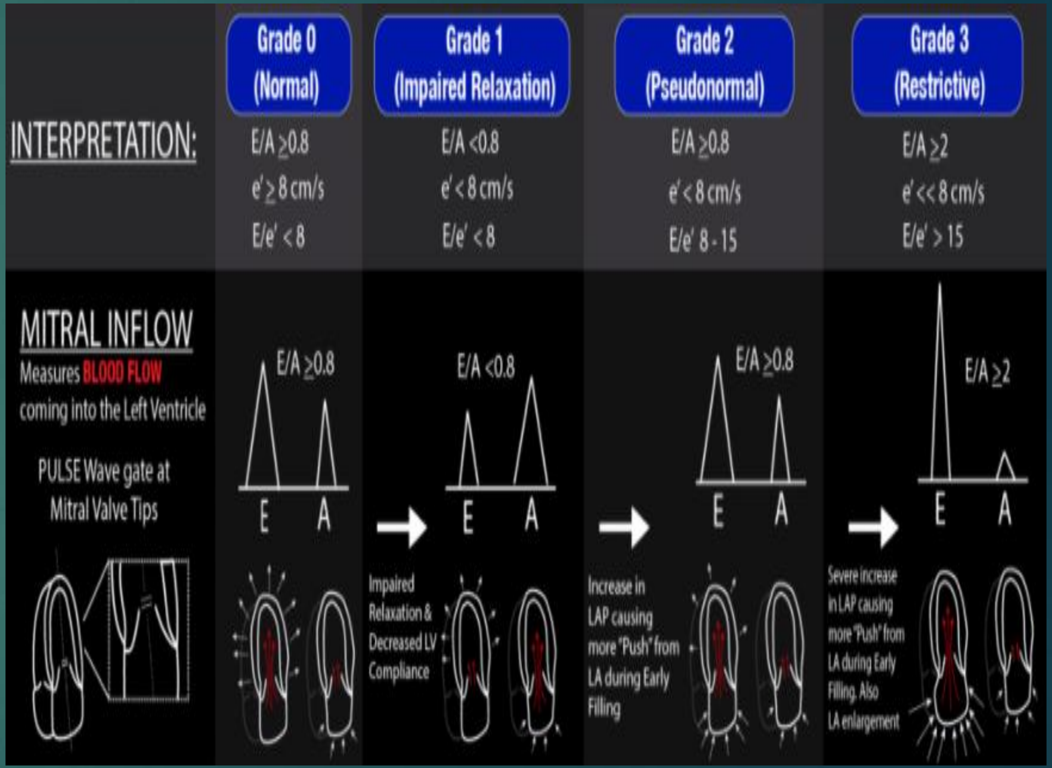
Calculating Pulmonary Artery Systolic Pressure (PASP)

- Doppler of TR jet measures maximum velocity (V_{max})
- CVP is obtained
- Peak gradient across the valve is calculated using modified Bernoulli equation ($4 \times v_{max}^2$)
- PASP=CVP + peak gradient
- For CVP 12, max TR velocity 2.3 m/s,
- PASP=12 + (4×2.3^2)=**33 mmHg**



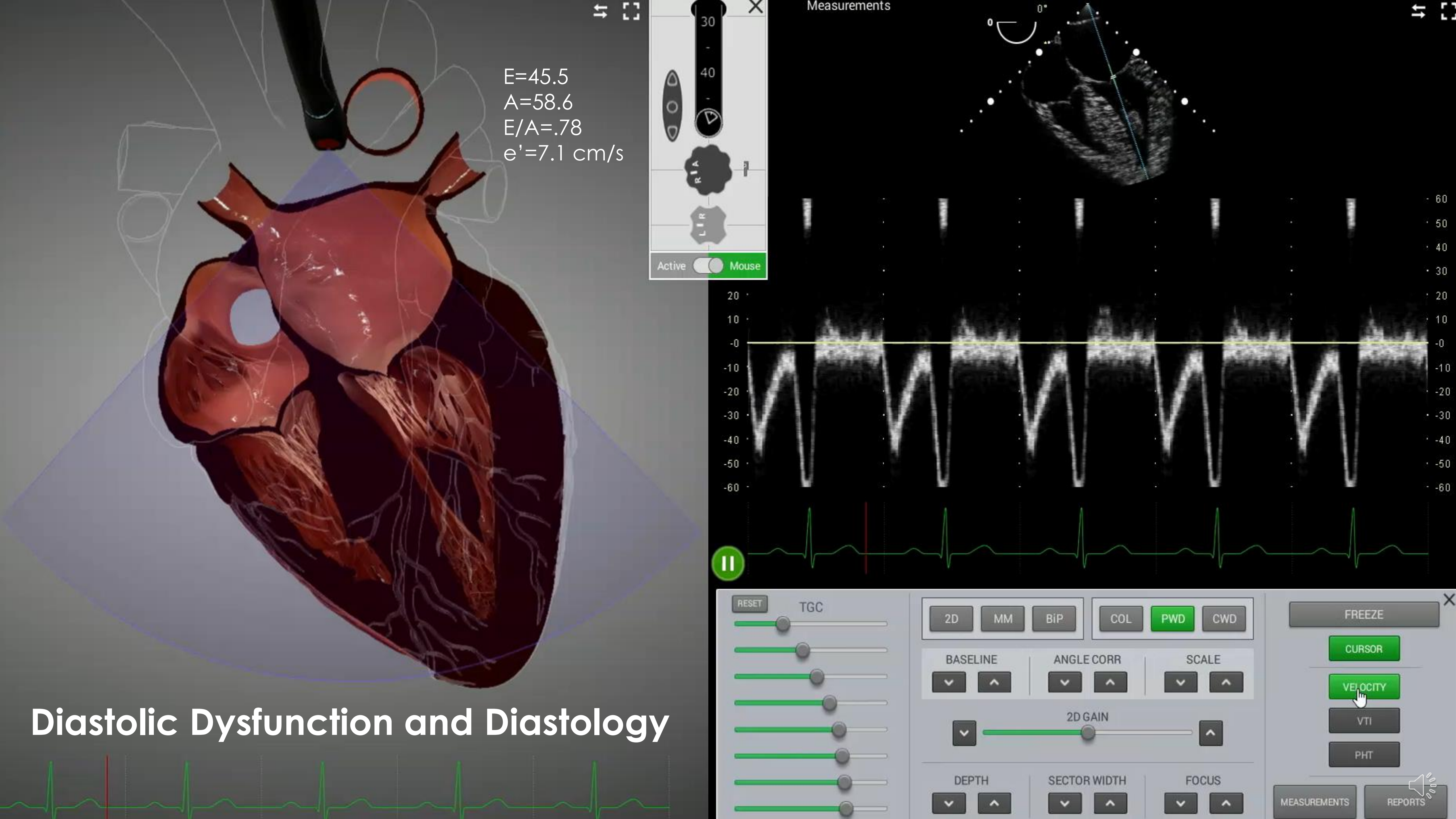
Assessing Diastolic Function

- 38% of the time diastolic assessment is unsuccessful or inaccurate
- E:A ratio is simple yet less than precise
- Tissue Doppler Imaging necessary to make true diagnosis
- Regardless estimate of diastolic dysfunction may be possible
  - Normal: E/A > 0.8, e' > 8 cm/s
  - Grade 1 (Impaired): E/A < 0.8, e' < 8 cm/s
  - Grade 2 (Pseudonormal): E/A > 0.8 with
  - Grade 3 (Rerstrictive): E/A > 2, e' < 8 cm/s



Swaminathan et al. Utility of a Simple Algorithm to Grade Diastolic Dysfunction and Predict Outcome After Coronary Artery Bypass Graft Surgery. Ann Thorac Surg, 2011;91:1844 –1851

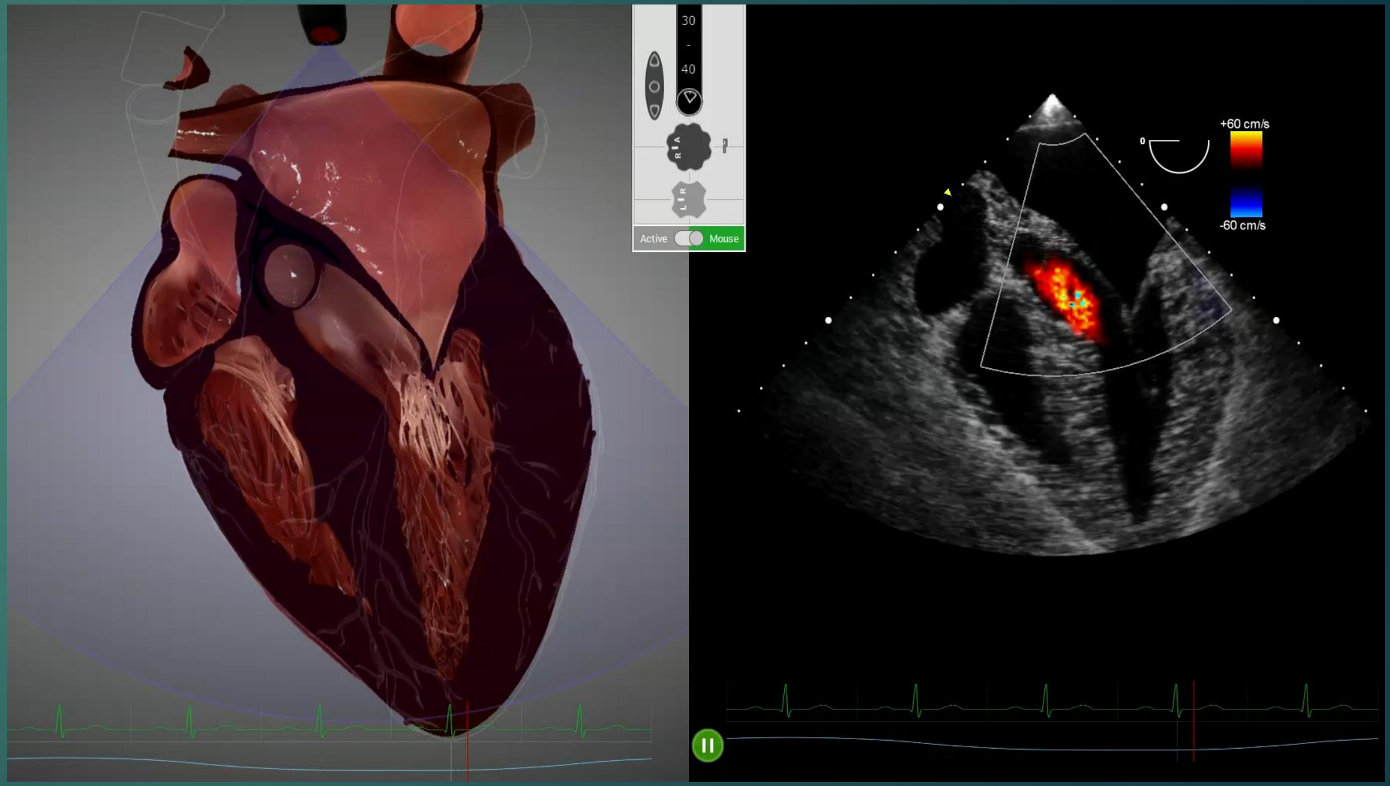
E=45.5
A=58.6
E/A=.78
e'=7.1 cm/s



Diastolic Dysfunction and Diastology

Assessing Ventricular and Valvular Pathology

- Qualitative assessment of ventricular and valvular pathology may be made with 2-D and color flow mapping
- Quantitative and semi-quantitative assessments may be made
  - Volumetric (EF, FAC)
  - Continuous and pulse wave doppler
  - Tissue velocity (Tissue Doppler Imaging)
  - Real-time 3-D TEE

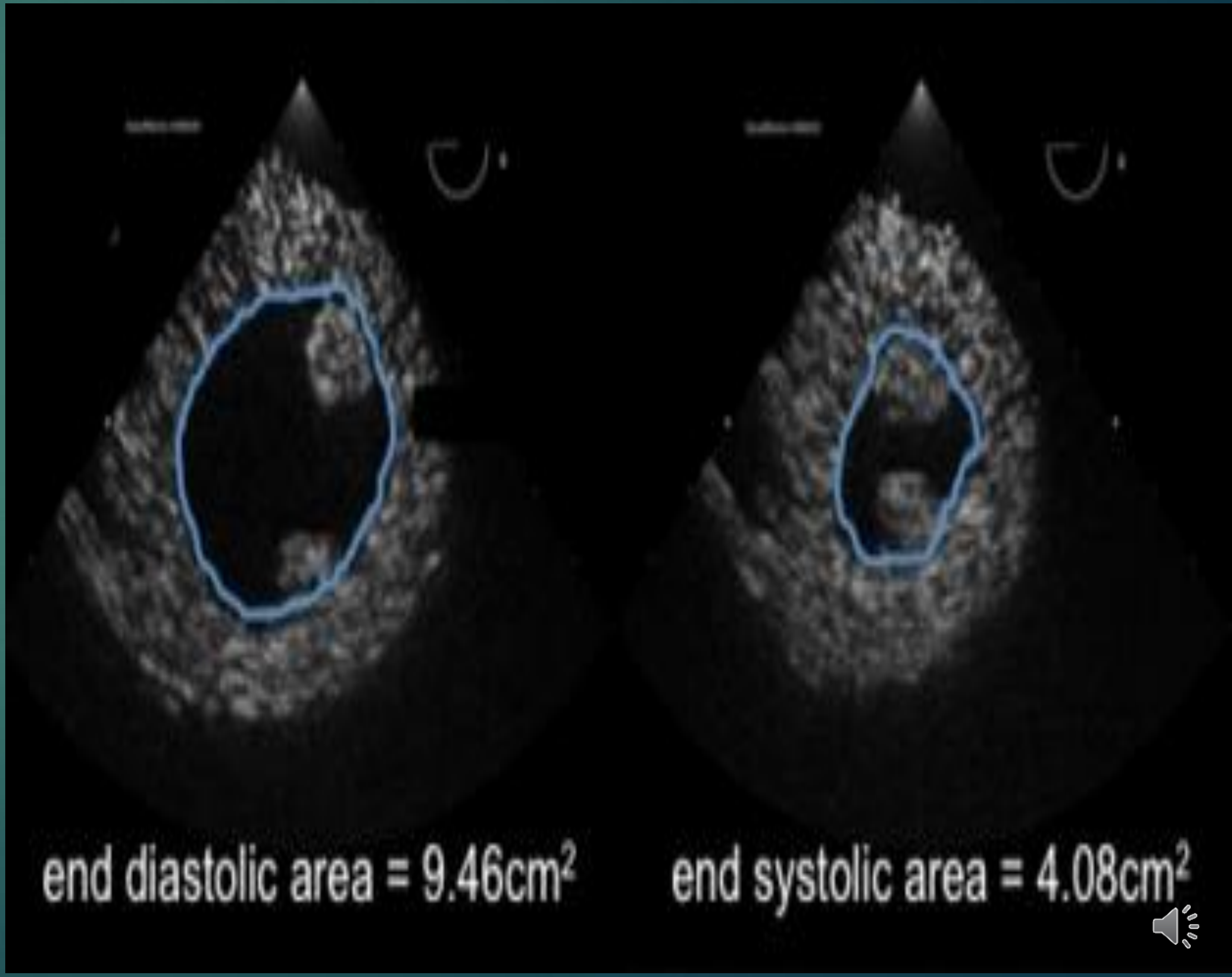


Calculating Ejection Fraction by Fractional Area Change (FAC)

- Ejection Fraction may be calculated by "eyeball EF" or formula
- Ejection Fraction=

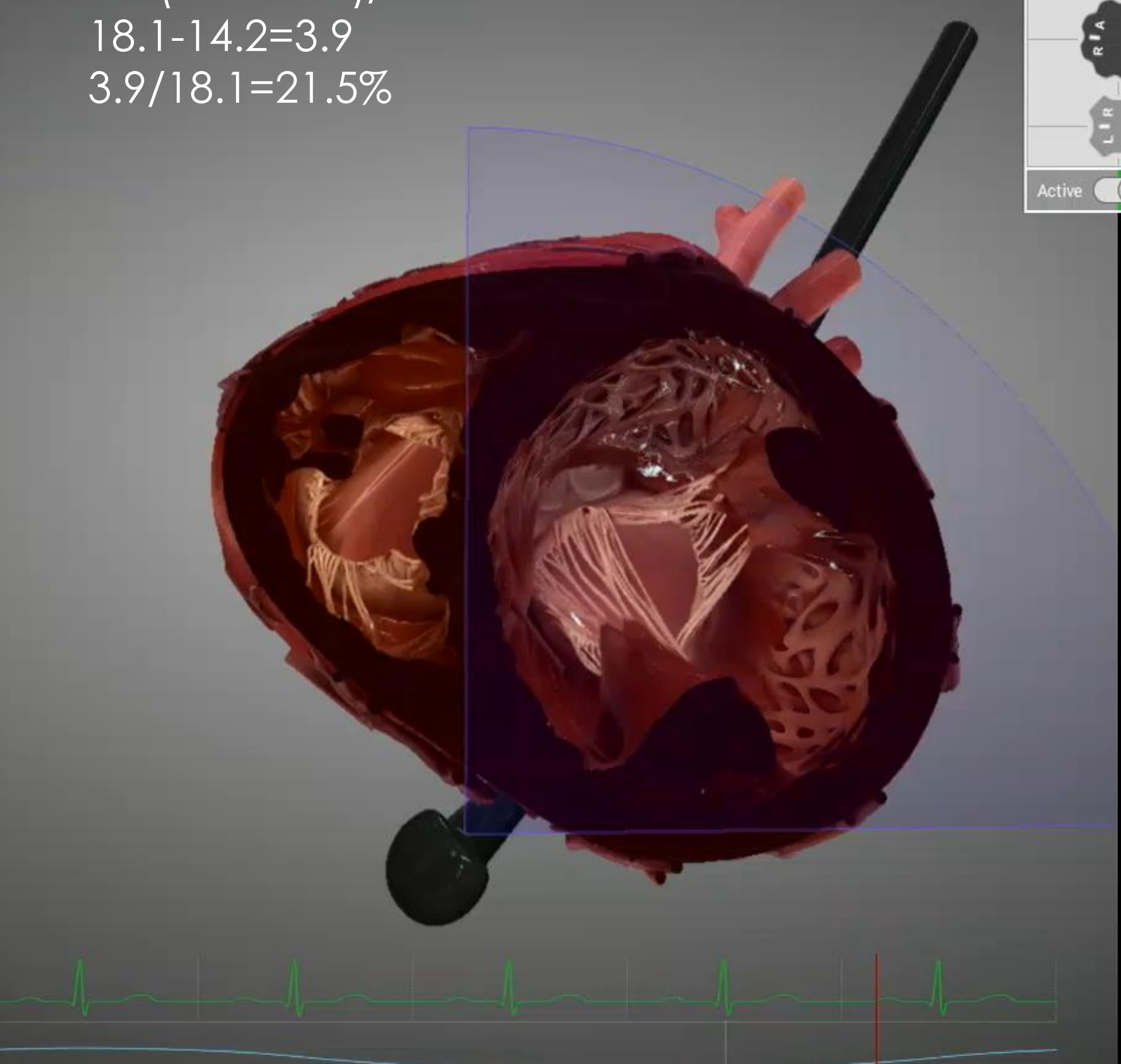
$$\frac{\text{End-diastolic area minus end-systolic area}}{\text{End-diastolic area}}$$

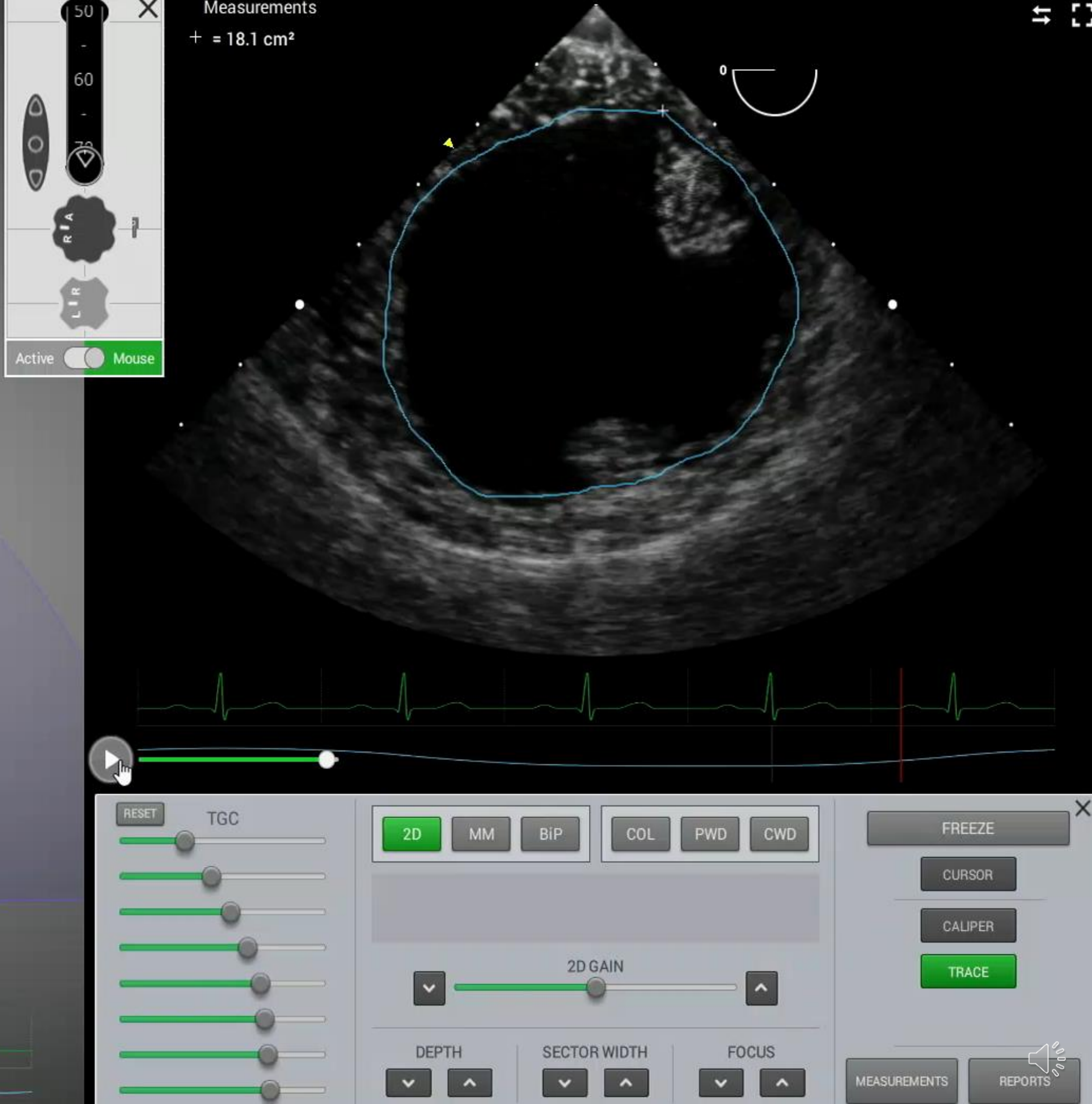
- EF=(EDA-ESA)/EDA
- EF=(9.46-4.08)/9.46=**57%**



Left Ventricular Function

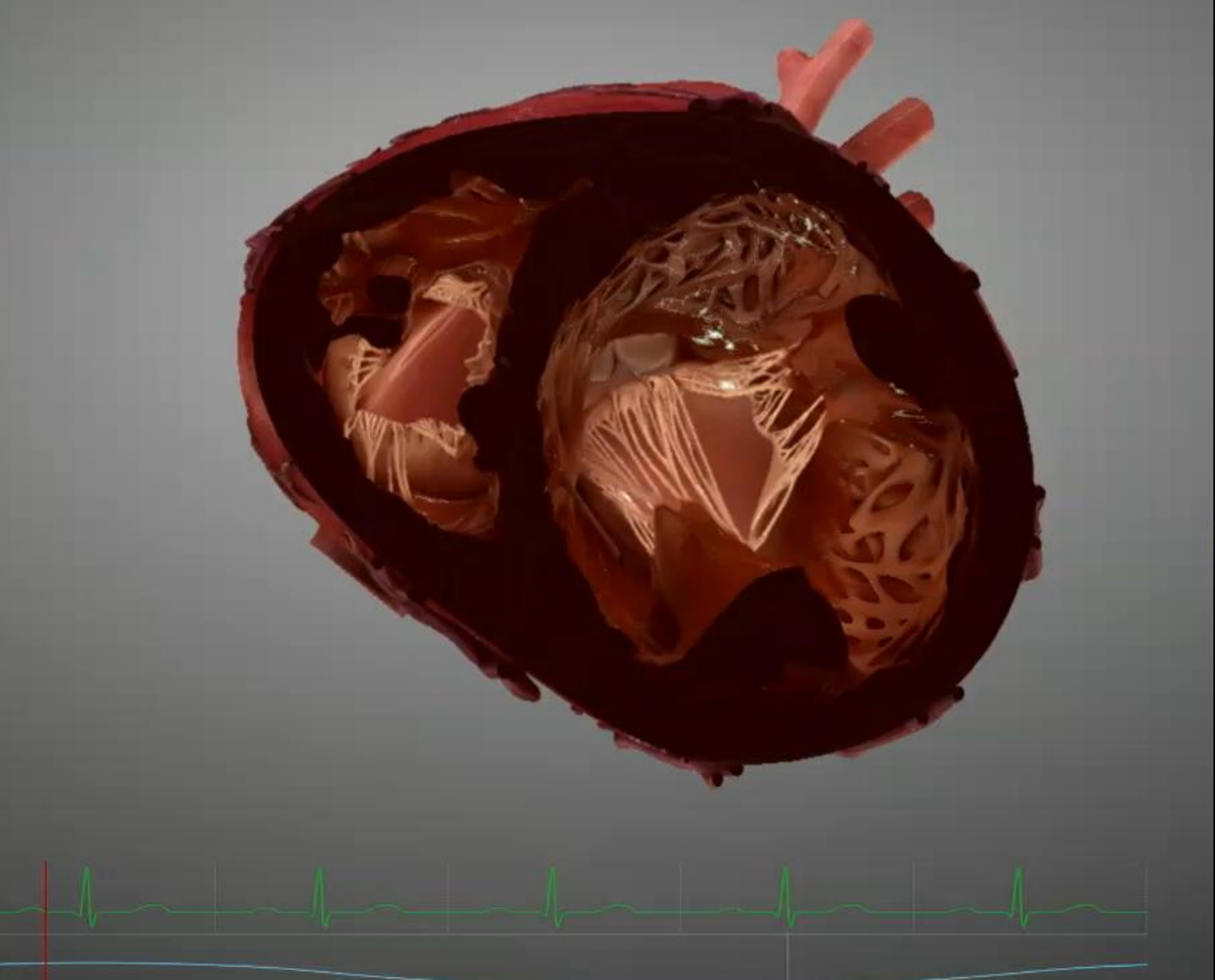
EF=(EDA-ESA)/EDA
18.1-14.2=3.9
3.9/18.1=21.5%

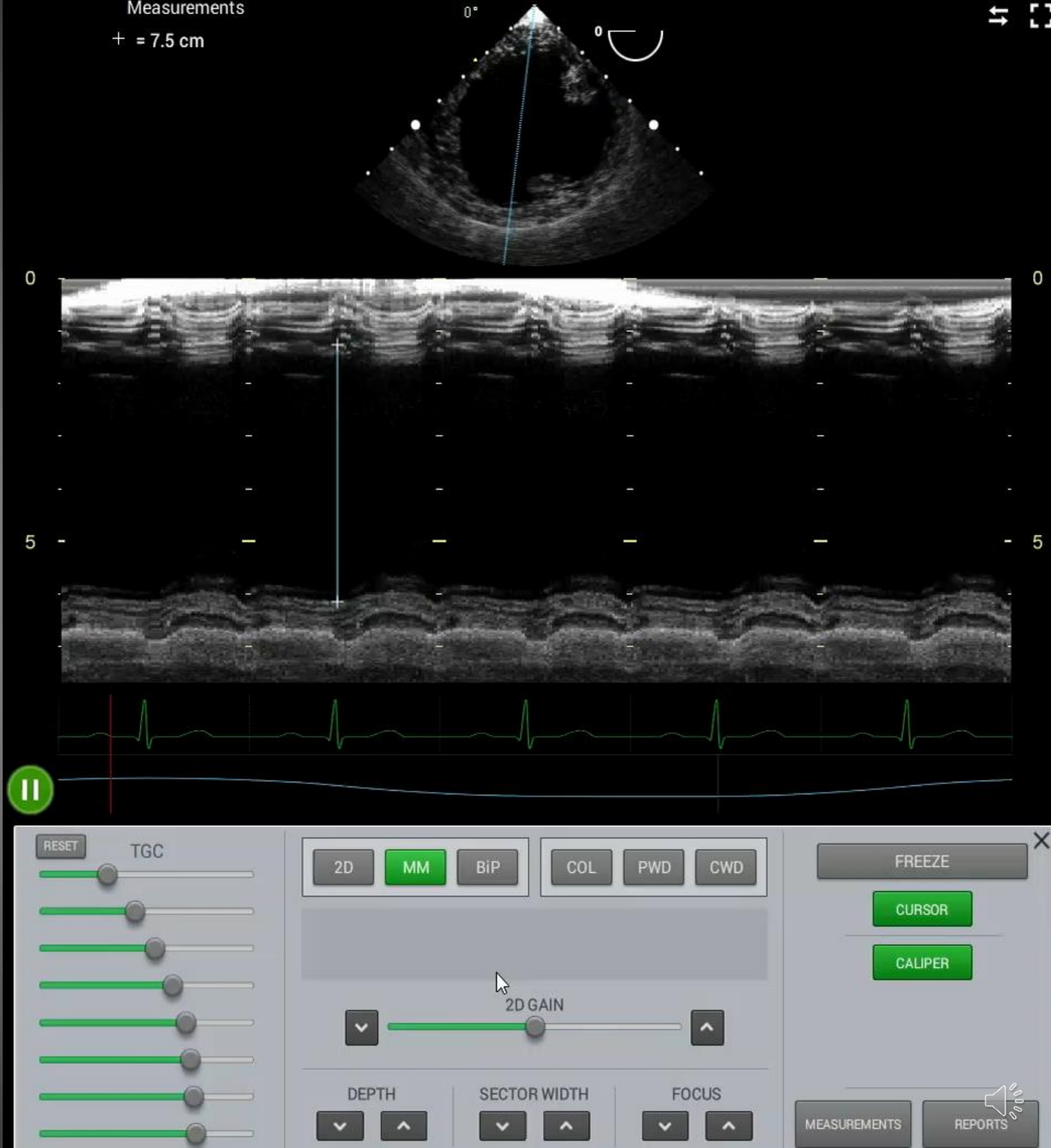




Left Ventricular Function with M-Mode

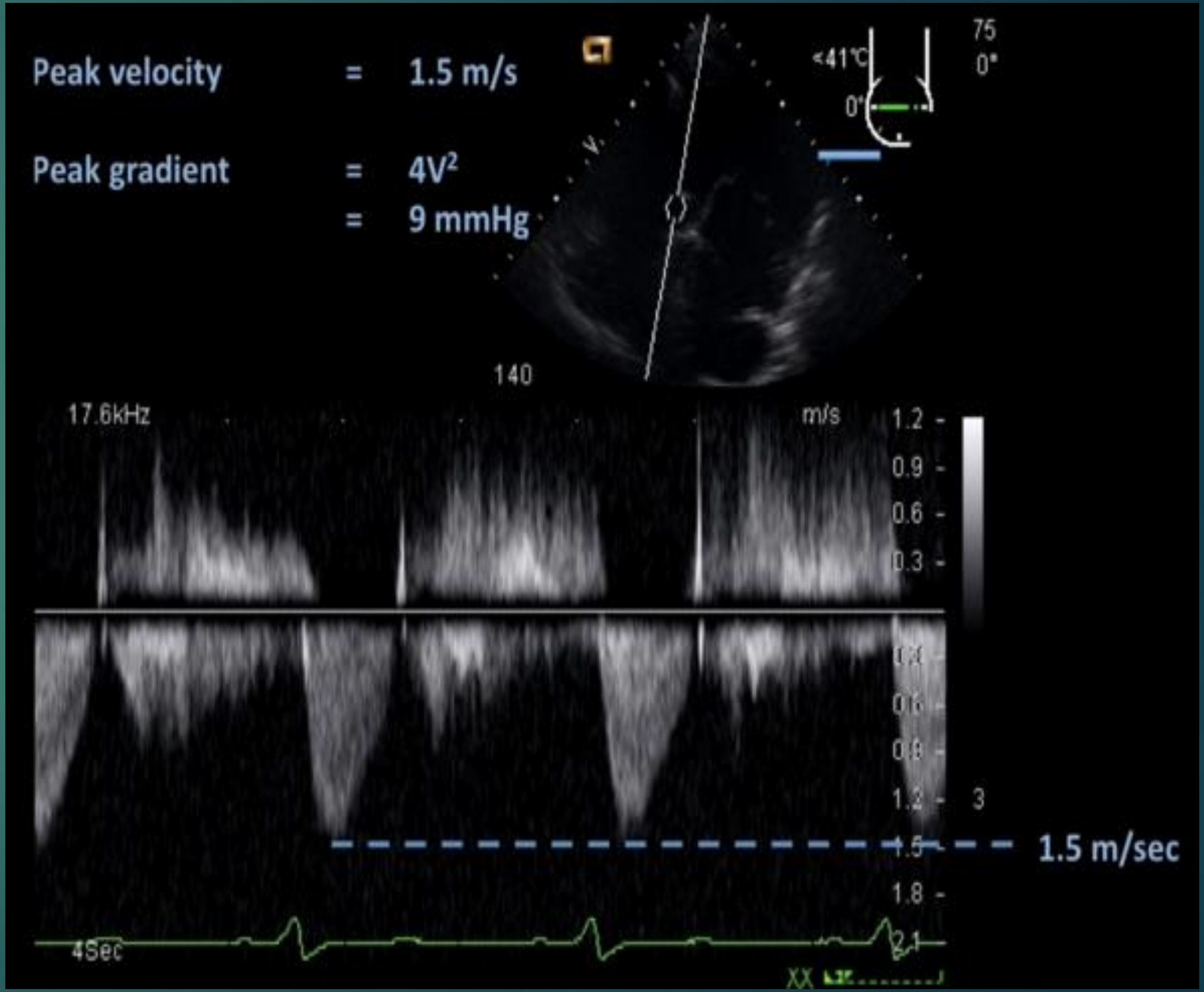
7.5-6.2=1.3
1.3/7.5=17.3%





Calculating Valve Gradients

- Pressure drop across an orifice may be calculated using the modified Bernoulli equation
  - Gradient=$4(V)^2$
  - “V” is the velocity across the orifice
- Gradient across a valve is calculated and degree of stenosis assessed

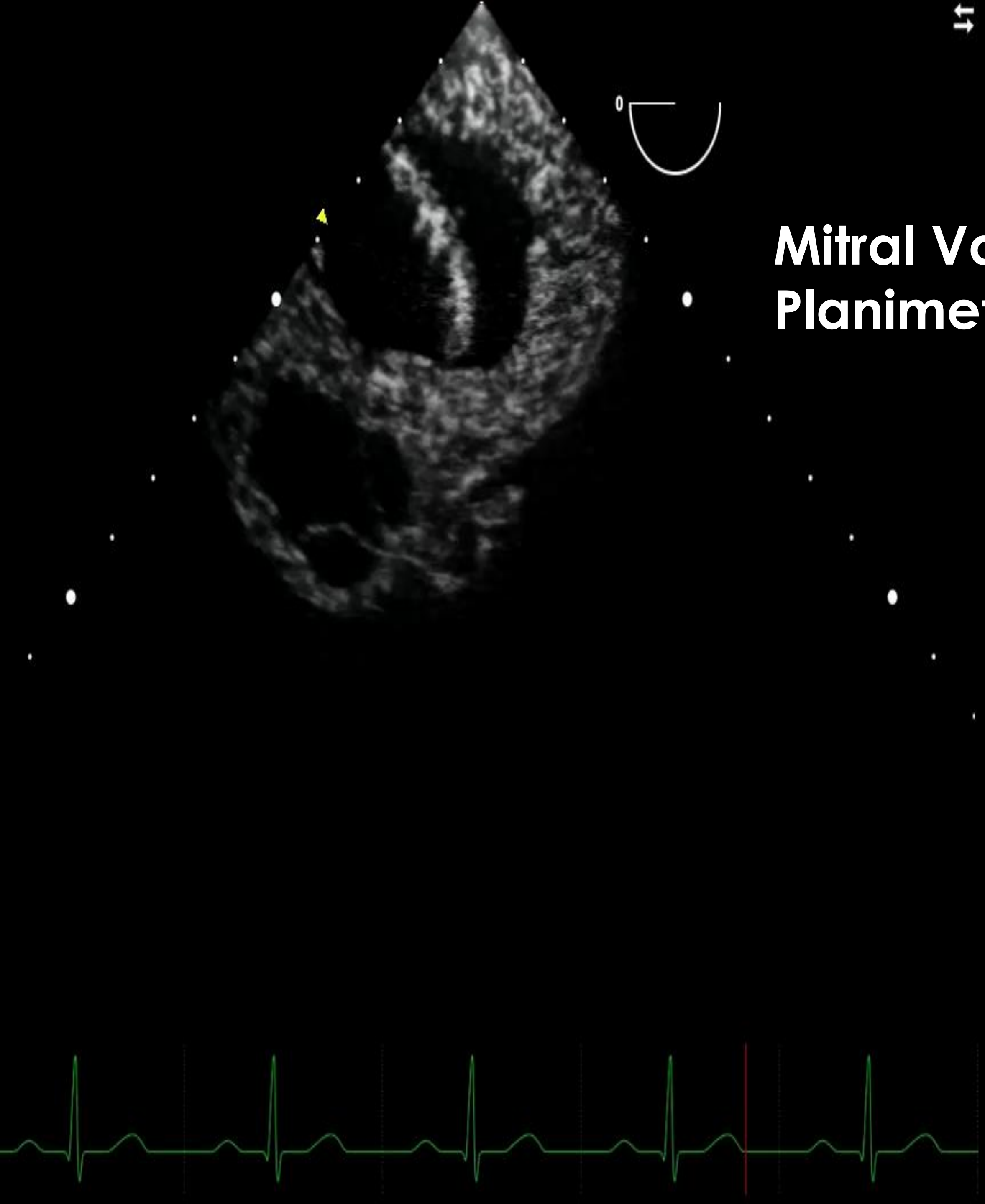


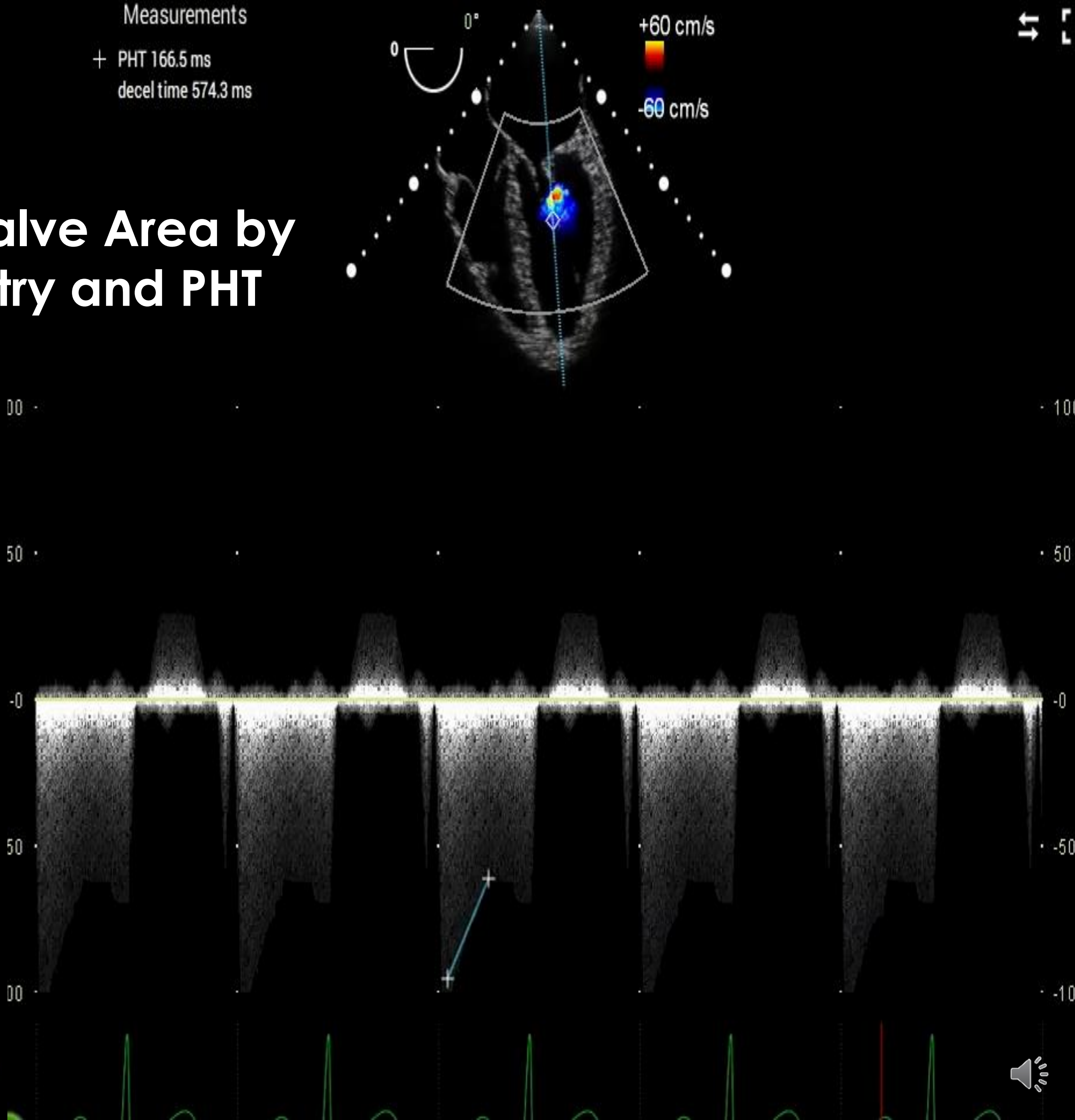
Gradient=4 x (1.5 m/s)^2=**9 mmHg**

Calculating Valve Gradients

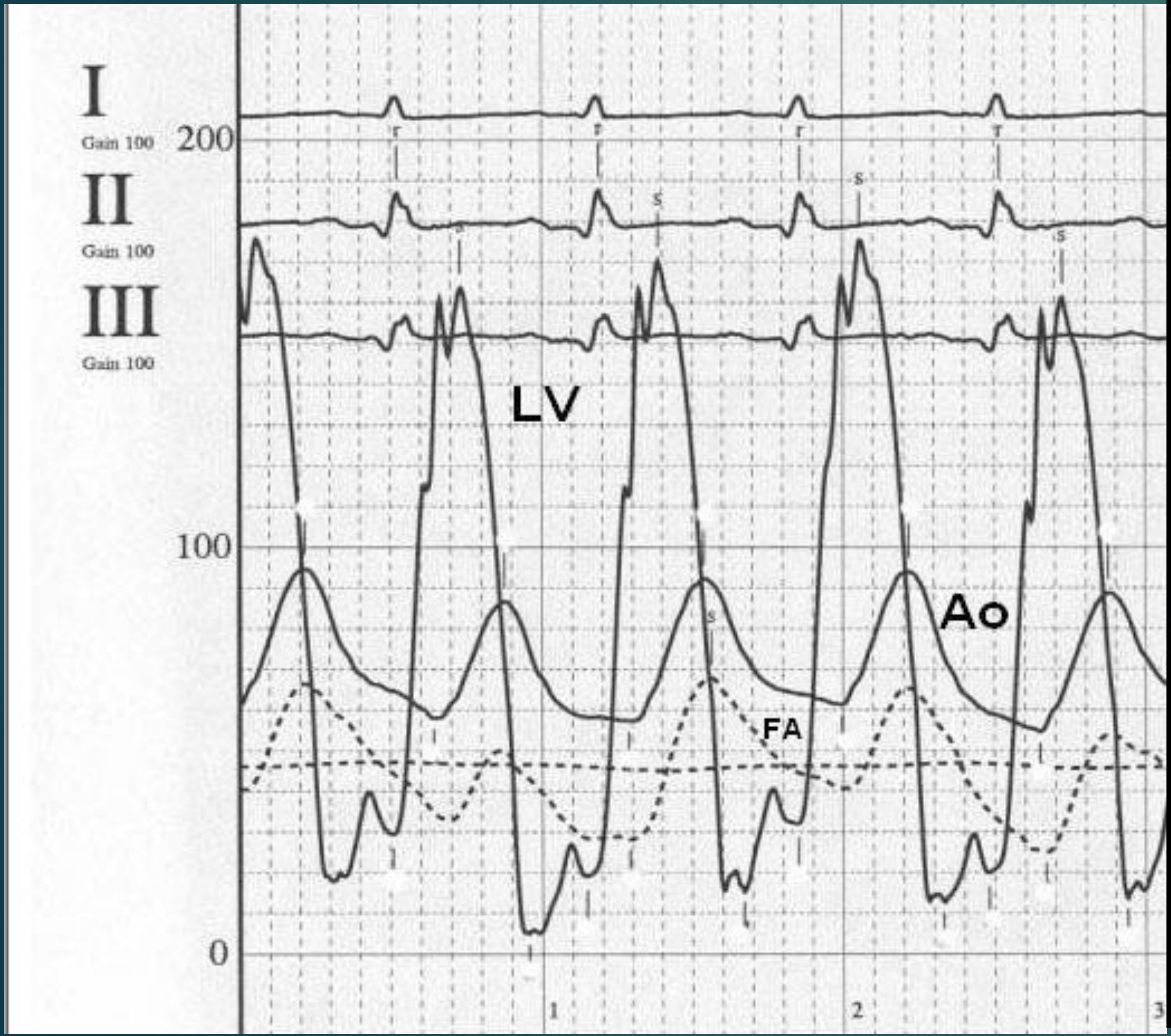
- Pressure drop across an orifice may be calculated using the modified Bernoulli equation
  - Gradient=$4(V)^2$
  - "V" is the velocity across the orifice
- Gradient across a valve is calculated and degree of stenosis assessed

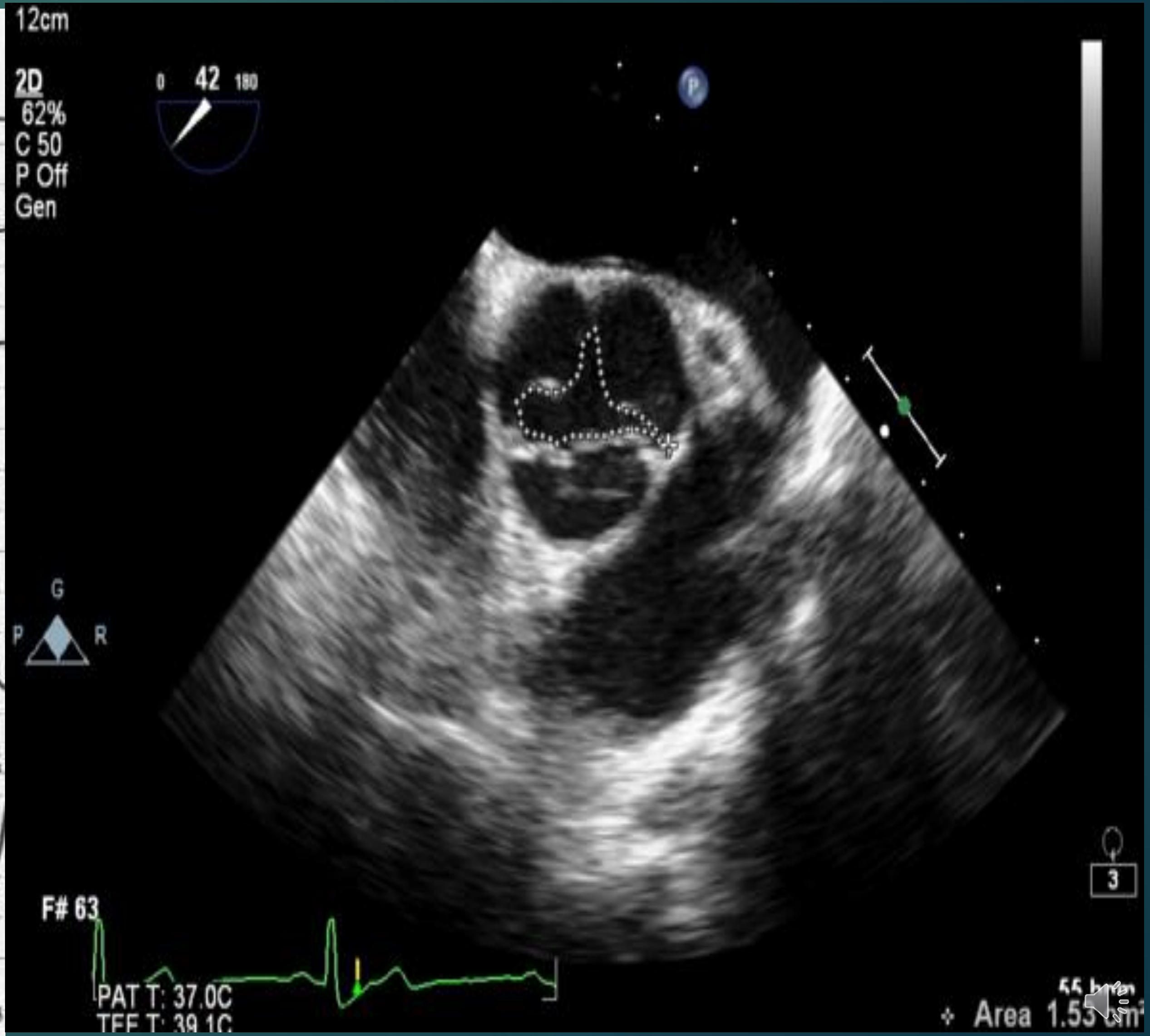
Mitral Valve Area by Planimetry and PHT





Conventional Aortic Stenosis Assessment

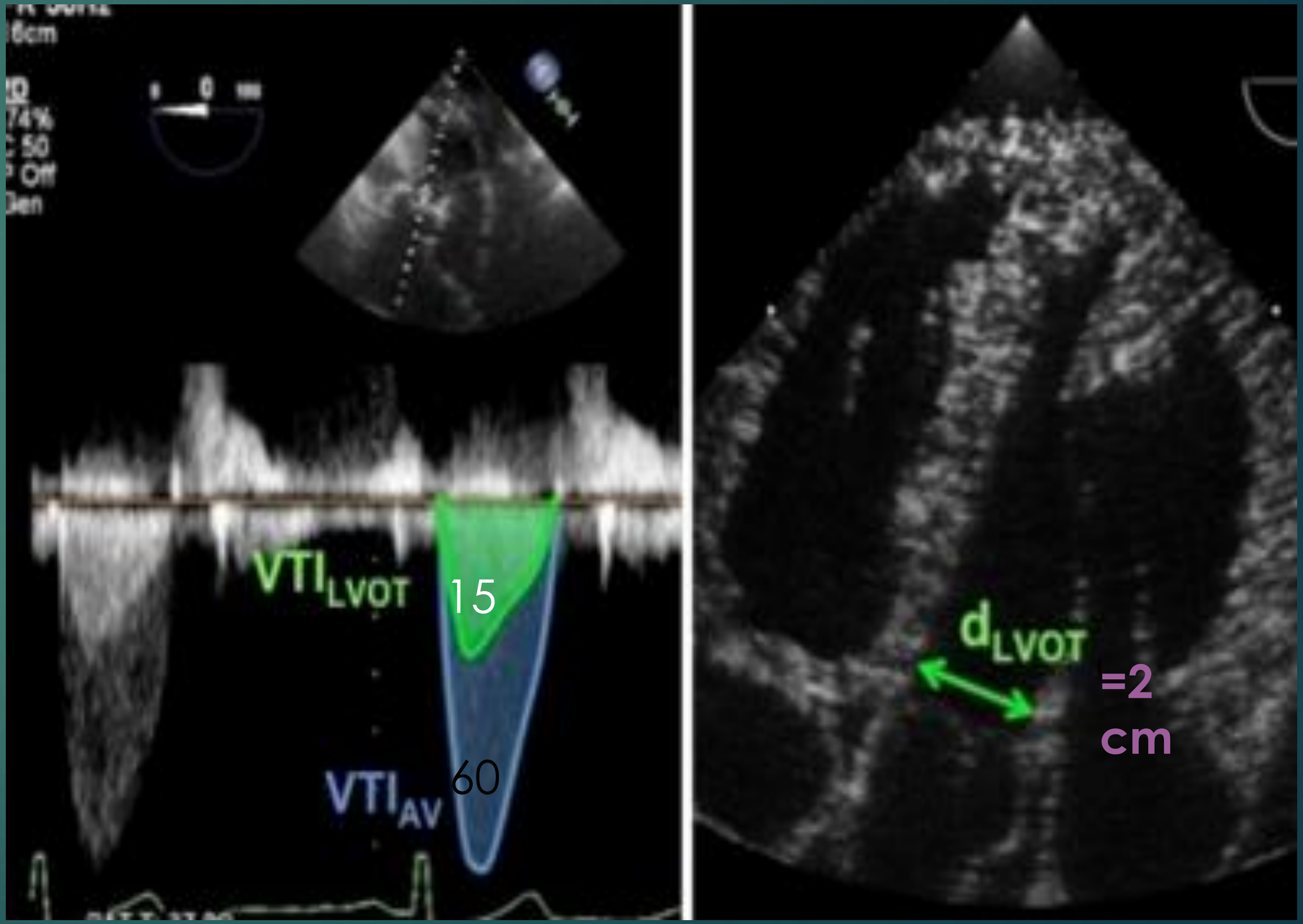




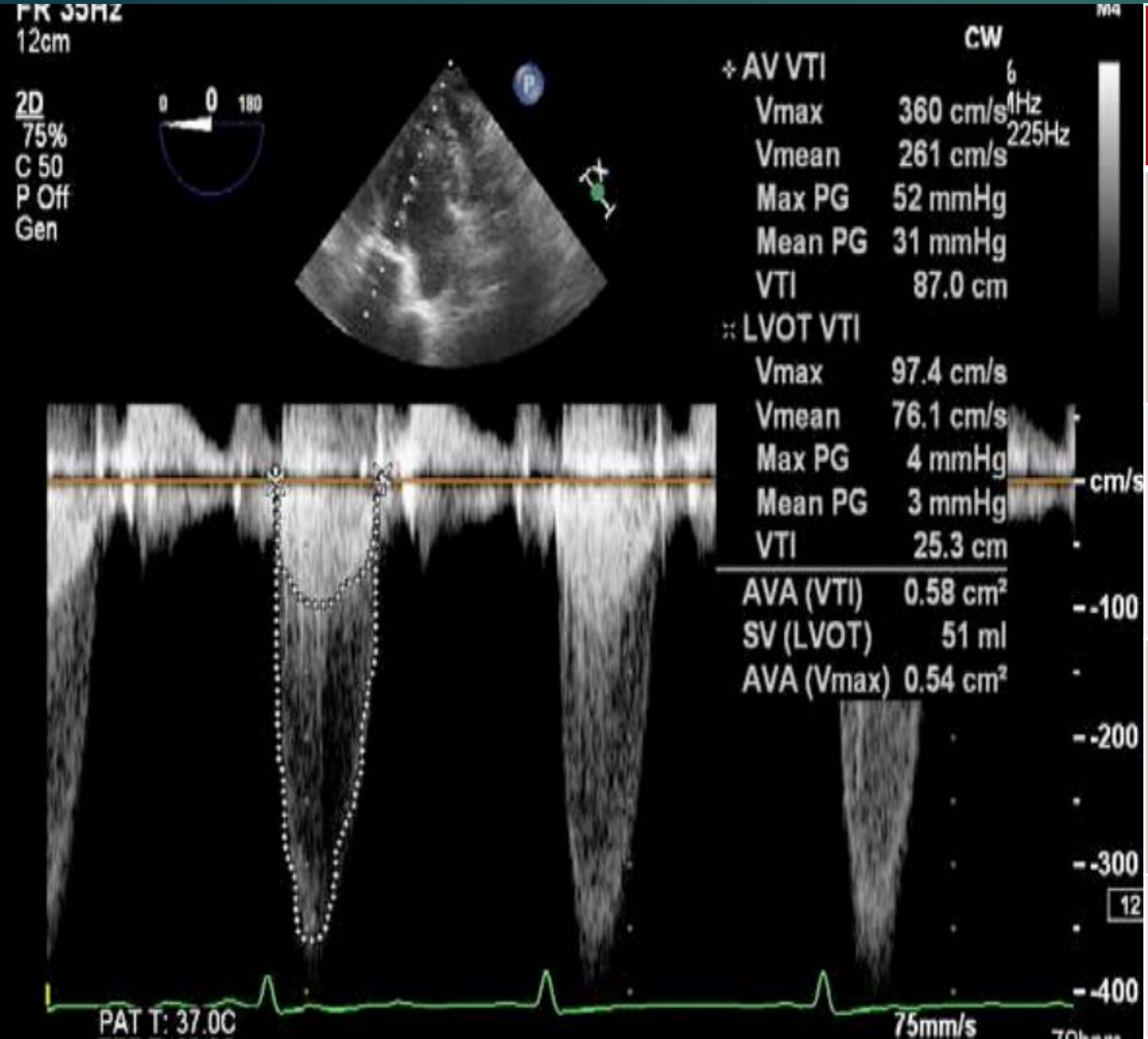
Calculating Valve Area Using the Continuity Equation

- To assess aortic valve area:
  - Cross section LVOT=

    $\pi \; x \; radius^2$ =3.14 cm
  - VTI LVOT = 15 cm/second
  - VTI Aortic Valve=60 cm/second
- CSA_{AV}=3.14 x (15/60)=0.79 cm
- **Aortic Valve Area = 0.79 cm (severe Aortic Stenosis)**



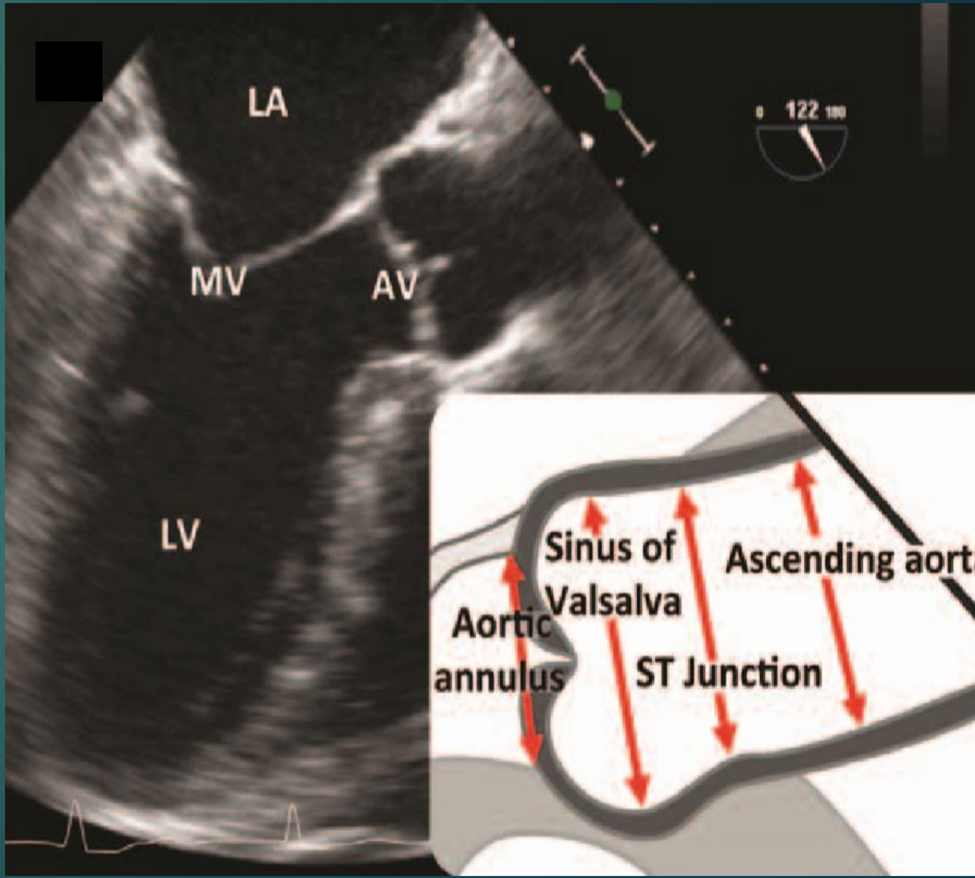
Aortic Stenosis Severity by TEE



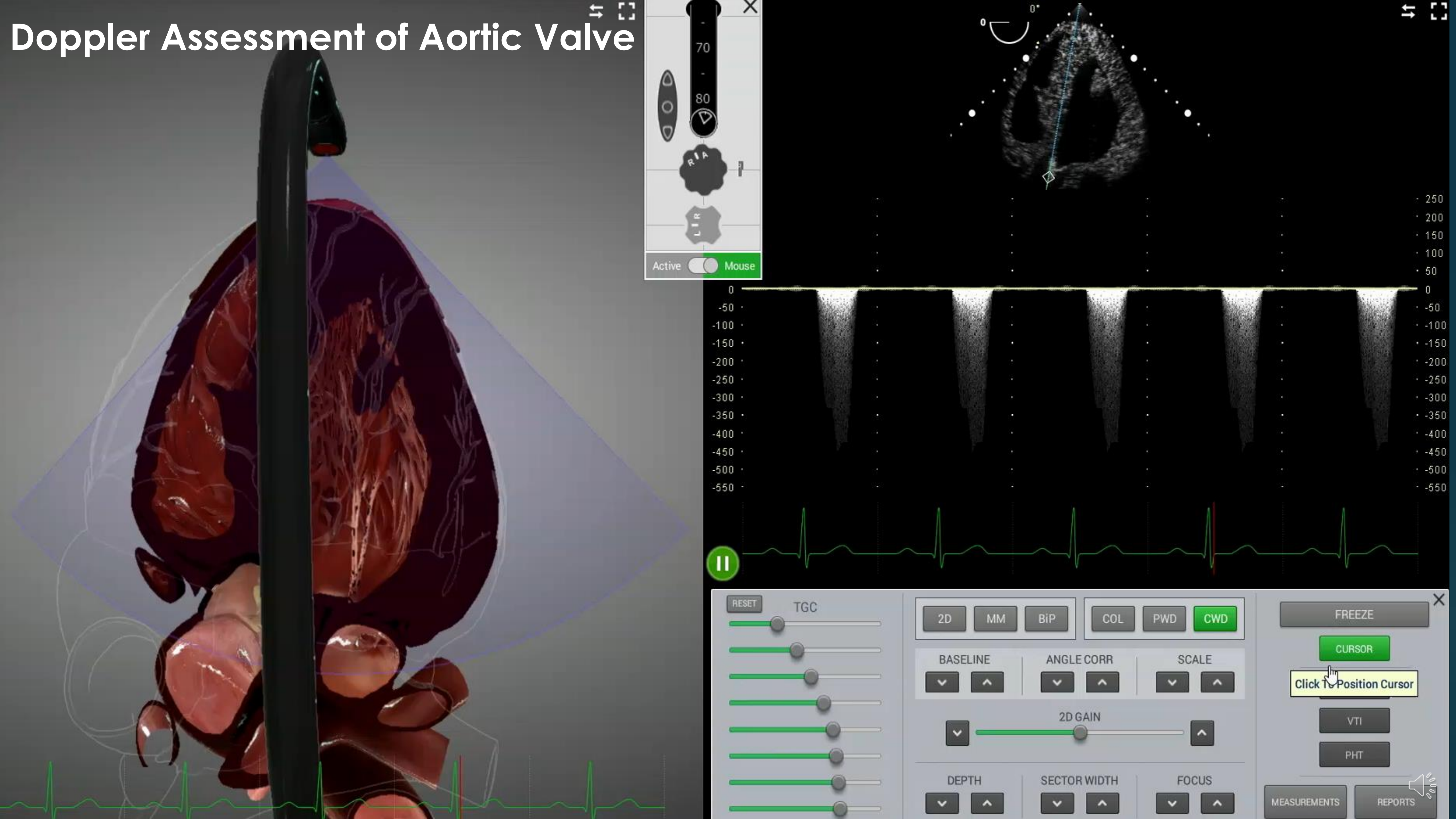
Parameter	Normal	Mild	Moderate	Severe
Peak Velocity (m/s)	1-1.5	<3	3-4	>4.0
Peak Gradient (mmHg)		<36	36-64	>64
Mean Gradient (mmHg)		<20	20-40	>40
AVA (cm^2)	2-4	>1.5	1.0-1.5	<1.0

Perioperative Role of TEE with Aortic Stenosis

- Measure aortic valve area using the continuity equation
- Measure gradient across the valve
- Measure annulus size for prosthetic valve
- Measure ascending aorta
- Assess for coexisting valve issues
- Assess biventricular function
- Assess for paravalvular leak and gradient after valve replacement

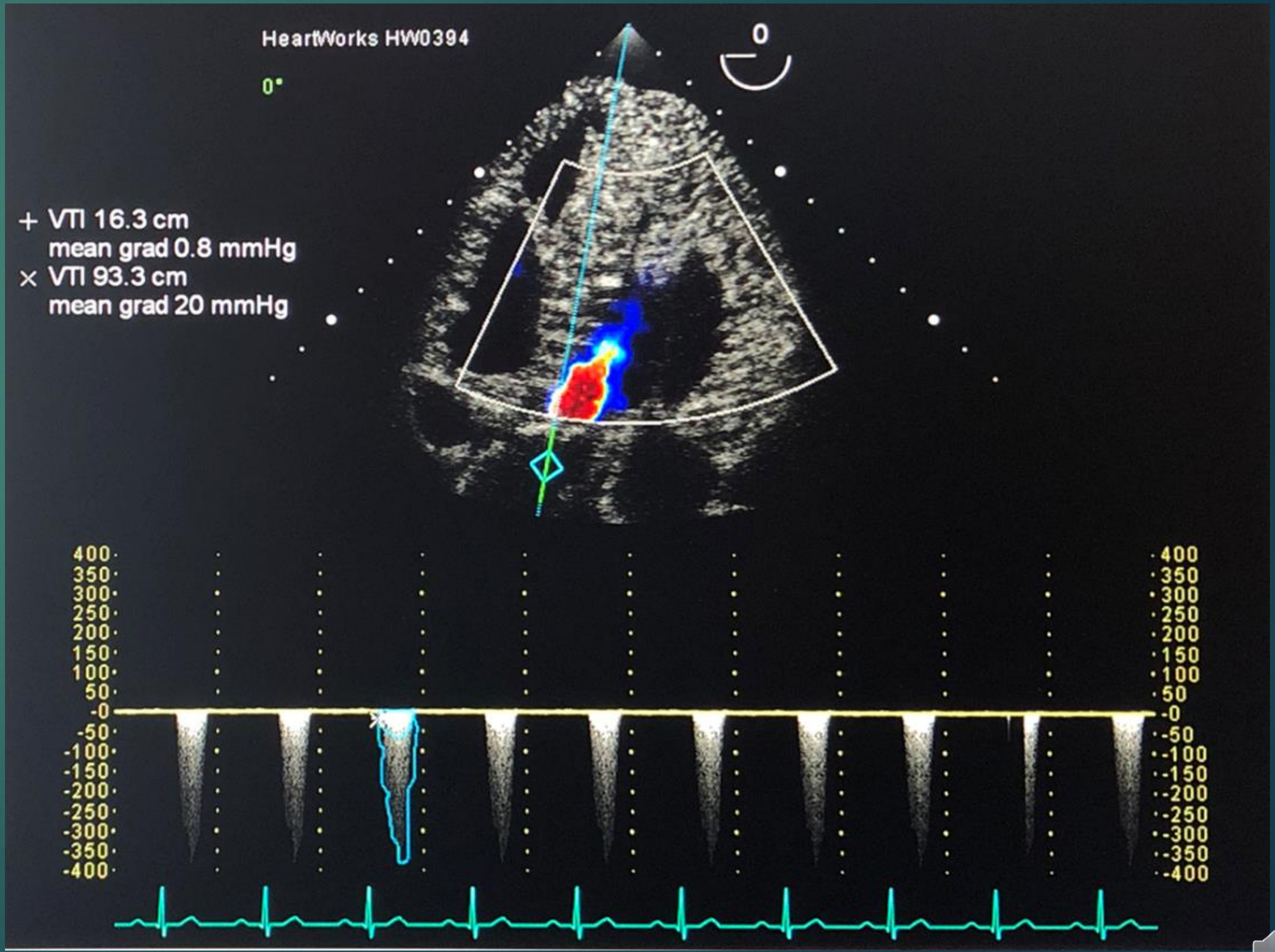


Doppler Assessment of Aortic Valve

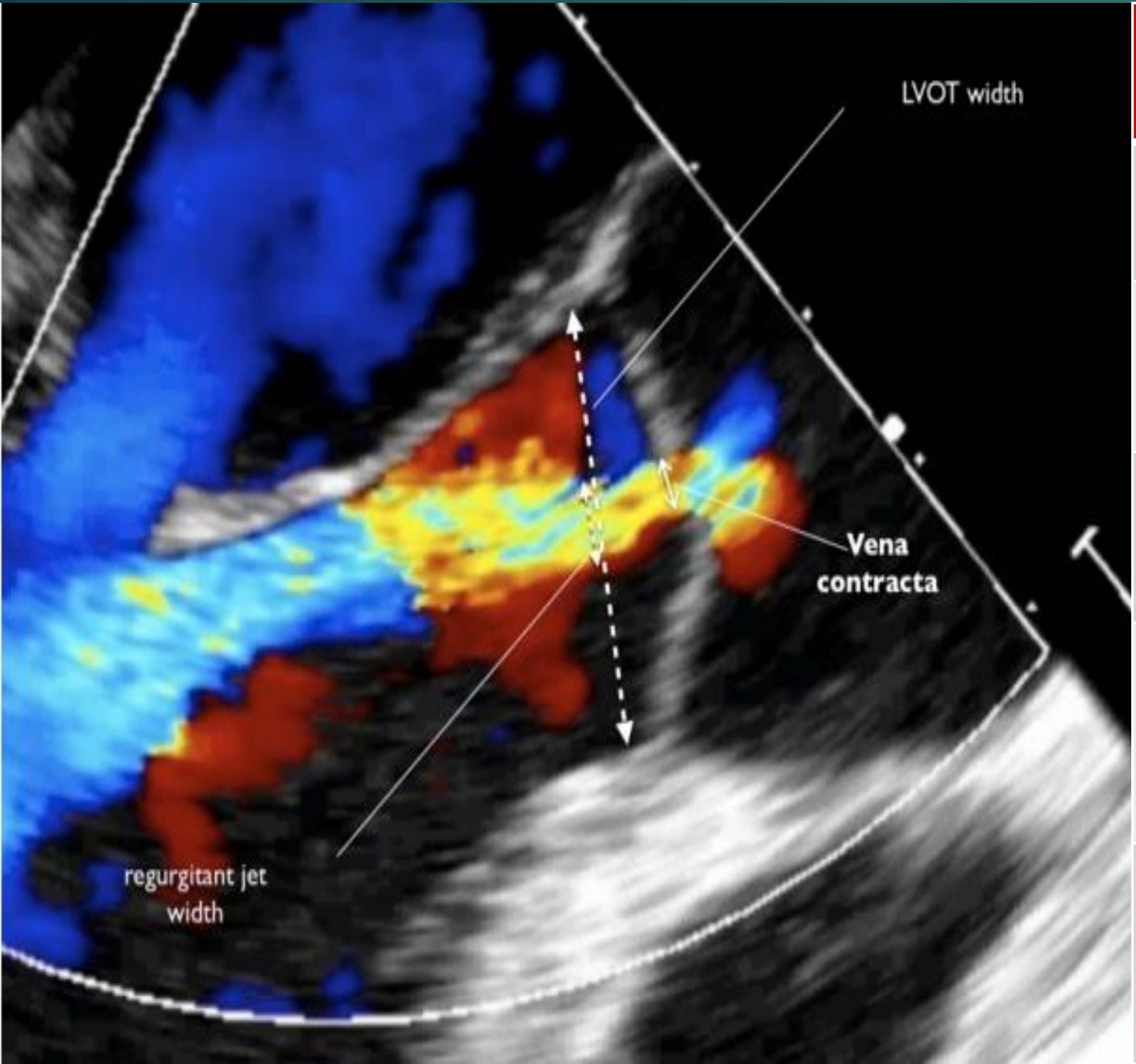


Results of Doppler Assessment of Aortic Valve

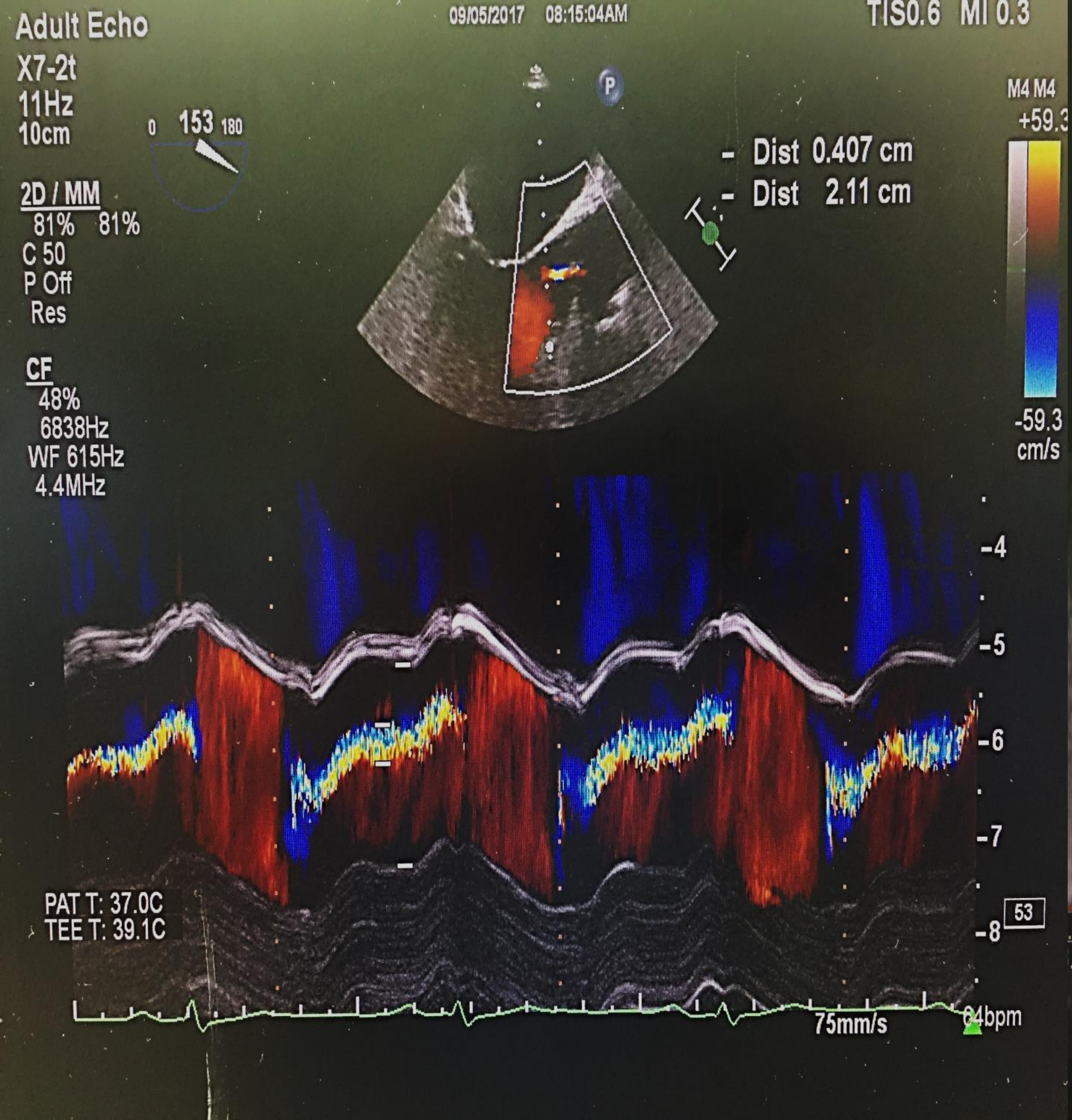
- Velocity of flow across aortic valve: 3.8 m/s
- Gradient across valve: 57 mmHg
- LVOT diameter: 1.8 cm
- VTI LVOT: 16.3 cm
- VTI AV: 93.3 cm
- Aortic valve area: 0.44 cm

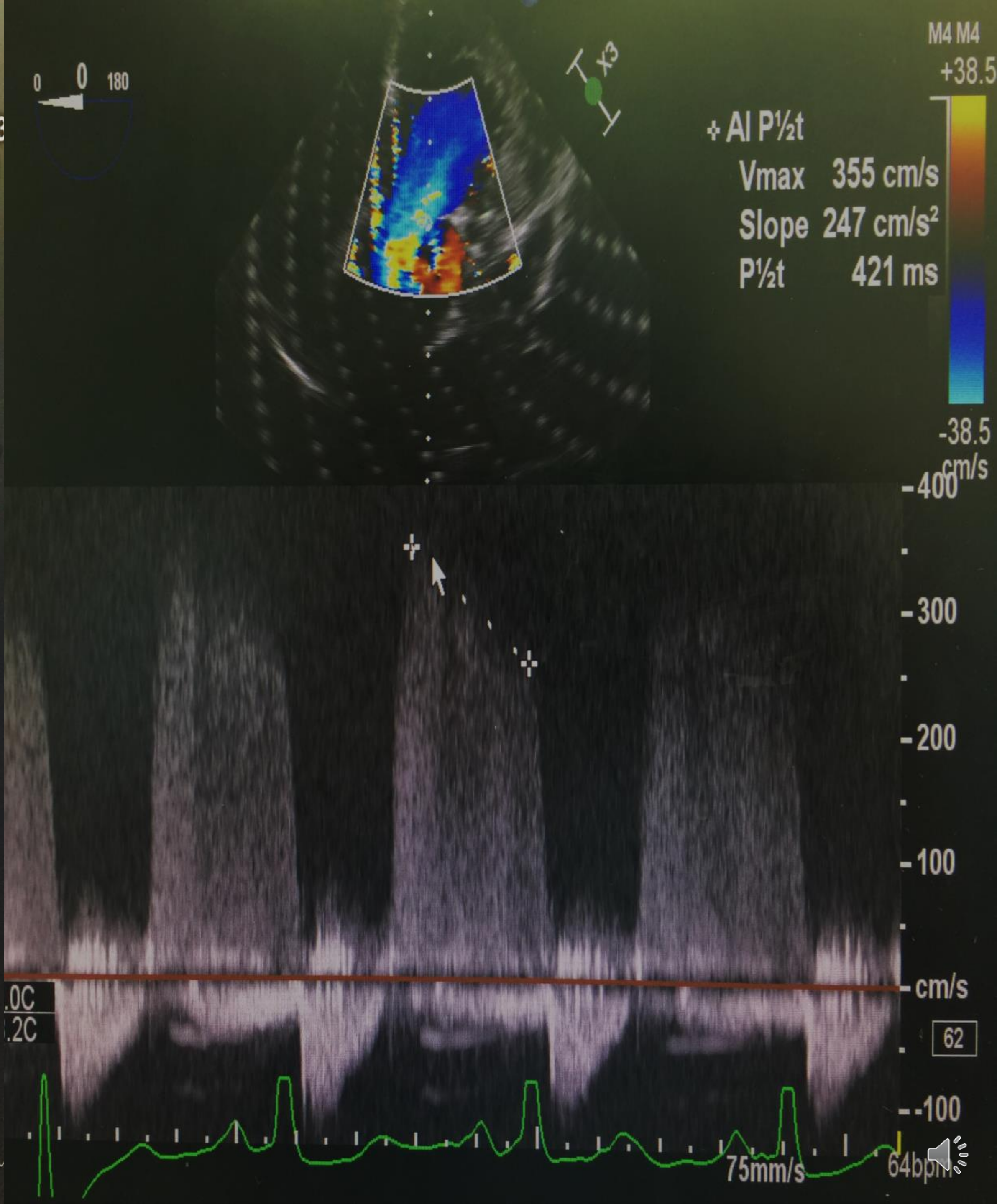


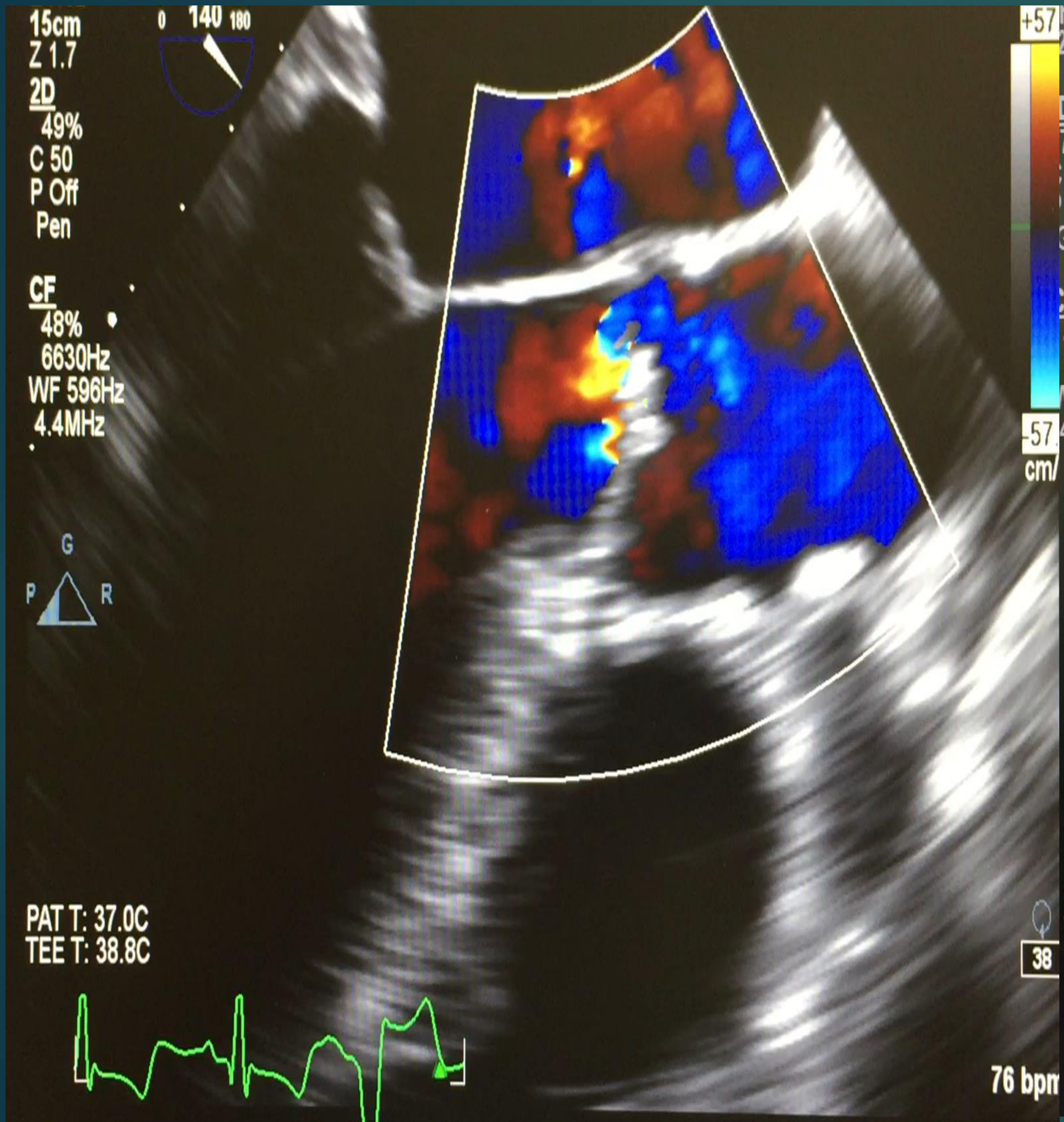
Aortic Regurgitation Severity



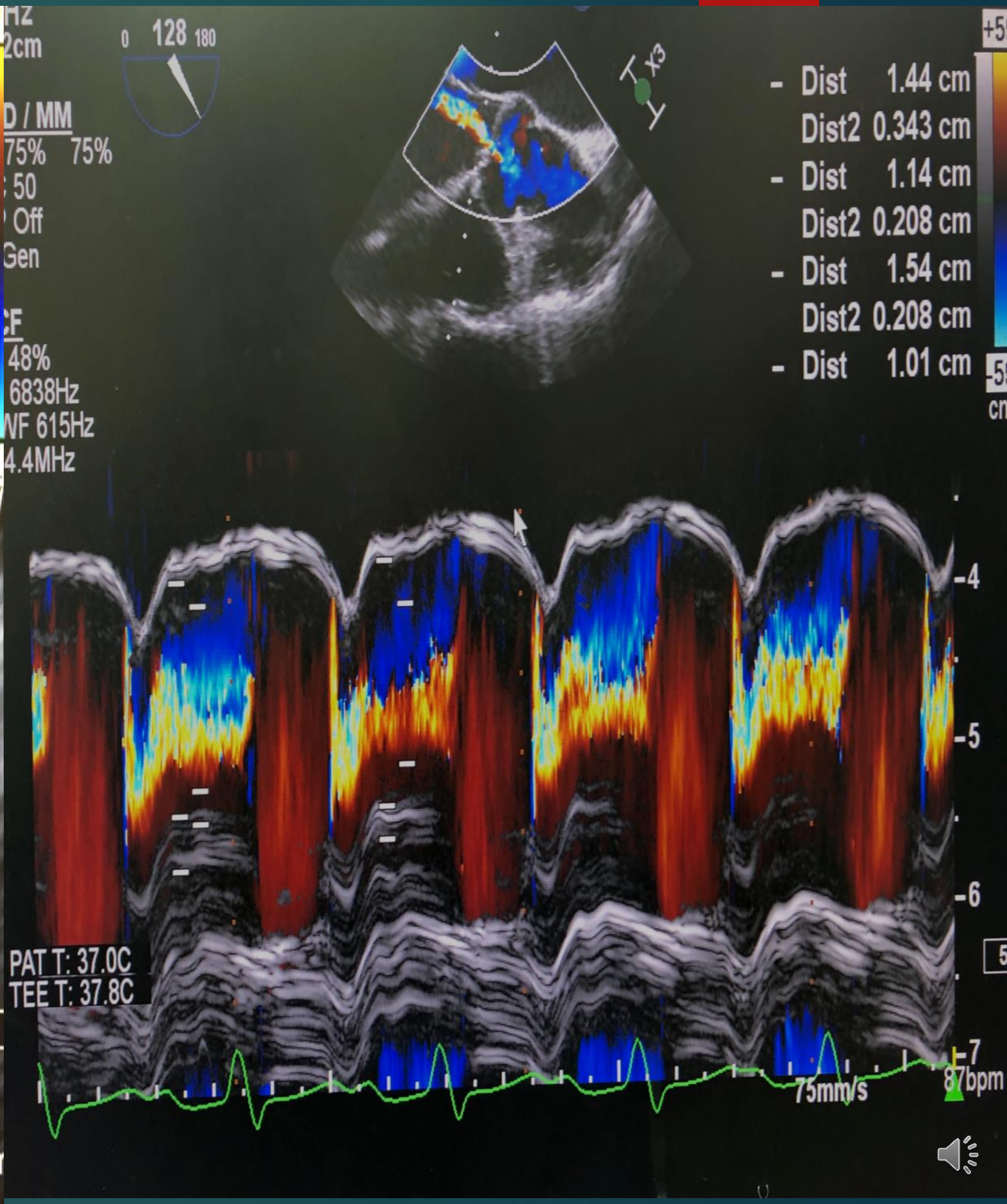
Method	Mild	Moderate	Severe
Jet/LVOT Width	<25%	25-65%	>65%
Color Wave Density	Faint	Dense	Dense
Pressure Half Time (ms)	>500	200-500	<200
Vena contracta (mm)	<3	3-6	>6
Regurgitant orifice area (cm^2)	<0.1	0.1-0.3	>0.3


Adult Echo
X7-2t
11Hz
10cm
09/05/2017 08:15:04AM
TIS0.6 MI 0.3
0 153 180
2D / MM
81% 81%
C 50
P Off
Res
CF
48%
6838Hz
WF 615Hz
4.4MHz
Dist 0.407 cm
Dist 2.11 cm
M4 M4
+59.3
-59.3
cm/s
-4
-5
-6
-7
-8
53
PAT T: 37.0C
TEE T: 39.1C
75mm/s
64bpm

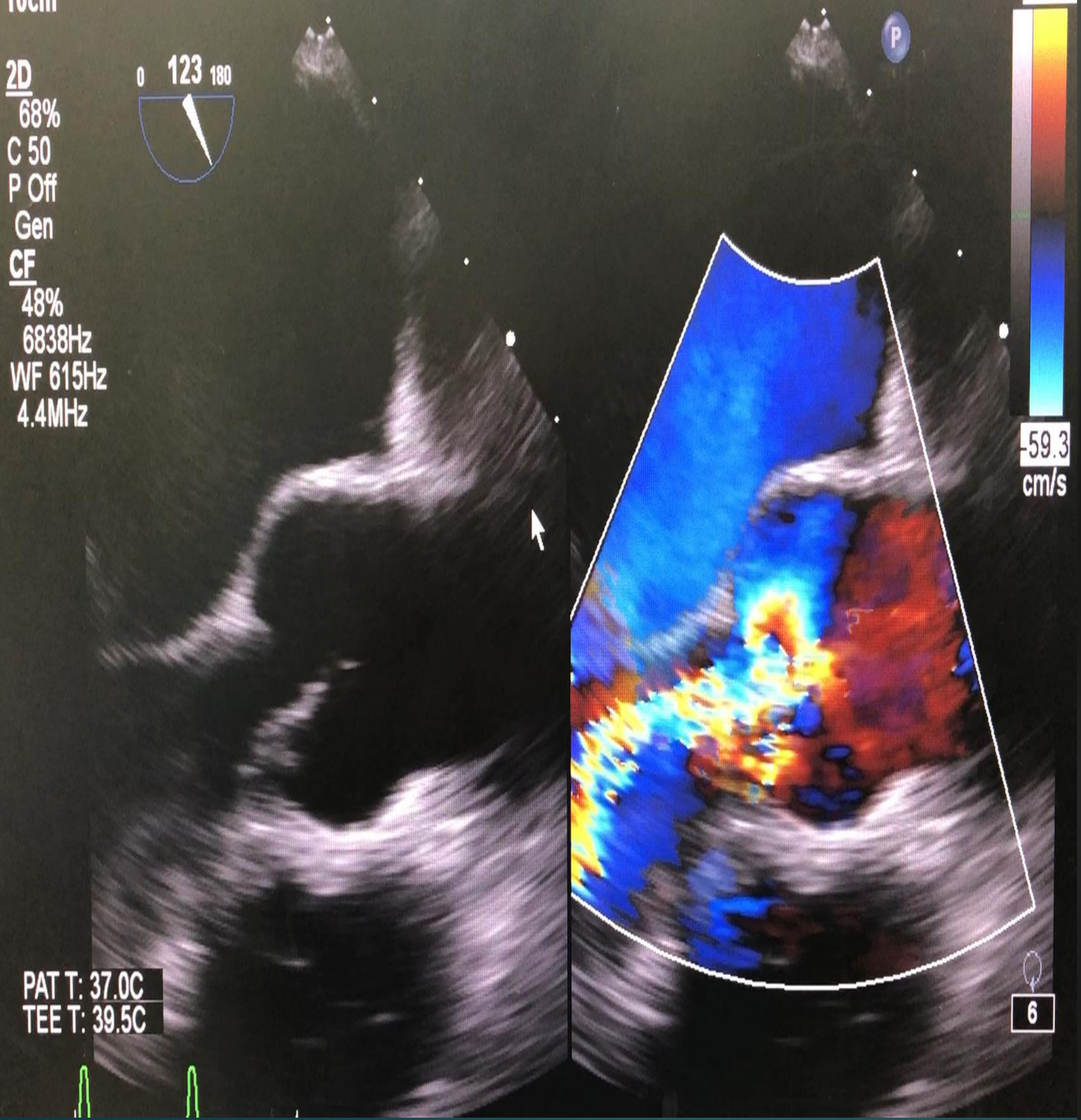
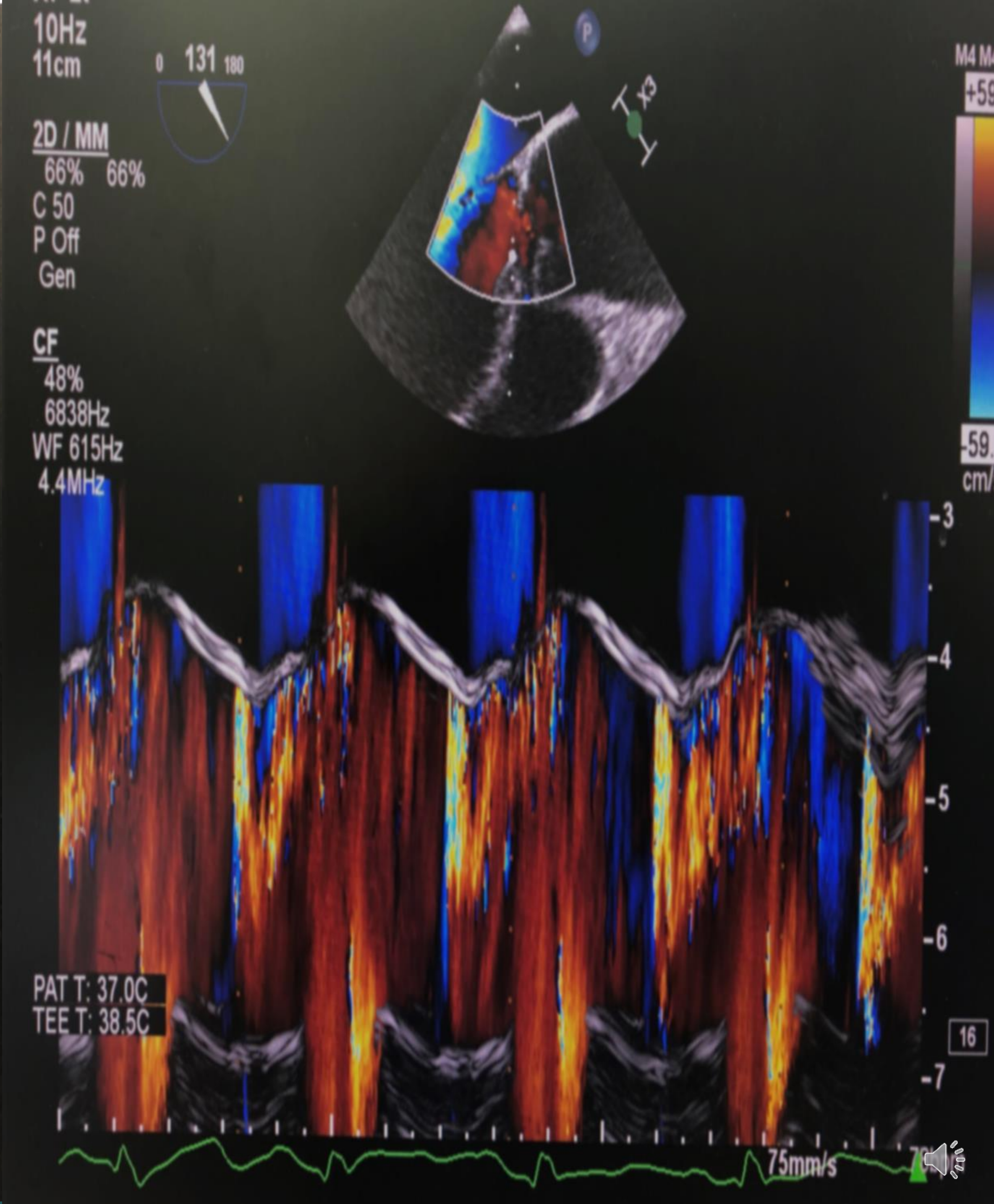

0 0 180
X3
M4 M4
+38.5
-38.5
cm/s
AI P½t
Vmax 355 cm/s
Slope 247 cm/s²
P½t 421 ms
-400
-300
-200
-100
cm/s
62
--100
75mm/s
64bpm



15cm
Z 1.7
0 140 180
2D
49%
C 50
P Off
Pen
CF
48%
6630Hz
WF 596Hz
4.4MHz
G
P R
+57
-57
cm/
PAT T: 37.0C
TEE T: 38.8C
38
76 bpm

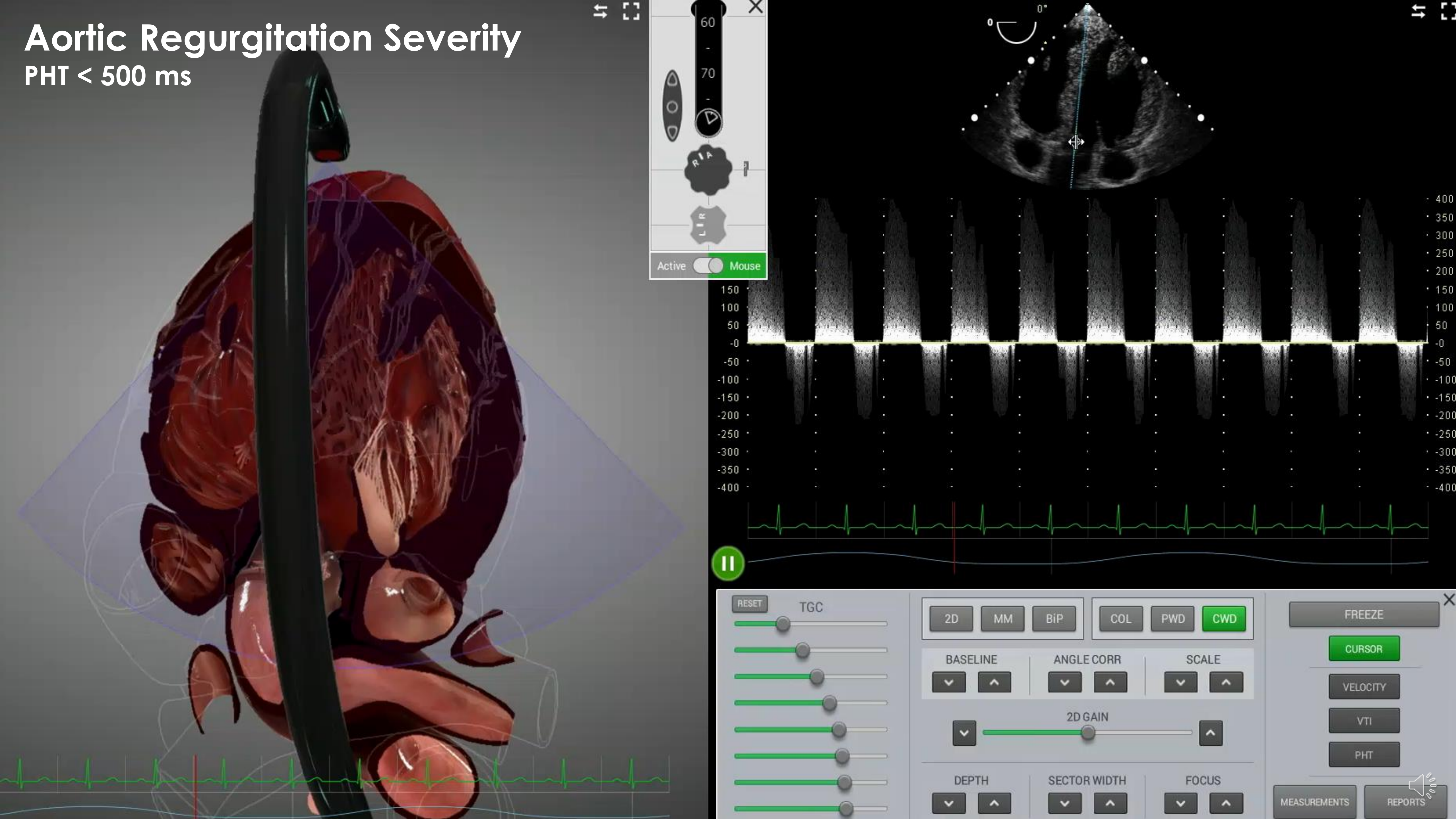


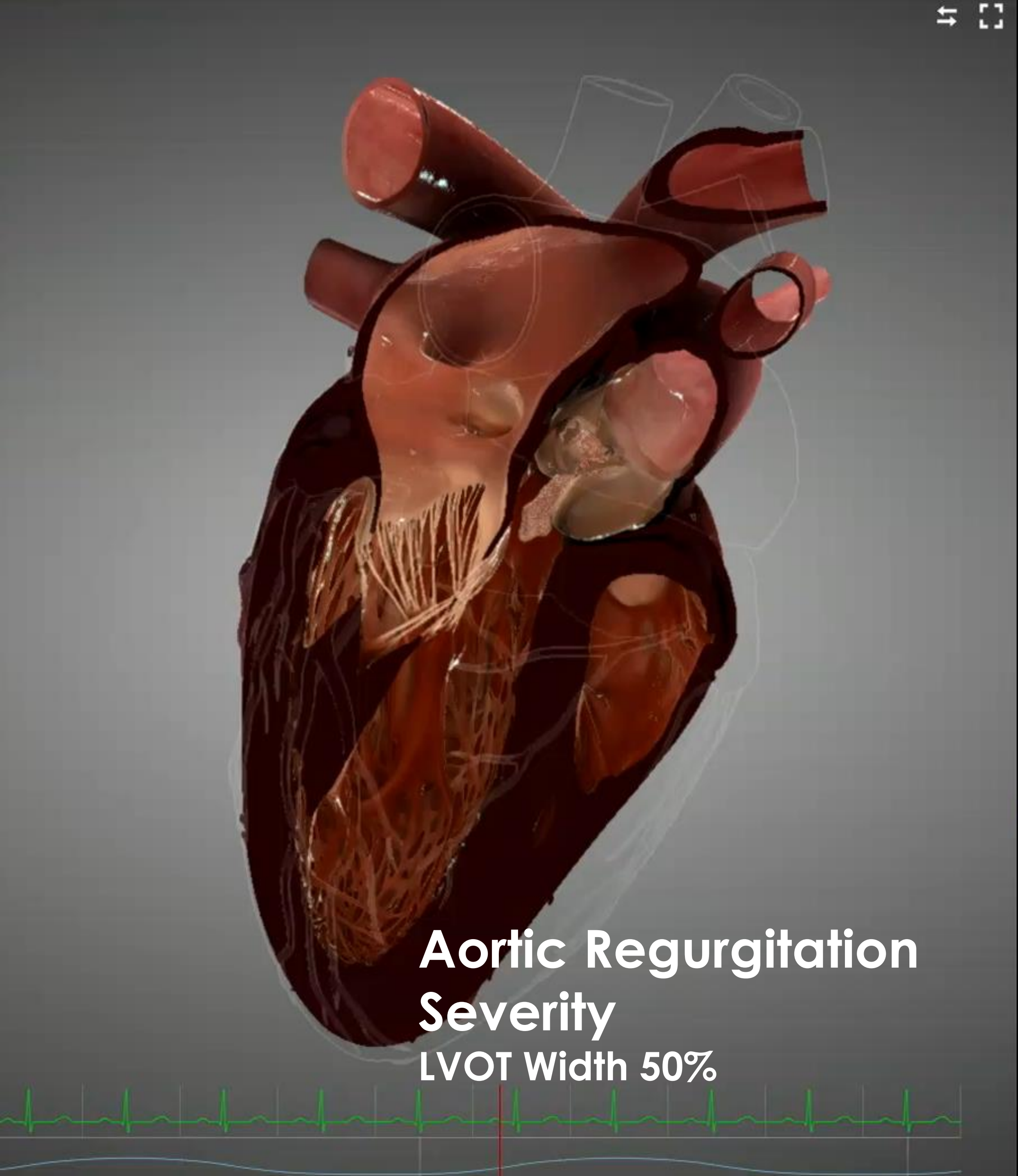
2cm
0 128 180
75% 75%
50
Off
Gen
48%
6838Hz
WF 615Hz
4.4MHz
Dist 1.44 cm
Dist2 0.343 cm
Dist 1.14 cm
Dist2 0.208 cm
Dist 1.54 cm
Dist2 0.208 cm
Dist 1.01 cm
-4
-5
-6
-7
PAT T: 37.0C
TEE T: 37.8C
75mm/s
87bpm

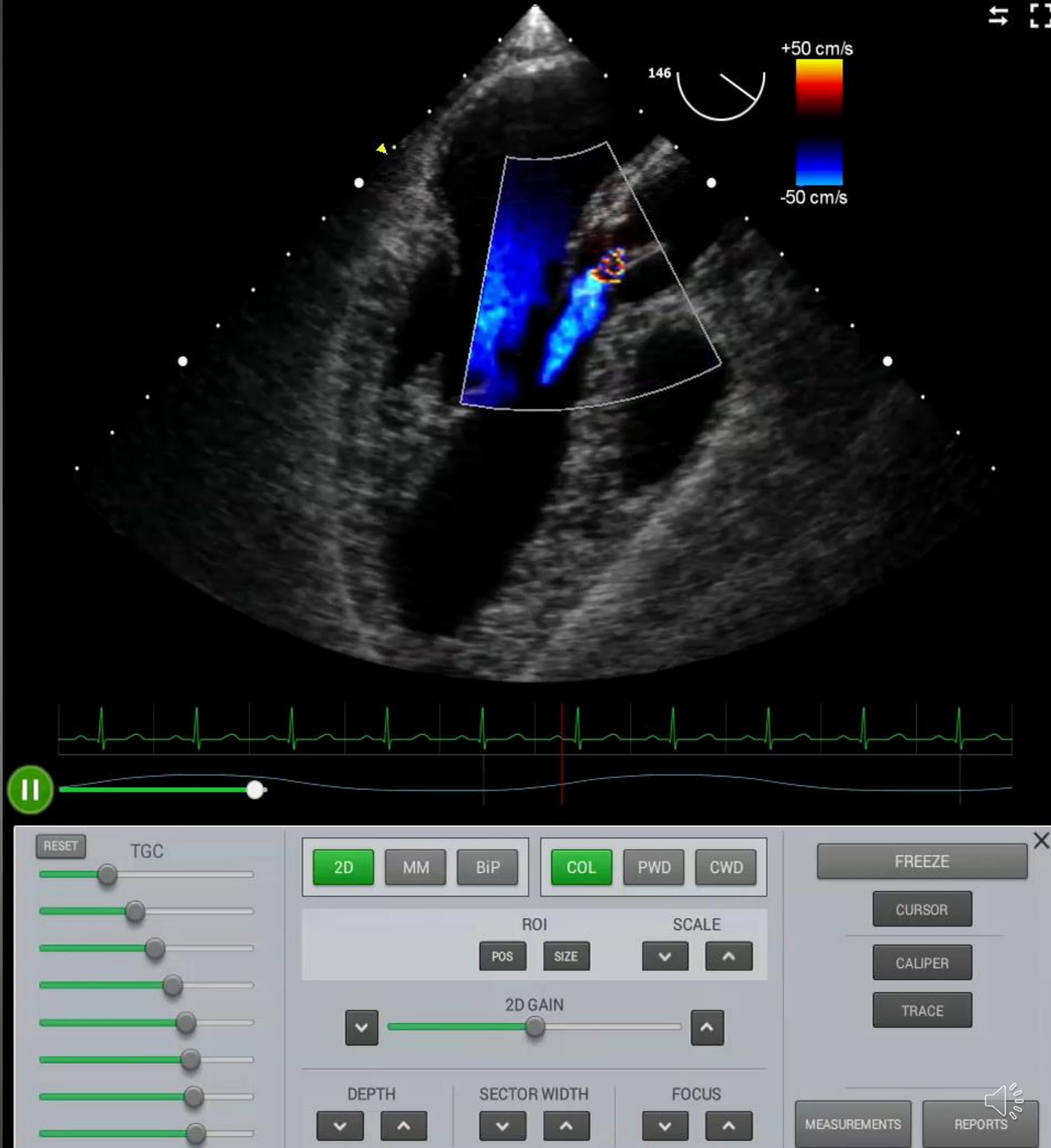

2D
68%
C 50
P Off
Gen
CF
48%
6838Hz
WF 615Hz
4.4MHz
0 123 180
-59.3
cm/s
6
PAT T: 37.0C
TEE T: 39.5C

10Hz
11cm
0 131 180
2D / MM
66% 66%
C 50
P Off
Gen
CF
48%
6838Hz
WF 615Hz
4.4MHz
PAT T: 37.0C
TEE T: 38.5C
75mm/s
16

Aortic Regurgitation Severity

PHT < 500 ms



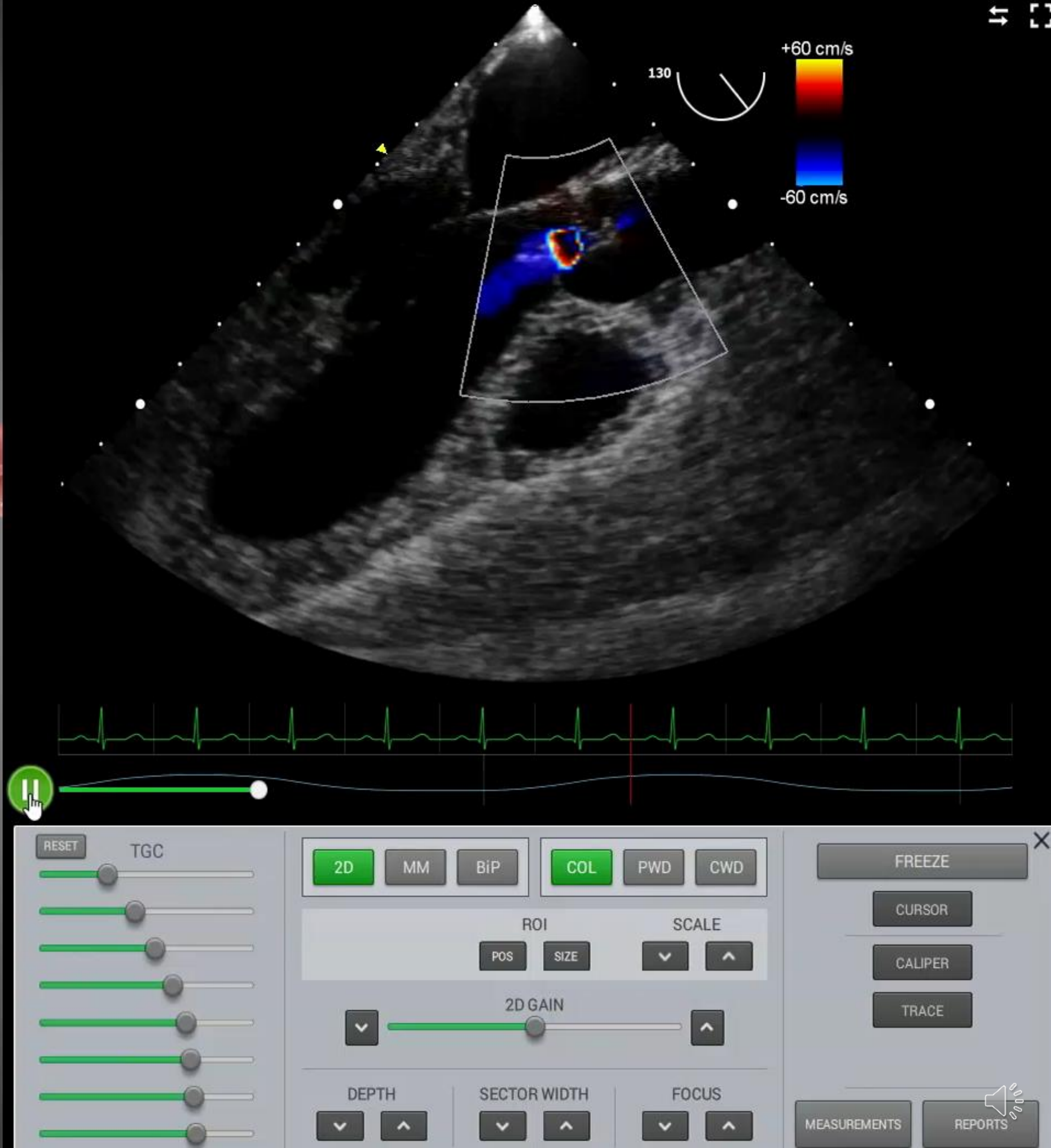




Aortic Regurgitation Severity

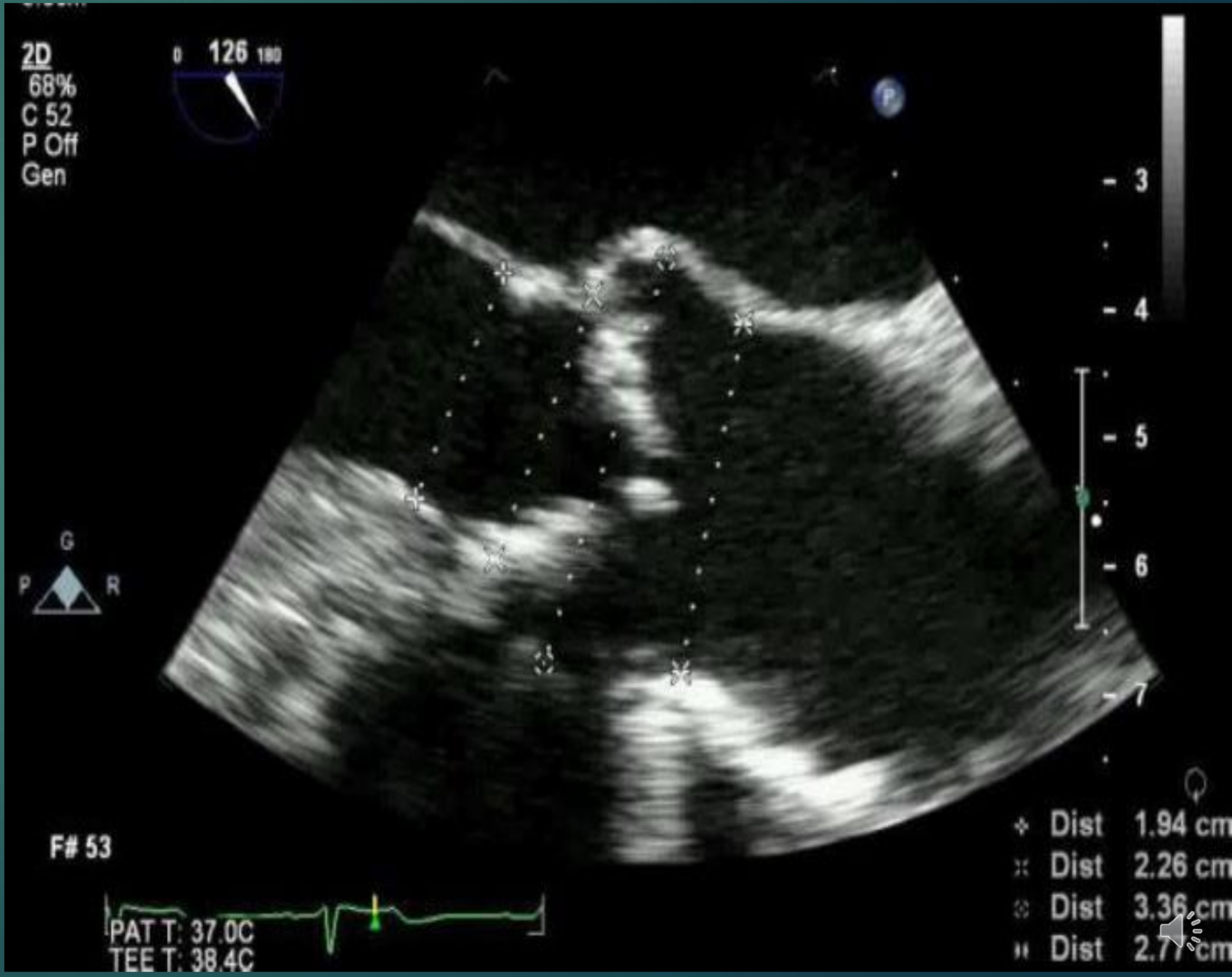
LVOT Width 50%

Aortic Regurgitation Severity
Vena Contracta

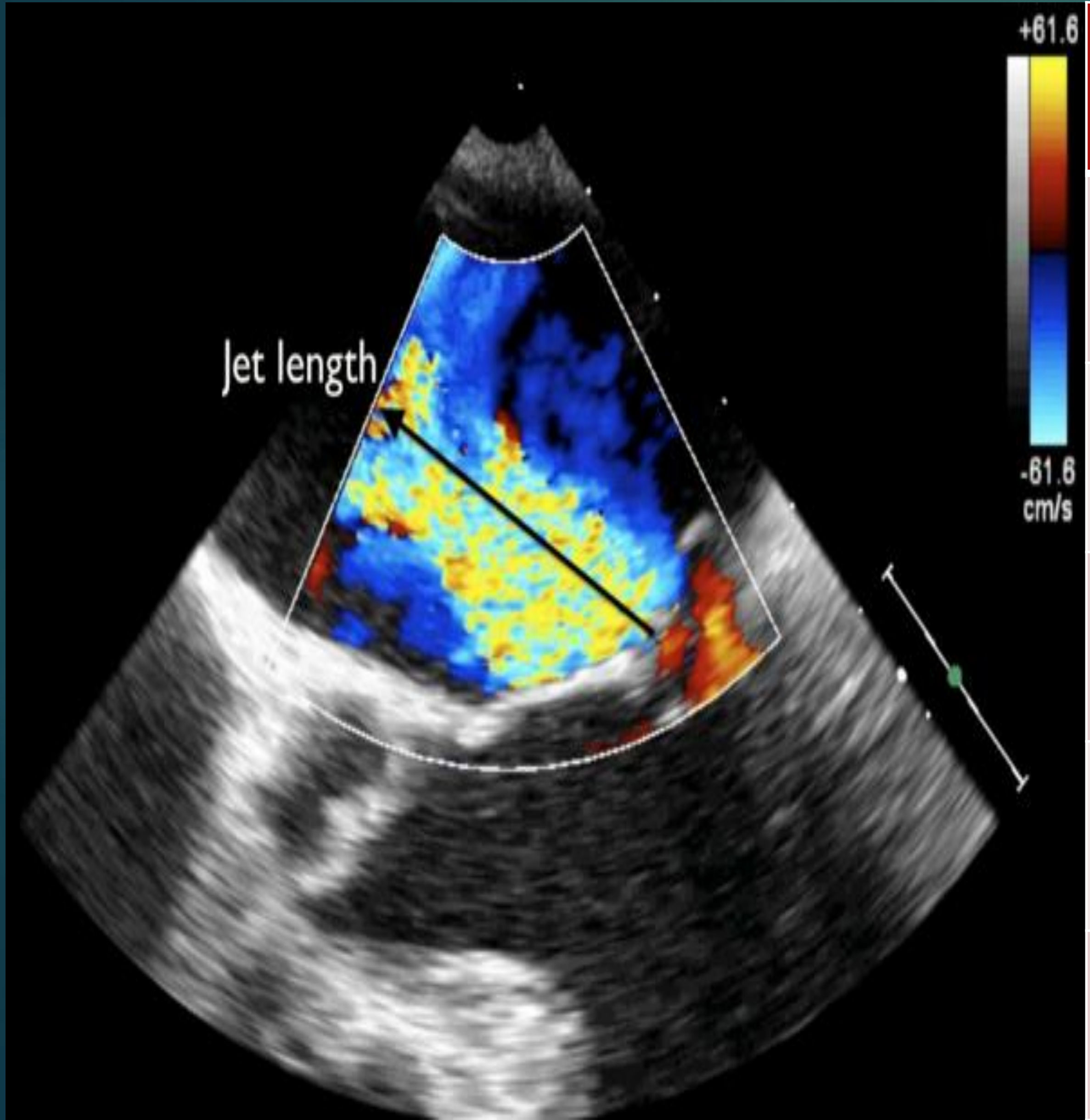


Utility of TEE for Aorta Surgery

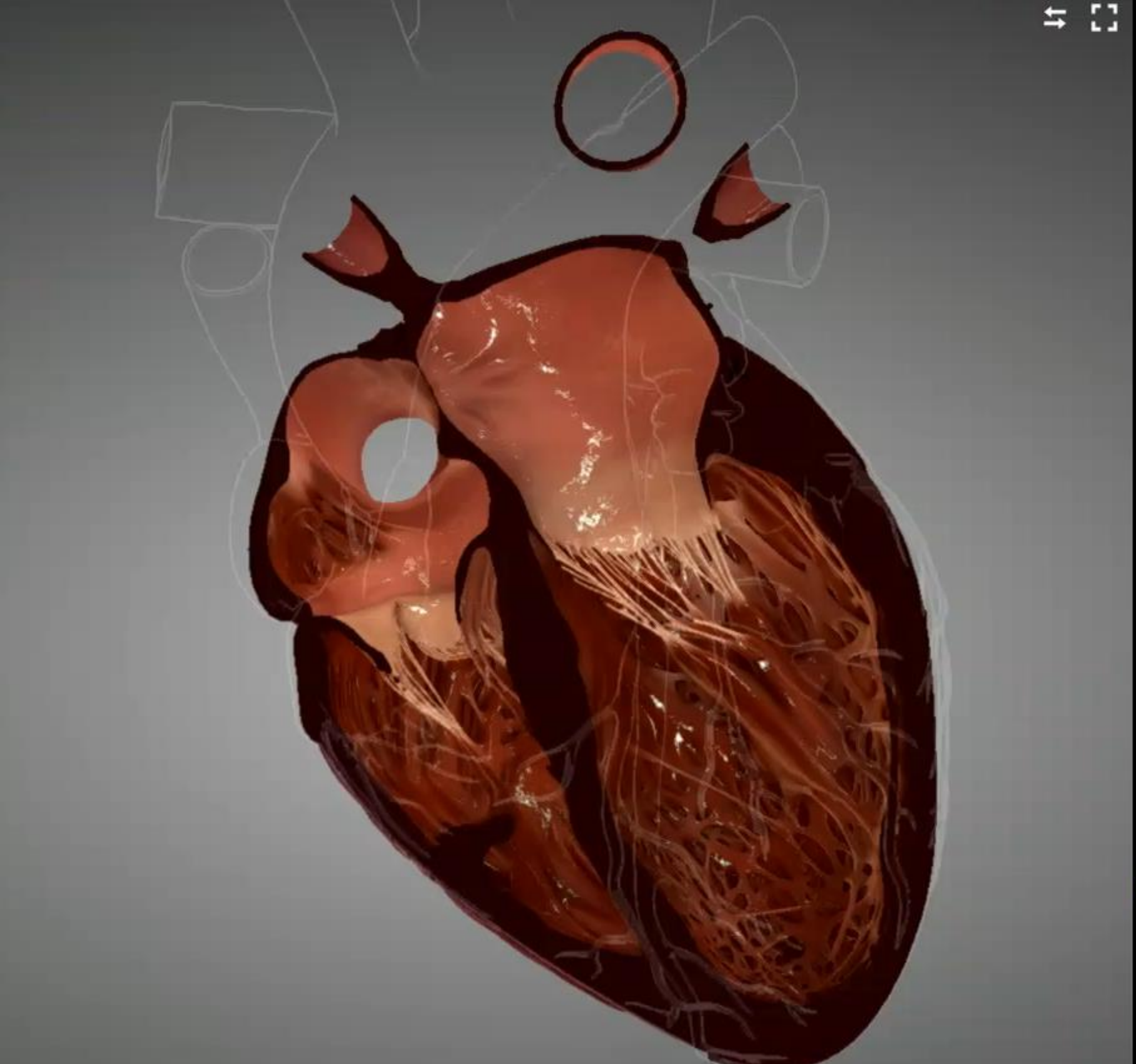
- Chamber/wall/aorta dimensions
  - LV/RV/LA
  - LVOT
  - AV Annulus
  - ST Junction
  - Ascending aorta
- Guidance for cannulation
- Assessment for air
- Assessment after repair or replacement
  - Paravalvular leak
  - Gradient across the valve



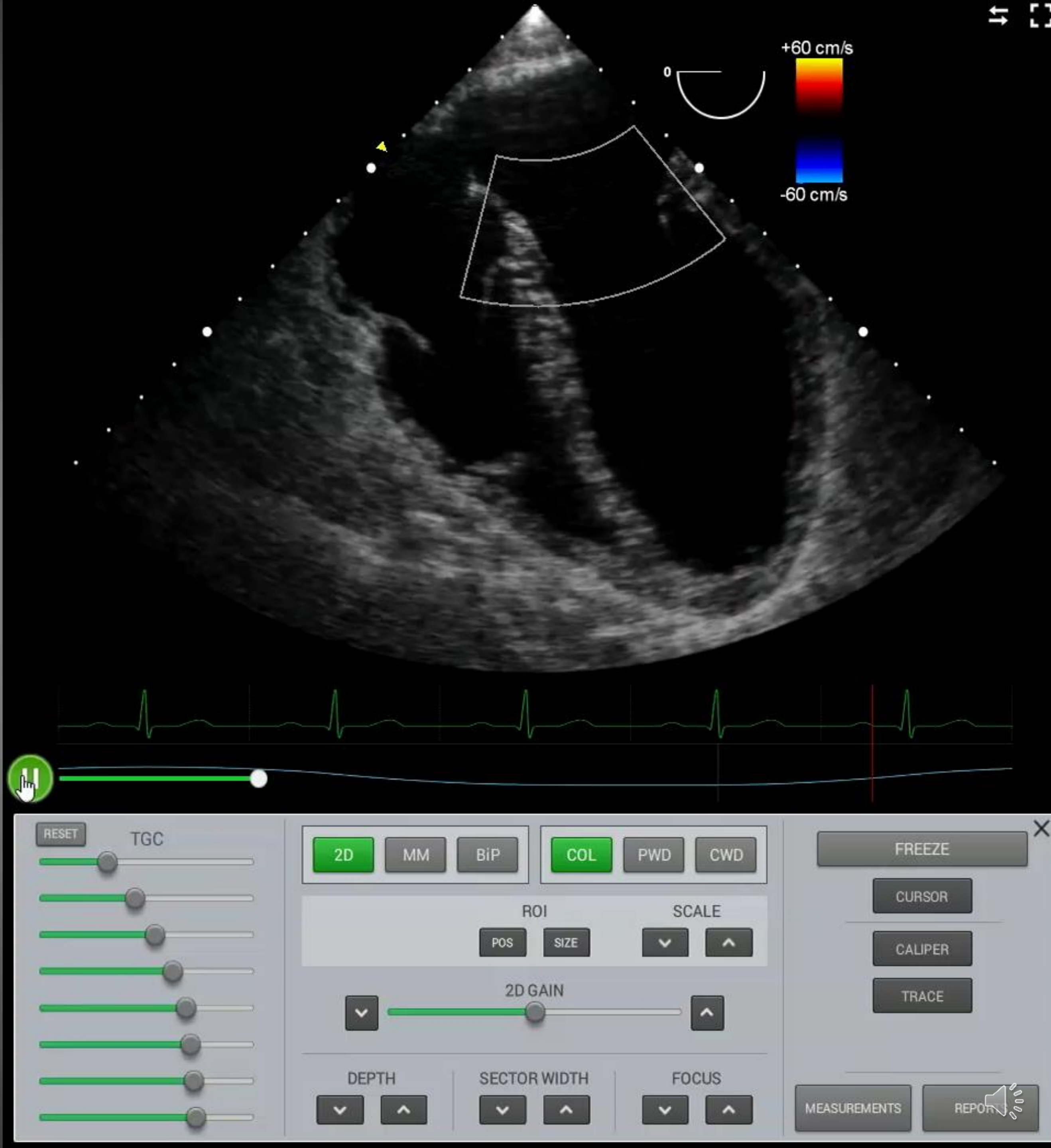
Mitral Regurgitation Severity



Parameter	Mild (1-2+)	Moderate (2-3+)	Severe (3-4+)
Jet area (% of LA area, cm^2)	20%; <4	20-40%; 4-8	>40%; >8
Vena contracta (cm)	<0.3	0.3-0.6	>0.6
Pulmonary venous S wave	S>D	Blunting	Reversal
Regurgitant fraction (%)	<25	25-55	>55
Regurgitant Orifice Area (cm^2)	<0.2	0.2-0.4	>0.4

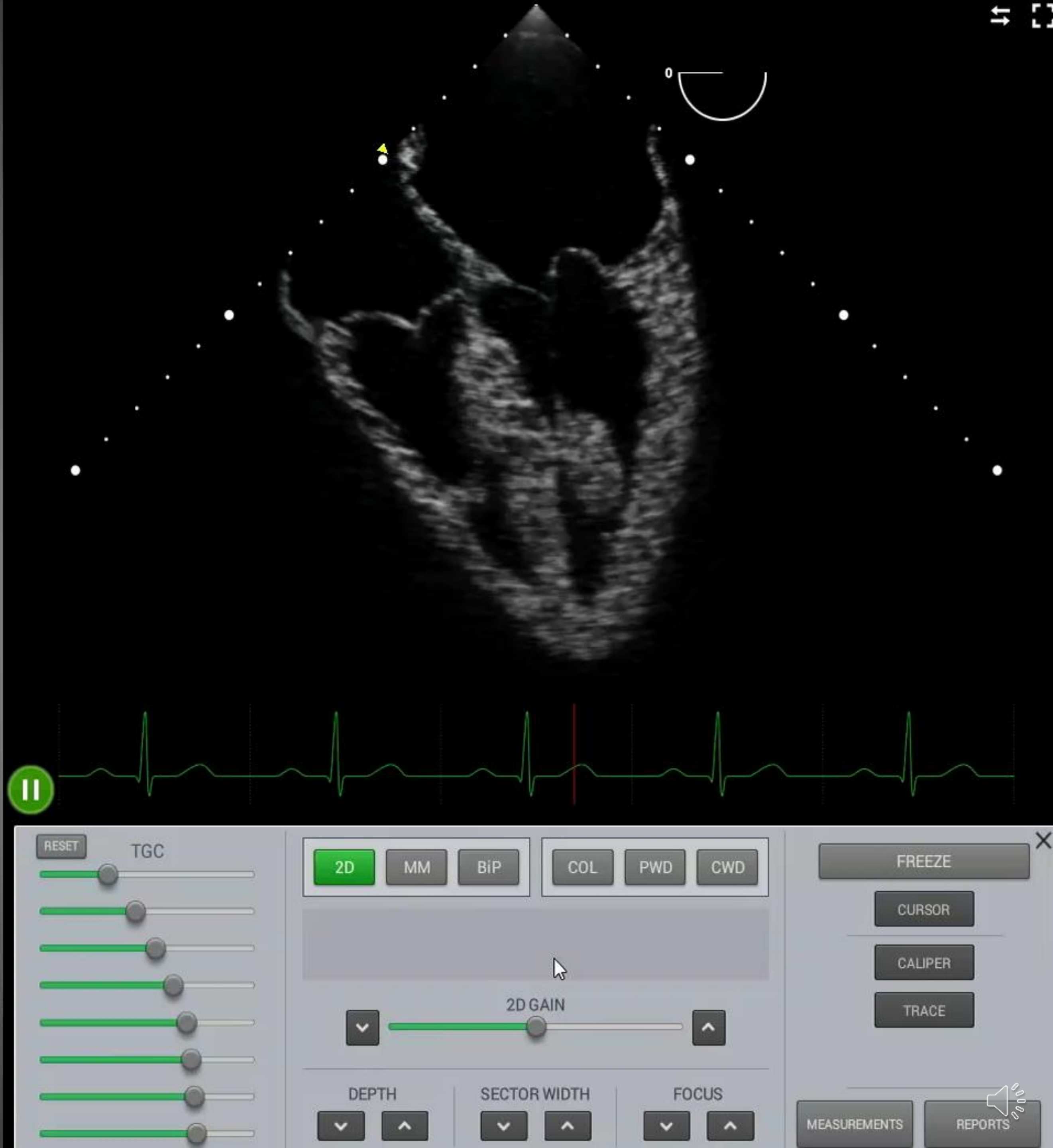


Mitral Regurgitation Severity
Vena Contracta (Mild)



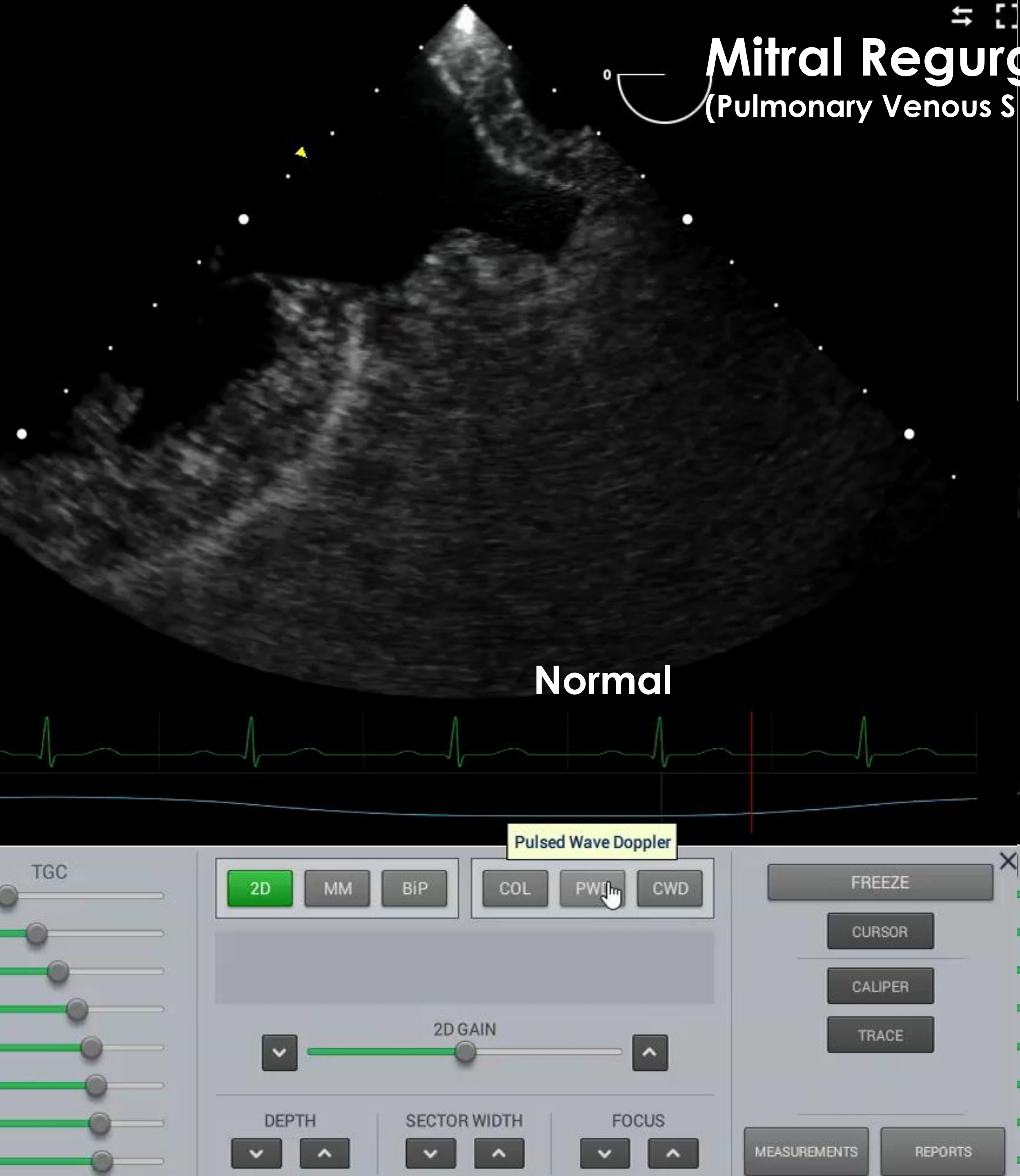
Mitral Regurgitation Severity

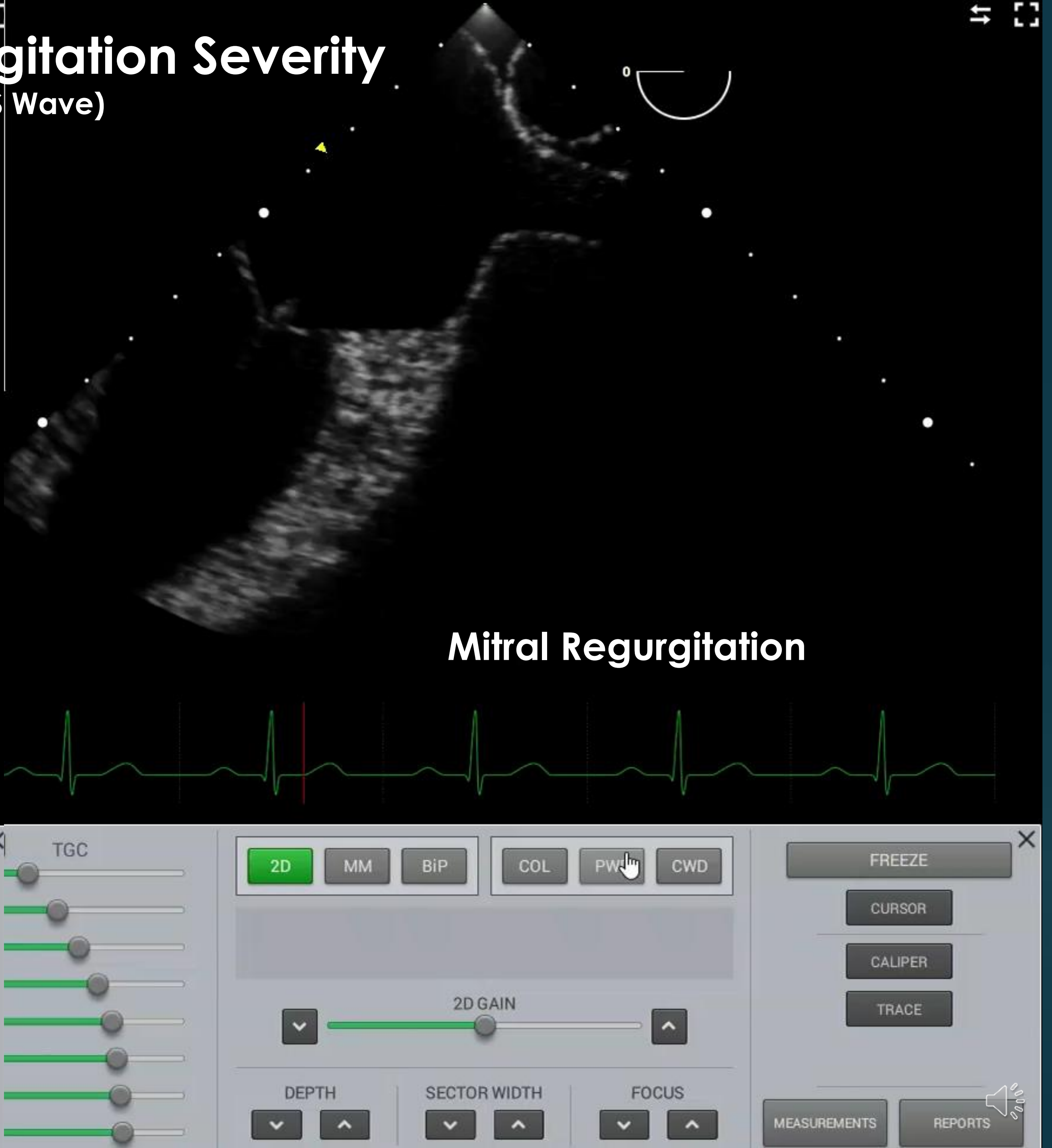
Vena Contracta (Severe)



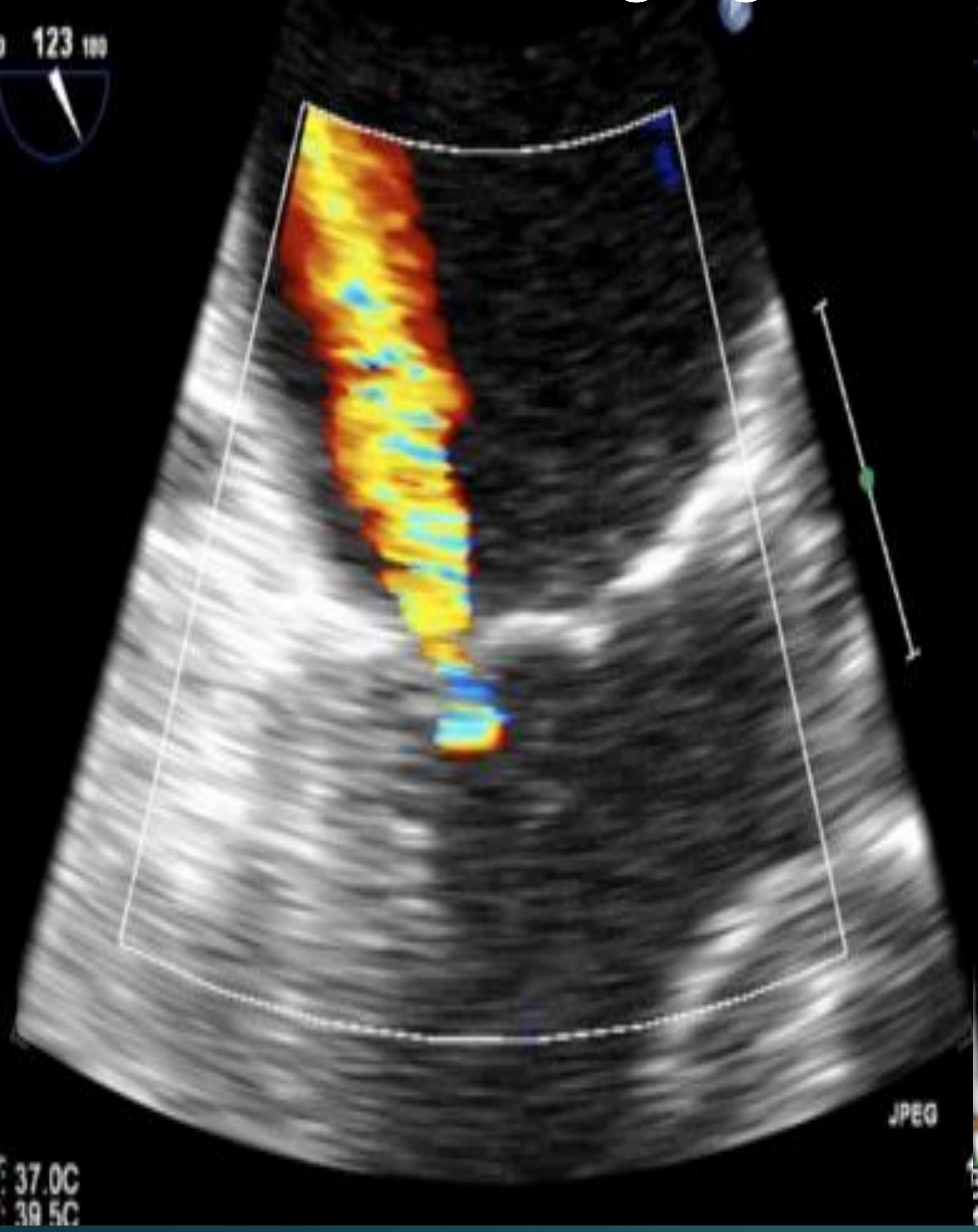
Mitral Regurgitation Severity

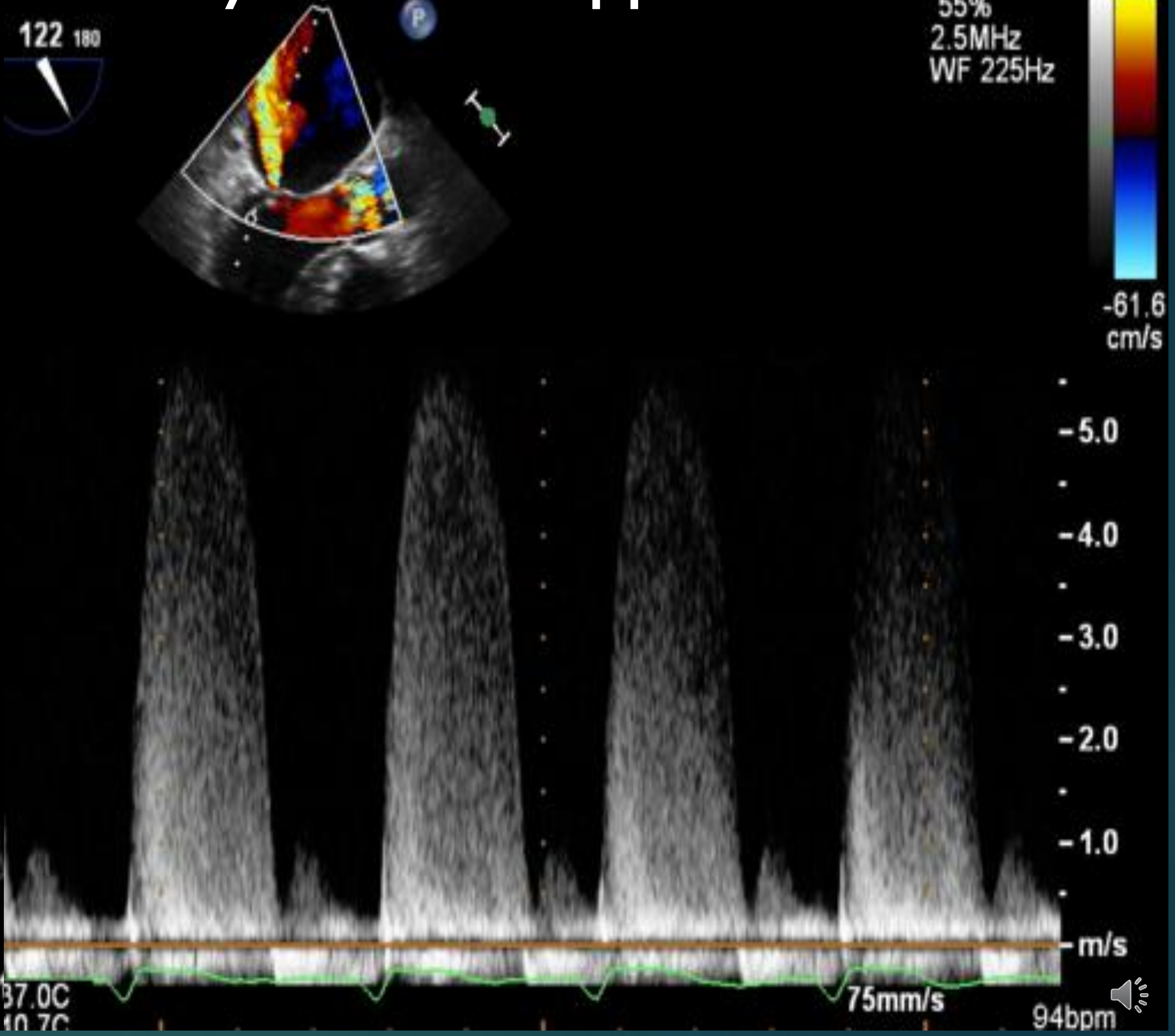
(Pulmonary Venous S Wave)



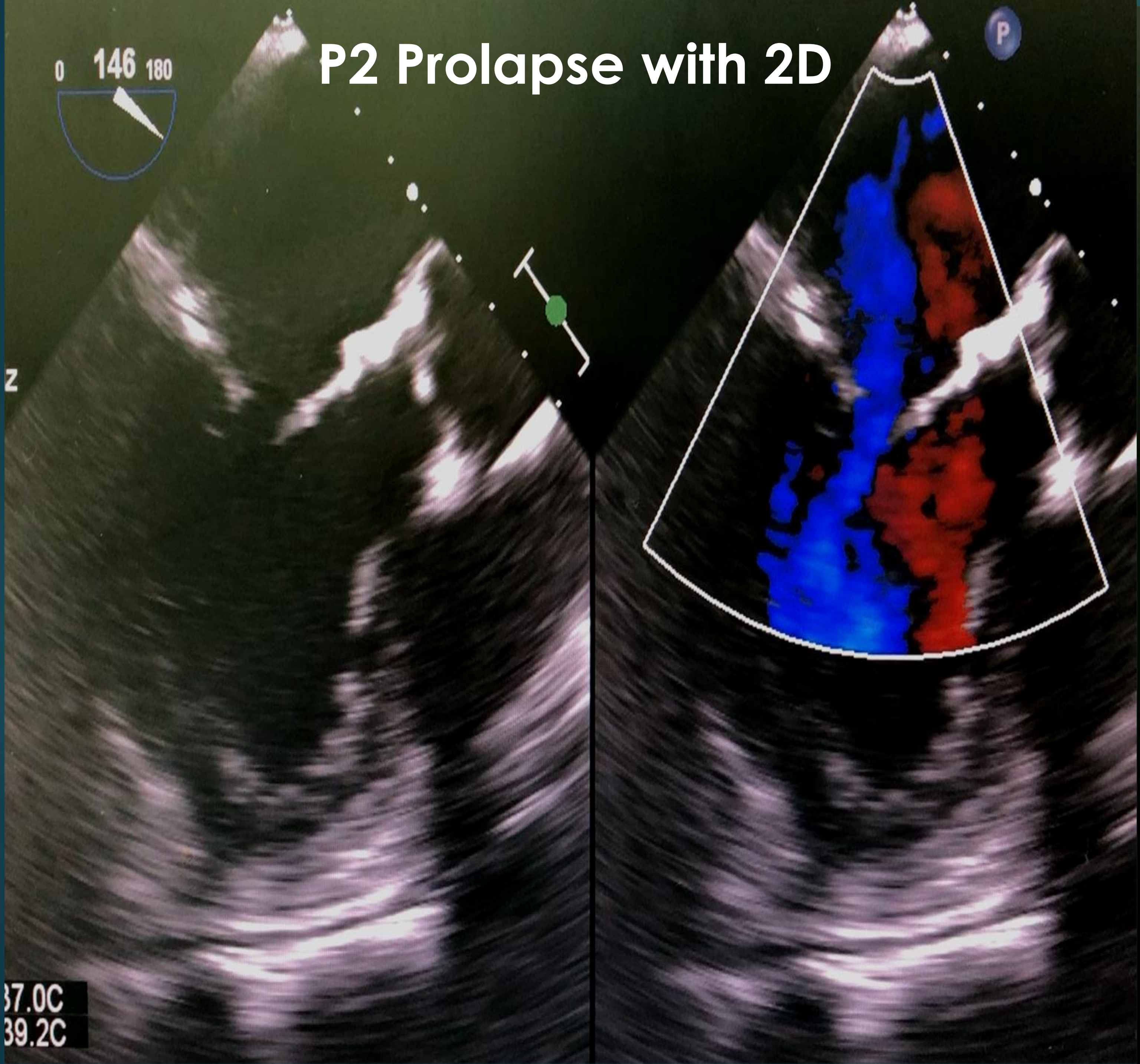


Mitral Regurgitation Velocity with CW Doppler

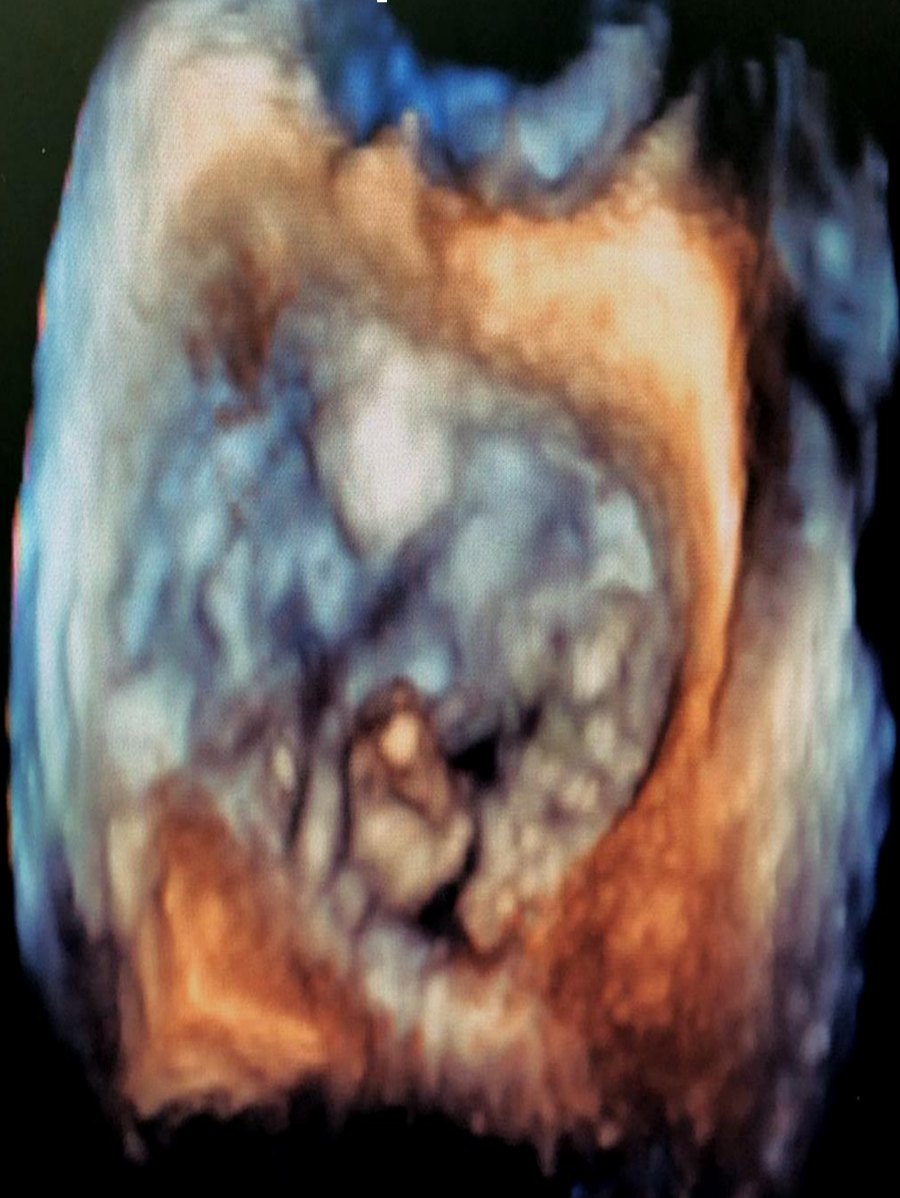


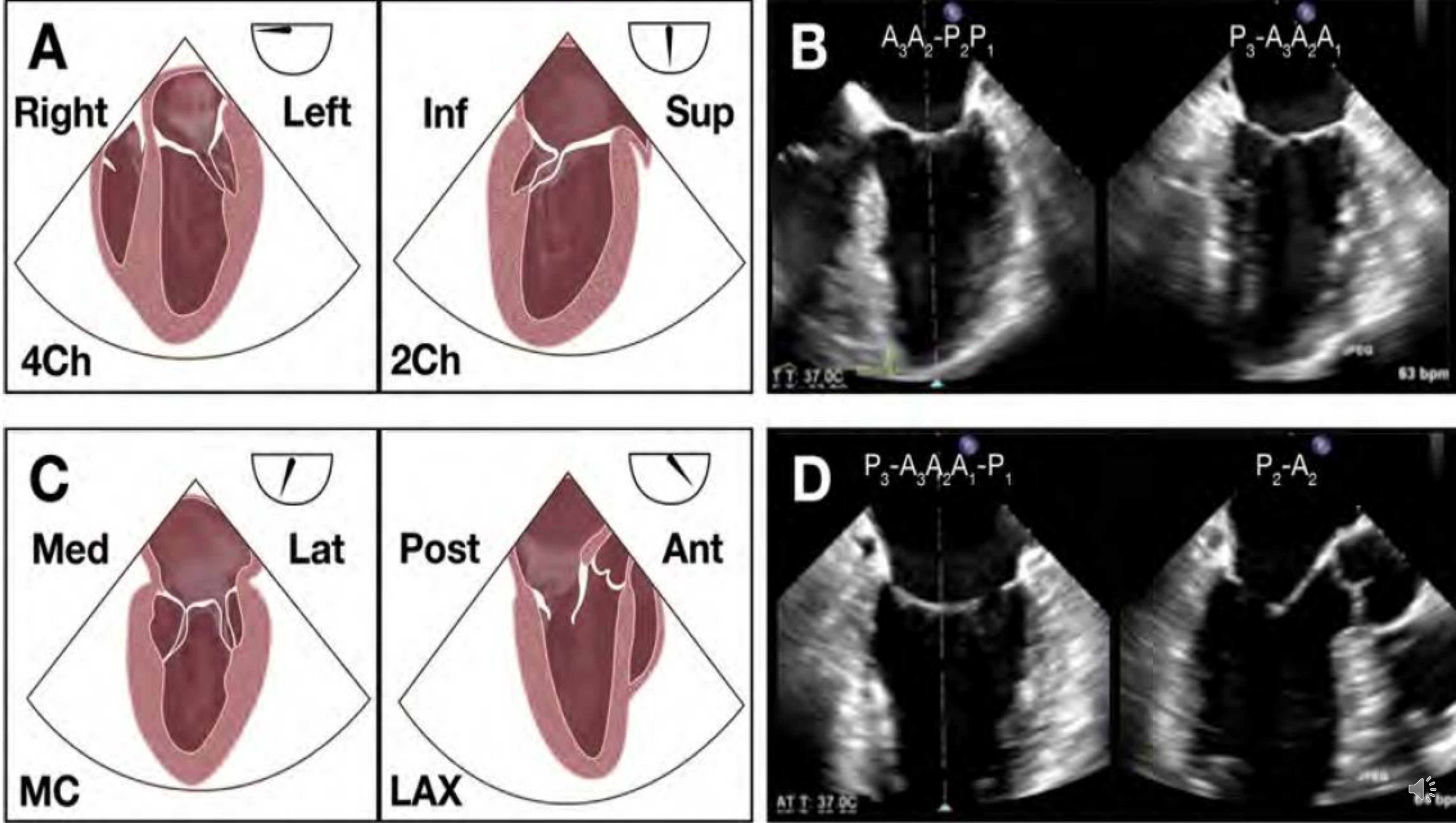


P2 Prolapse with 2D



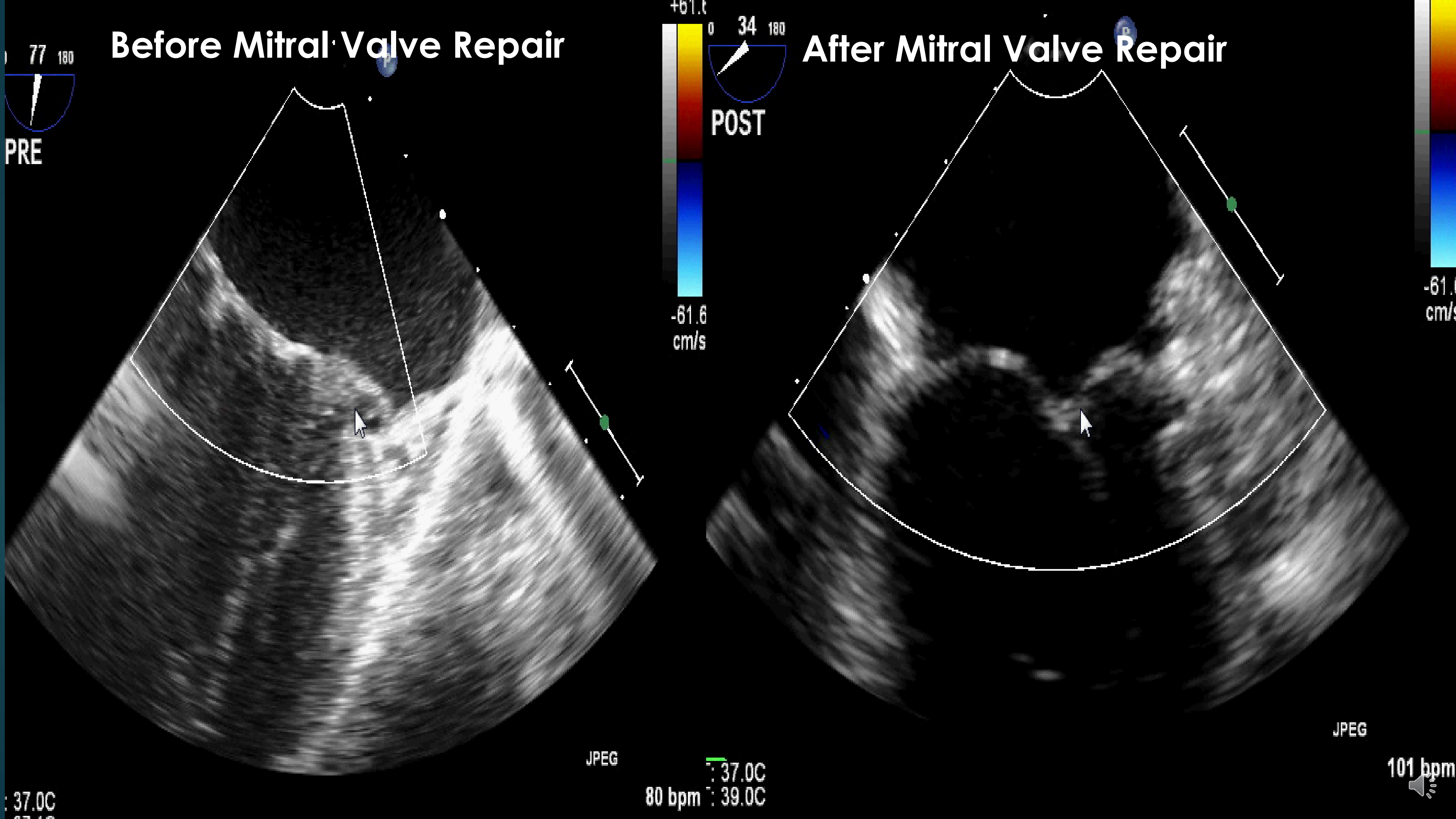
P2 Prolapse with 3D



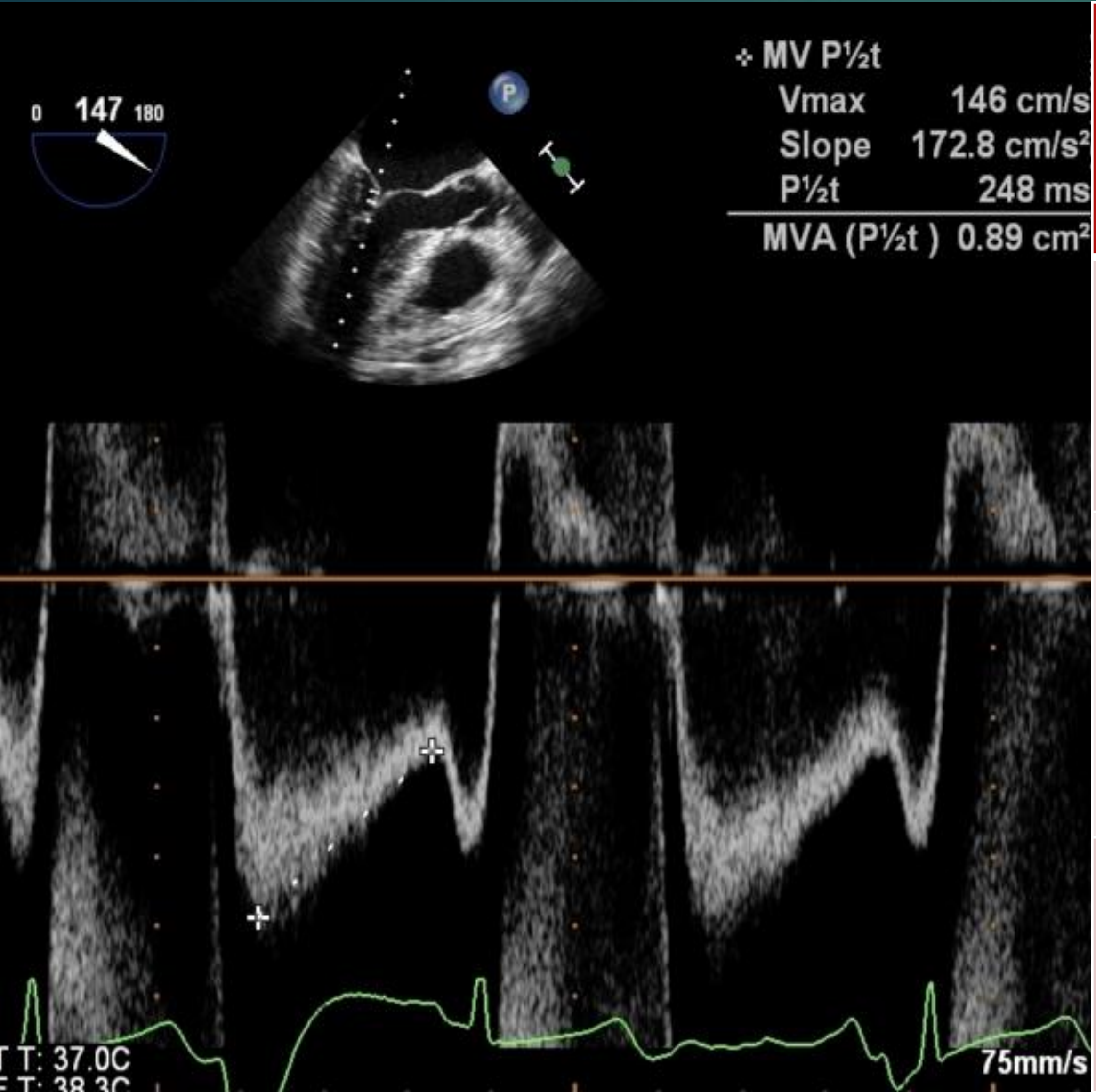

A
Right
Left
4Ch
Inf
Sup
2Ch
B
A_3A_2-P_2P_1
P_3-$A_3A_2A_1$
C
Med
Lat
MC
Post
Ant
LAX
D
P_3-$A_3A_2A_1$-P_1
P_2-A_2

Mitral Valve Repair

- A ring may be sewn around the annulus to improve size or shape
- Leaflets may be better approximated by ring, depending on size of annulus
- Flail leaflet may be anchored with stitch or incised and re-sutured

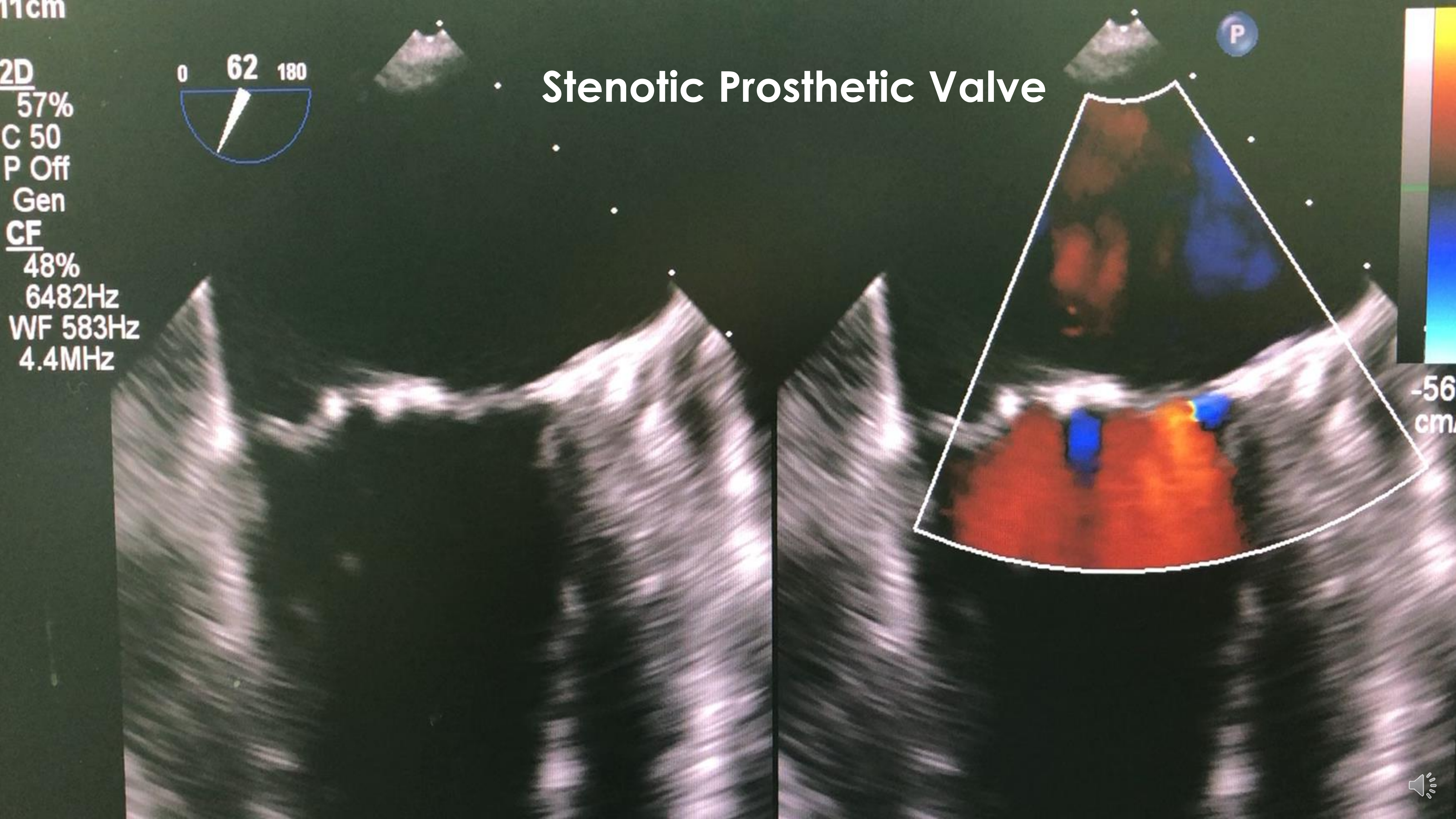

Before Mitral Valve Repair
77
180
PRE
JPEG
37.0C
+61.6
-61.6
cm/s
80 bpm
37.0C
39.0C
After Mitral Valve Repair
0
34
180
POST
JPEG
101 bpm
-61.
cm/s

Mitral Stenosis Severity



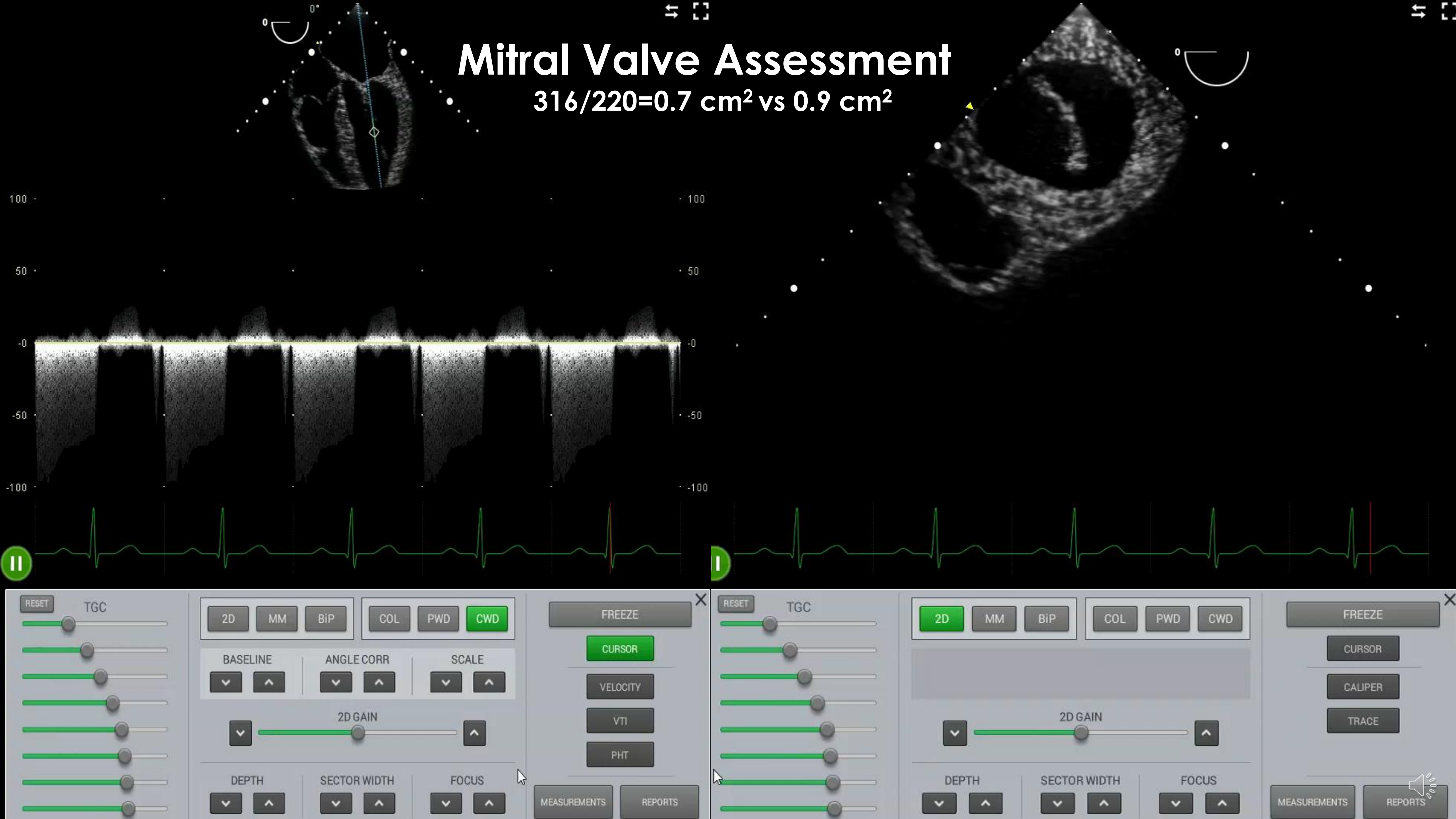
Parameter	Mild	Moderate	Severe
Orifice area (cm^2)	1.5-2	1.0-1.5	< 1.0
Mean gradient (mmHg)	<5	5-10	>10
Pressure Half Time (ms)	<150	150-220	>220

Stenotic Prosthetic Valve

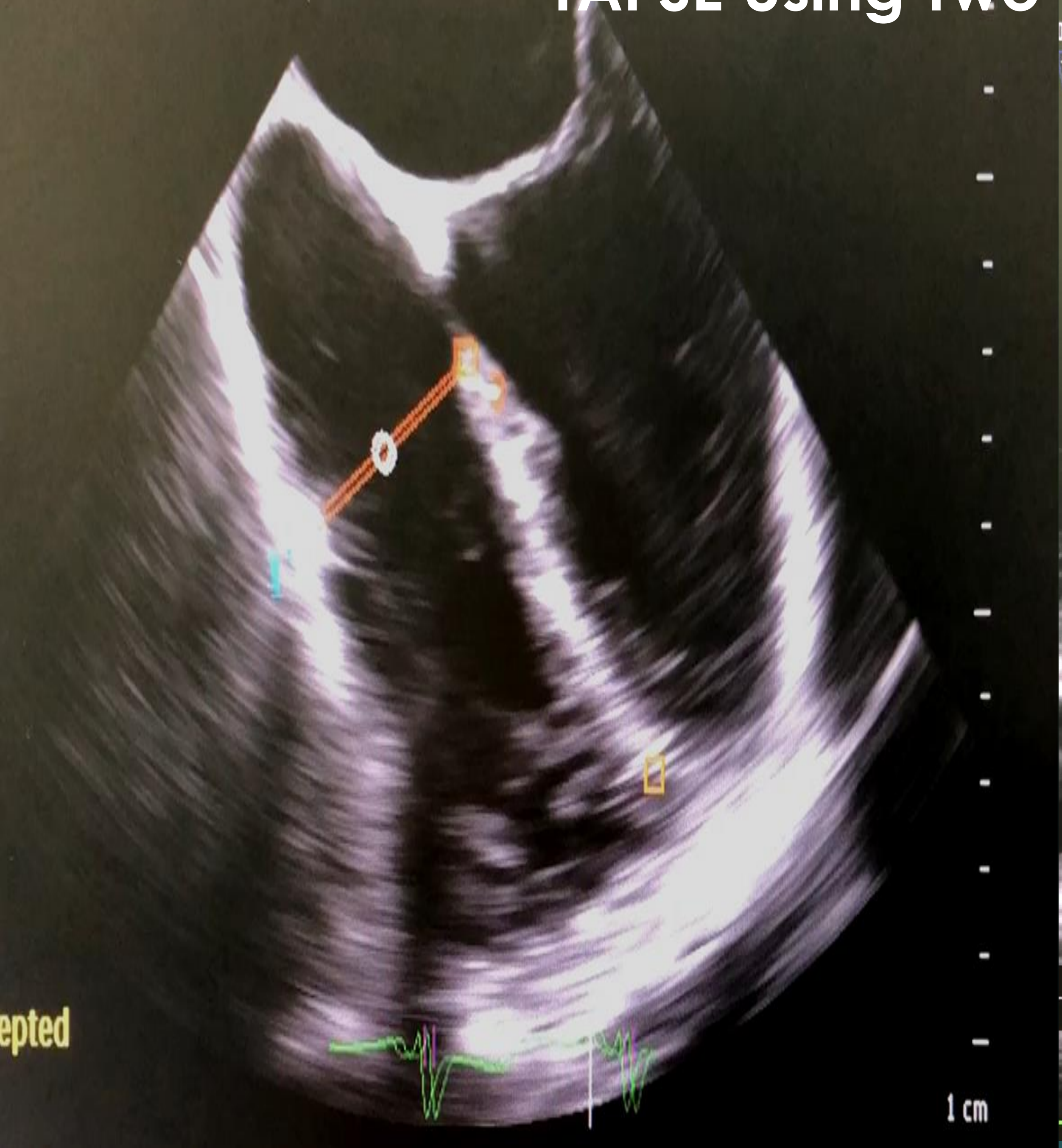


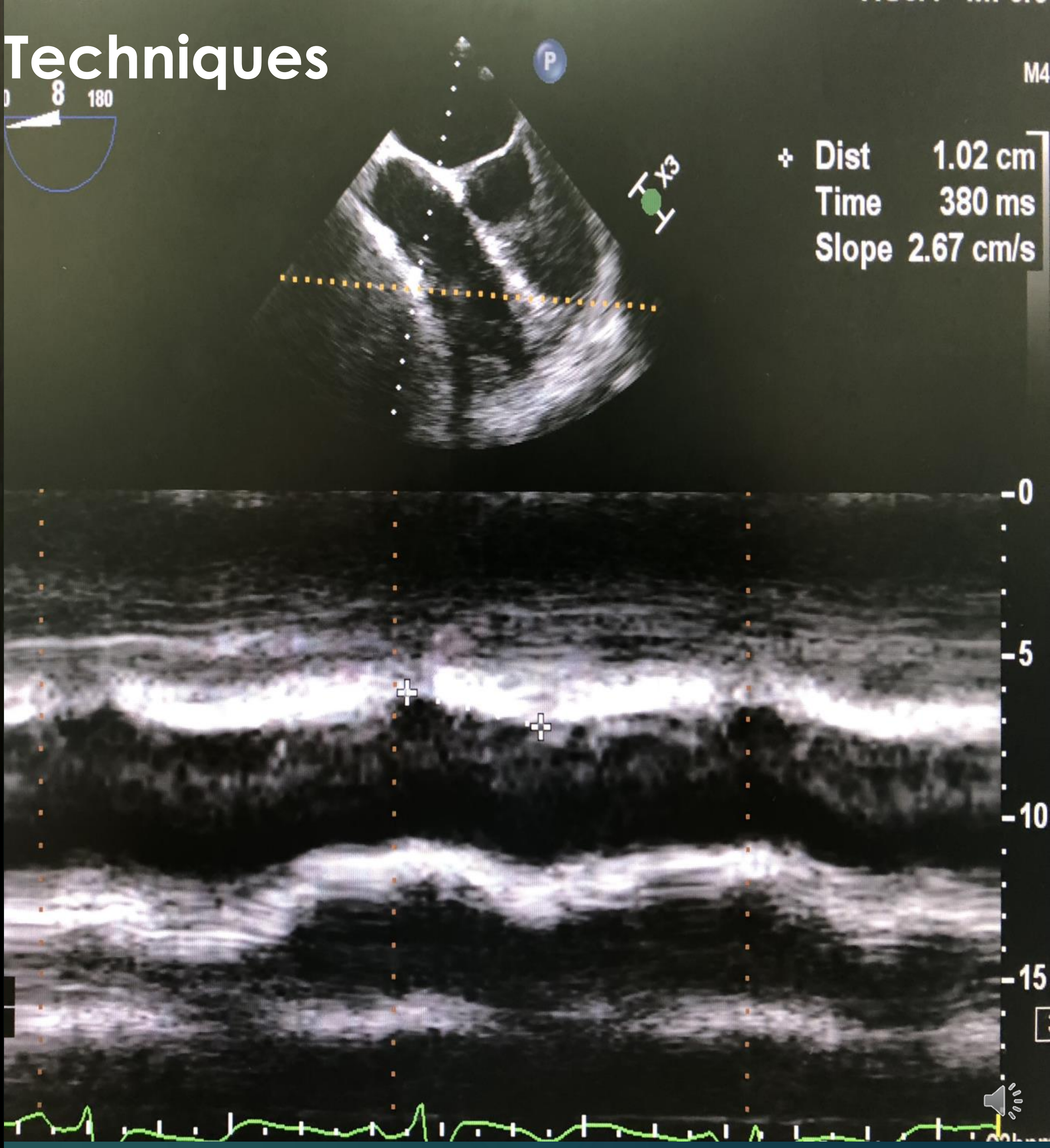
Mitral Valve Assessment

$316/220=0.7\ cm^2$ vs $0.9\ cm^2$



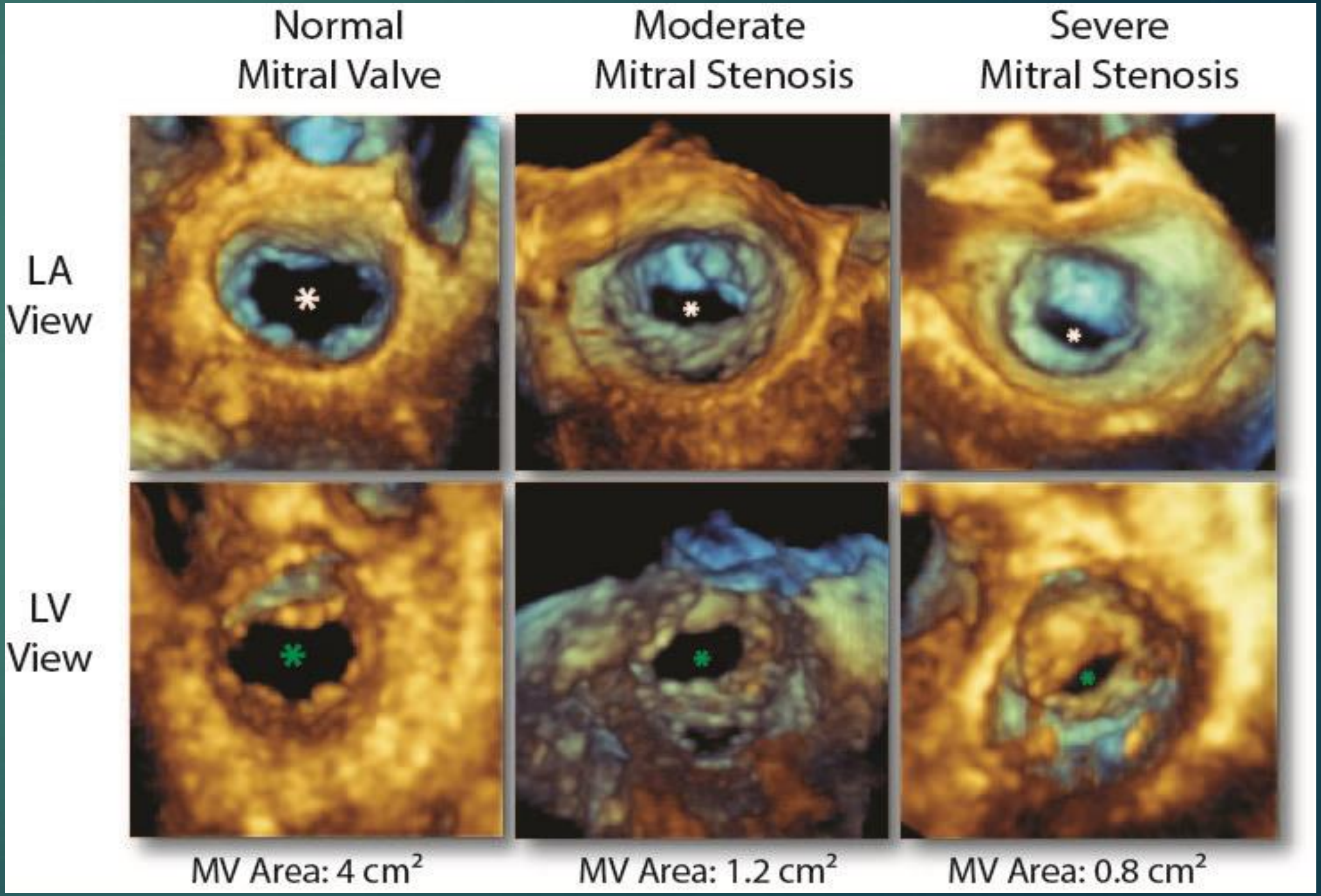
TAPSE Using Two Techniques



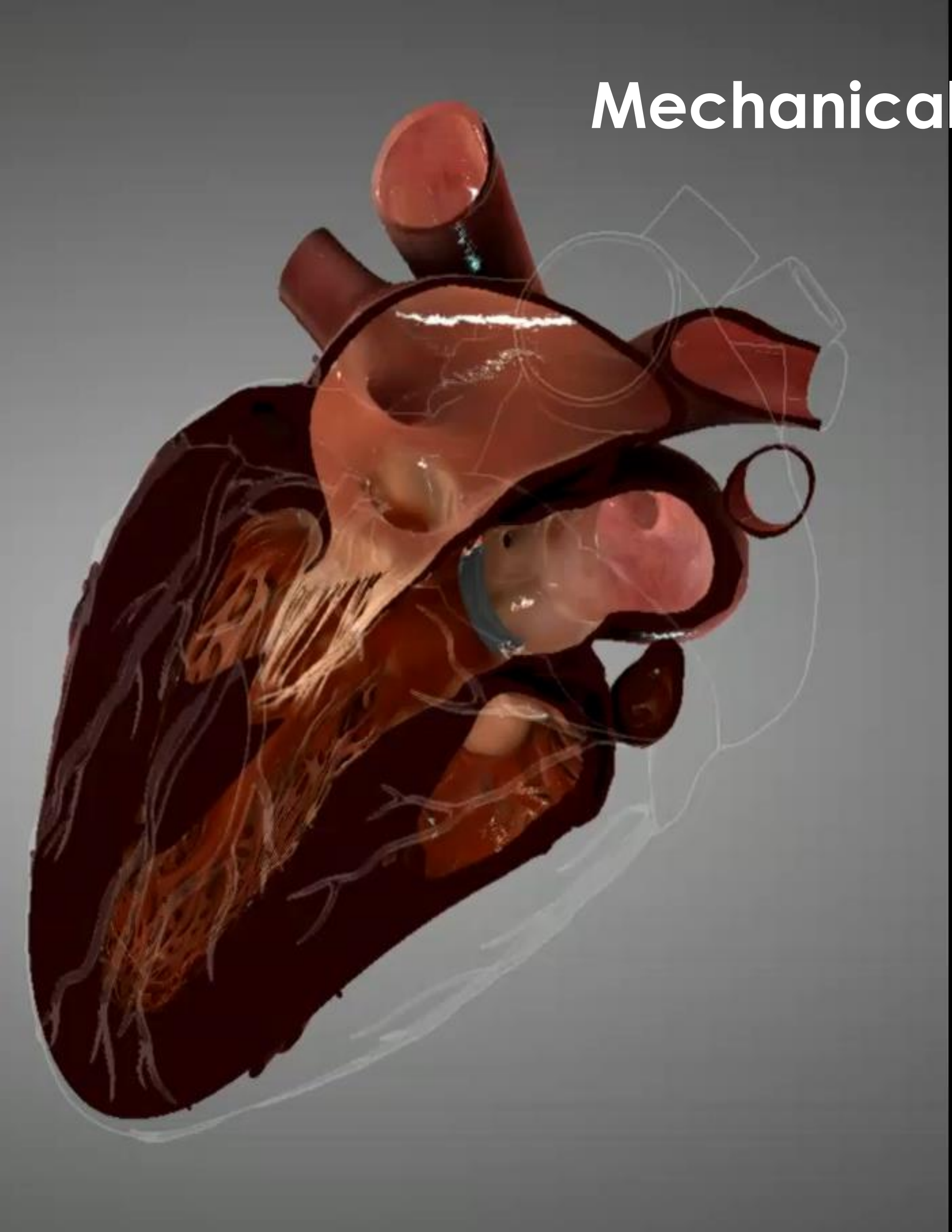


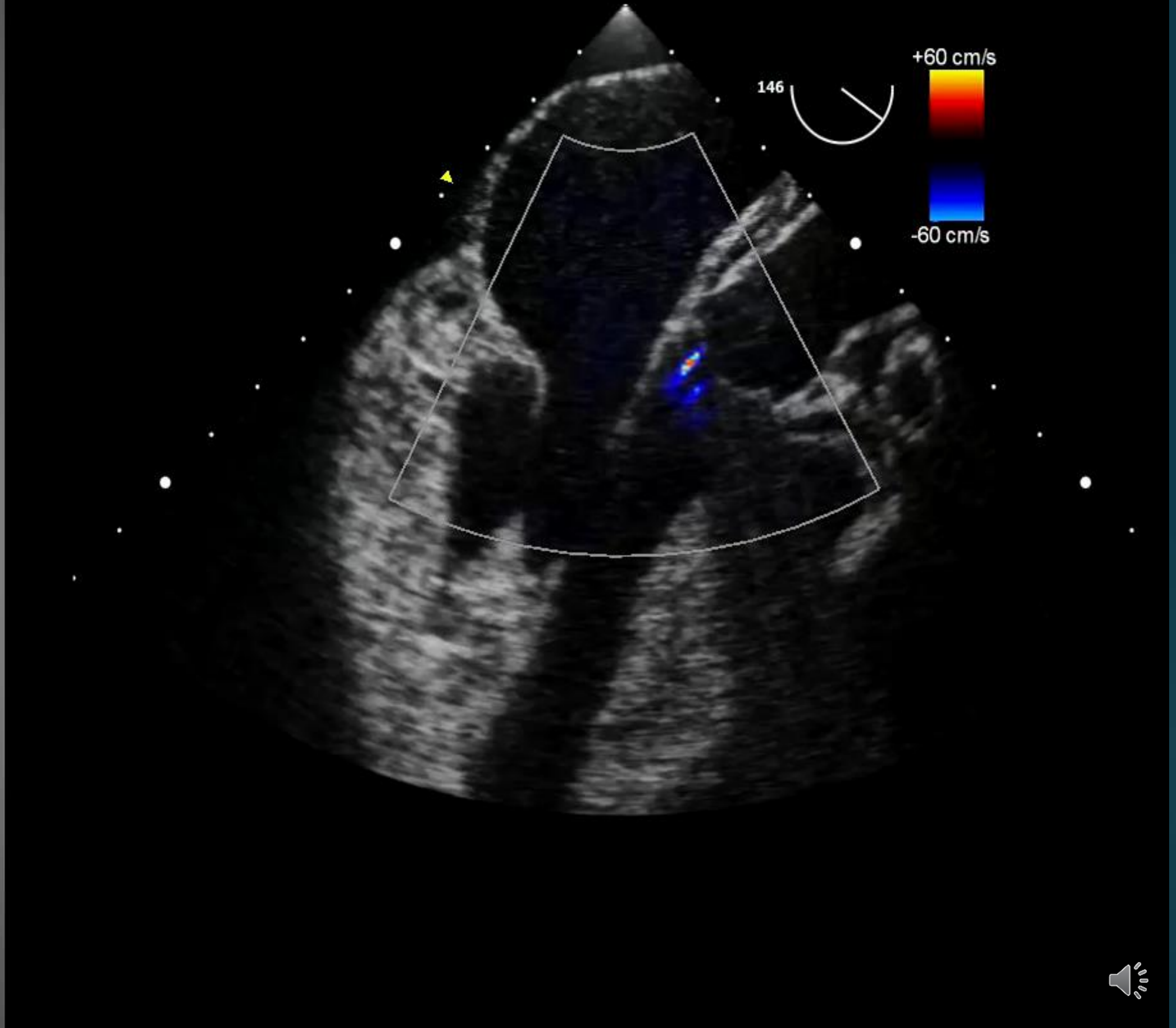
Role of TEE with Mitral Stenosis

- Assess pulmonary artery pressures
- Assess tricuspid valve function
- Assess biventricular function especially RV
- Assess LV filling
- Assess for other issues such as patent foramen ovale

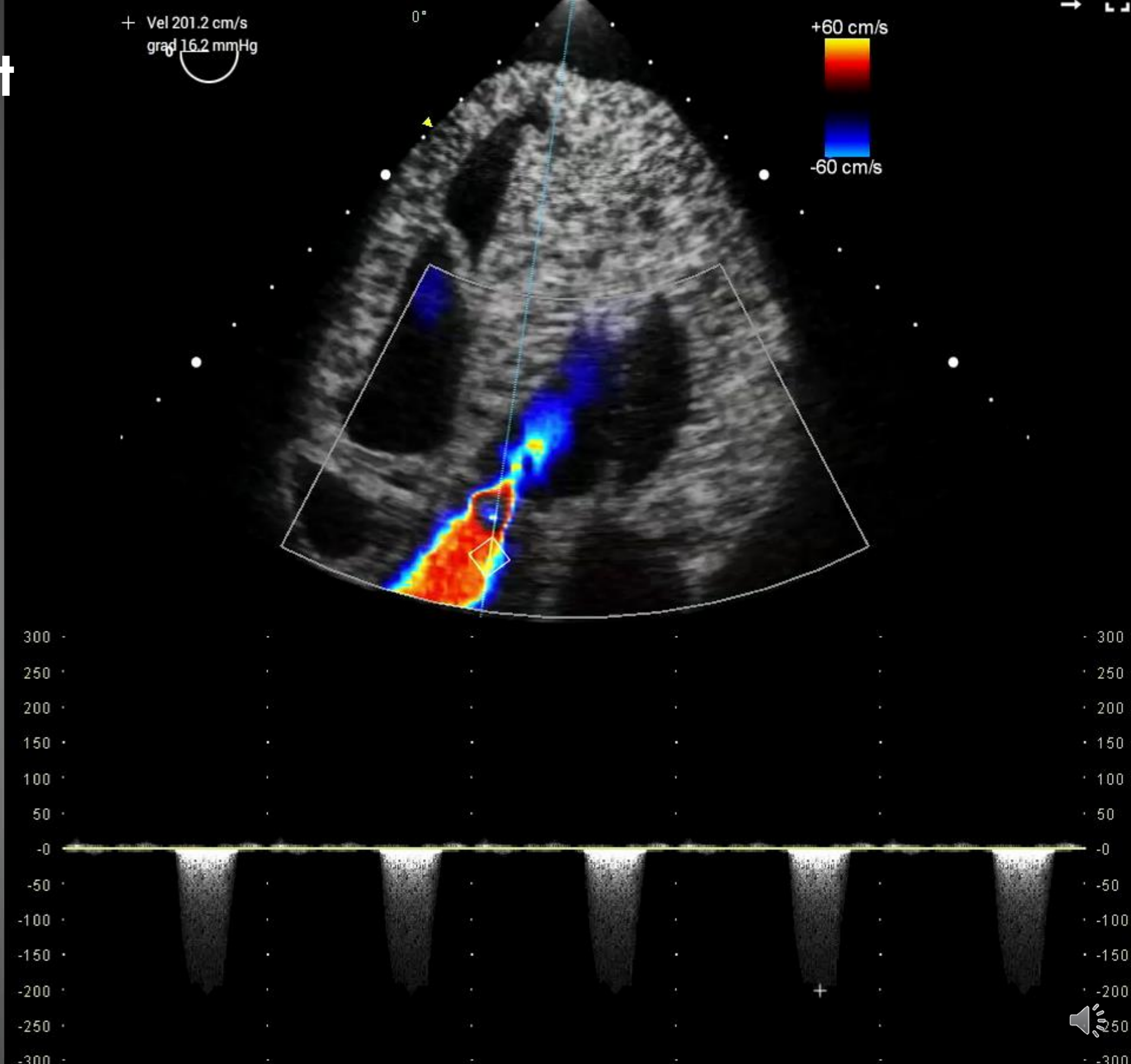


Mechanical AV Assessment





Mechanical AV Assessment



Summary

- Advanced TEE may be used as a supplement for line placement, de-airing and cannulation
- Diagnostic use of advanced TEE includes native and prosthetic valve assessment
- Continuous and pulse wave doppler modes have high utility in advanced TEE