Aortic Regurgitation

Evaluation by 2-D and Doppler Echocardiography

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MAYO CLINIC

DISCLOSURES

Relevant Financial Relationship(s)

None

Off Label Usage

None

Etiology of Aortic Regurgitation

Valvular

Chronic

- Degenerative/calcific
- Bicuspid aortic valve
- Infective endocarditis
- Prosthetic valve failure
- Rheumatic fever
- Inflammatory (RA, SLE, Crohn's, Whipple, Ankylosing Spondylitis)
- Congenital (SubAo Stenosis, VSD)
- Myxomatous disease
- Drug induced

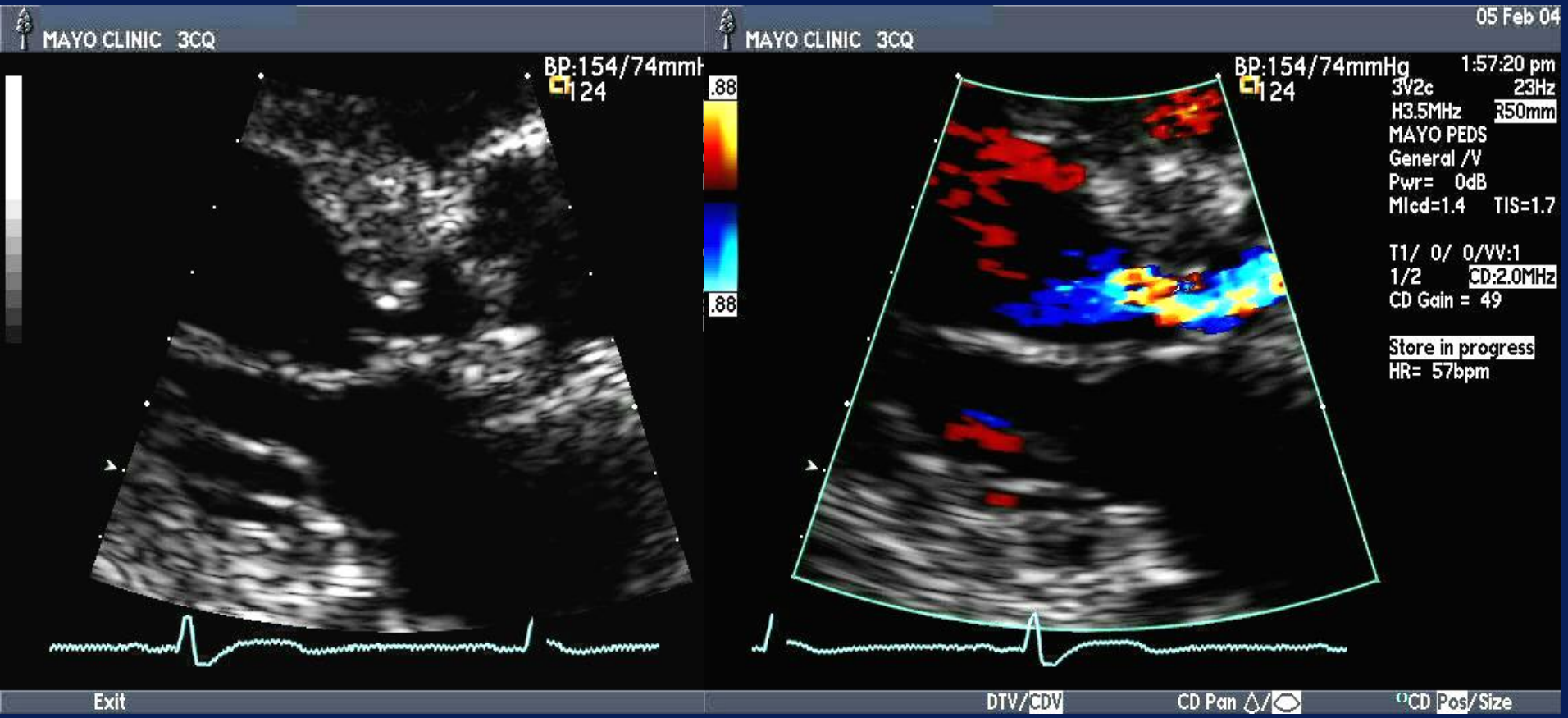
Acute

- Infective endocarditis
- Traumatic

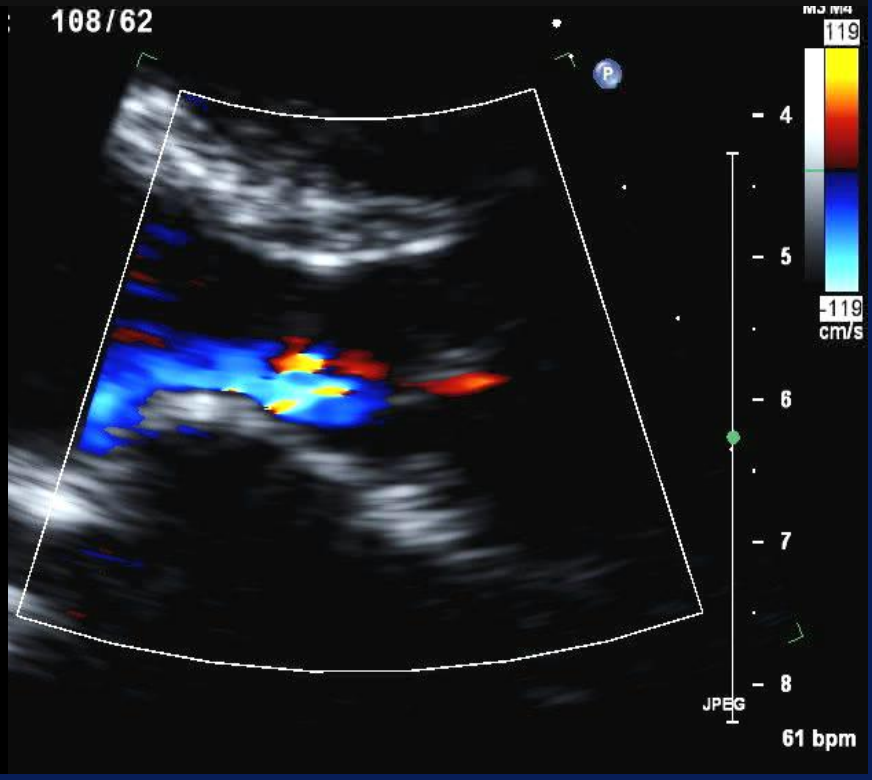
Bicuspid Aortic Valve and Aortopathy

Bicuspid Aortic Valve and Aortopathy

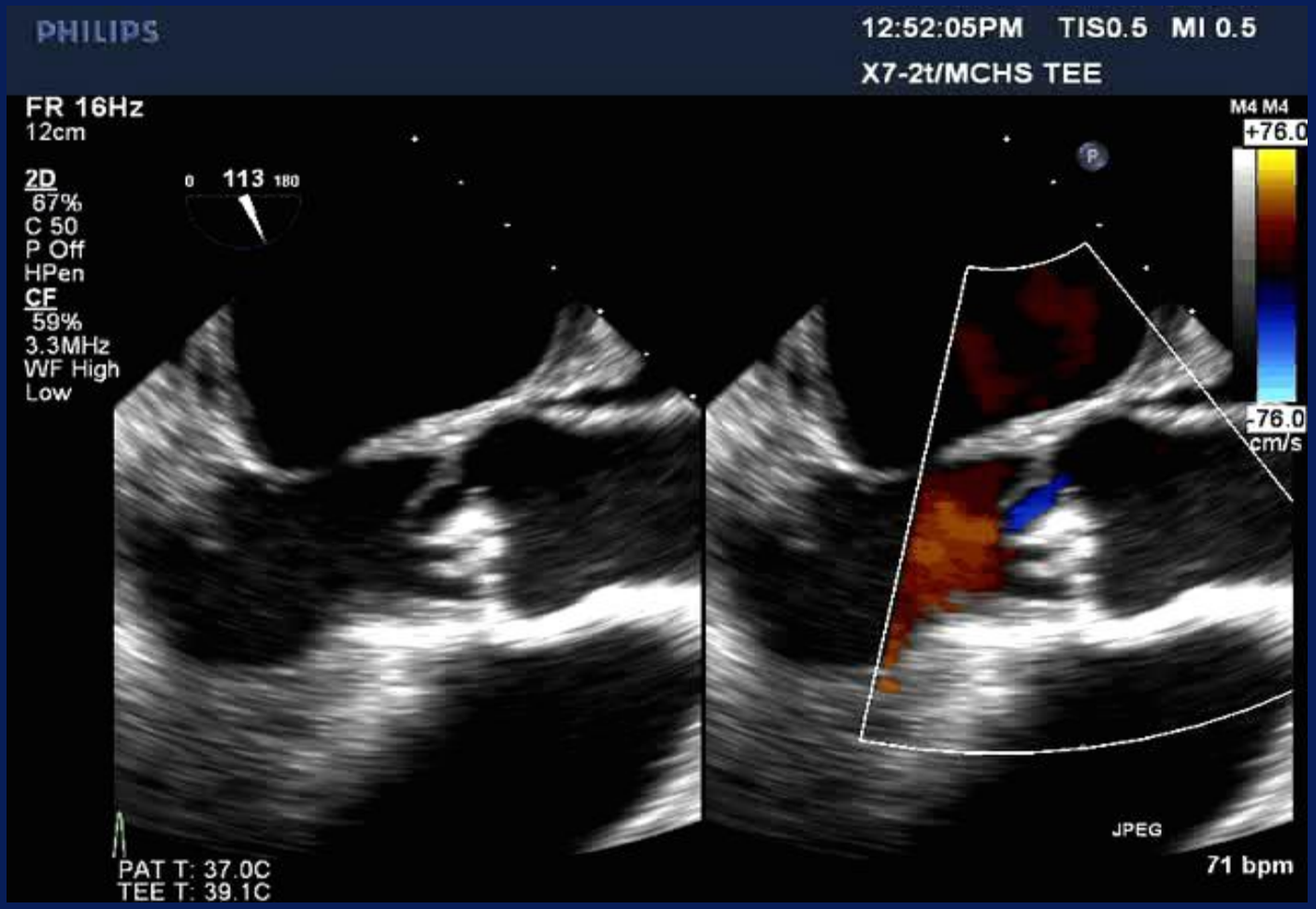
Congential Subaortic Stenosis



Rheumatic Aortic Valve Disease



Infective Endocarditis



Etiology of Aortic Regurgitation

Ascending Aorta

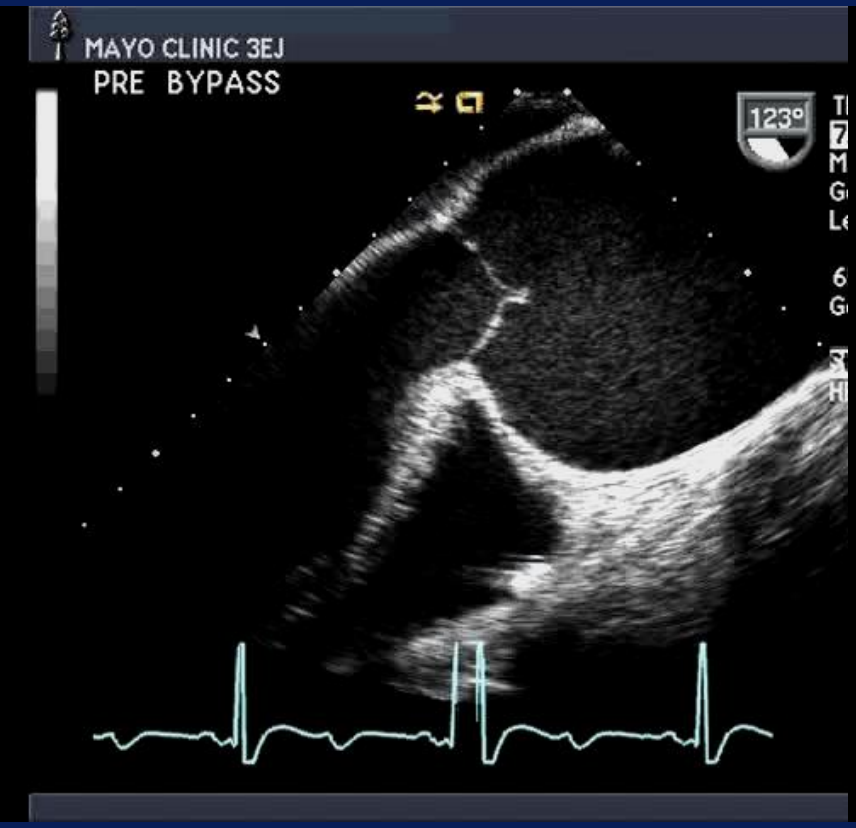
Chronic

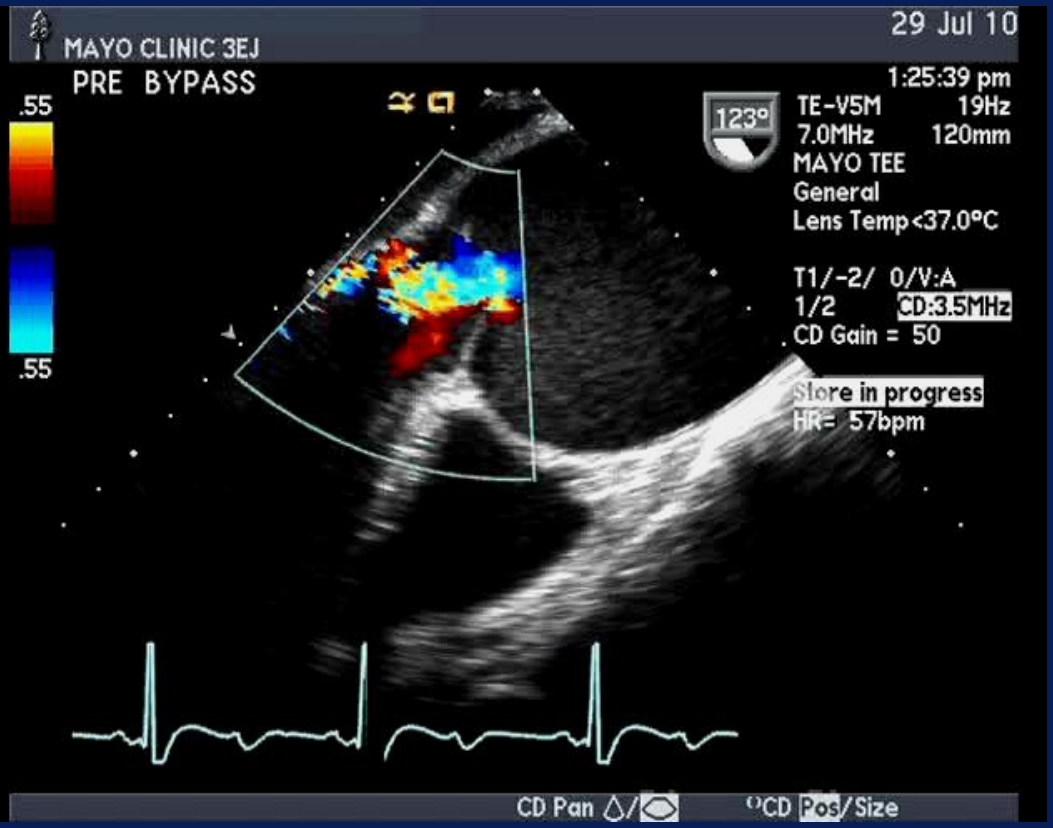
- Degenerative
- Hypertension
- Bicuspid aortopathy
- Collagen vascular disease (Marfan, Loeys Dietz, Ehlers Danlos Syndromes)
- Inflammatory (Reiters, Behcets, ankylosing spondylitis, relapsing polychondritis, psoriatic arthritis, giant cell arteritis)

Acute

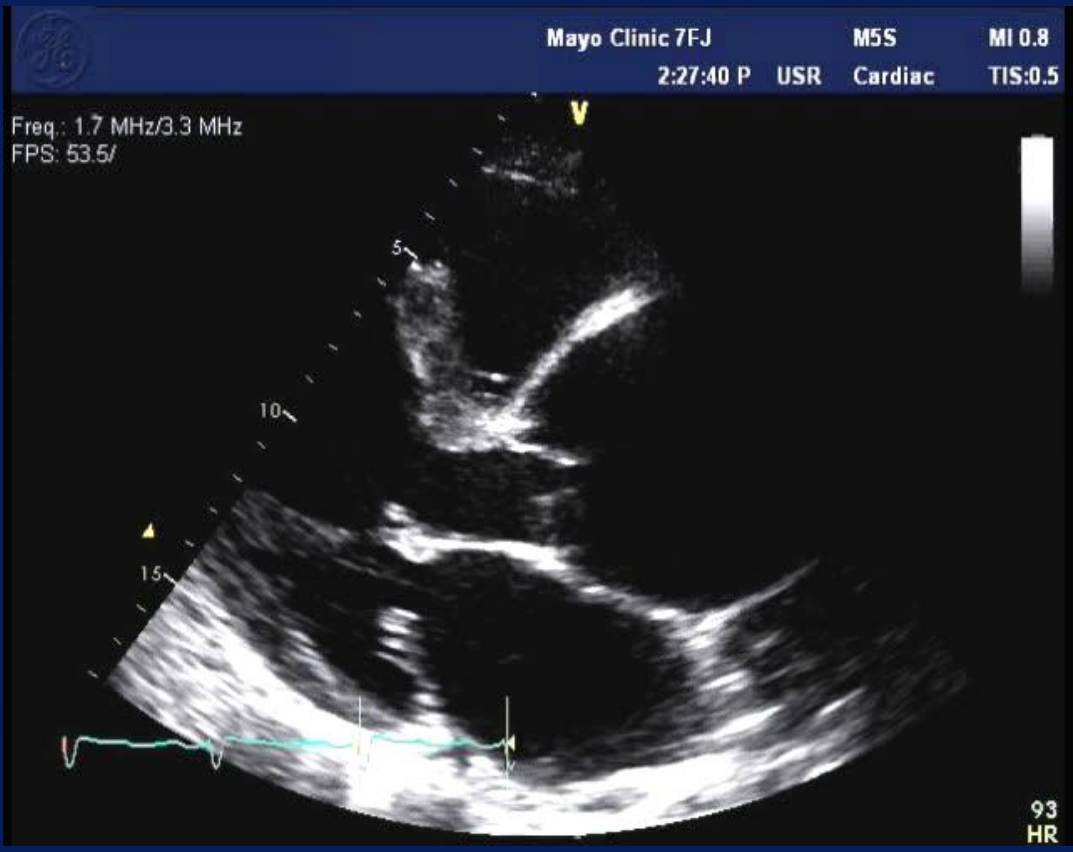
- Type A dissection
- Type A aortic intramural hematoma
- Traumatic

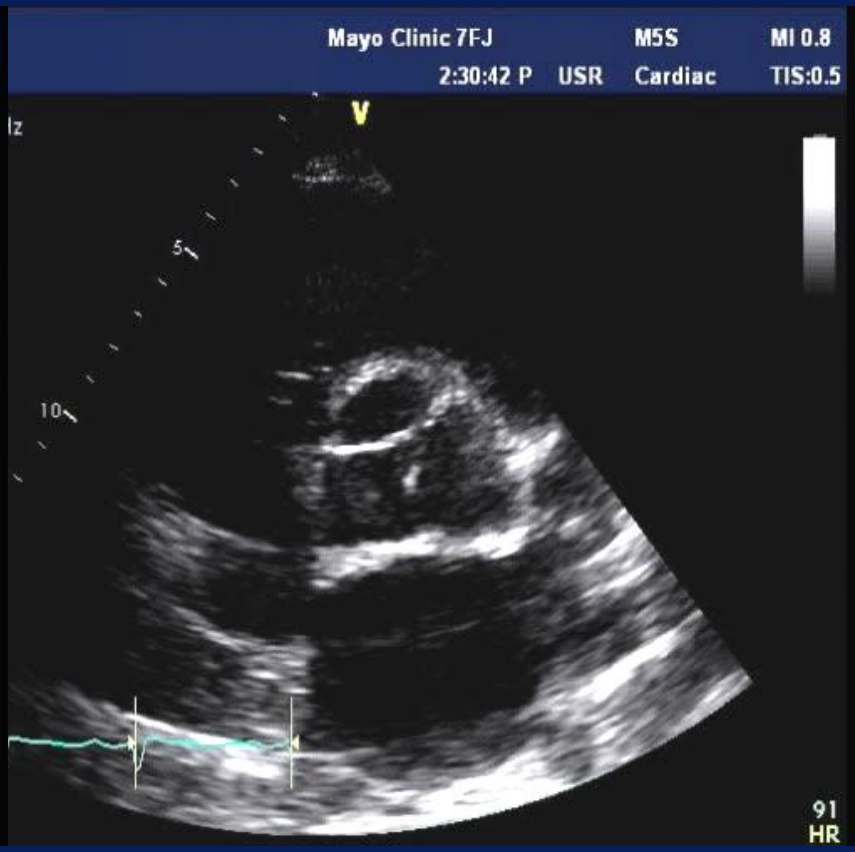
Ascending Aortic Aneurysm
Marfan Syndrome



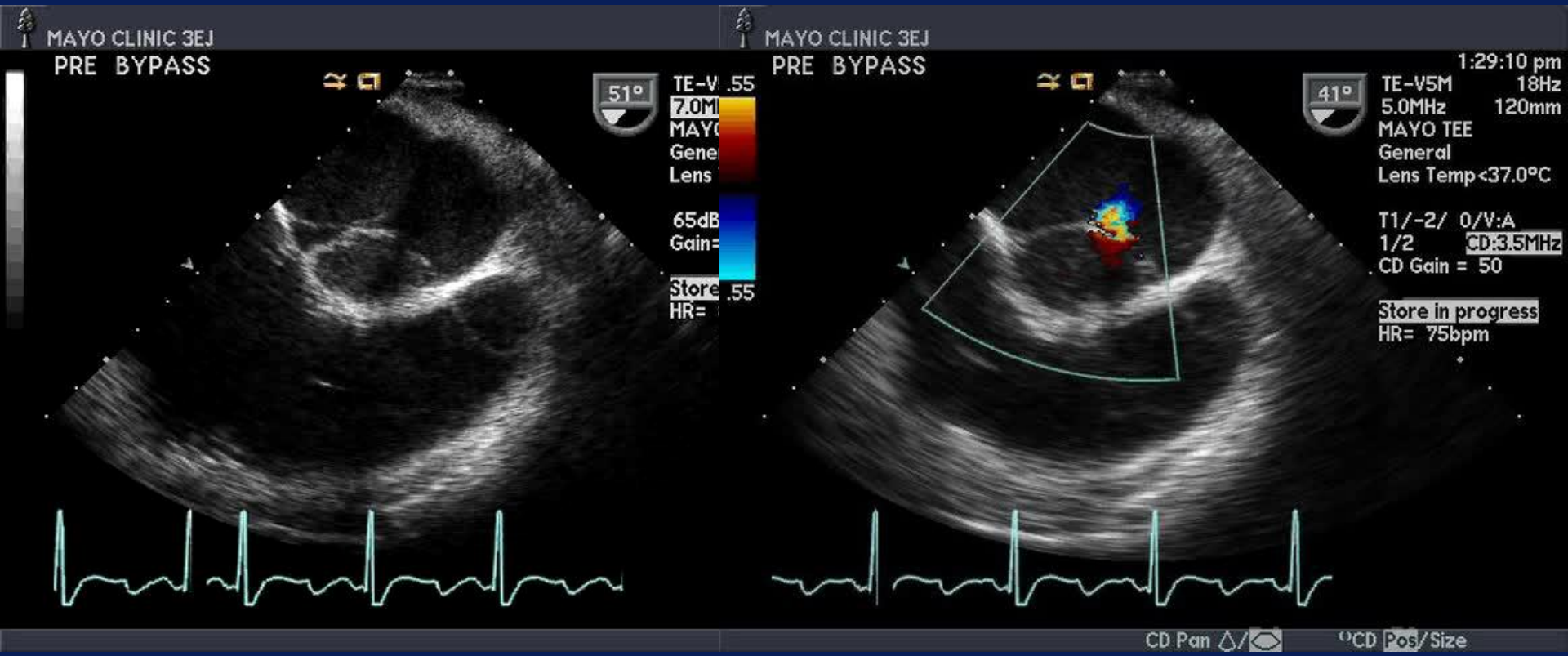


Ascending Aortic Aneurysm

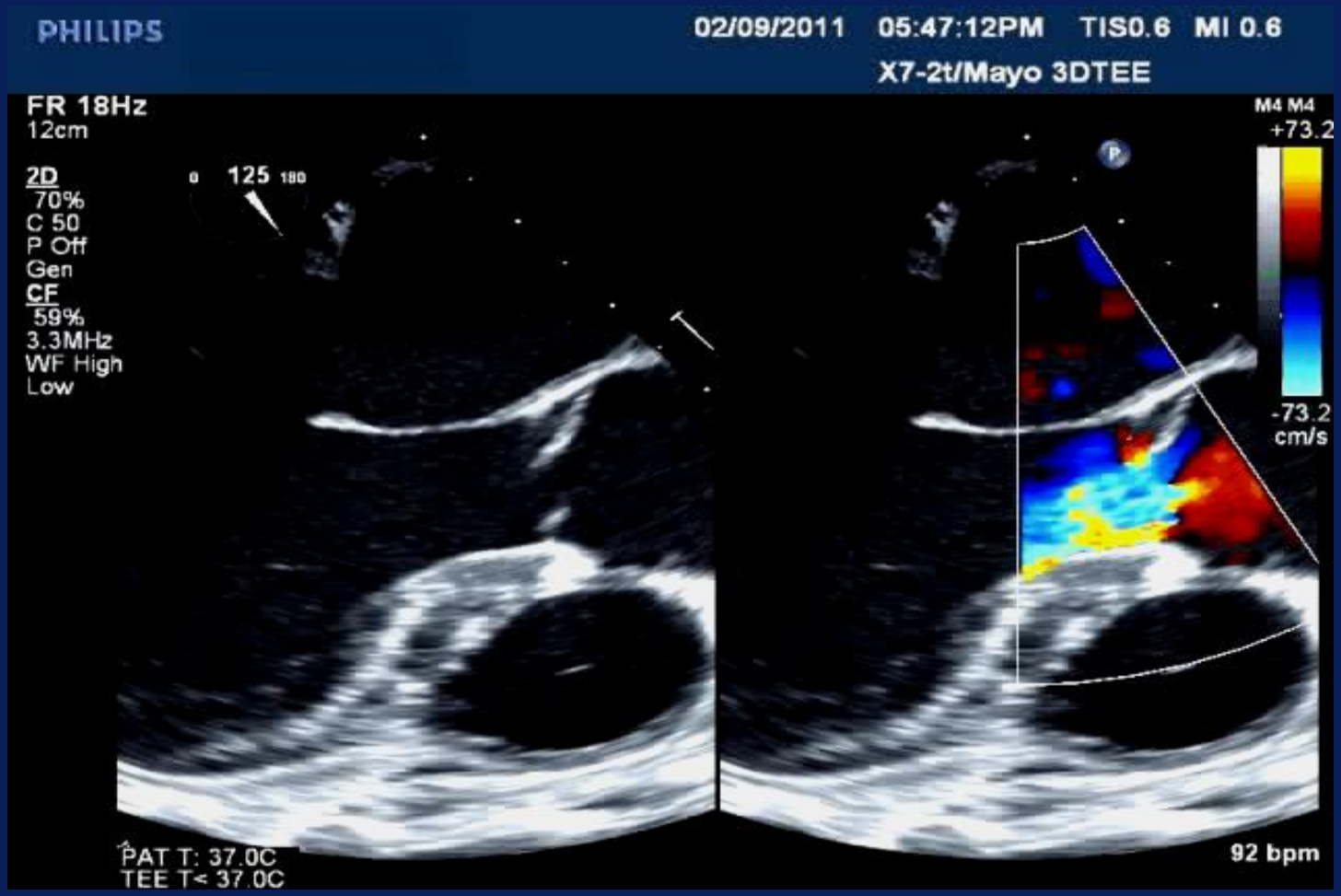




Ascending Aortic Aneurysm
Marfan Syndrome

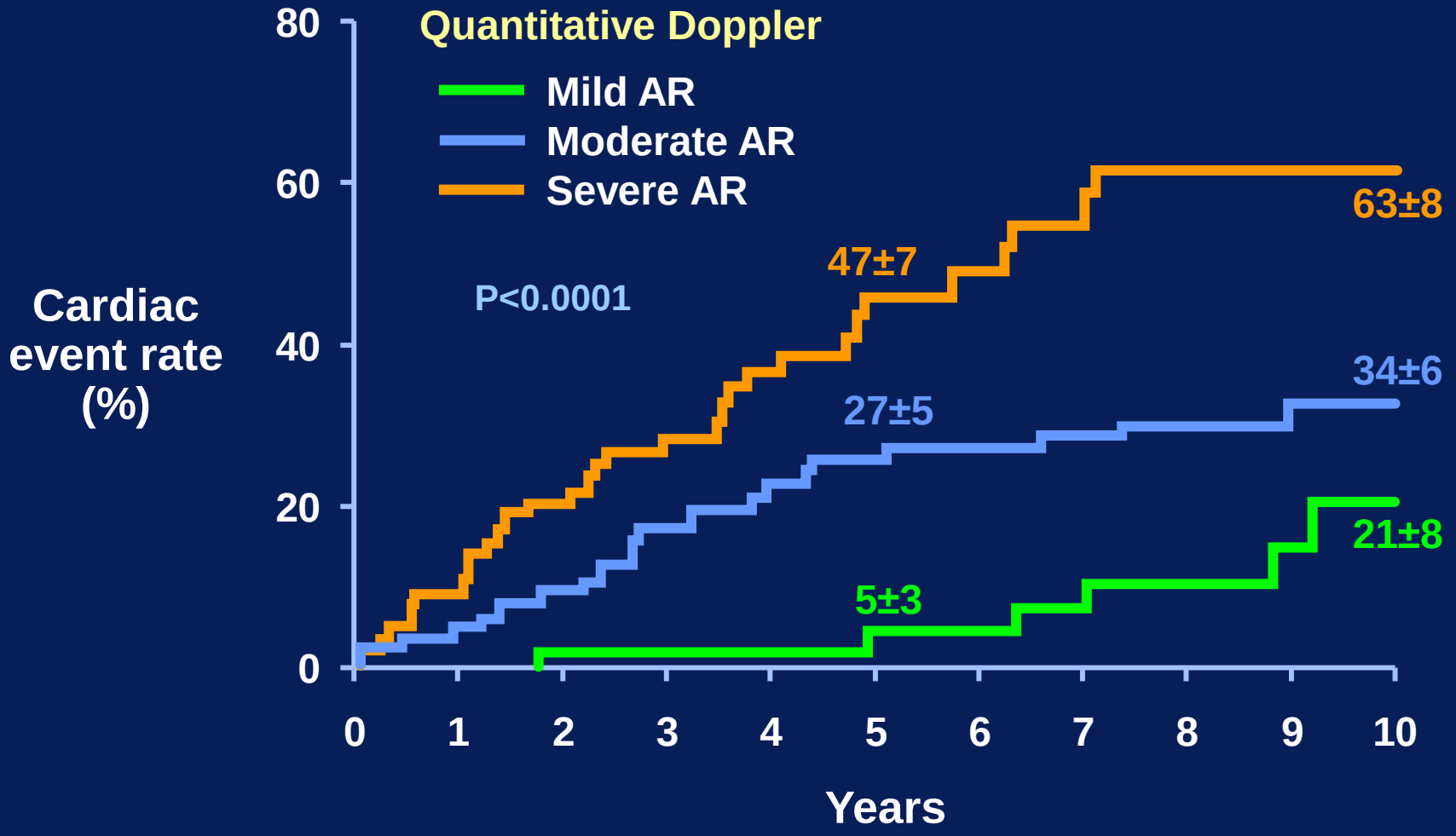


Type A Aortic Dissection



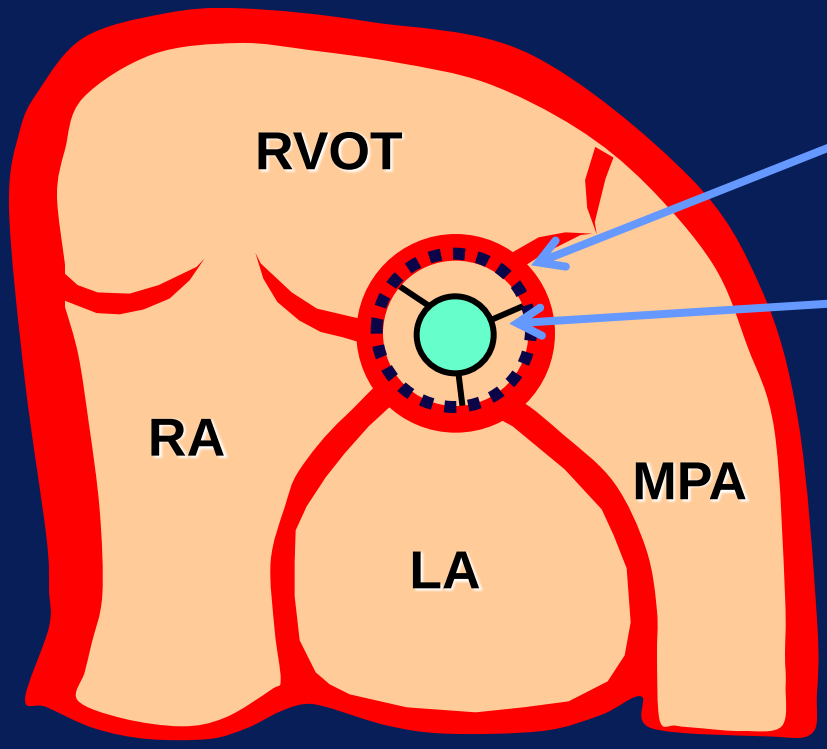
Initially Asymptomatic Aortic Regurgitation

Events: Heart Failure, New AFib, Cardiac Death



Detaint D, et al: JACC 2008; 1:1

Aortic Regurgitation: Semiquantification
Color Flow Doppler
Parasternal Short- Axis



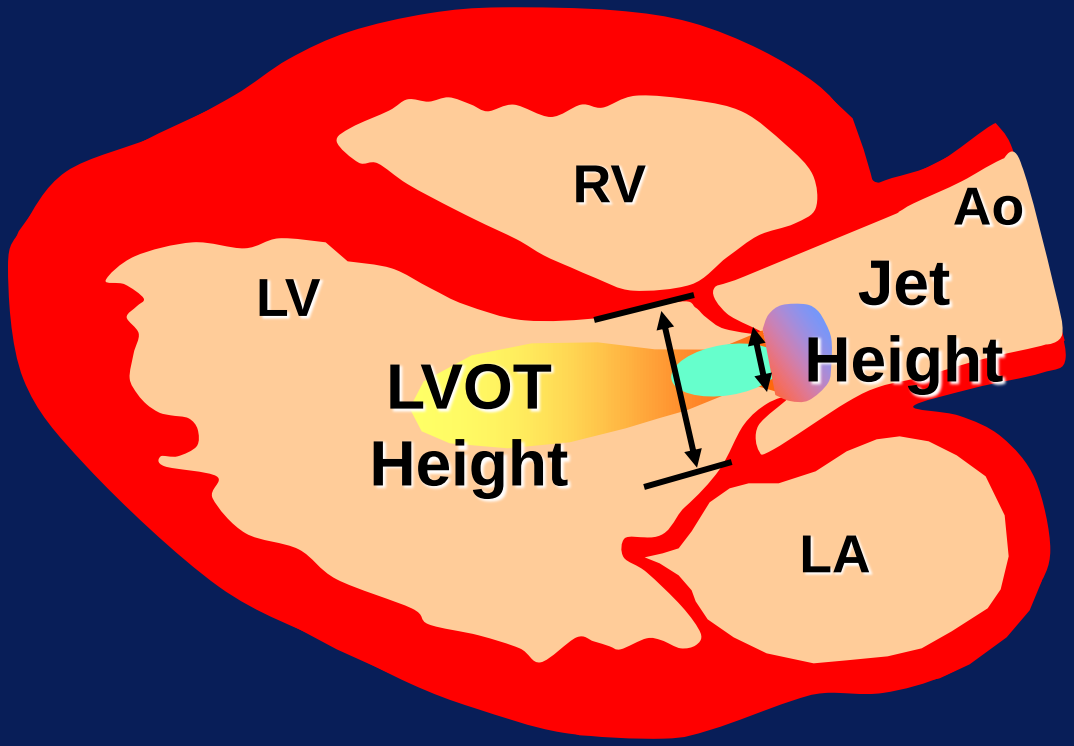
LVOT Area

Regurgitant Jet Area

Jet / LVOT Area

Oh JK et al: The Echo Manual; 3rd Edition
Perry GJ, et al JACC 1987

Aortic Regurgitation: Semiquantification
Color Flow Doppler
Parasternal Long- Axis



Jet / LVOT Height

Oh JK et al: The Echo Manual; 3rd Edition
Perry GJ, et al JACC 1987

Aortic Regurgitation: Semiquantification

Color Flow Doppler

Severity	Jet/LVOT Area (%)	Jet/LVOT Height (%)
Grade I	<5	<25
Grade II	5-24	25-46
Grade III	25-59	47-60
Grade IV	≥60	≥60

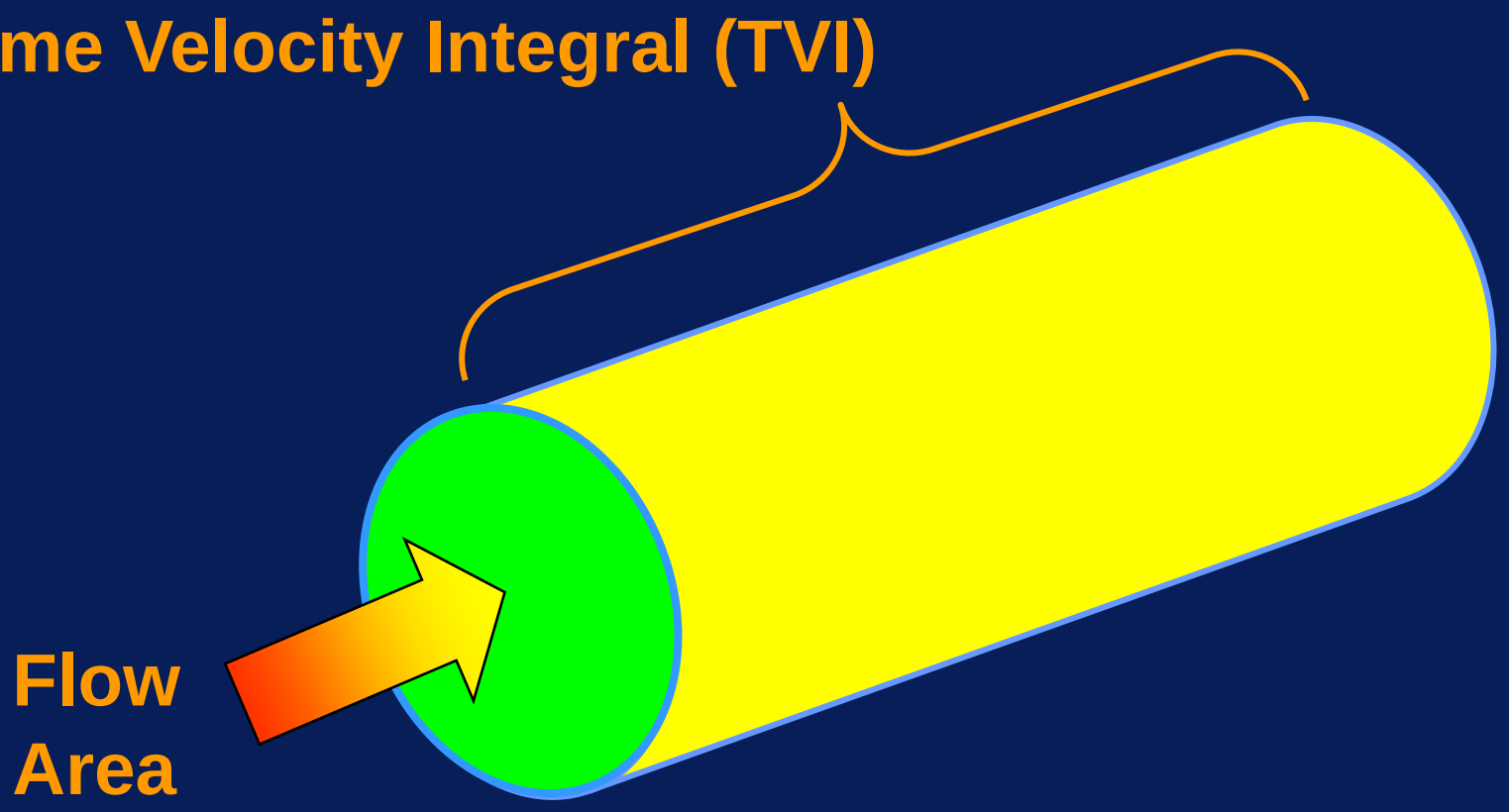
Perry GJ, et al JACC 1987

Quantitation of Aortic Regurgitation

Continuity Method

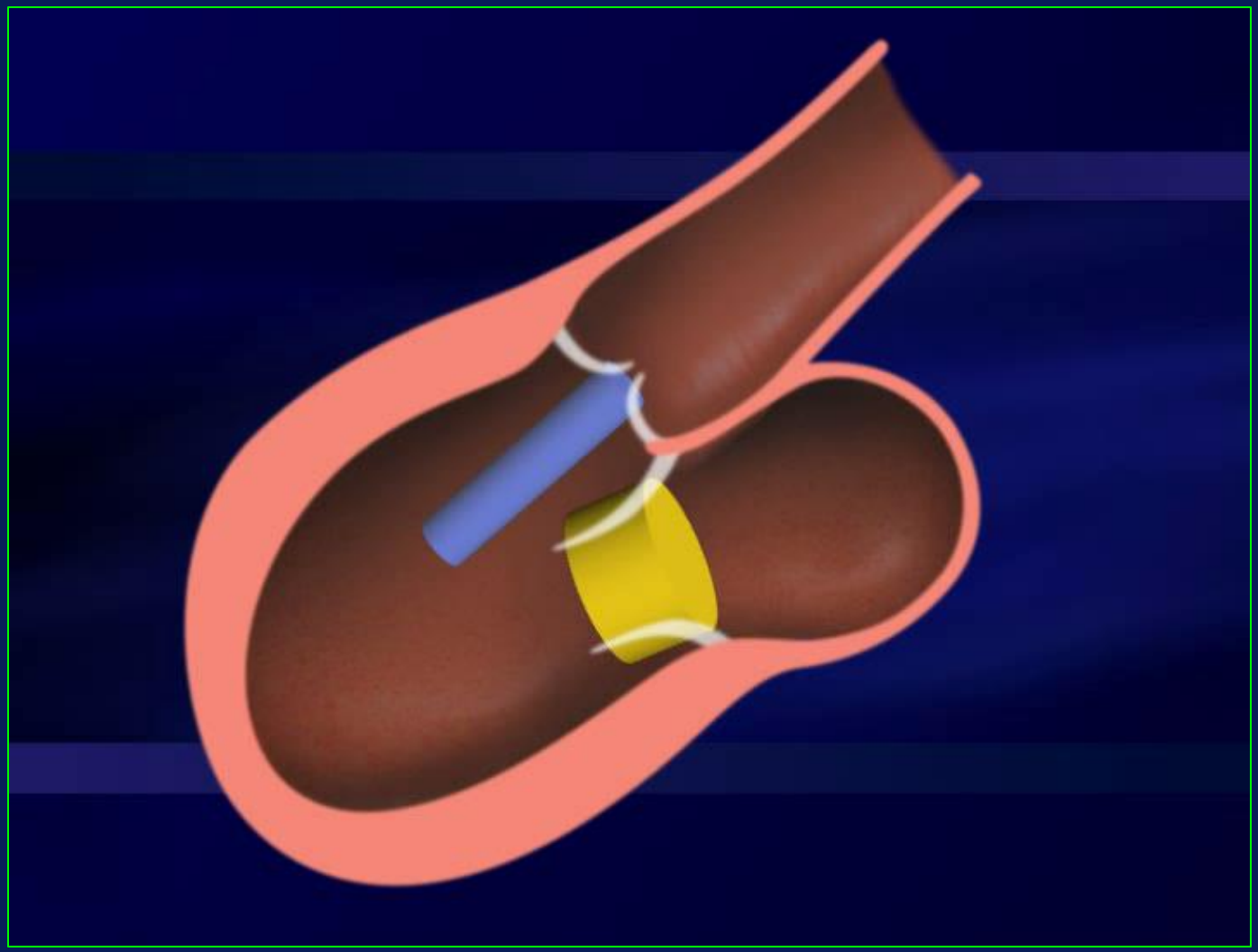
Pulsed-Wave Doppler

Doppler Quantitation: Volume

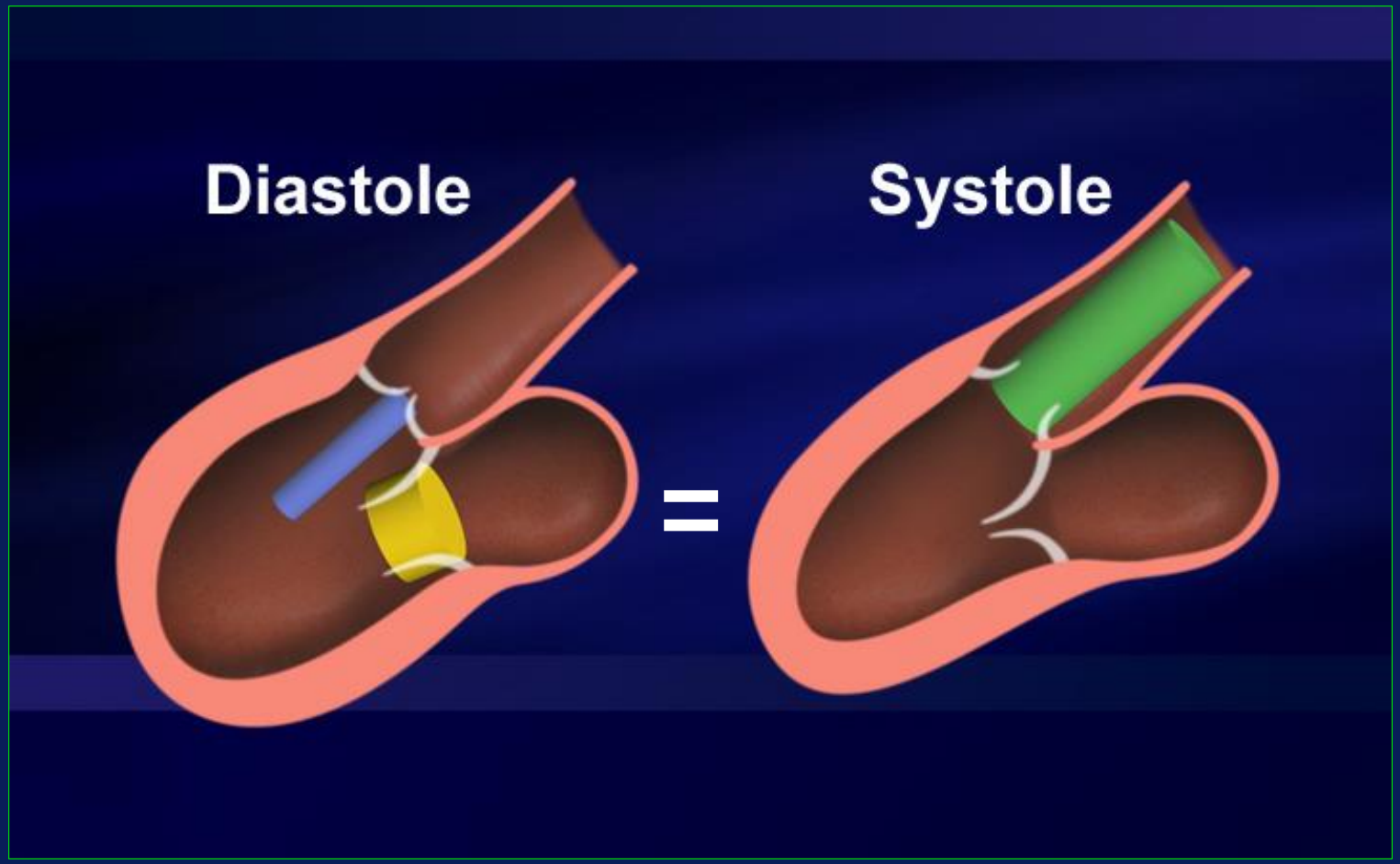


Stroke Volume = $\pi(D/2)^2$ x TVI = 0.785 D^2 x TVI

Doppler Quantitation of AR
Continuity Method

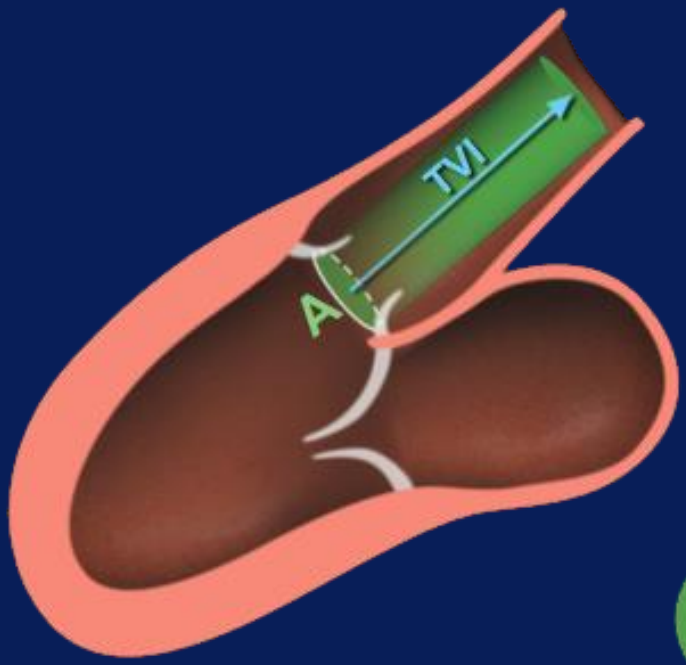


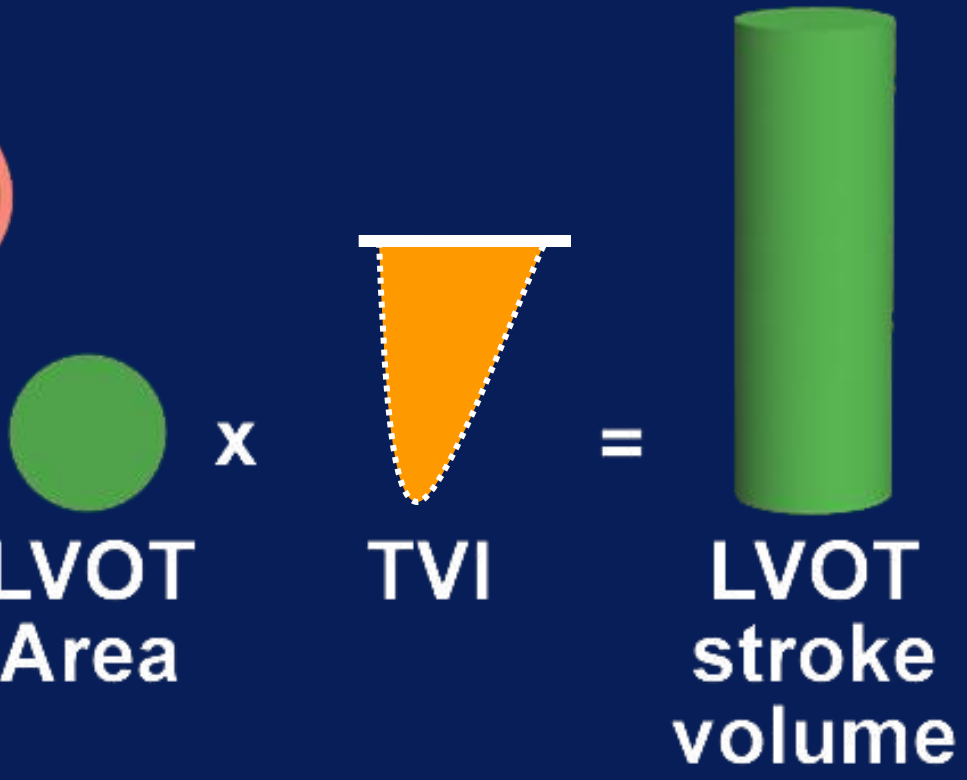
Doppler Quantitation of AR
Continuity Method



Quantitation of AR by the Continuity Method

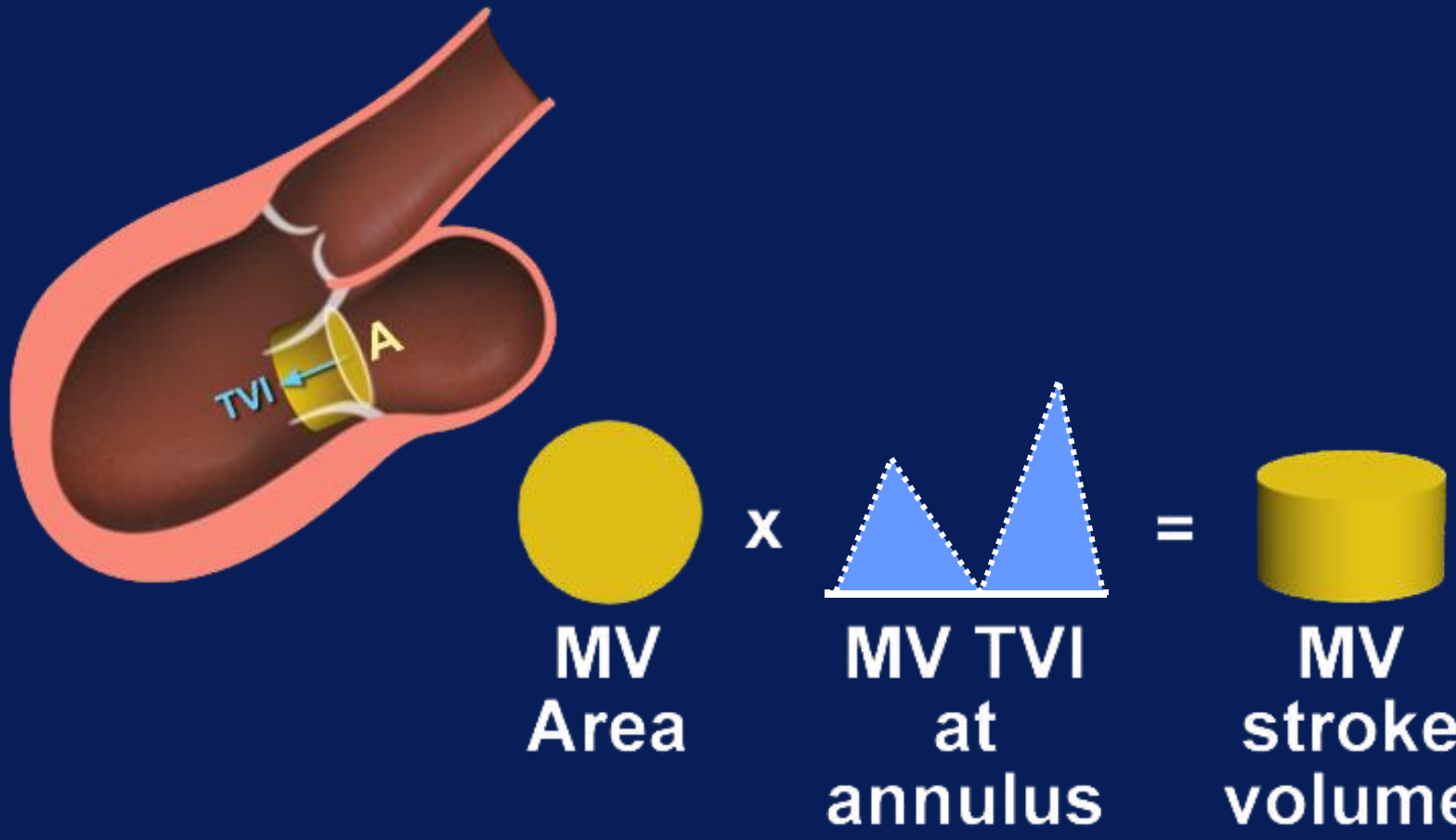
Step 1: Calculate LVOT Stroke Volume





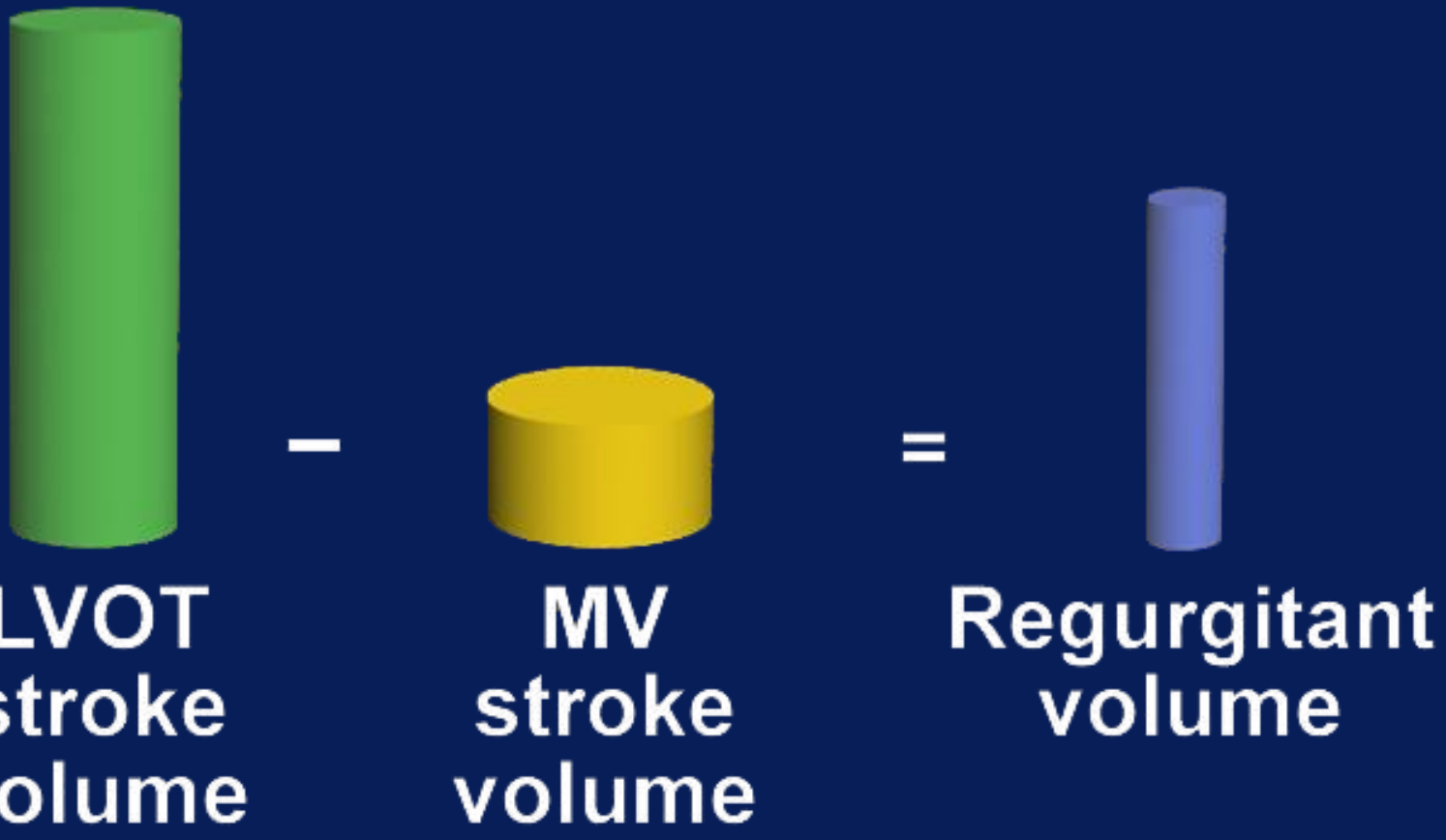
Quantitation of AR by the Continuity Method

Step 2: Calculate MV Stroke Volume

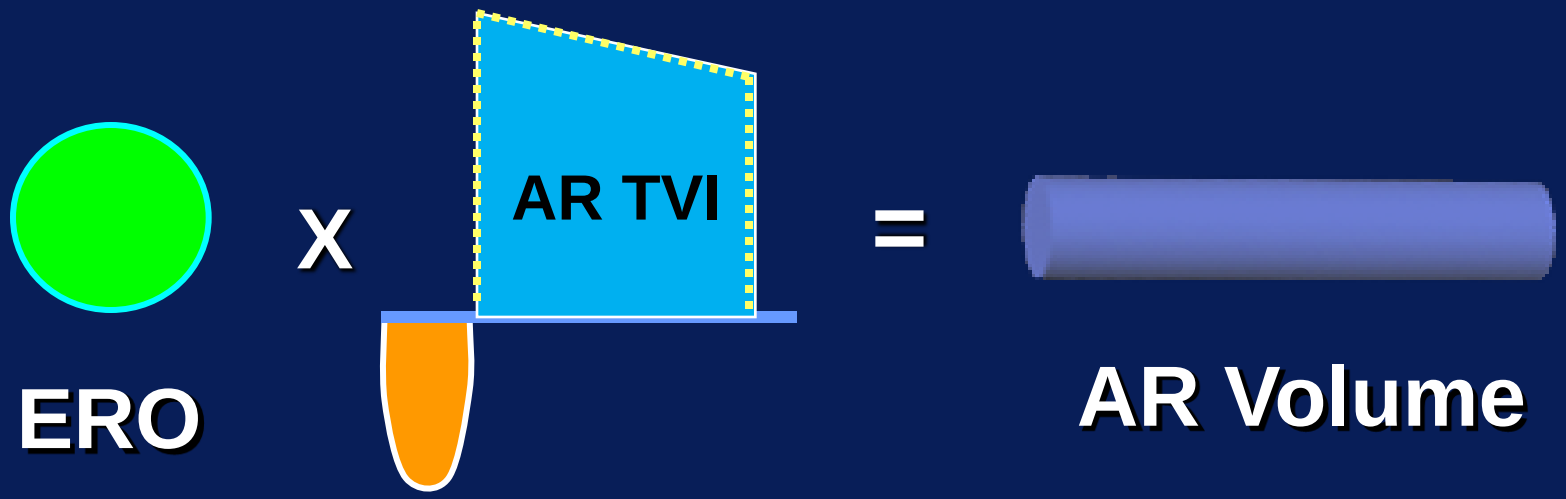


Quantitation of AR by the Continuity Method

Step 3: Calculate AR Volume

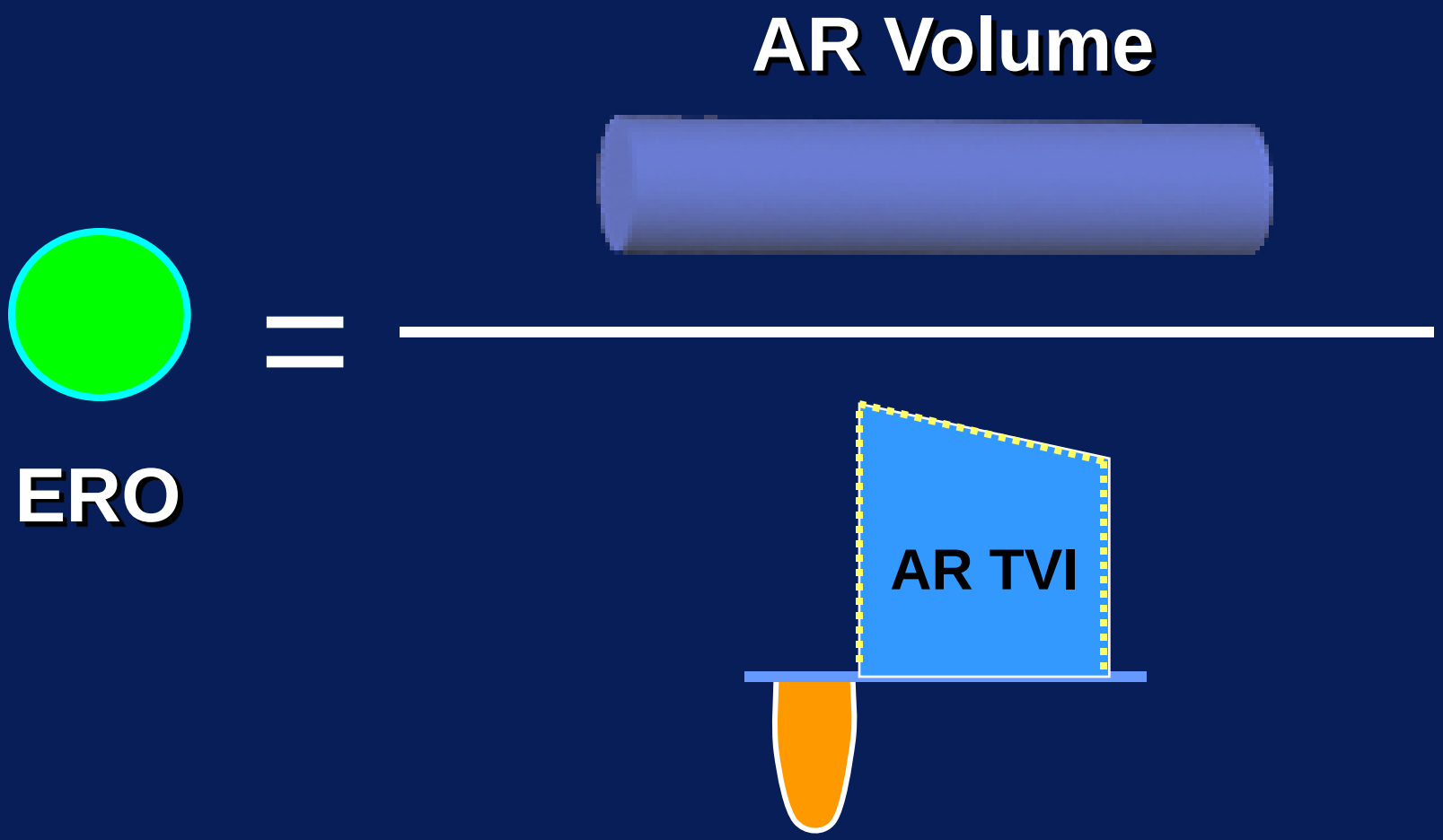


Doppler Quantitation of AR
Continuity Method



Quantitation of AR by the Continuity Method

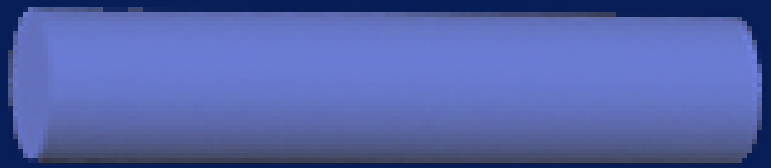
Step 4: Calculate ERO



Quantitation of AR by the Continuity Method

Step 5 : Calculate Regurgitant Fraction (RF)

$$RF = \frac{\text{AR Volume}}{\text{LVOT Stroke Volume}}$$



61 y/o Female: Dyspnea and heart failure

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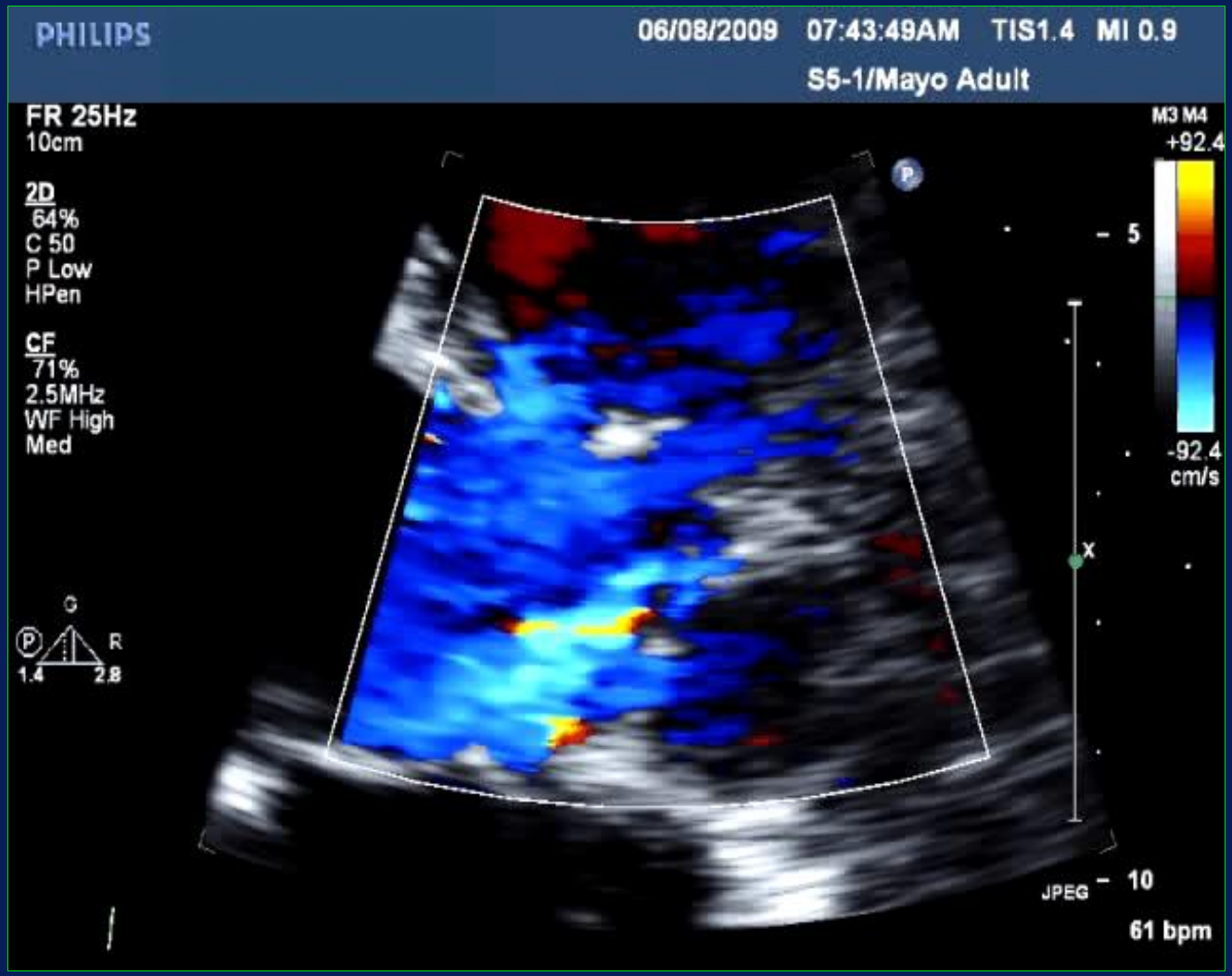
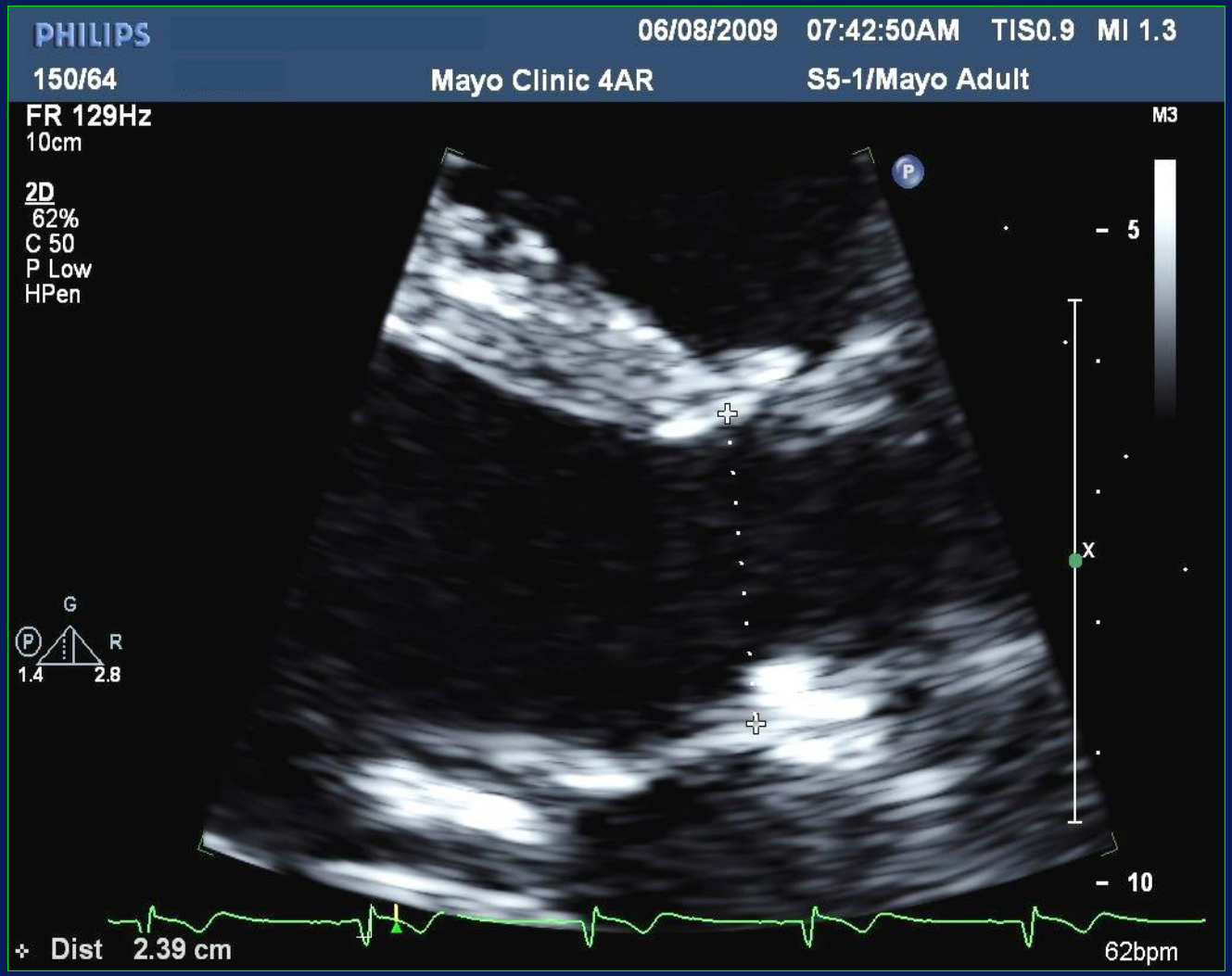
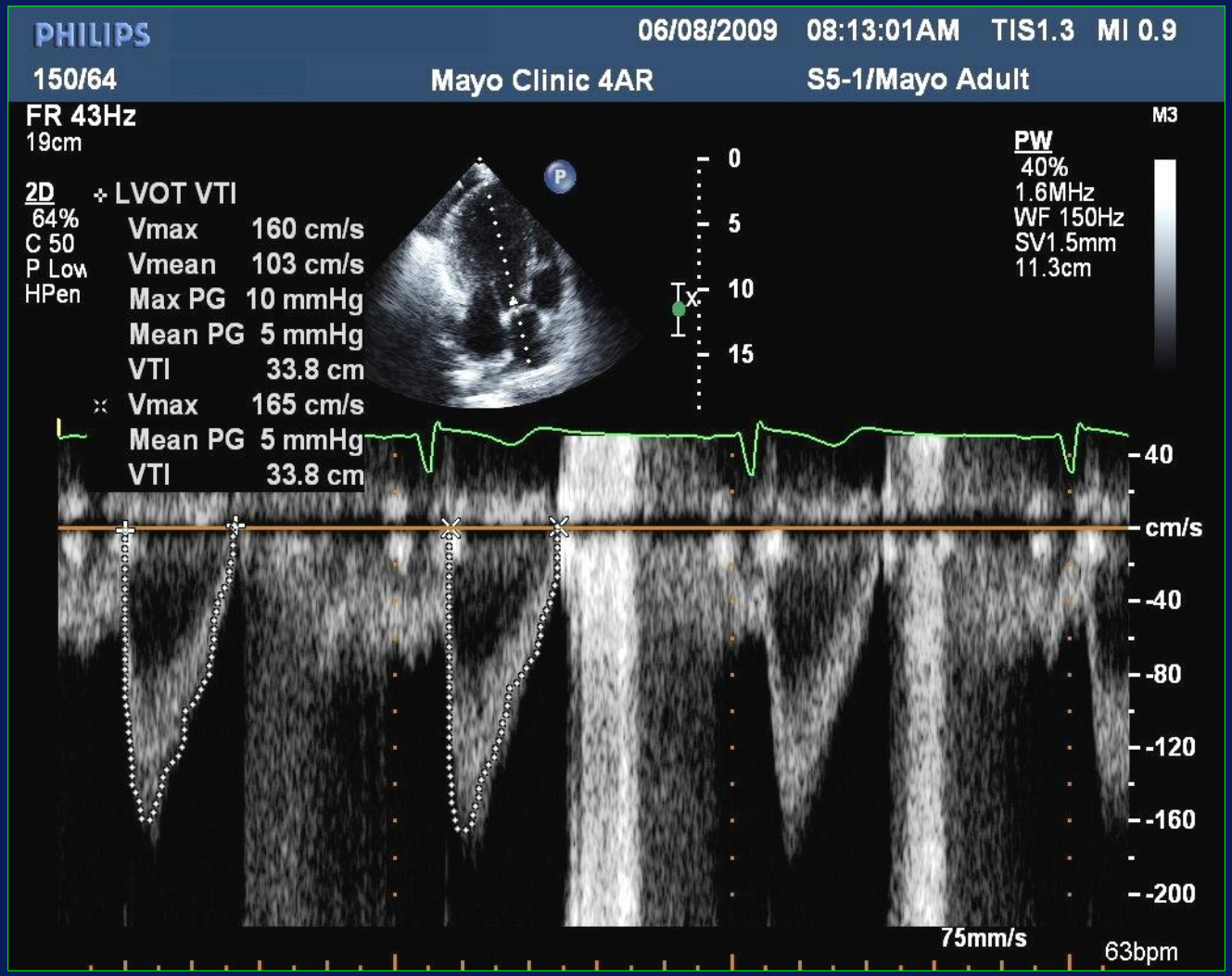


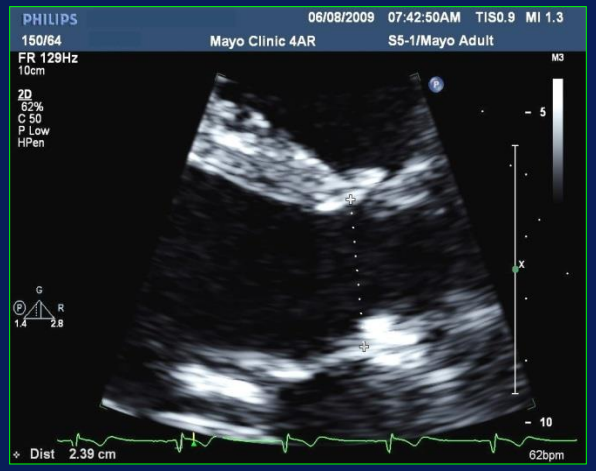
LVOT Diameter = 2.4 cm



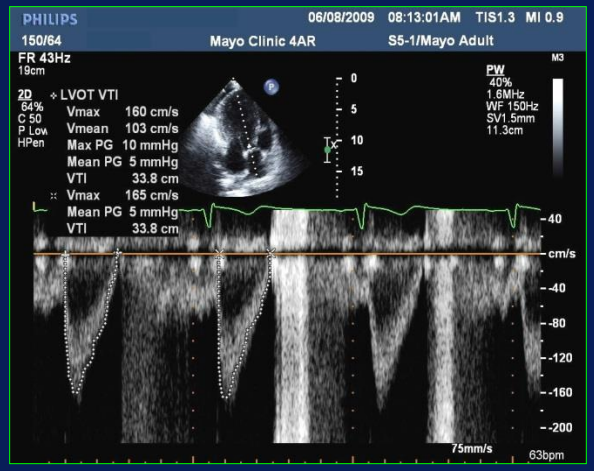
LVOT TVI = 34 cm



Step 1: Calculate LVOT Stroke Volume



LVOT Diameter = 2.4 cm



LVOT TVI = 34 cm

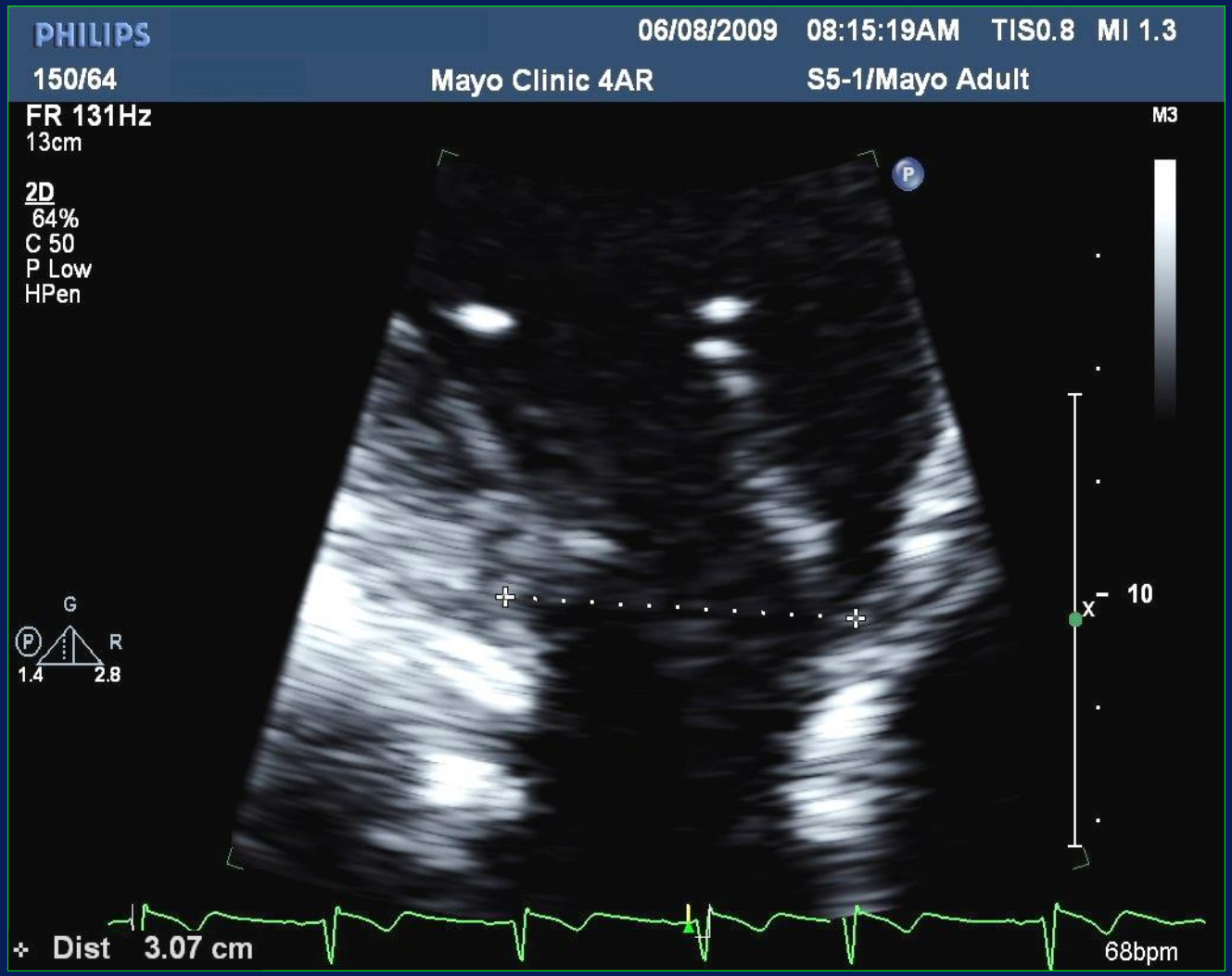
$$\text{LVOT Stroke Volume} = 0.785\,(2.4\text{ cm})^2 \times 34\text{ cm}$$

$$= 154\text{ cm}^3$$

Zoom MV

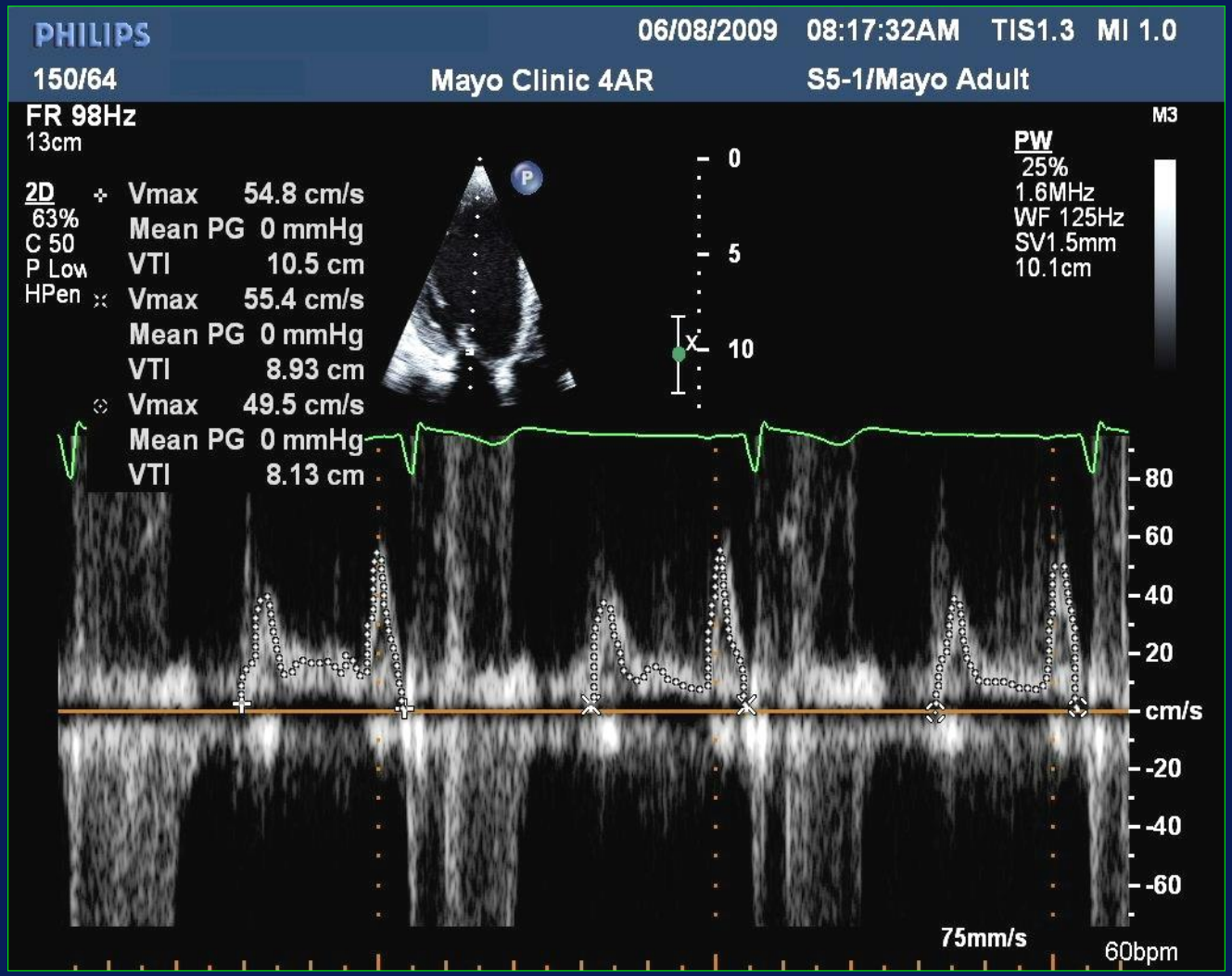

PHILIPS
06/08/2009 08:14:50AM TIS0.8 MI 1.3
S5-1/Mayo Adult
FR 131Hz
13cm
2D
64%
C 50
P Low
HPen
M3
10
C
P
R
1.4
2.8
JPEG
63 bpm

MV Annulus = 3.1 cm

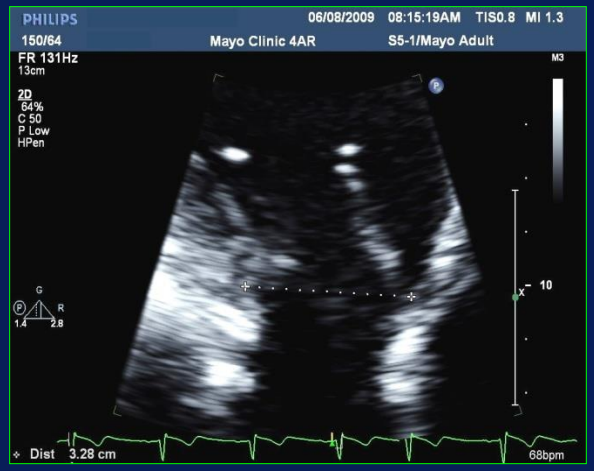


MV Annulus TVI = 9 cm

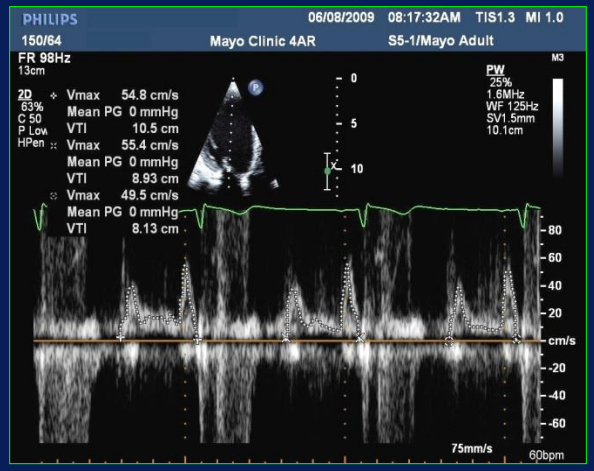
Sample volume at mitral annulus, not leaflet tips



Step 2: Calculate MV Stroke Volume



MV Annulus = 3.1 cm

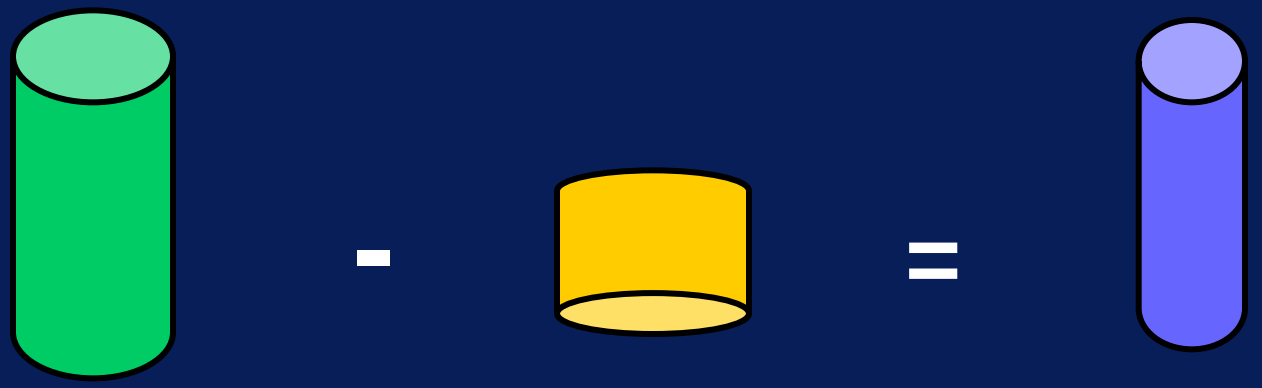


MV Annulus TVI = 9 cm

$$\text{MV Stroke Volume} = 0.785\,(3.1\text{ cm})^2 \times 9\text{ cm}$$

$$= 68\text{ cm}^3$$

Step 3: Calculate AR Volume



LVOT Stroke Volume

MV Stroke Volume

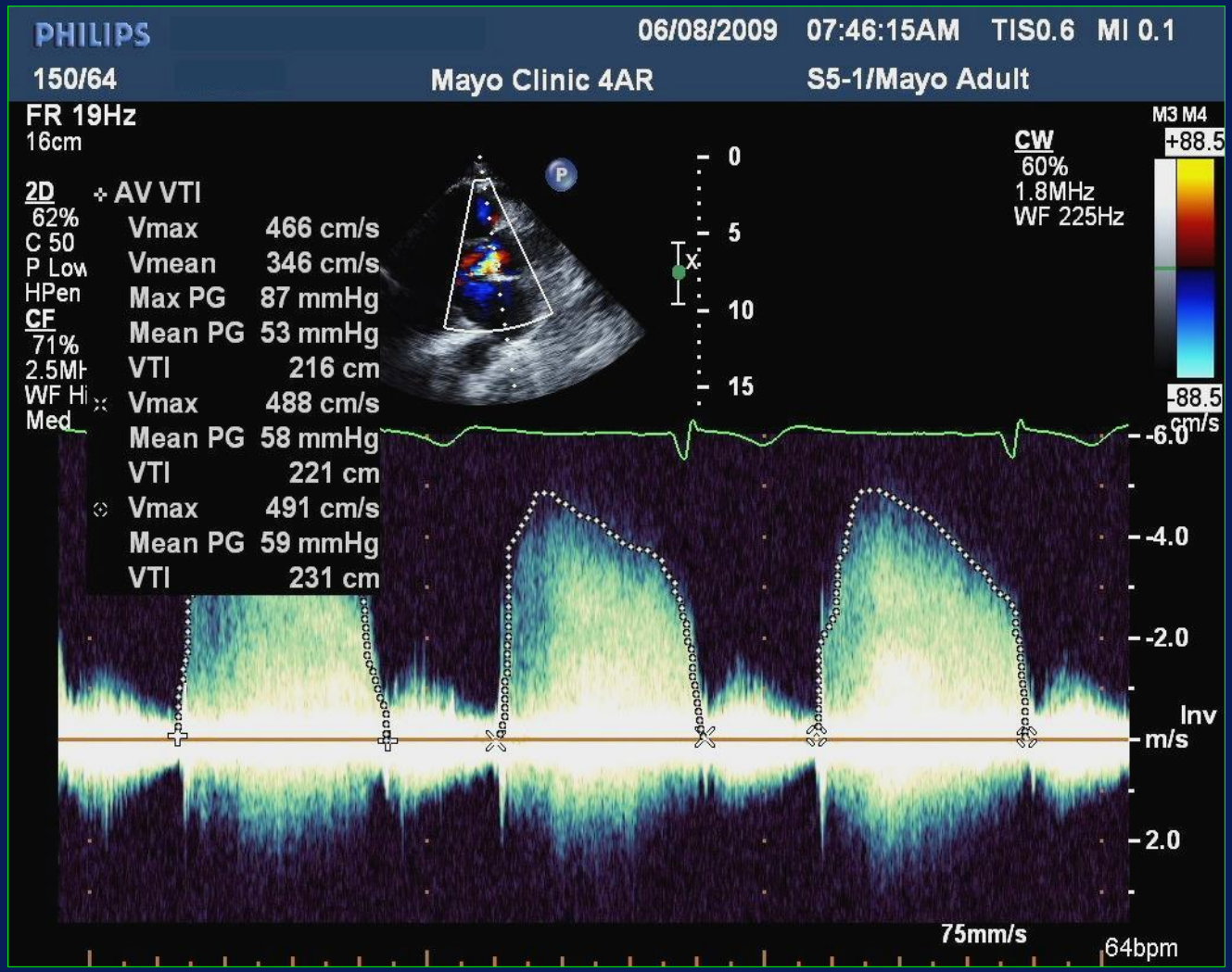
AR Volume

154 cm^3 - 68 cm^3 = 86 cm^3

Step 4: Calculate Regurgitant Fraction (RF)

$$\text{Aortic RF} = \frac{\text{AR Volume}}{\text{LVOT Stroke Volume}} = \frac{86\ \text{cm}^3}{154\ \text{cm}^3} = 56\%$$

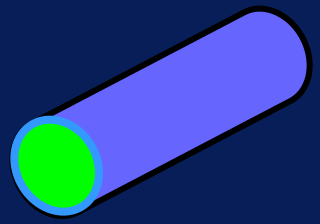
AR Peak Velocity 490 cm/sec; TVI = 223 cm



Step 5: Calculate AR ERO

E ffective
R egurgitant
O rifice

=



AR Volume (86 cm^3)

AR TVI (223 cm)

$$\text{ERO} = \frac{86\ cm^3}{223\ cm} = 0.39\ cm^2$$

Quantitation of Aortic Regurgitation
Continuity Method: PW Doppler

	Mild	Moderate		Severe
AR Volume (cm^3/beat)	<30	30 - 44	45 - 59	≥ 60
Regurgitant Fraction (%)	<30	30 - 39	40 - 49	≥ 50
ERO (cm^2)	<0.10	0.10-0.19	0.20-0.29	≥ 0.30

Zoghbi WA, et al. J Am Soc Echocardiogr 2003; 16: 777

Nishimura RA, CM Otto, et al. JACC 2014; 63: e57

Quantitation of Valvular Regurgitation

Continuity Method: PW Doppler

Potential Pitfalls

- Incorrect Doppler alignment to flow ($\theta > 20^{o}$)
- Incorrect sample volume placement
  (Place at annulus, not leaflet tips)
- Incorrect annular measurement: $(error)^2$,
  Mitral annular calcification (MAC)
- Failure to trace modal velocity (especially MV)

Quantitation of Valvular Regurgitation

Continuity Method: PW Doppler

Potential Pitfalls

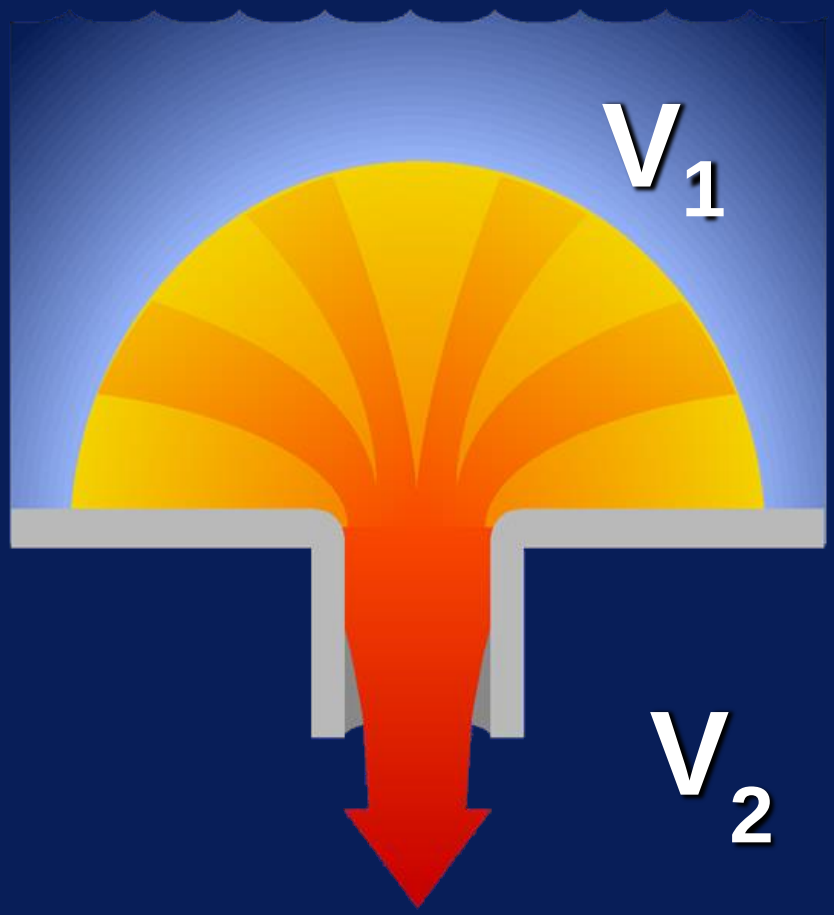
- Geometric assumptions of circular annulus
  (LVOT - good, MV - fair, TV - poor)
- Mitral regurgitation > mild
- Arrhythmia; inadequate data averaged
  (use at least 5-8 cycles for Afib)

Quantitation of Aortic Regurgitation

PISA Method

Color and CW Doppler

Conservation of Mass/Volume
Flow Convergence



Flow $_{\text{From Ao}}$

=

Flow $_{\text{Into LV}}$

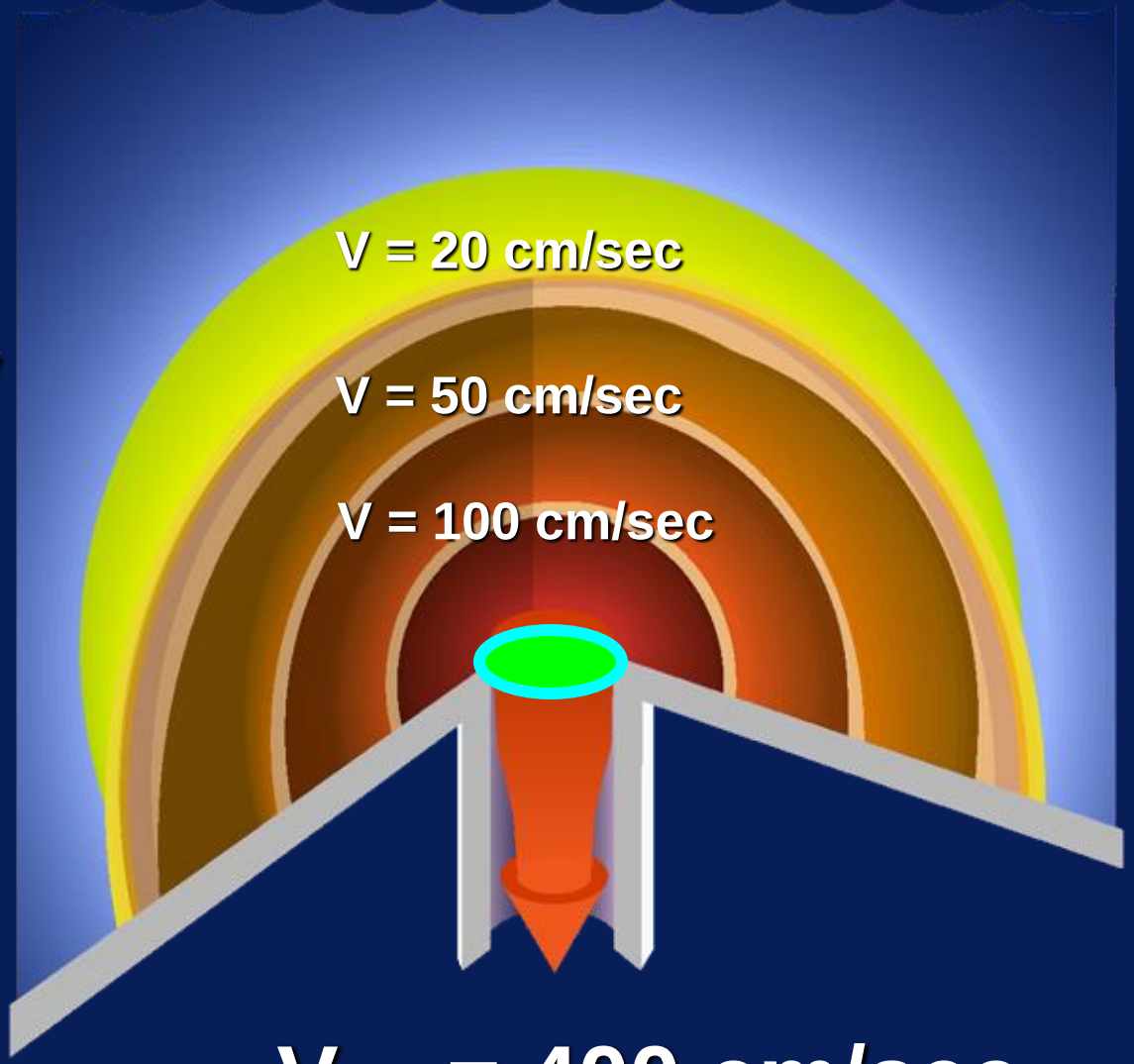
Flow Convergence

P roximal

I sovelocity

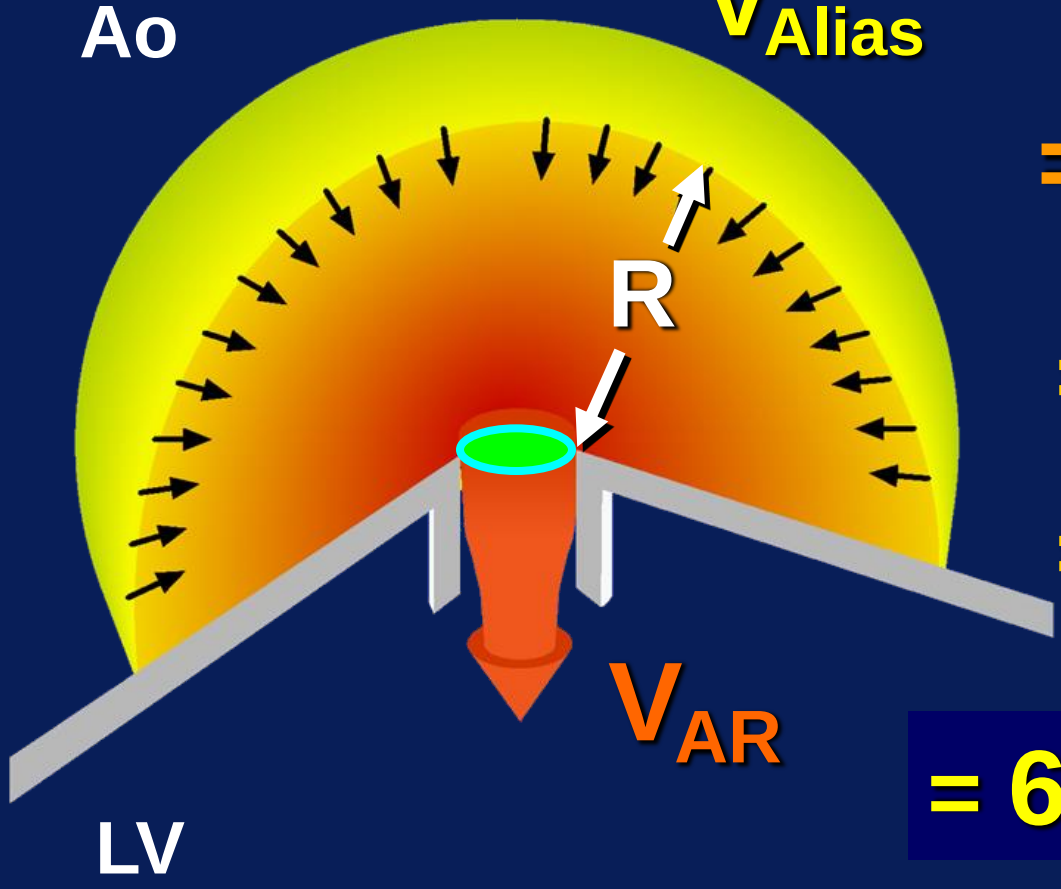
S urface

A rea



V_{AR} = 400 cm/sec

Quantitation of MR: PISA Method



Flow $_{\text{From Ao}}$

= Flow $_{\text{Into LV}}$

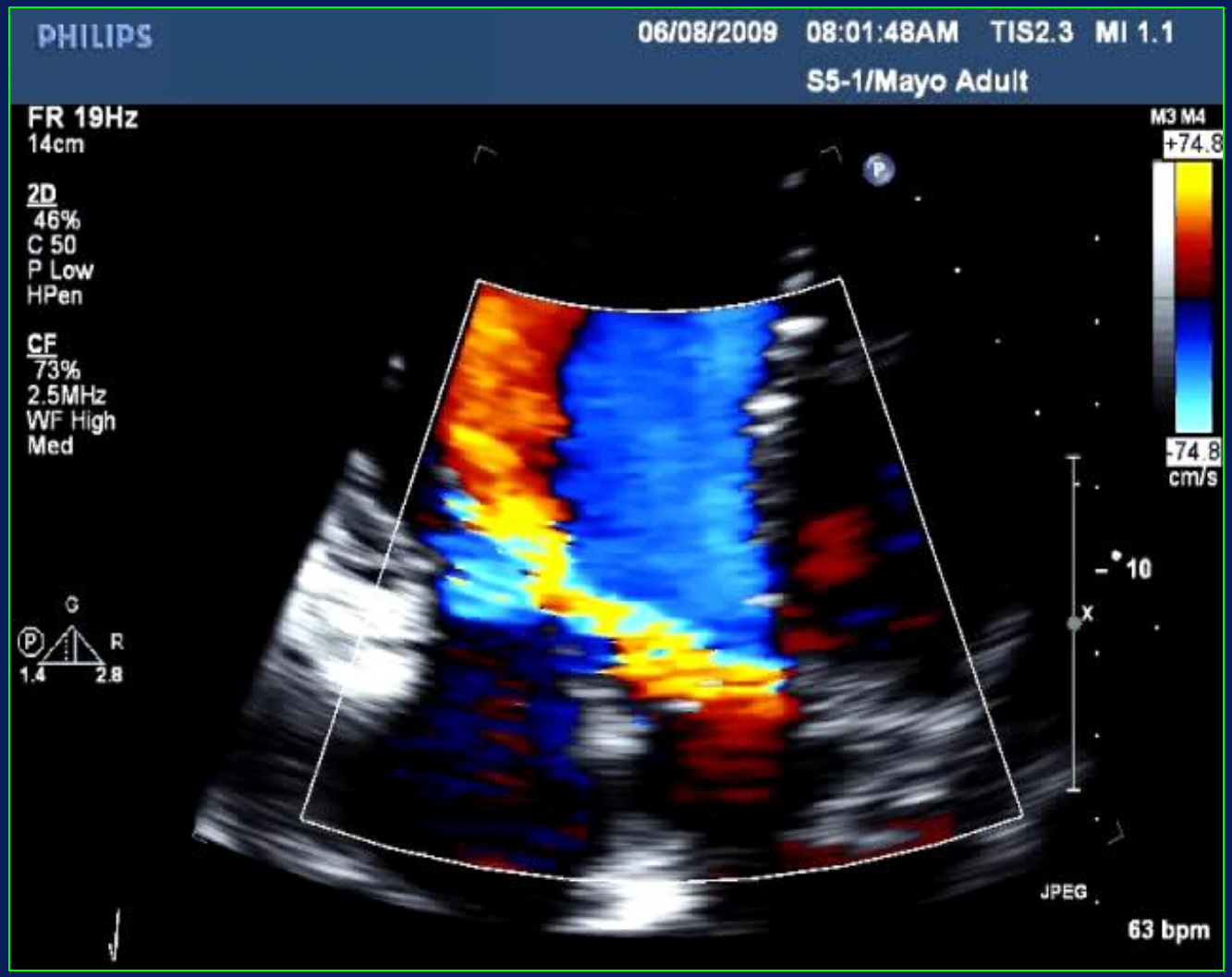
= $\text{Area}_{PISA} \times V_{Alias}$

= $2\pi \times R^2 \times V_{Alias}$

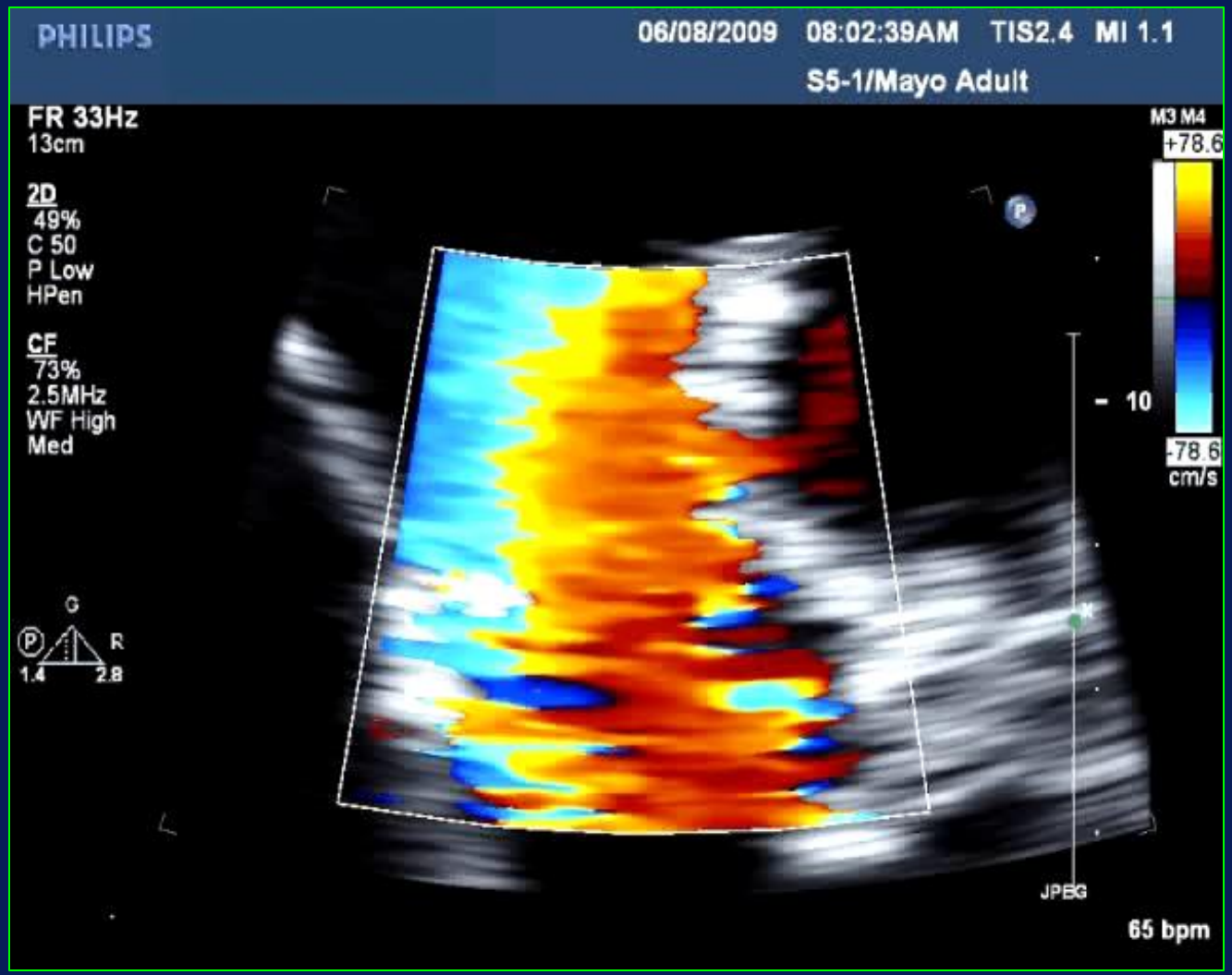
= $6.28 \times R^2 \times V_{Alias}$

= Effective Regurgitant Orifice (ERO)

61 y/o Female: Dyspnea and heart failure



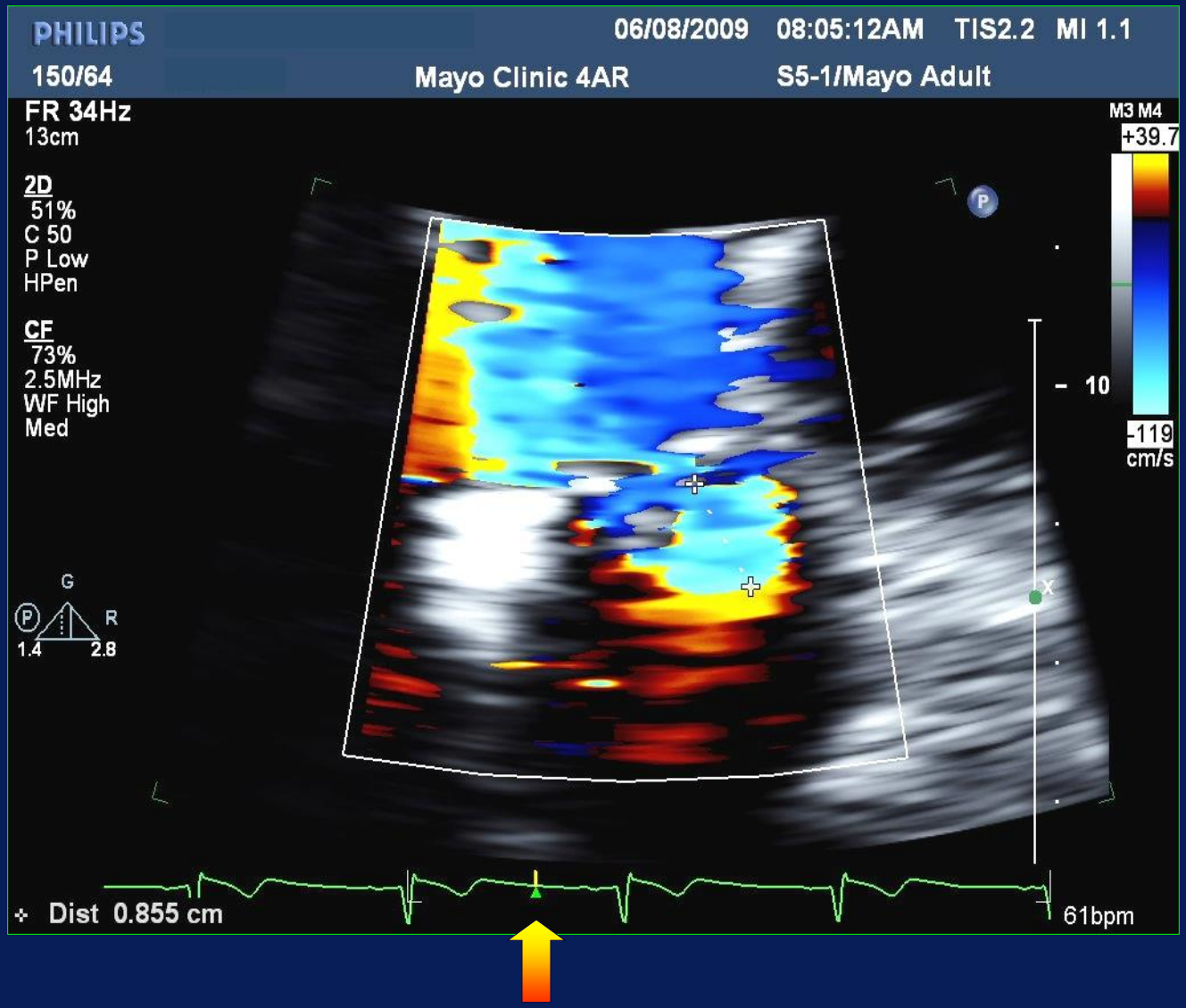
No color baseline shift



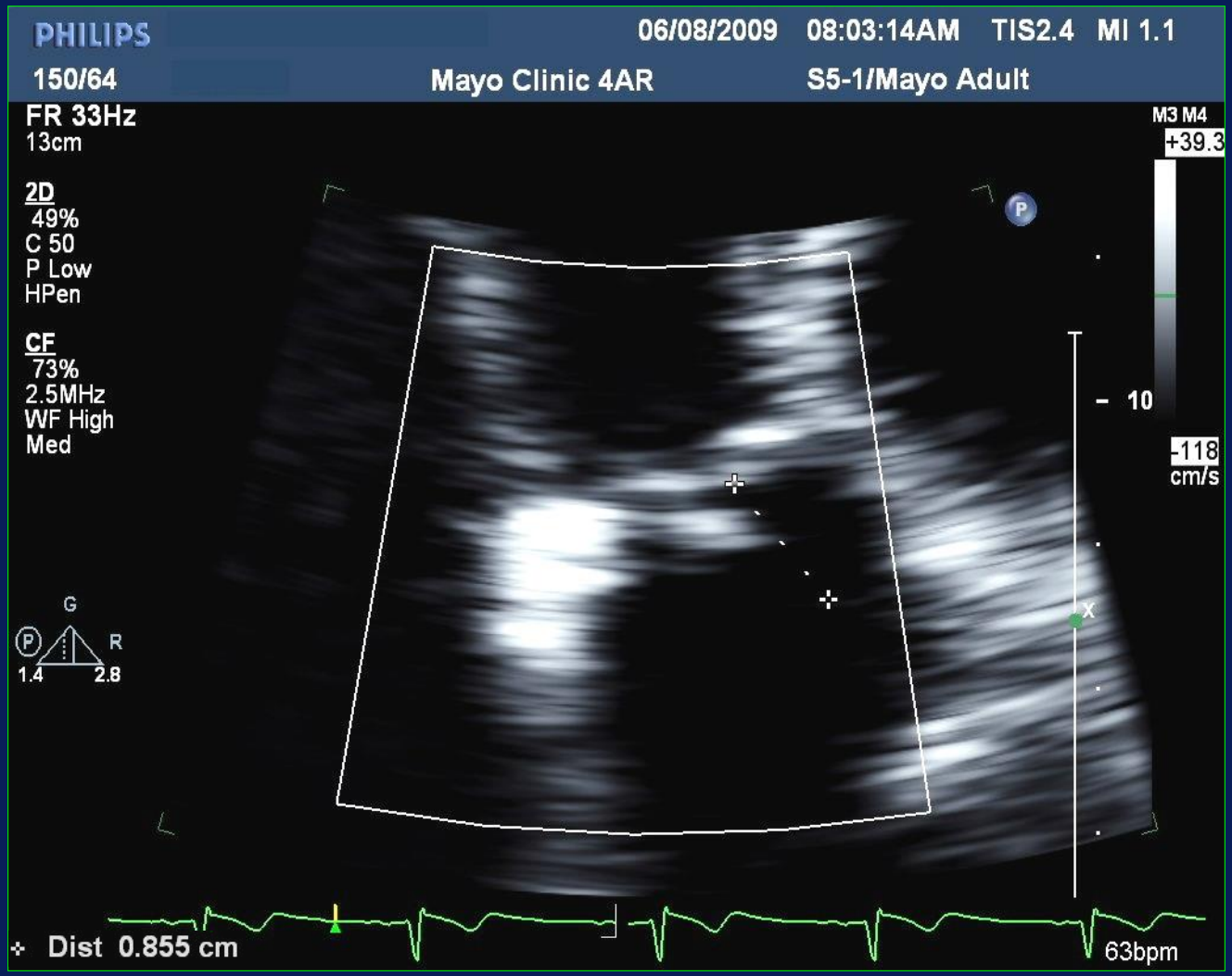
Aliasing velocity 50 cm/s

Aliasing velocity 40 cm/s

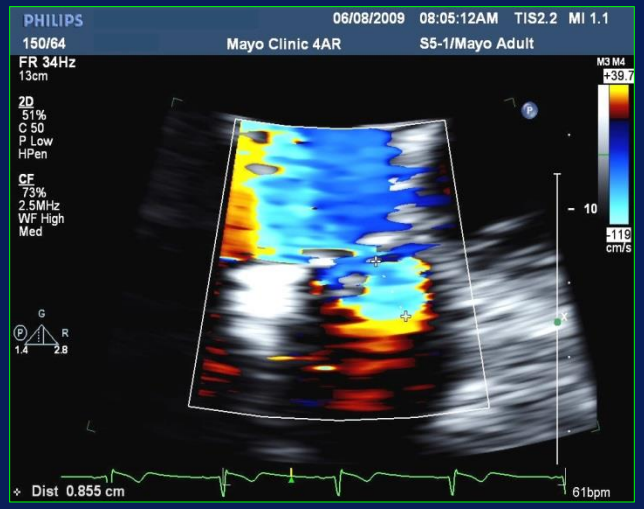
PISA R = 0.9 cm; Aliasing velocity 40 cm/sec



PISA R = 0.9 cm; Aliasing velocity 40 cm/sec



Step 1: Calculate proximal AR flow



$$Flow_{AR} = Area_{PISA} \times Velocity_{Alias}$$

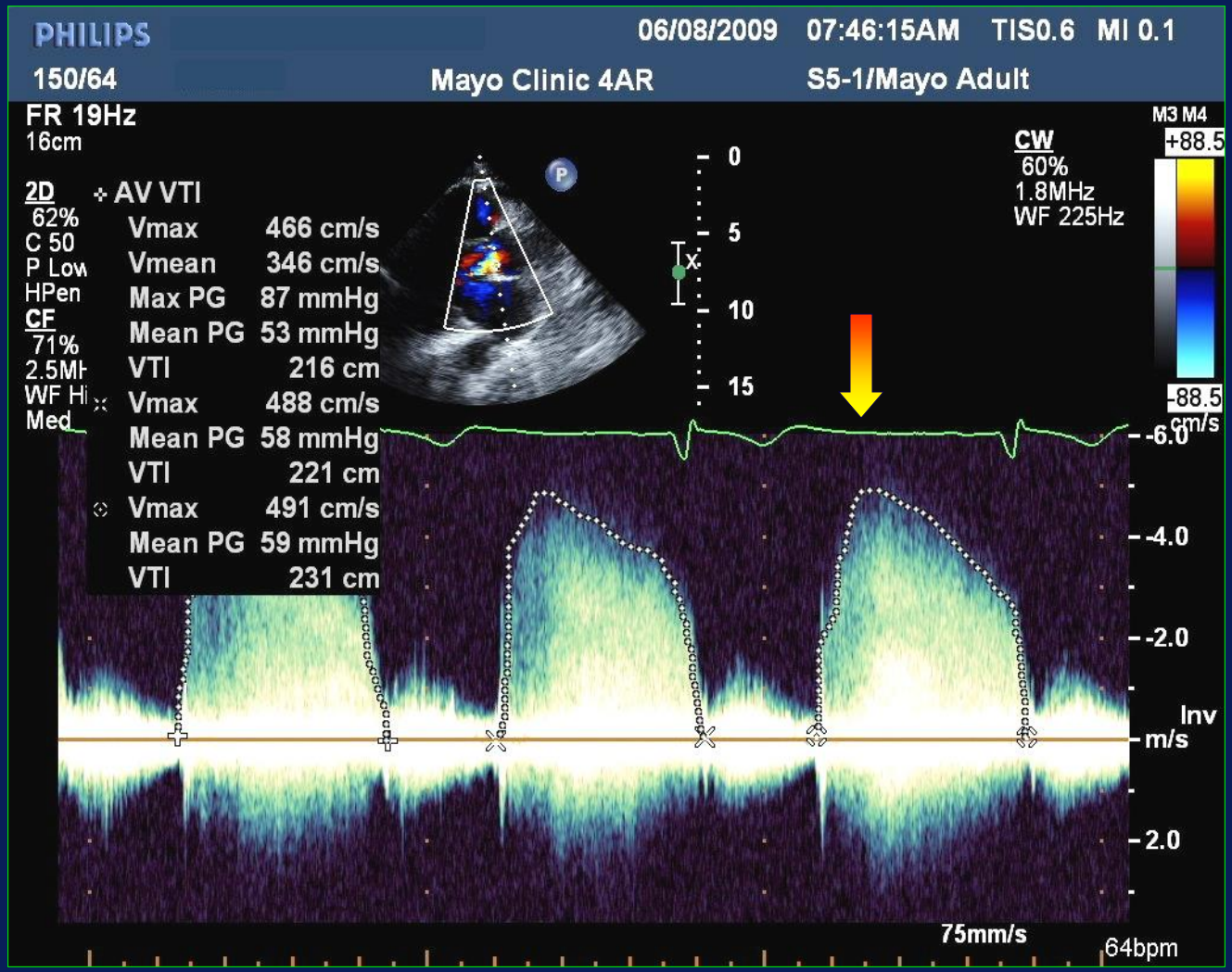
$$= 2\pi \times R^2 \times V_{Alias}$$

$$= 6.28 \times (0.9\ cm)^2 \times 40\ cm/sec$$

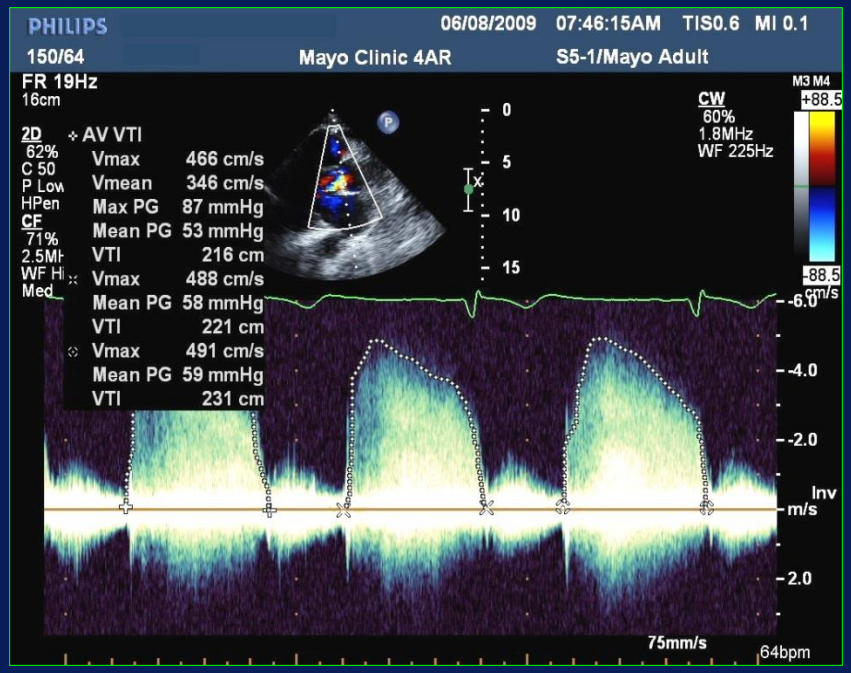
$$Flow_{AR} = 203\ cm^3/sec$$

AR Peak Velocity 490 cm/sec; TVI = 223 cm

Parasternal long-axis view



Step 2: Calculate the aortic ERO



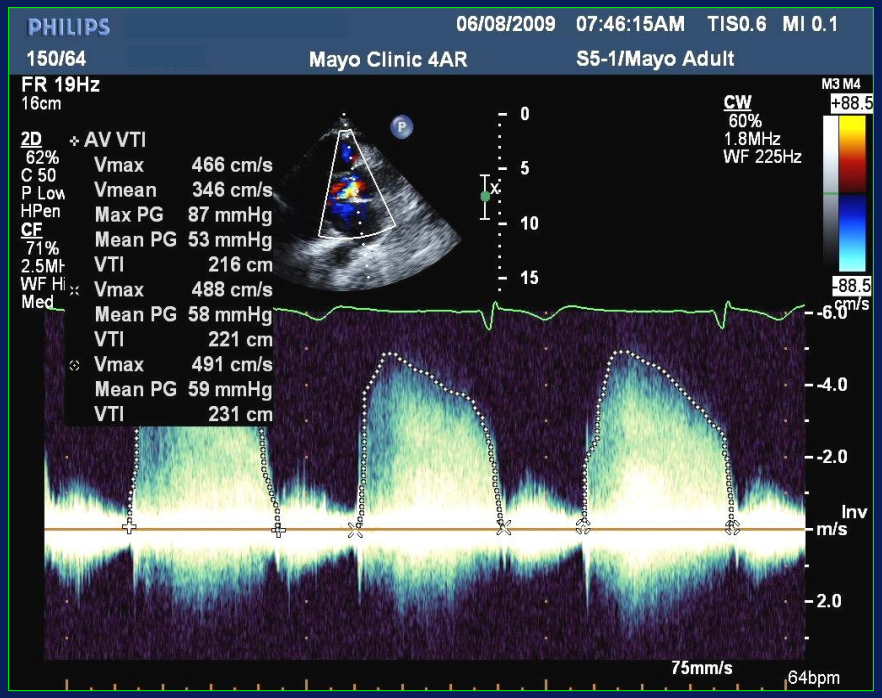
$$\text{ERO} = \frac{\text{Flow}_{AR}}{\text{Velocity}_{AR}}$$

$$= \frac{203\ \text{cm}^3/\text{sec}}{490\ \text{cm/sec}}$$

$\text{Velocity}_{AR} = 490\ \text{cm/sec}$

$\text{ERO} = 0.41\ \text{cm}^2$

Step 3: Calculate AR volume



$$\text{Volume}_{AR} = \text{ERO} \times \text{TVI}_{AR}$$

$$= 0.37\ \text{cm}^2 \times 223\ \text{cm}$$

$$\text{TVI}_{AR} = 223\ \text{cm} \qquad = 92\ \text{cm}^3$$

Locating the Color Flow Convergence

- **Zoom region of interest**
  (Decreases error of radius measurement)
- **Shift color Doppler baseline in the direction of the regurgitant jet**
- **Baseline shift to obtain an optimal hemispheric flow convergence signal for PISA measurement**
- **Time the radius measurement to coincide with the peak AR velocity by CW Doppler**

Quantitation of Aortic Regurgitation

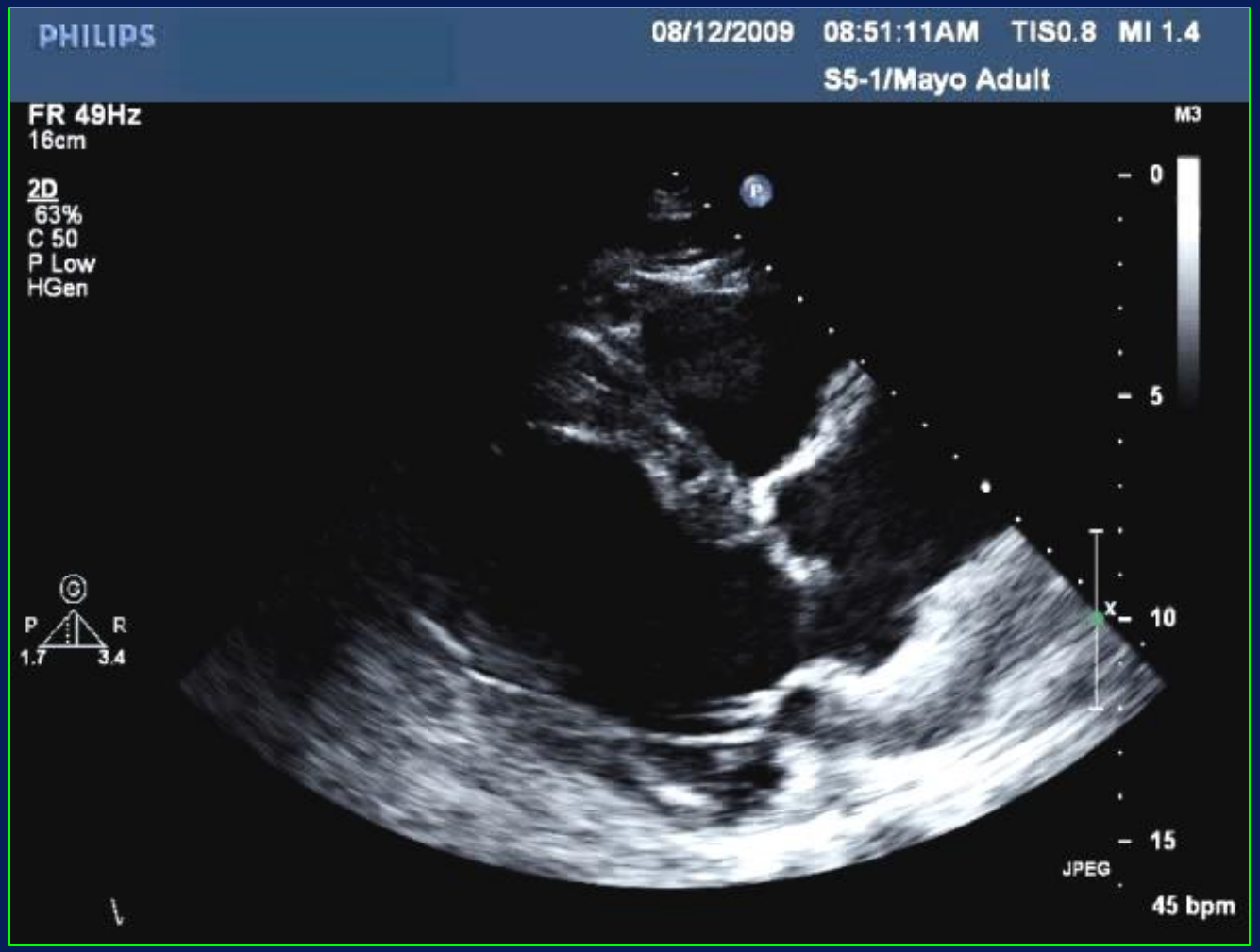
PISA Method: Color and CW Doppler

	Mild	Moderate		Severe
AR Volume (cm^3/beat)	<30	30 - 44	45 - 59	≥ 60
ERO (cm^2)	<0.10	0.10-0.19	0.20-0.29	≥ 0.30

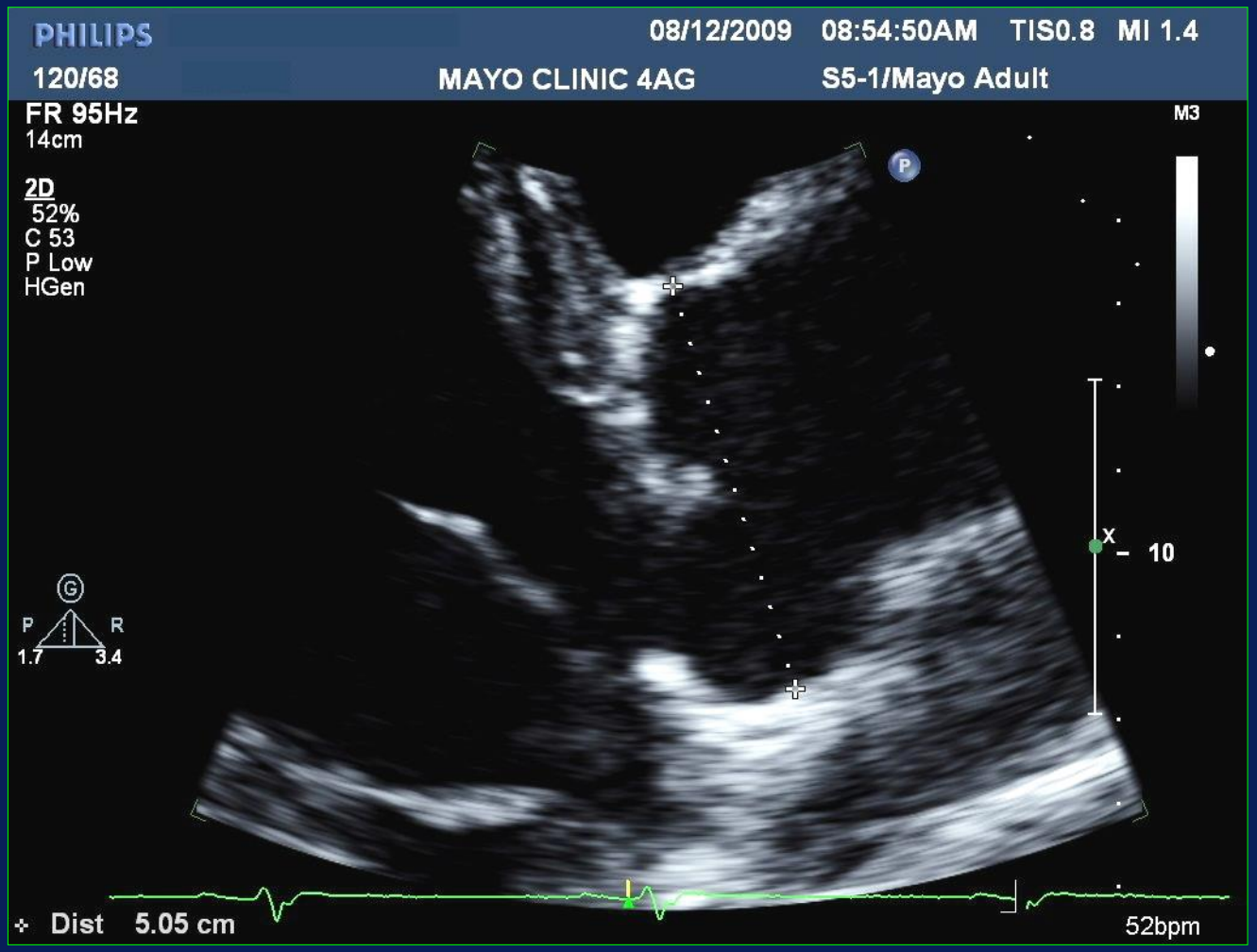
Zoghbi WA, et al. J Am Soc Echocardiogr 2003; 16: 777

Nishimura RA, CM Otto, et al. JACC 2014; 63: e57

48 y/o Farmer: Asymptomatic

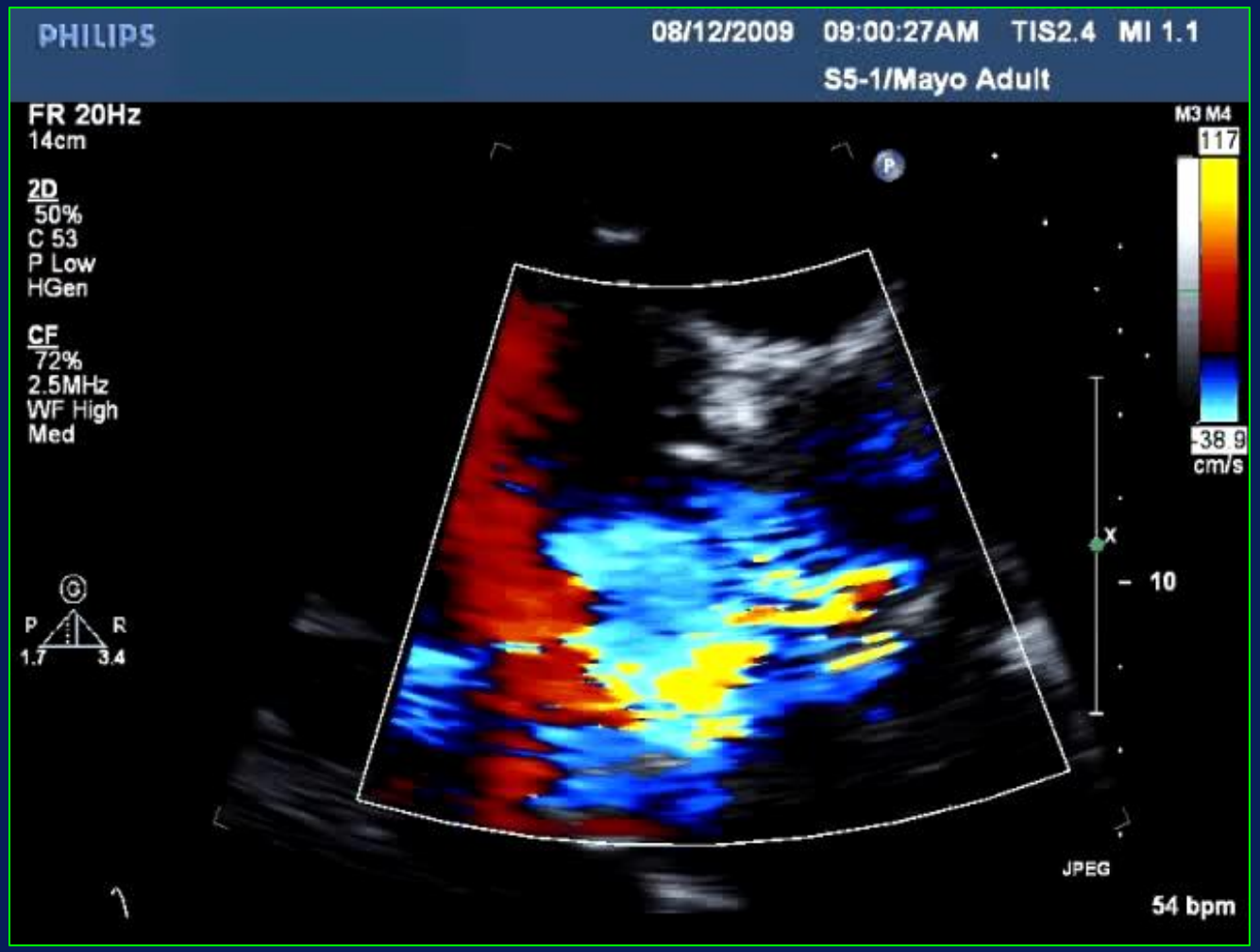


Aortic root = 5.1 cm

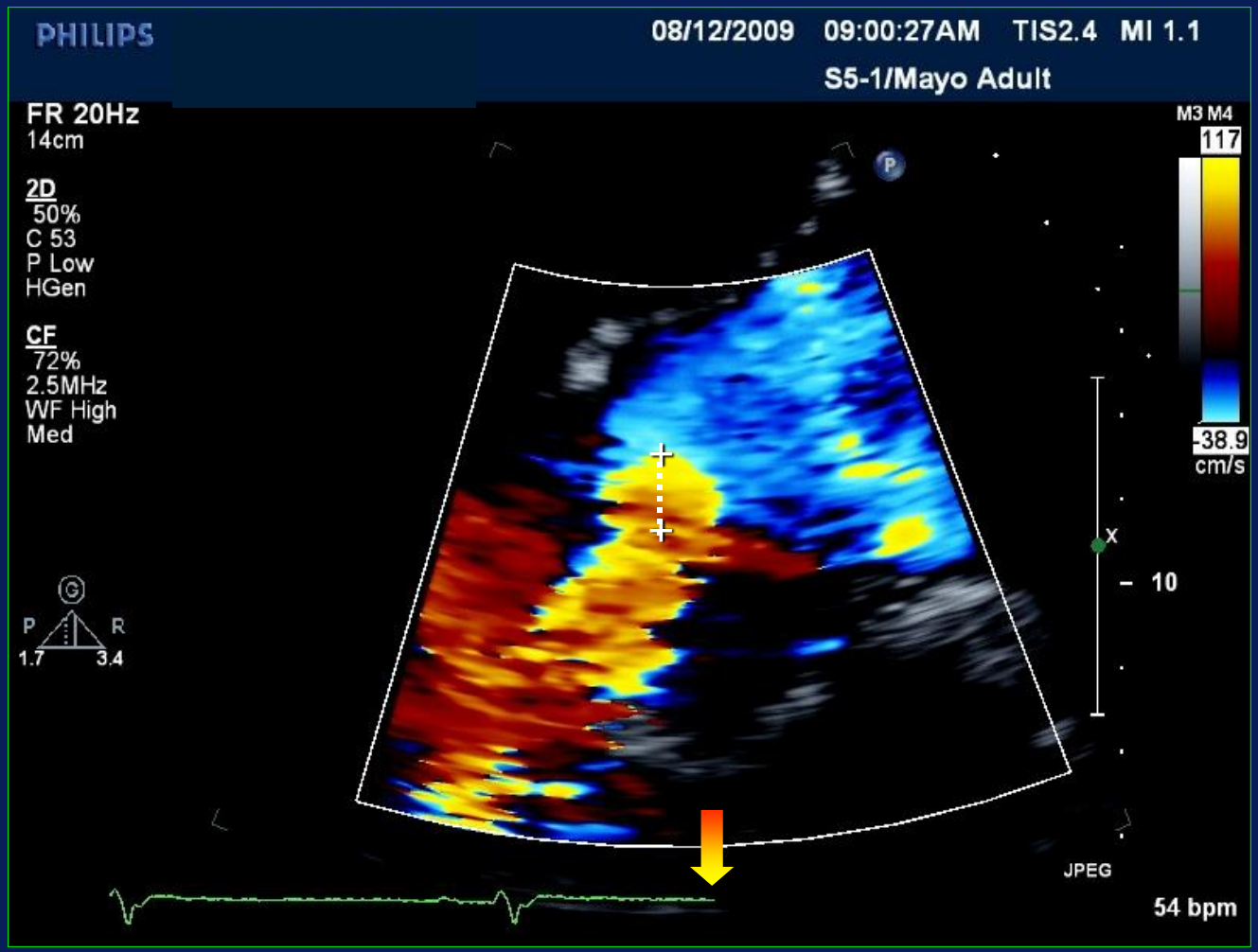


48 y/o Farmer: Asymptomatic

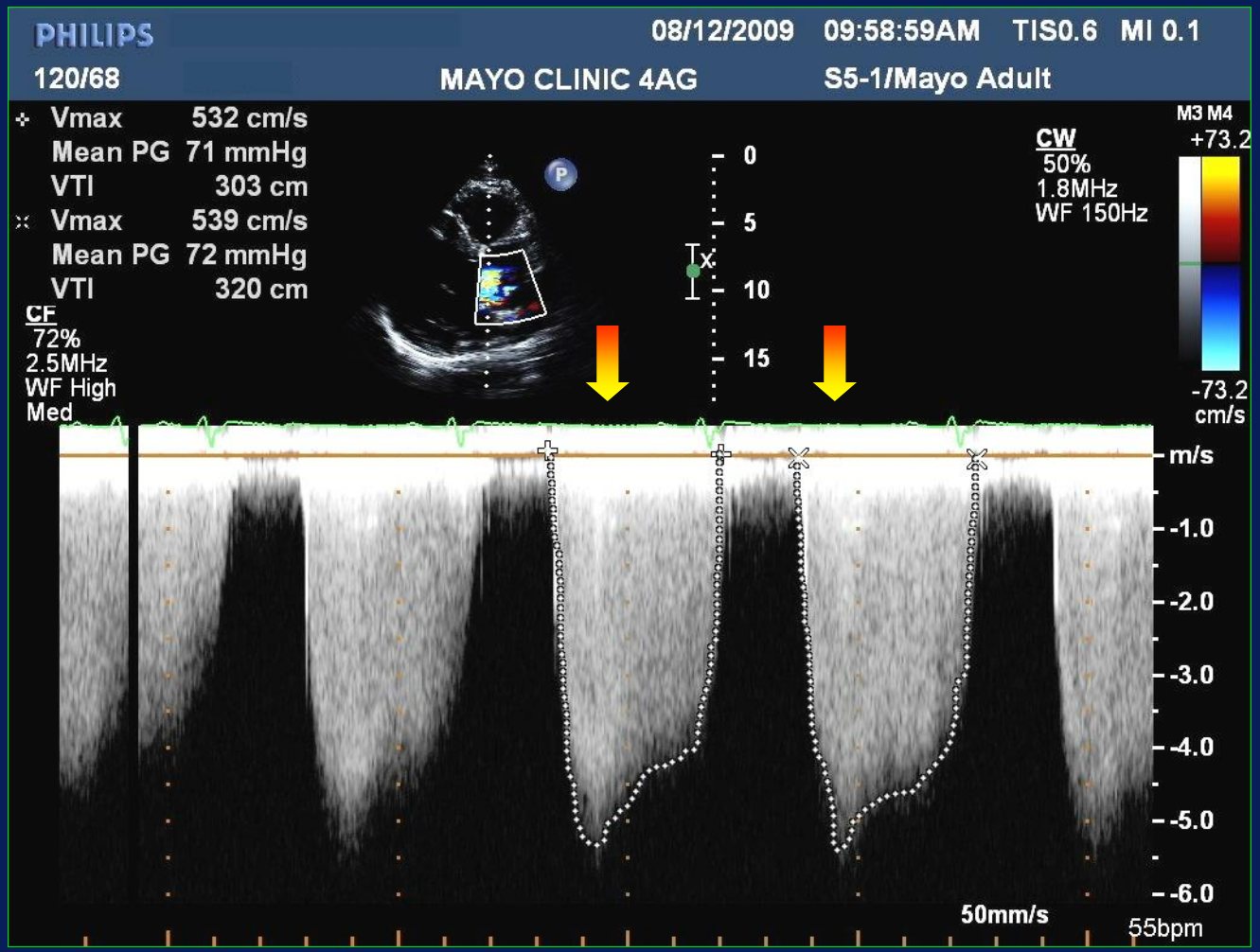
Aliasing velocity 39 cm/sec



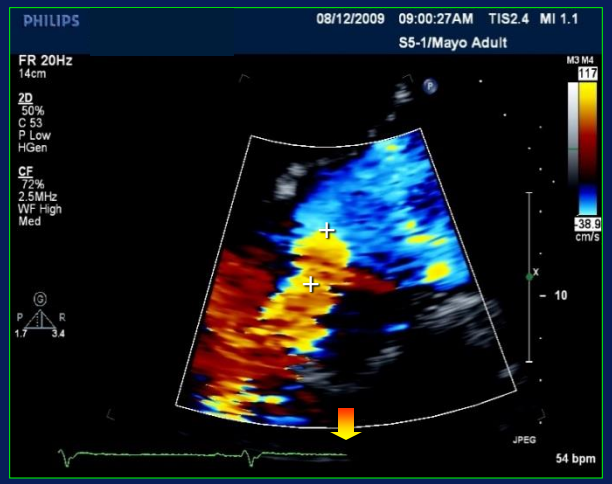
PISA R = 0.9 cm; Aliasing velocity 39 cm/sec



AR Peak Velocity 535 cm/sec; TVI = 310 cm
Parasternal long-axis view



Step 1: Calculate proximal AR flow



$$\text{Flow}_{AR} = \text{Area}_{PISA} \times \text{Velocity}_{Alias}$$

$$= 2\pi \times R^2 \times V_{Alias}$$

$$= 6.28 \times (0.9\text{cm})^2 \times 39\ \text{cm/sec}$$

$$\text{Flow}_{AR} = 198\ \text{cm}^3/\text{sec}$$

Aliasing velocity 35 cm/sec

PISA R = 1.0 cm; Aliasing velocity 35 cm/sec

Step 1: Calculate proximal AR flow

$$Flow_{AR} = Area_{PISA} \times Velocity_{Alias}$$

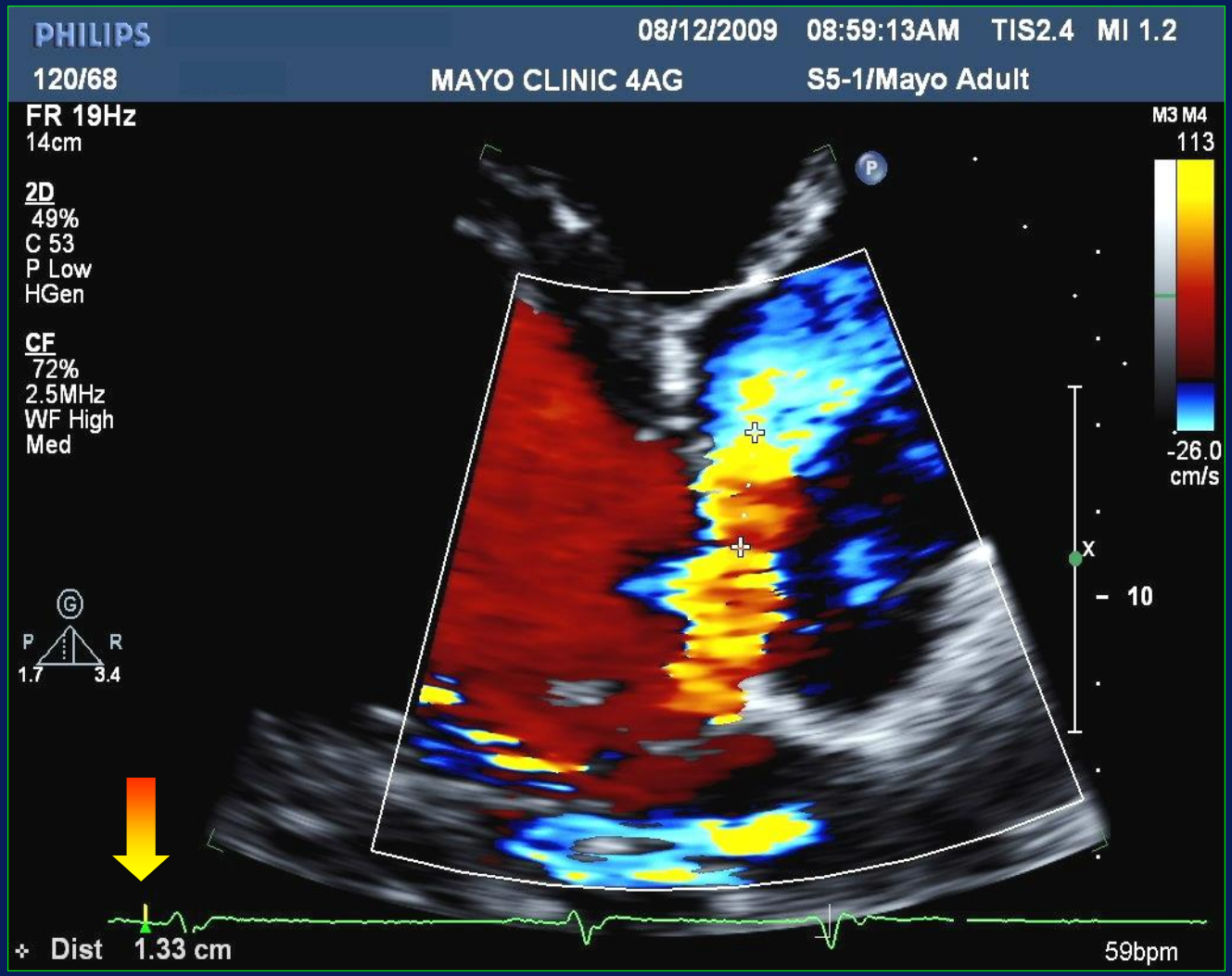
$$= 2\pi \times R^2 \times V_{Alias}$$

$$= 6.28 \times (1.0cm)^2 \times 35\ cm/sec$$

$$Flow_{AR} = 220\ cm^3/sec$$

Aliasing velocity 26 cm/sec: Blooming

PISA R = 1.3 cm; Aliasing velocity 26 cm/sec
Late diastolic timing



Step 1: Calculate proximal AR flow

$Flow_{AR} = Area_{PISA} \times Velocity_{Alias}$

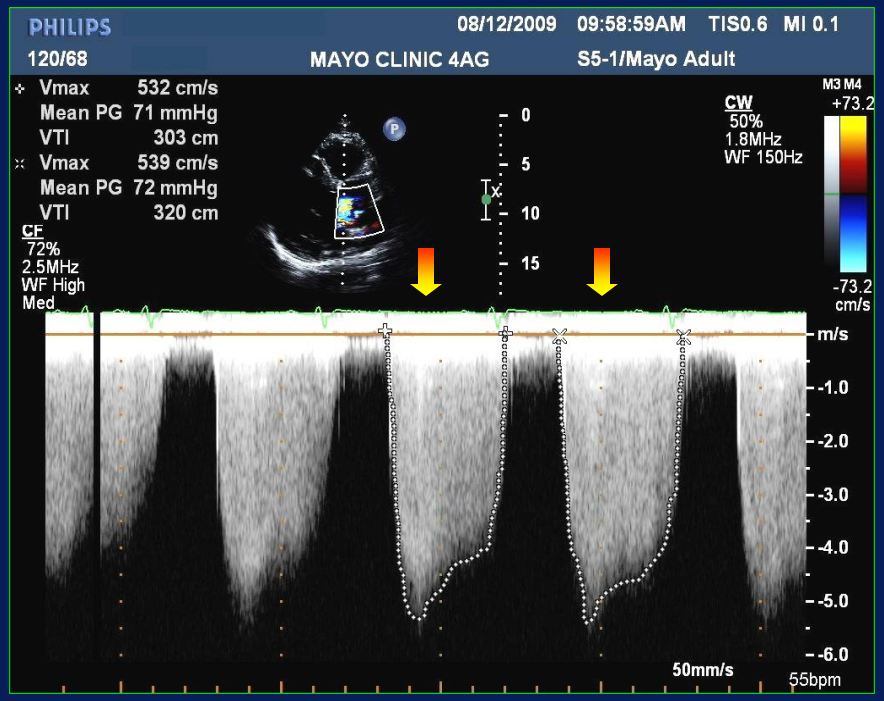
$= 2\pi \times R^2 \times V_{Alias}$

$= 6.28 \times (1.3cm)^2 \times 26\ cm/sec$

$Flow_{AR} = 276\ cm^3/sec$

ERROR

Step 2: Calculate the aortic ERO



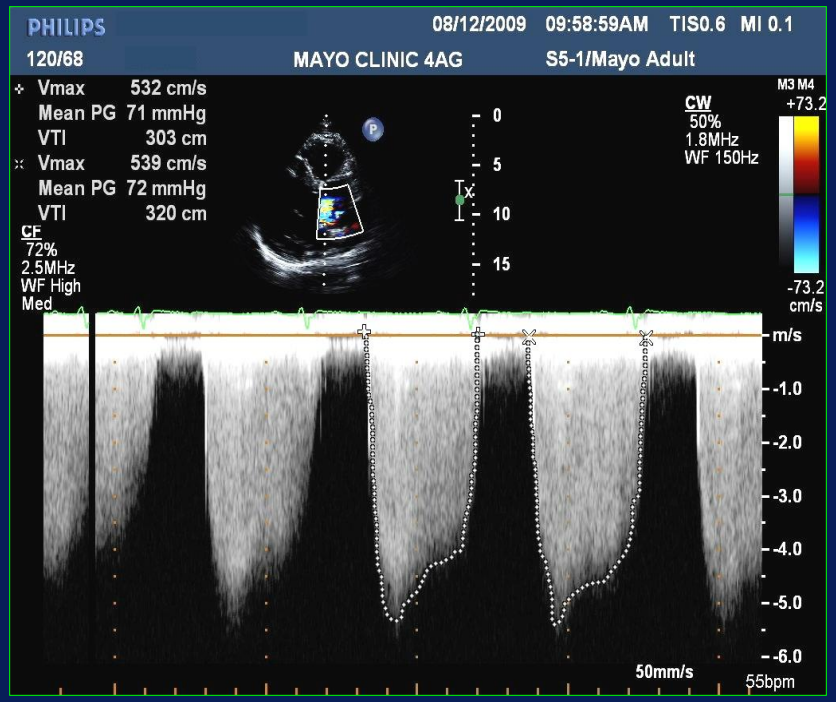
$$ERO = \frac{Flow_{AR}}{Velocity_{AR}}$$

$$= \frac{198\ cm^3/sec}{535\ cm/sec}$$

$Velocity_{AR} = 535\ cm/sec$

$ERO = 0.37\ cm^2$

Step 3: Calculate AR volume



TVI_{AR} = 310 cm

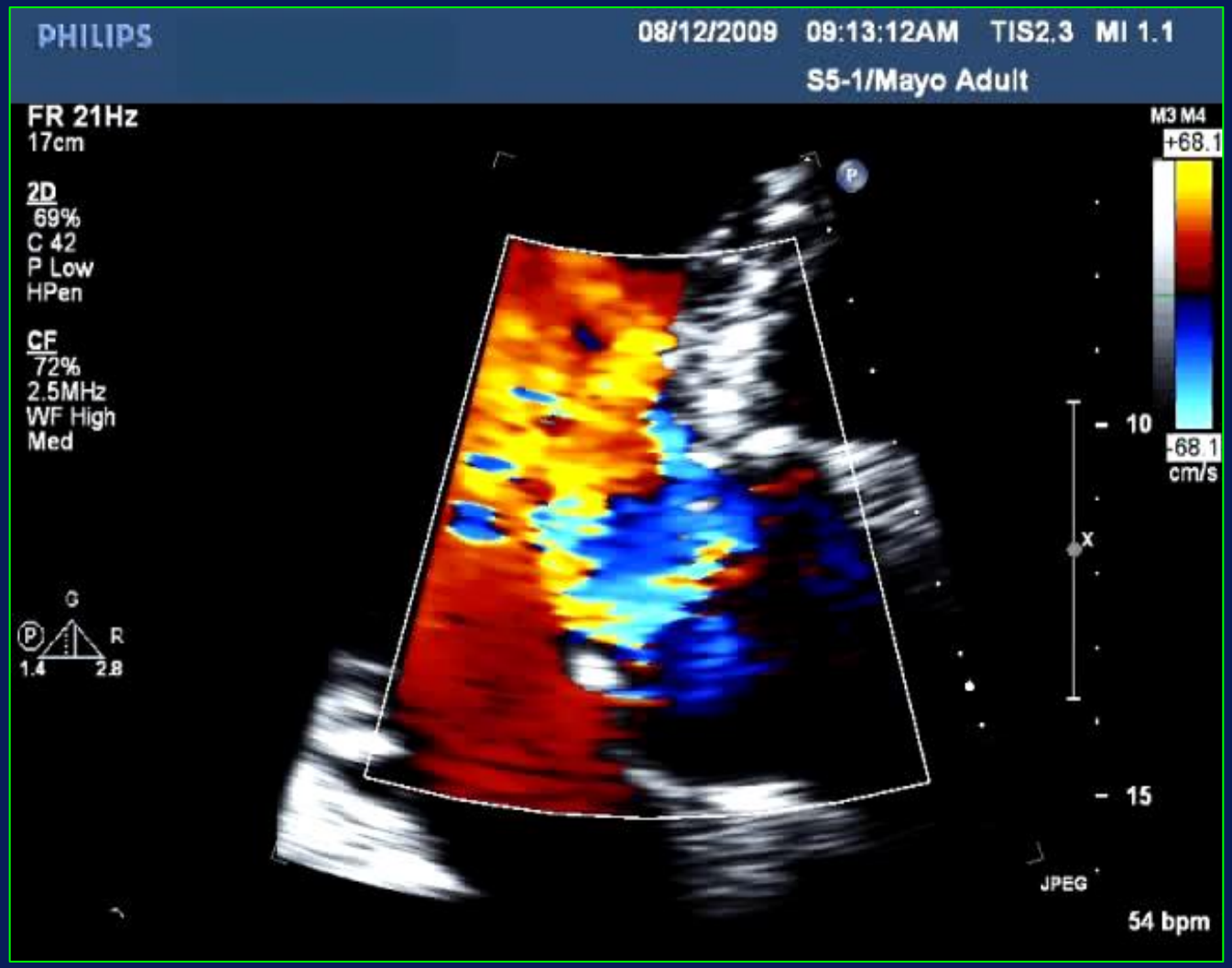
$Volume_{AR}$

= ERO x TVI_{AR}

= 0.37 cm^2 x 310 cm

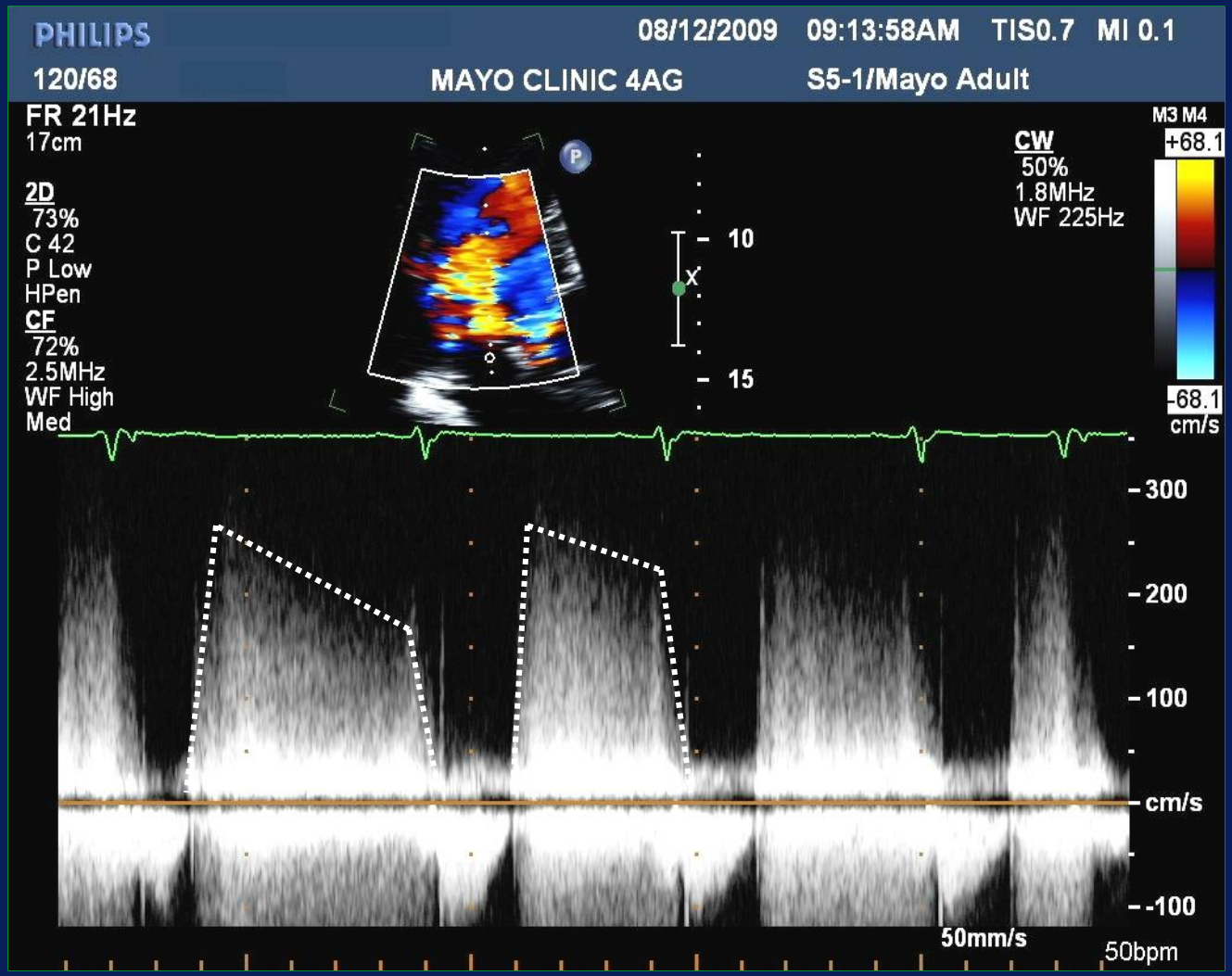
= **115 cm^3**

Apical Window: AR

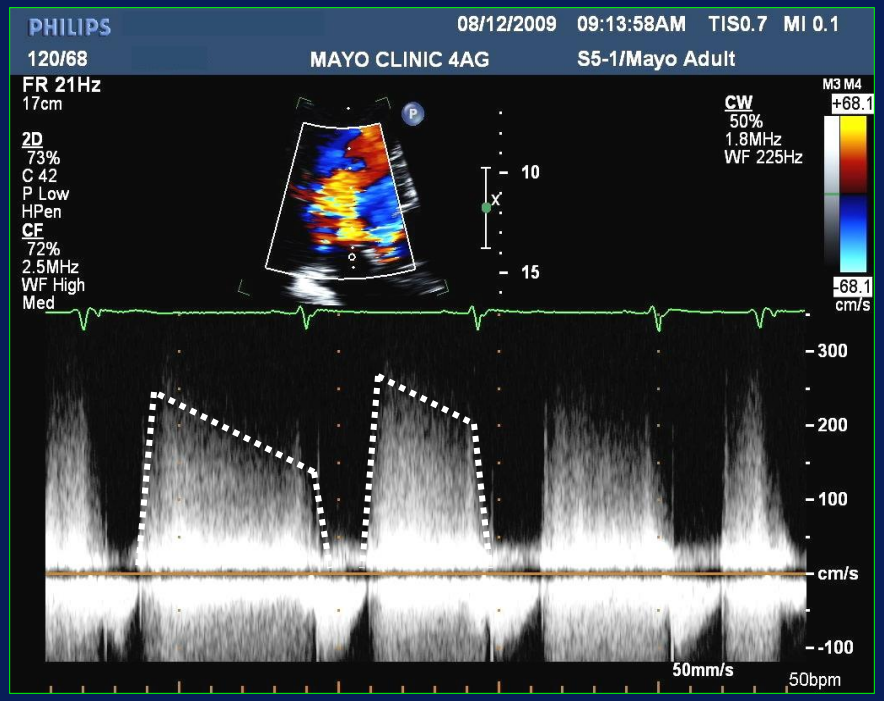


AR Peak Velocity 240 cm/sec; TVI = 170 cm

Apical CW Doppler: AR



Step 2: Calculate the aortic ERO



$$\text{ERO} = \frac{\text{Flow}_{AR}}{\text{Velocity}_{AR}}$$

$$= \frac{198\ \text{cm}^3/\text{sec}}{240\ \text{cm/sec}}$$

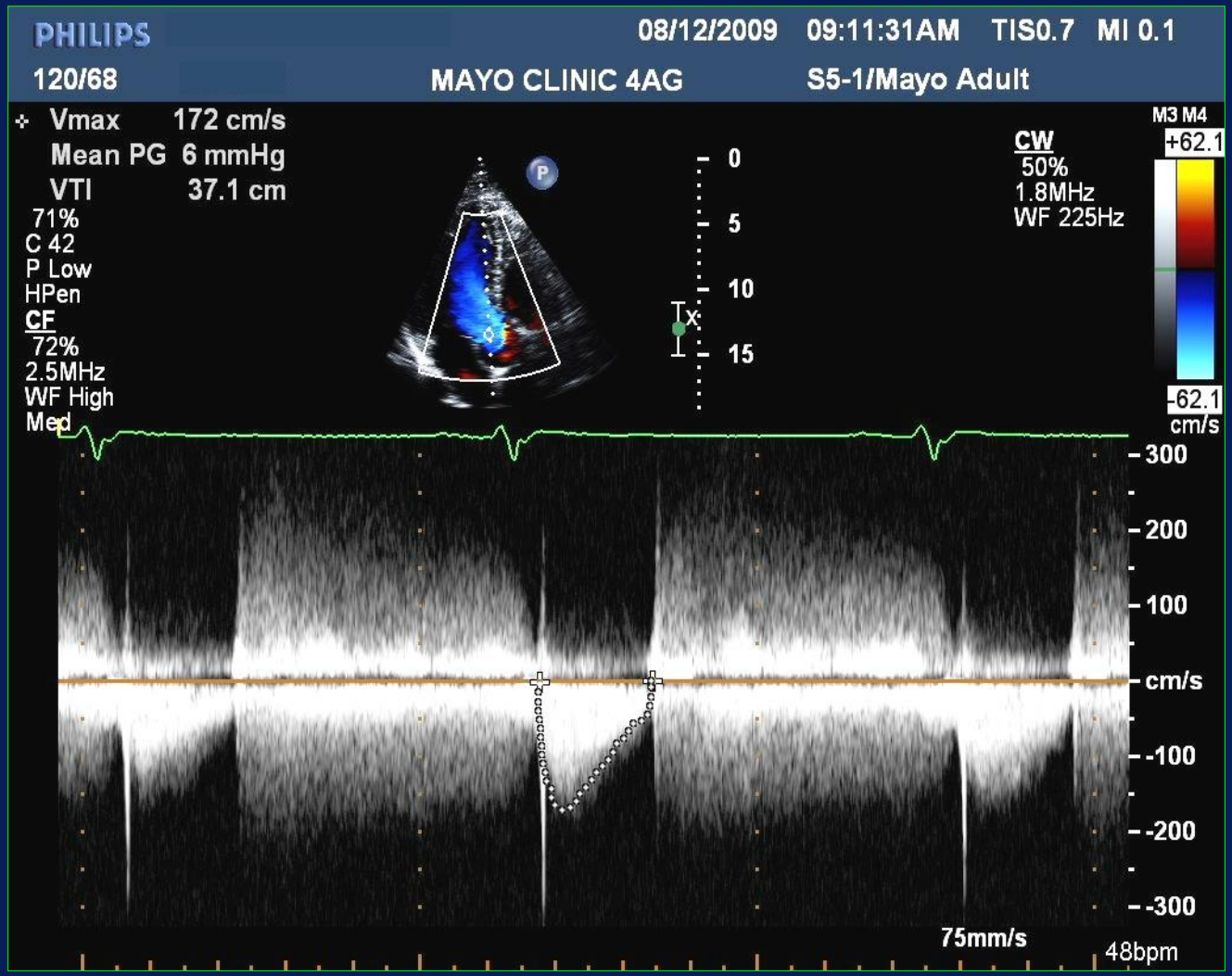
$\text{Velocity}_{AR} = 240\ \text{cm/sec}$

ERROR

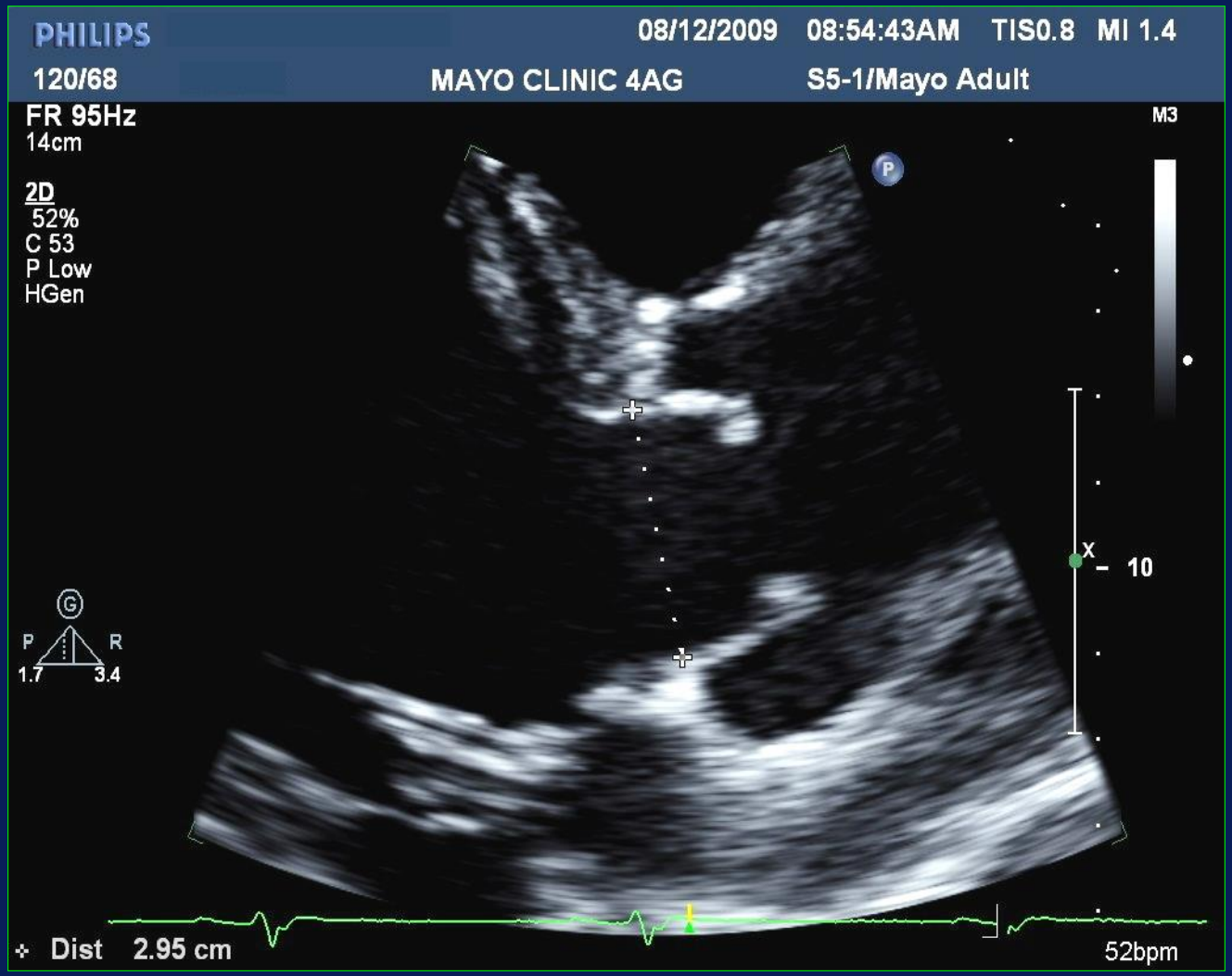
$\text{ERO} = 0.83\ \text{cm}^2$

Apical CW Doppler: AR

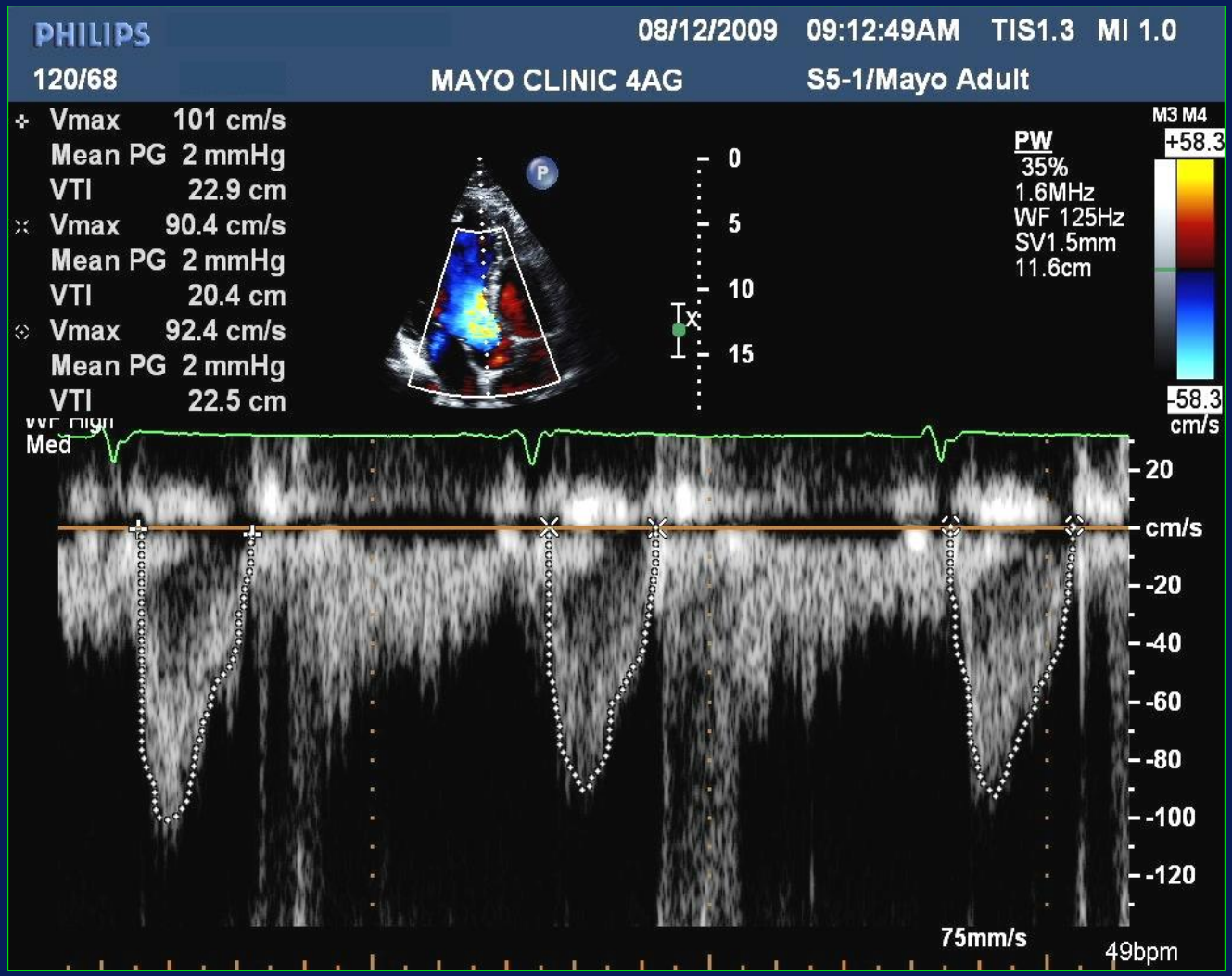
Interrogation angle error



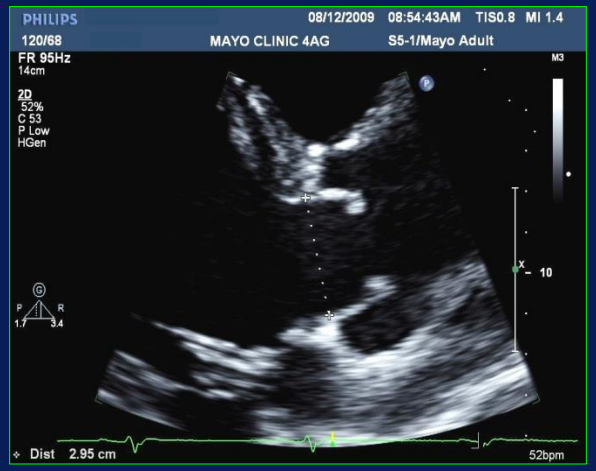
LVOT Diameter = 3.0 cm



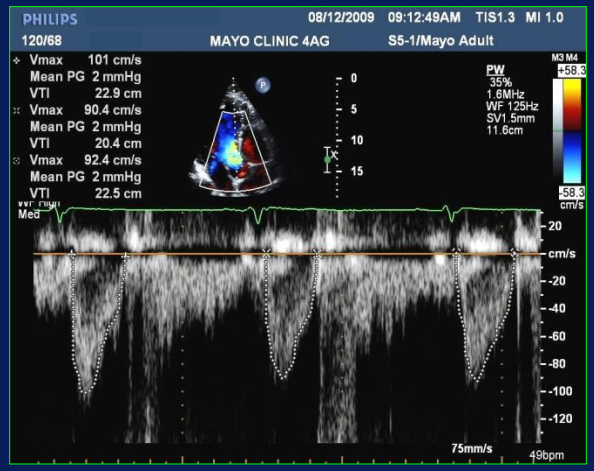
LVOT TVI = 23 cm



Step 1: Calculate LVOT Stroke Volume



LVOT Diameter = 3.0 cm



LVOT TVI = 23 cm

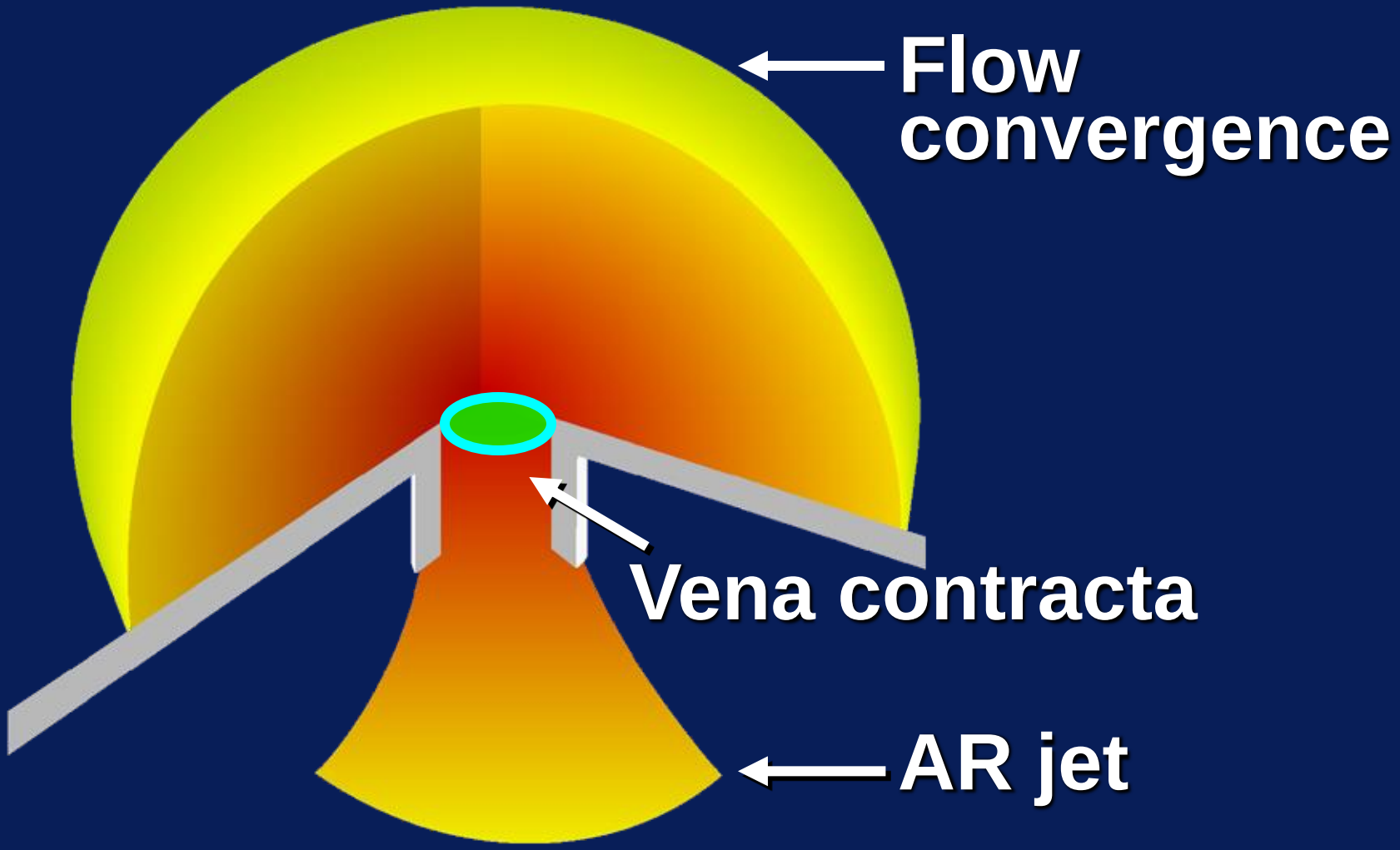
$$\text{LVOT Stroke Volume} = 0.785\ (3.0\ \text{cm})^2 \times 23\ \text{cm}$$

$$= 162\ \text{cm}^3$$

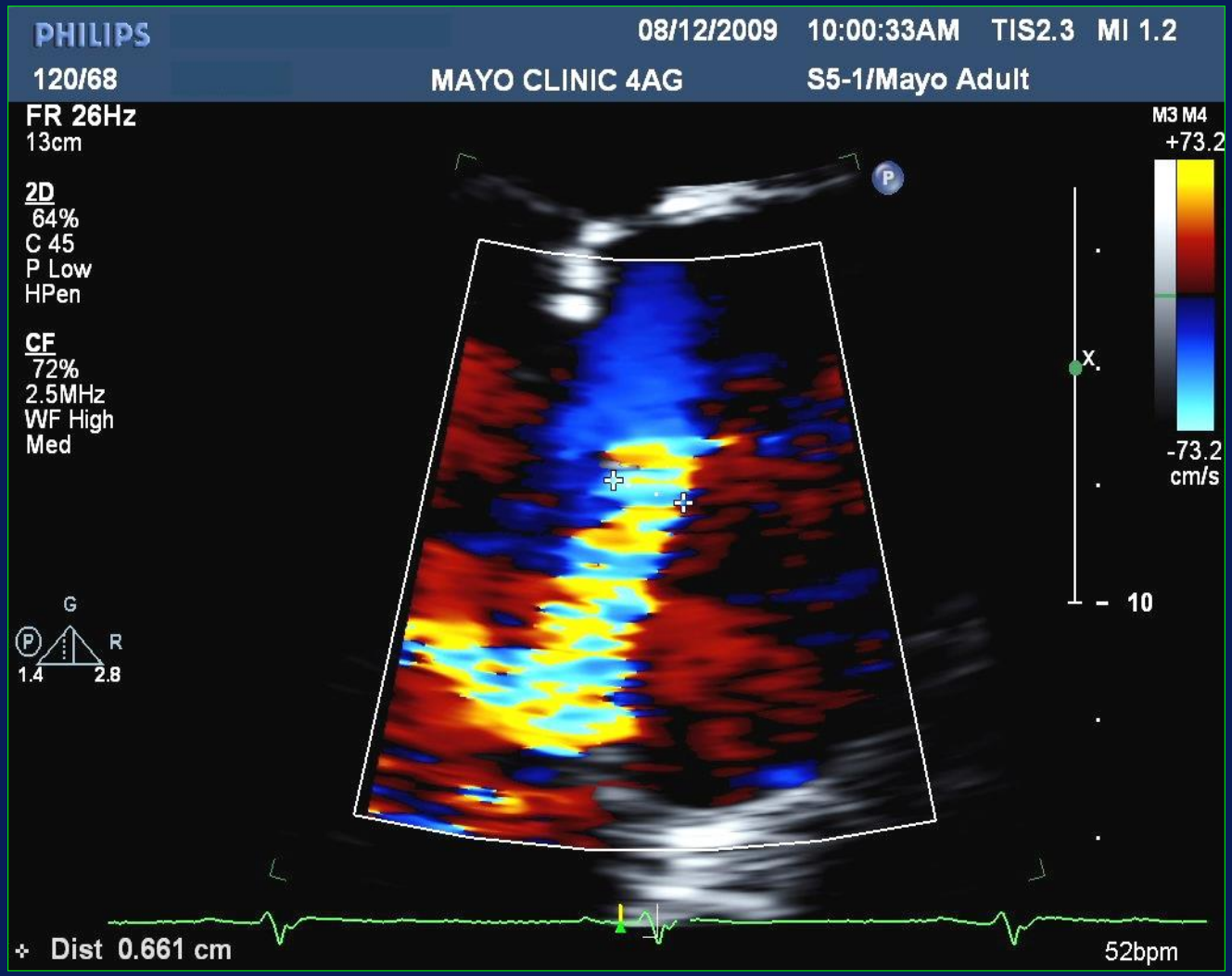
Step 4: Calculate Regurgitant Fraction (RF)

$$\text{Aortic RF} = \frac{\text{AR Volume}}{\text{LVOT Stroke Volume}} = \frac{115\ cm^3}{162\ cm^3} = 71\%$$

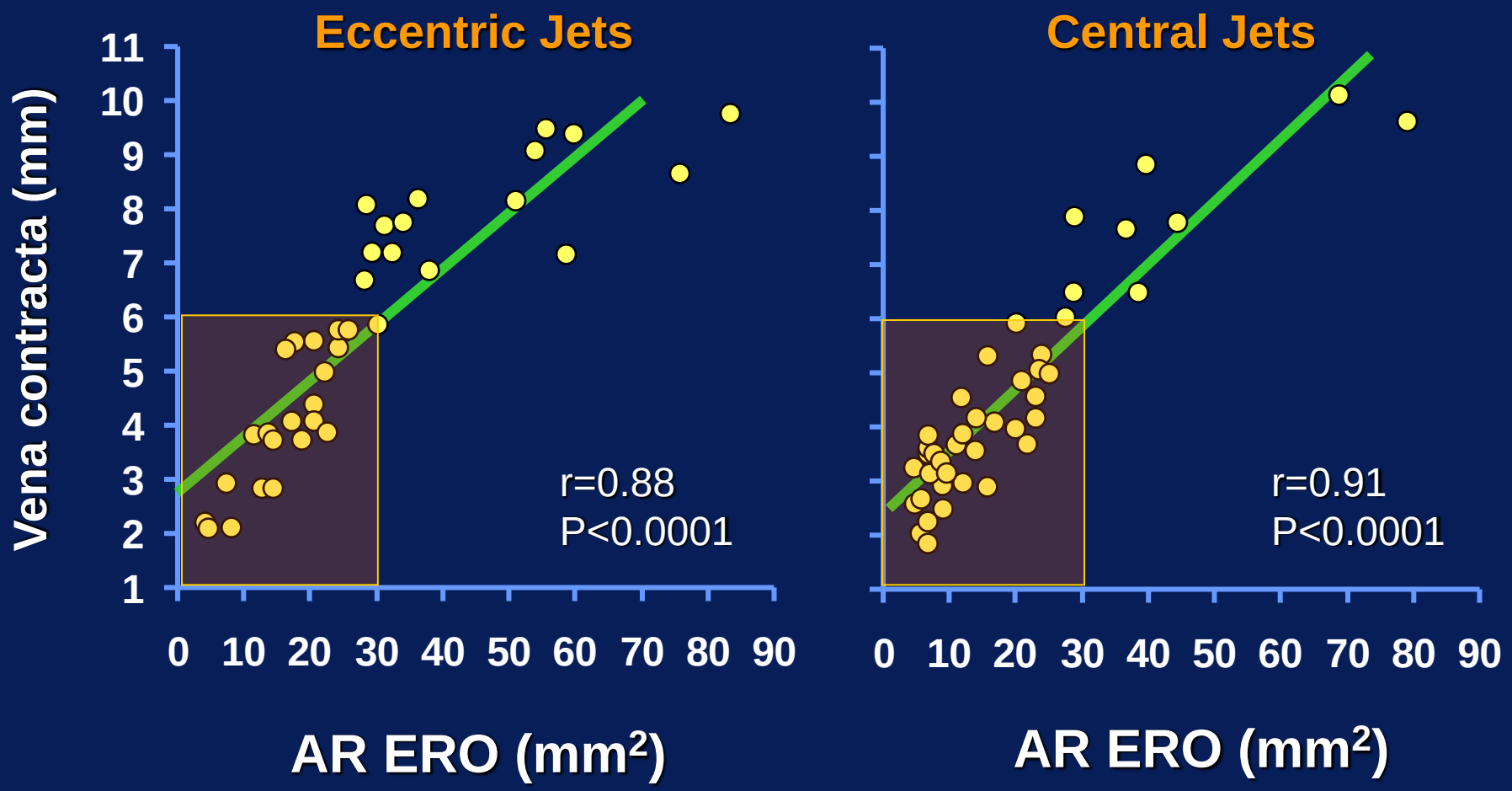
Vena Contracta: AR



Vena Contracta = 7 mm



Quantitation of AR: Vena Contracta Width
Comparison to ERO



Tribouilloy CM et al: Circulation 102:558, 2000

Quantitation of Aortic Regurgitation

PISA Method: Color and CW Doppler

	Mild	Moderate		Severe
AR Volume (cm^3/beat)	<30	30 - 44	45 - 59	≥ 60
ERO (cm^2)	<0.10	0.10-0.19	0.20-0.29	≥ 0.30
Vena Contracta Width (cm)	< 0.3	0.3 - 0.60		> 0.6

Zoghbi WA, et al. J Am Soc Echocardiogr 2003; 16: 777

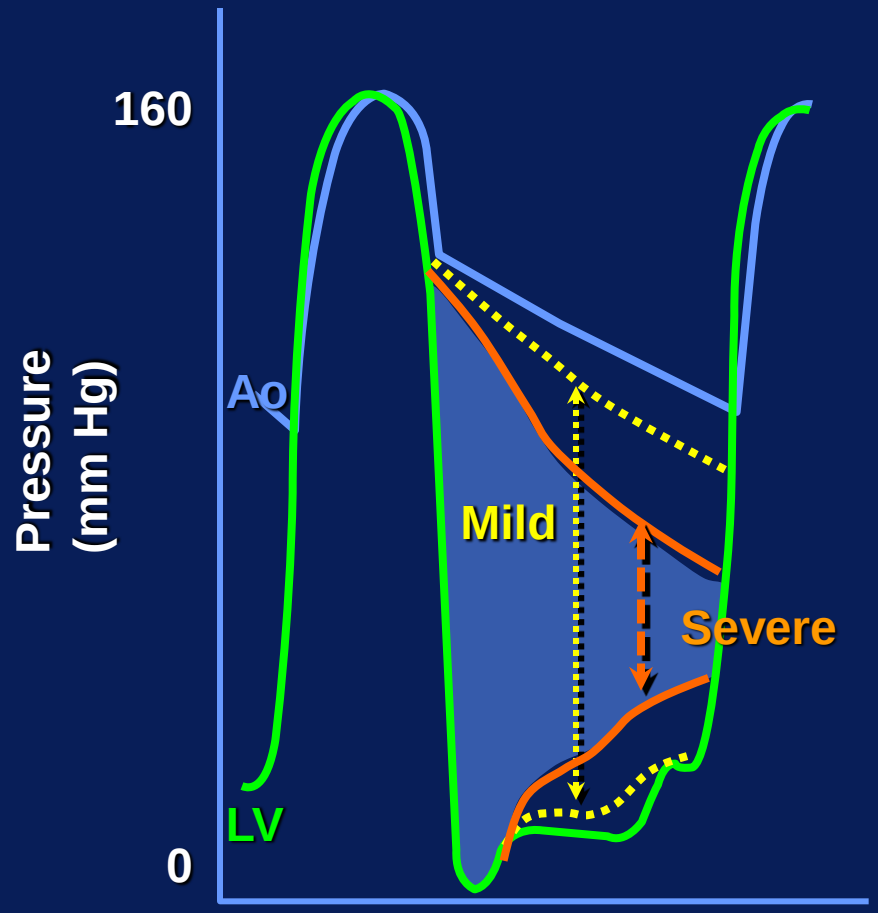
Nishimura RA, CM Otto, et al. JACC 2014; 63: e57

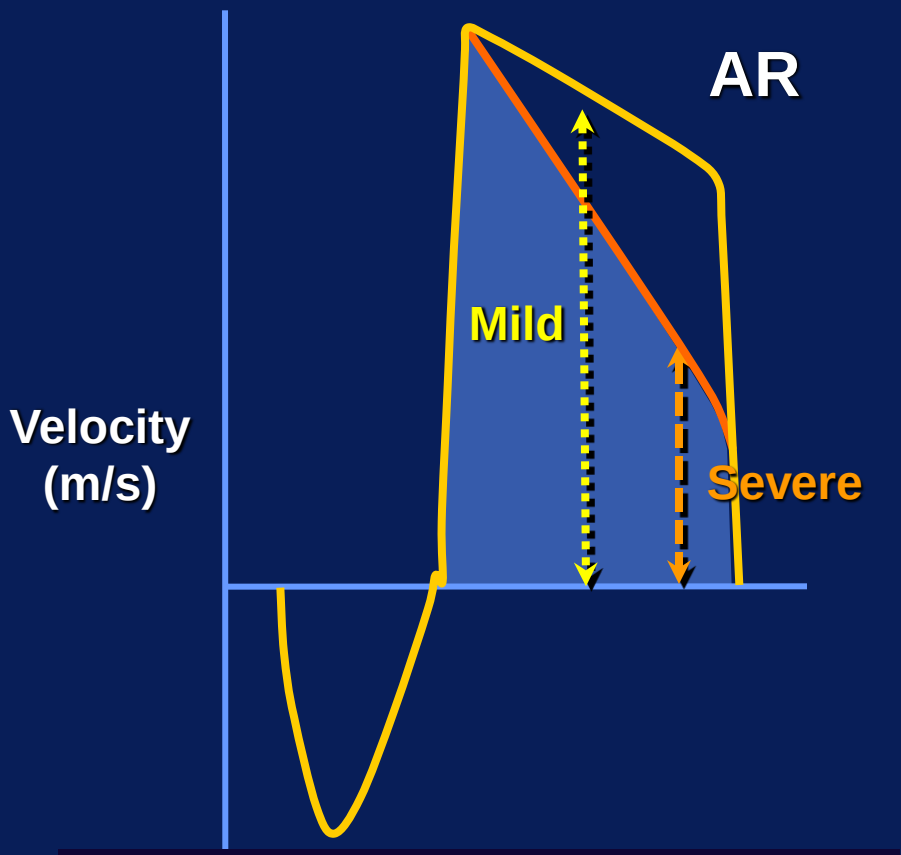
Quantitation of Aortic Regurgitation

Corroborating Findings

Hemodynamics of Aortic Regurgitation

Doppler Pressure Half-Time



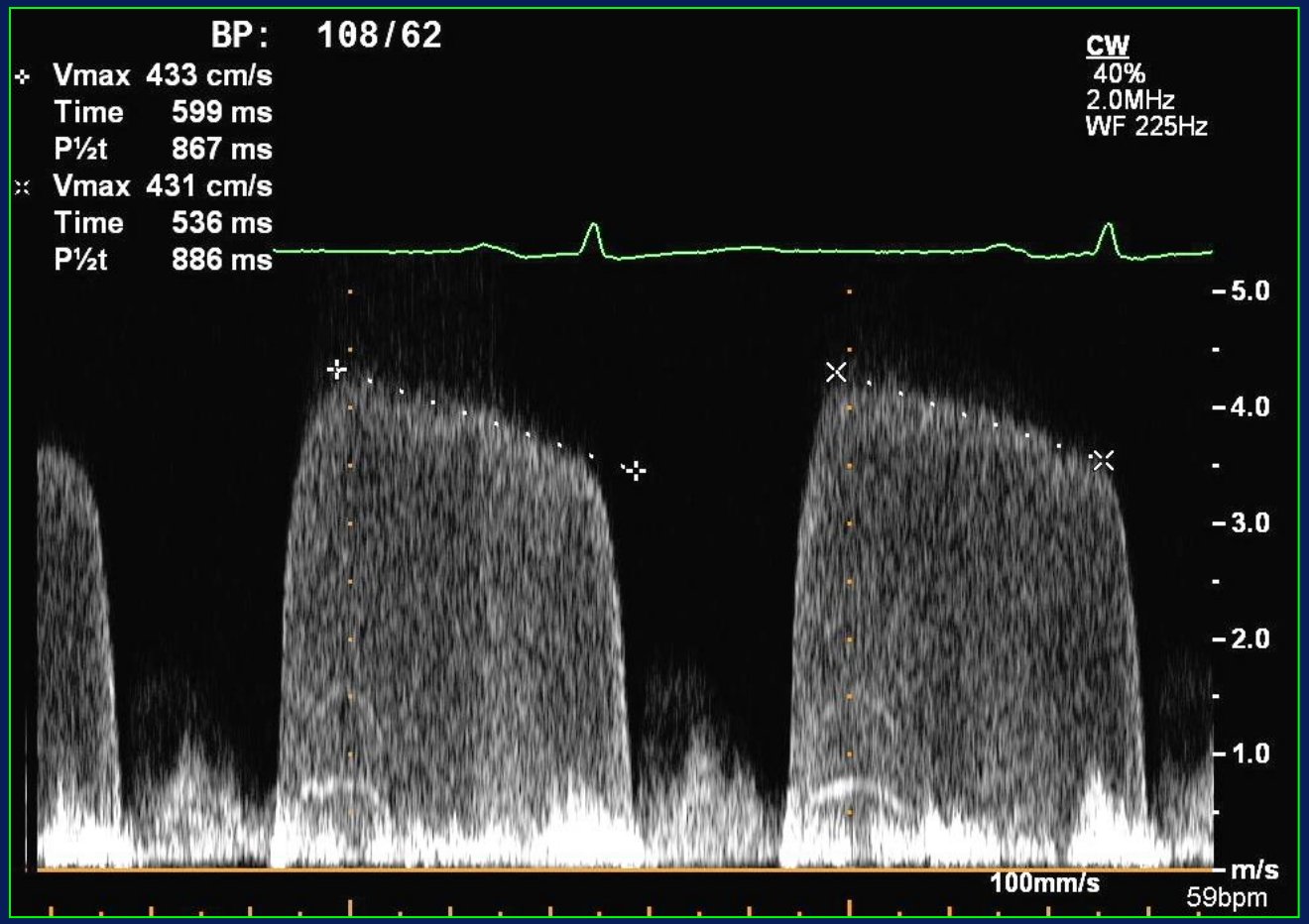


AR Pressure Half-time

Mild AR: **> 600 msec**

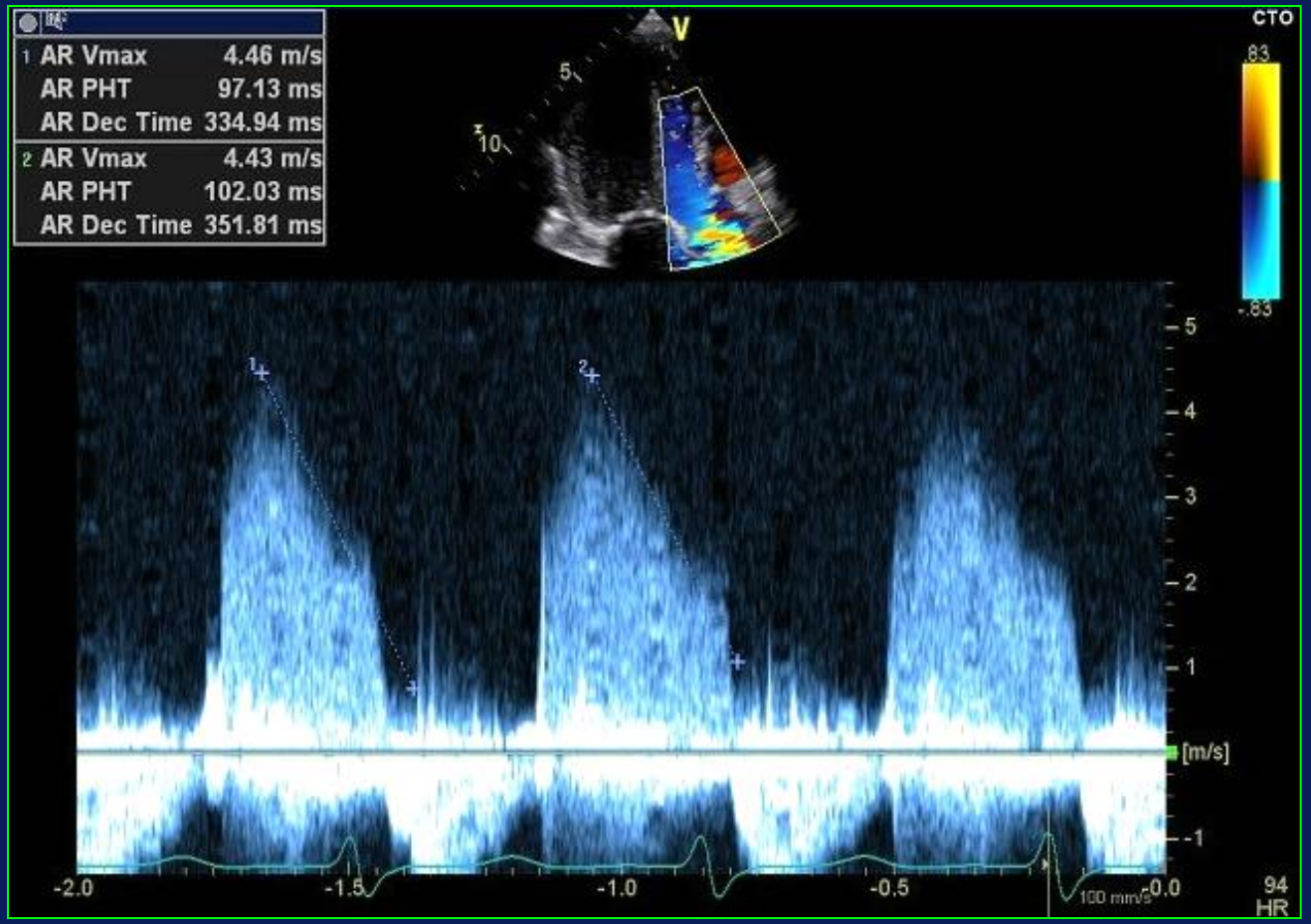
Severe AR: **< 250 msec**

Mild AR: CW Doppler
Pressure Half-time = 870 msec



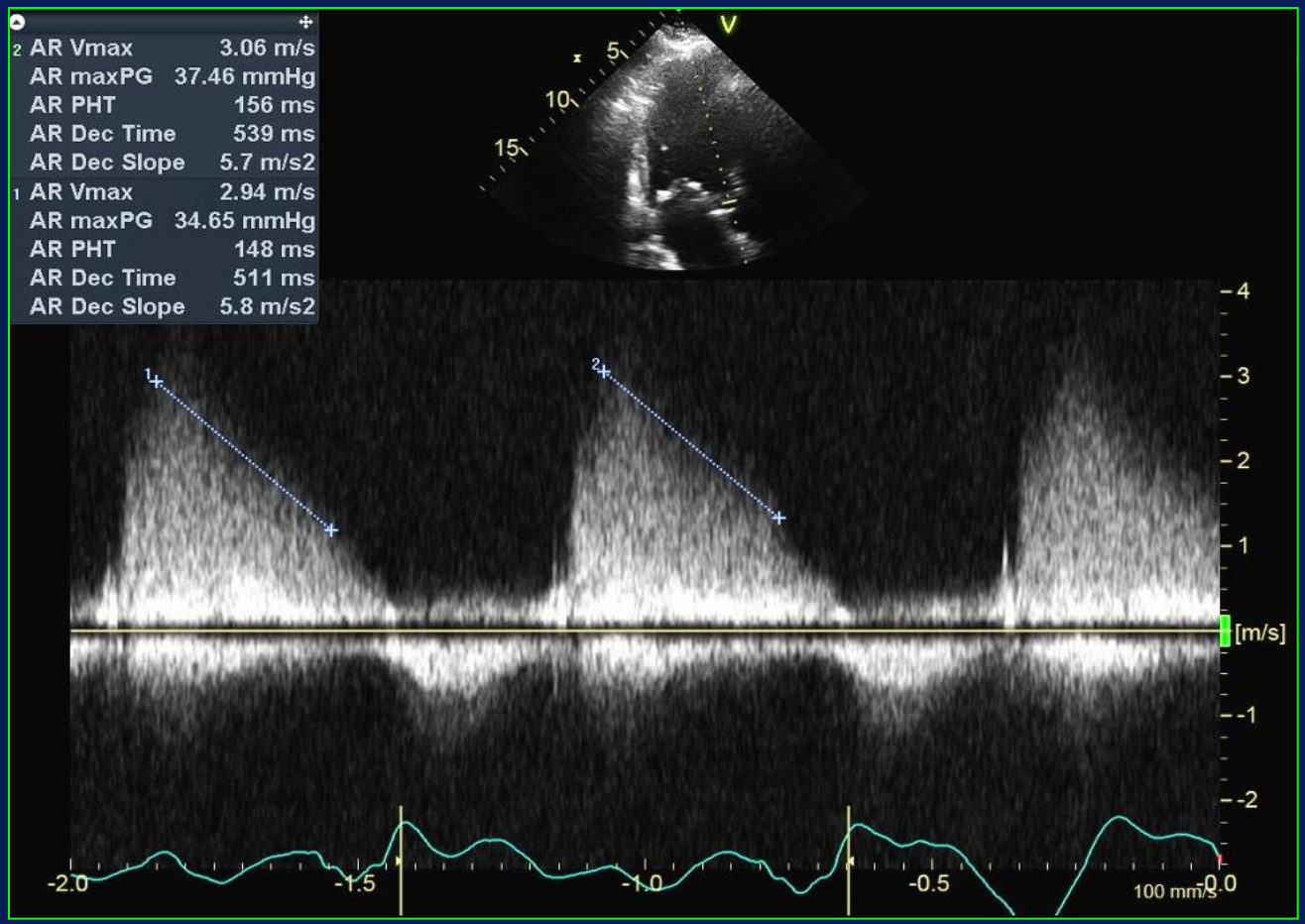
Acute Severe AR: CW Doppler

Pressure Half-time = 100 msec



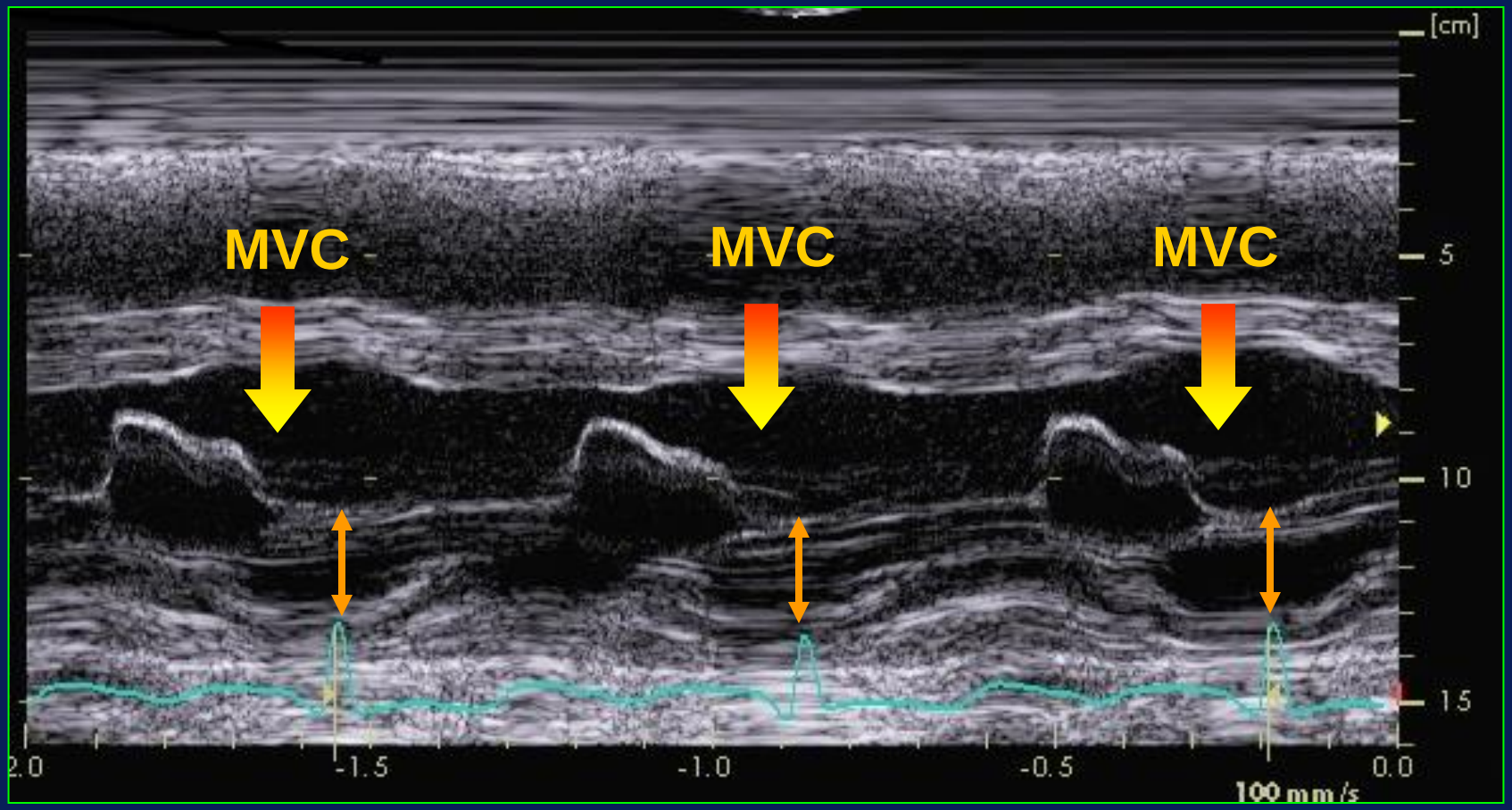
Acute Severe AR: CW Doppler

Pressure Half-time = 150 msec

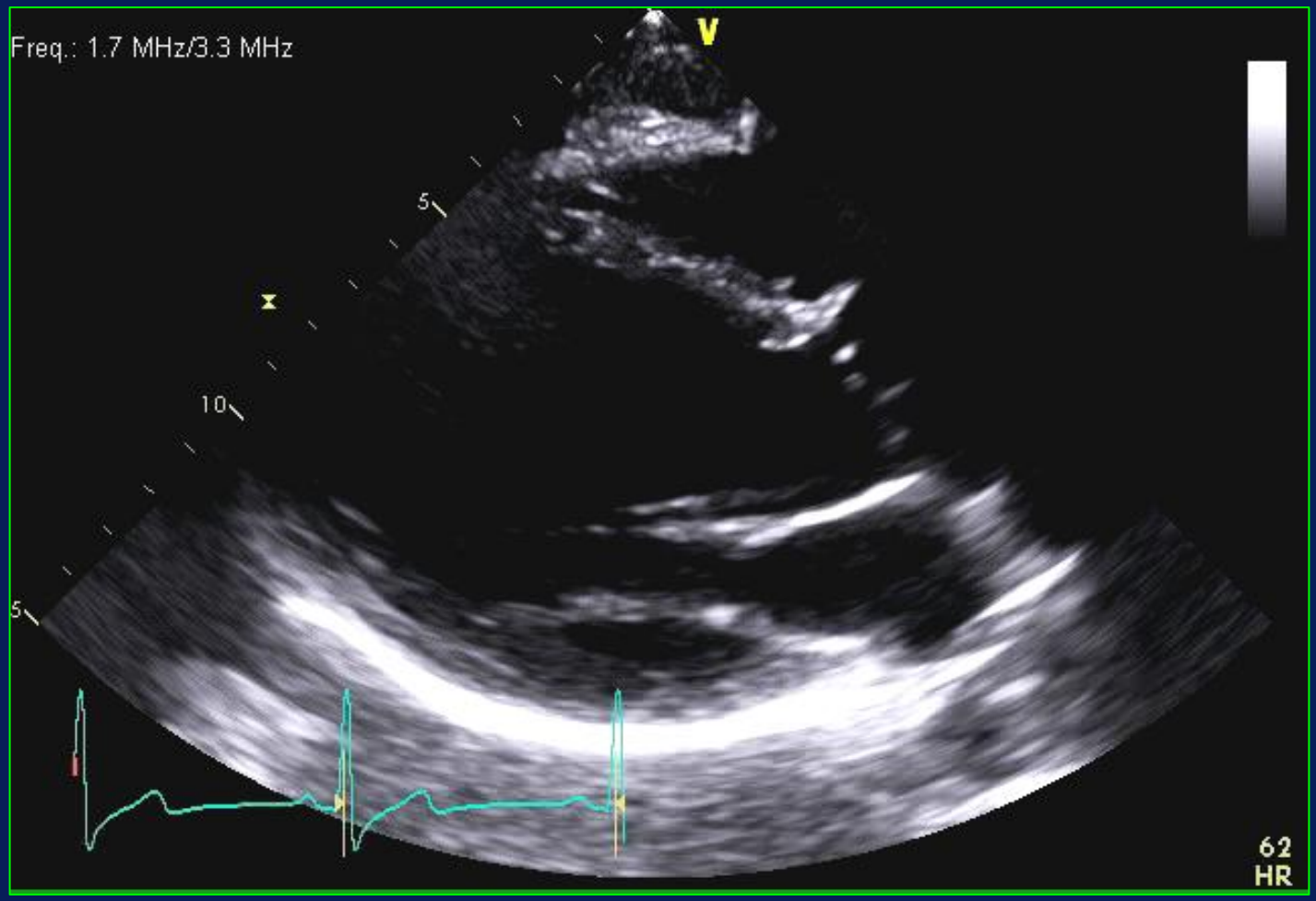


Acute Severe AR: M-Mode

Premature closure of mitral valve

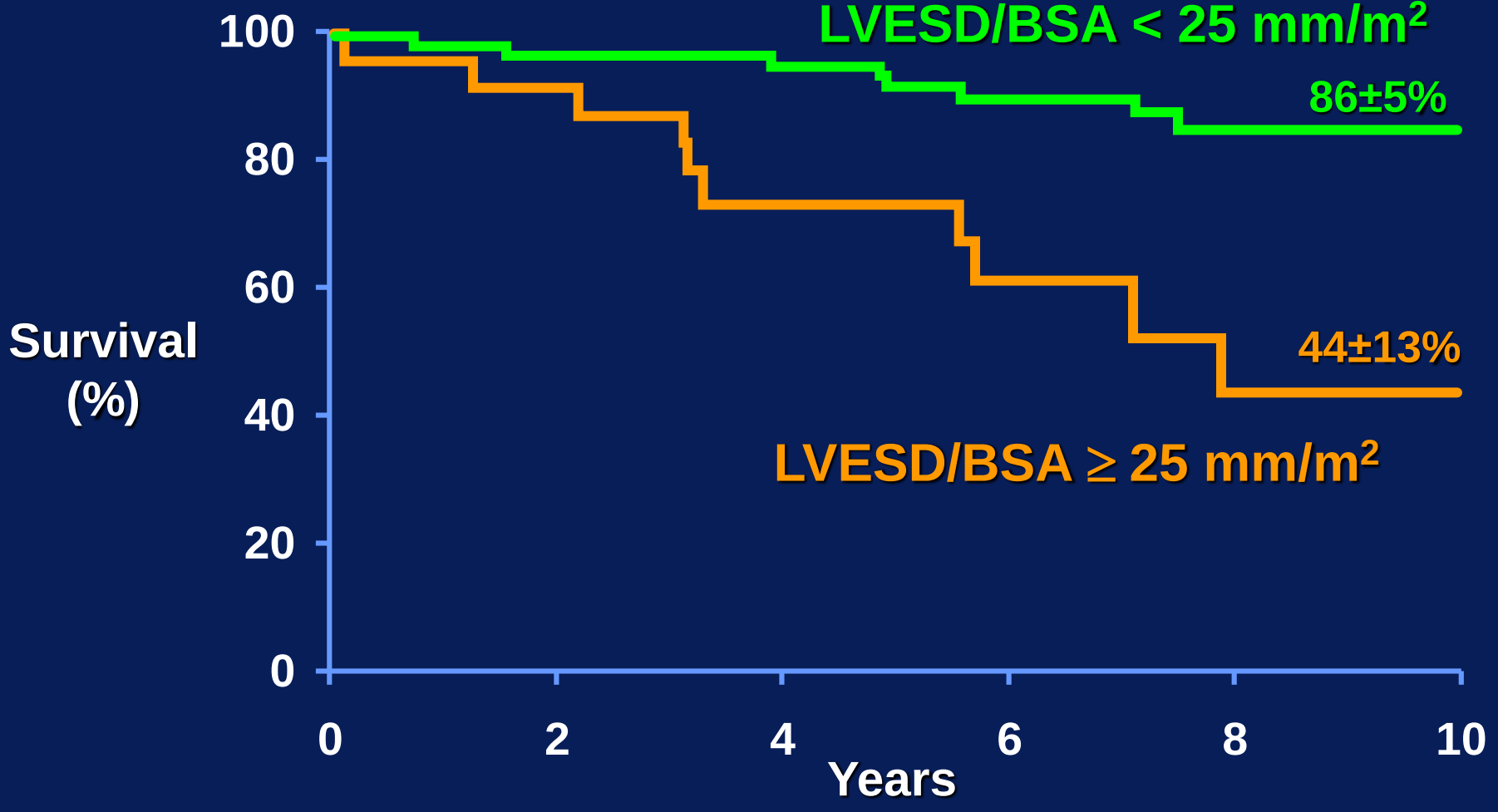


? Severity of Aortic Regurgitation



Chronic Aortic Regurgitation

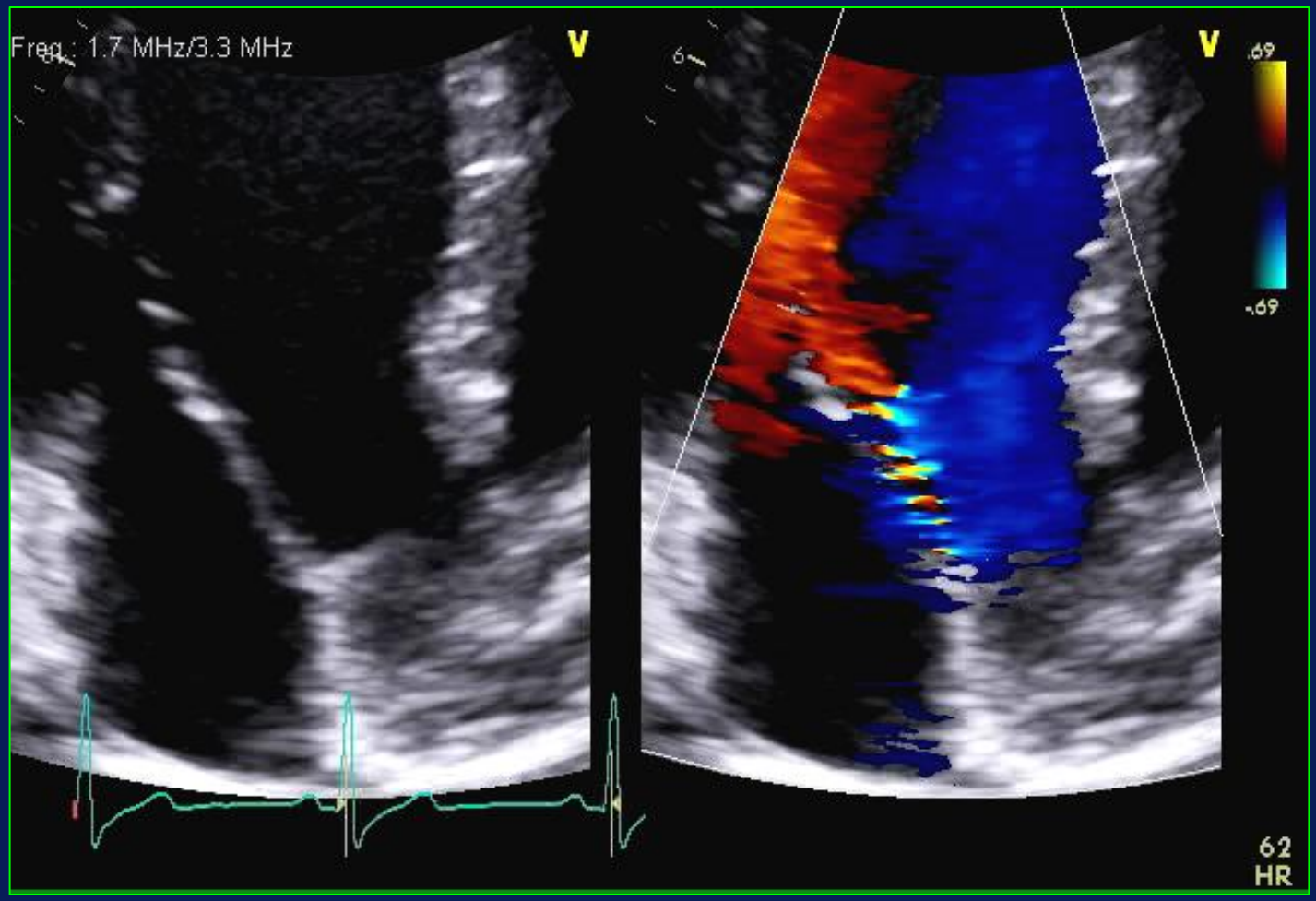
LV End-Systolic Dimension (LVESD) Index



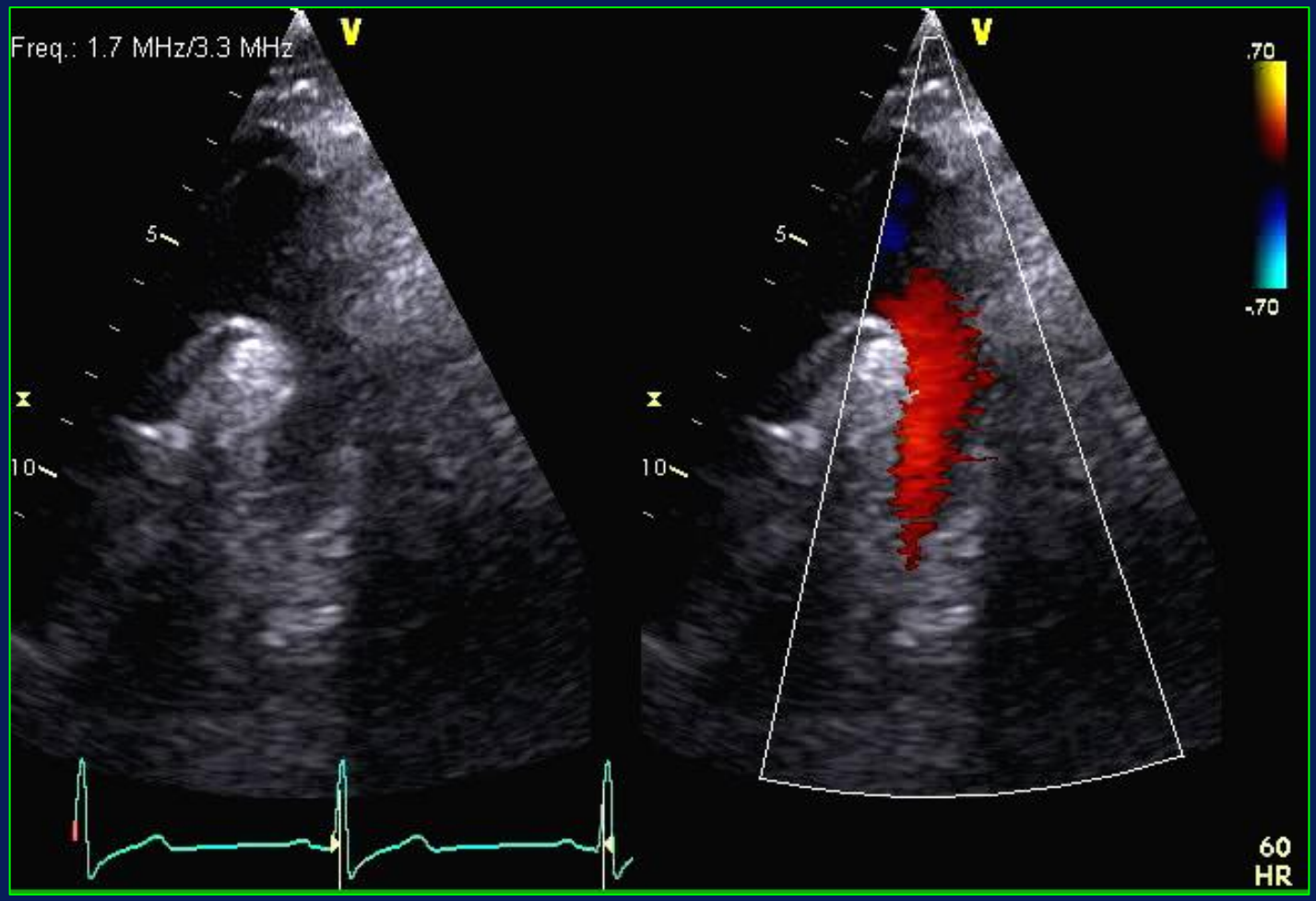
MAYO CLINIC

Dujardin KS et al: Circulation1999; 99: 1851

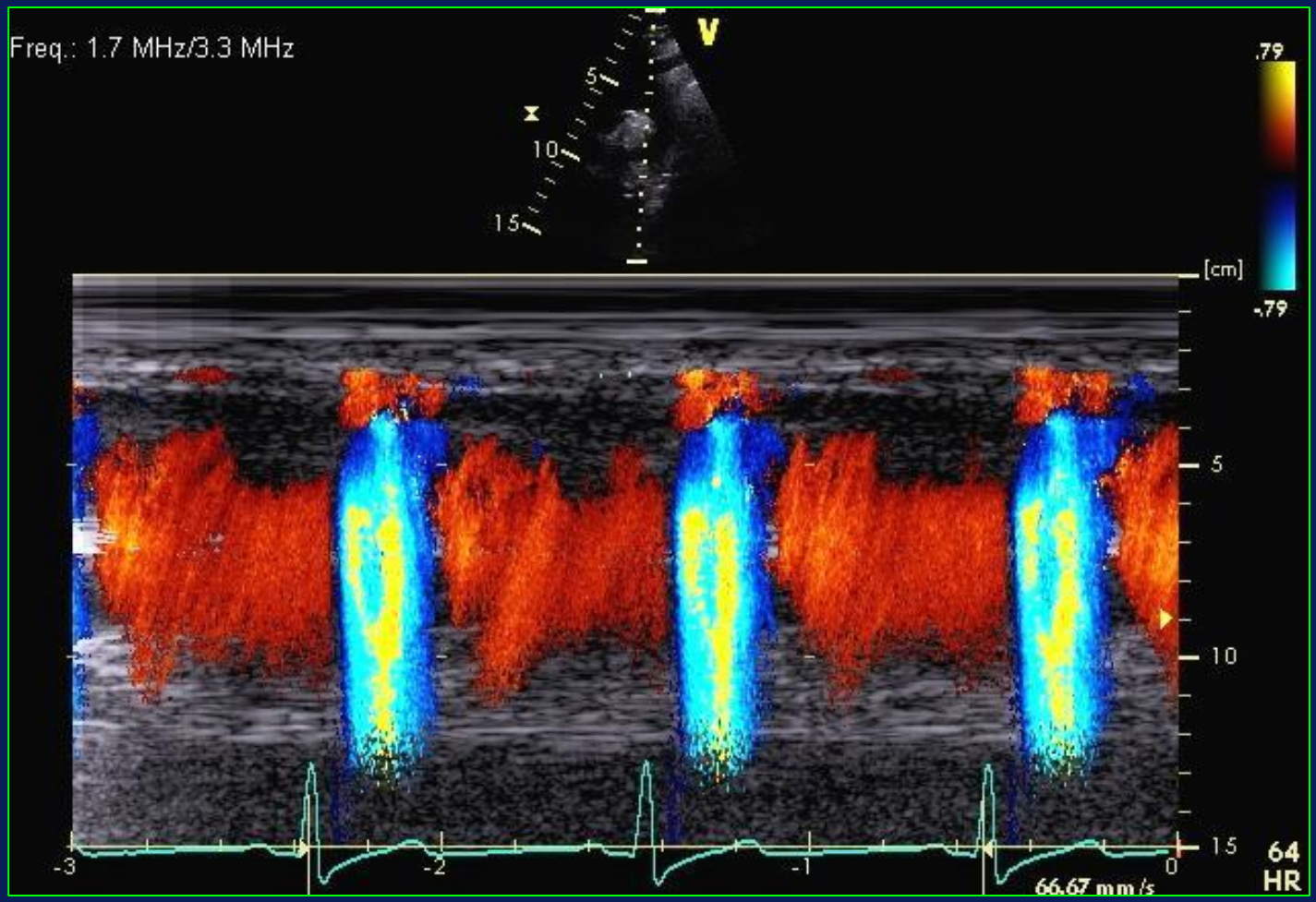
? Severity of Aortic Regurgitation



Descending aorta



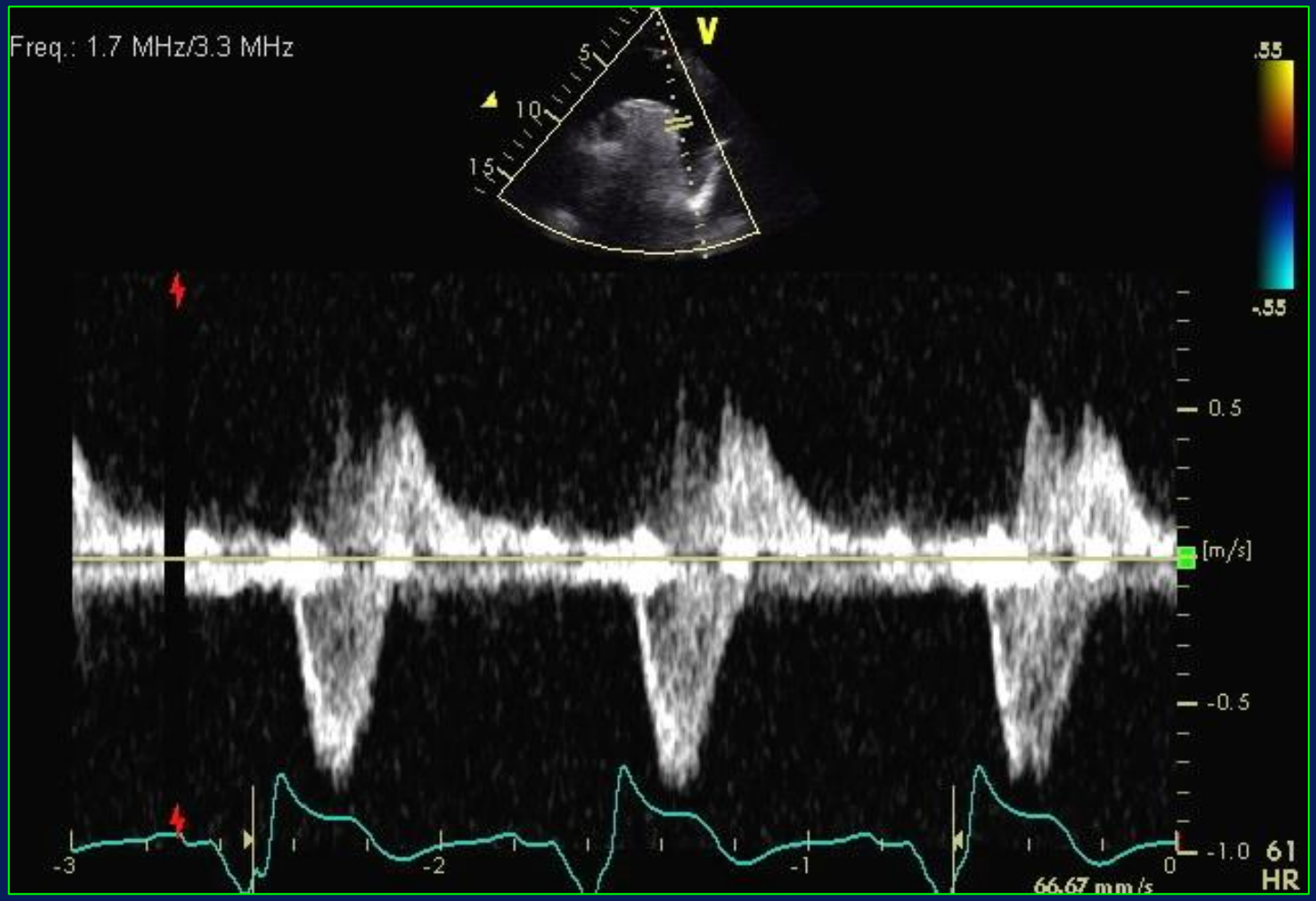
Descending aorta: Color M-mode



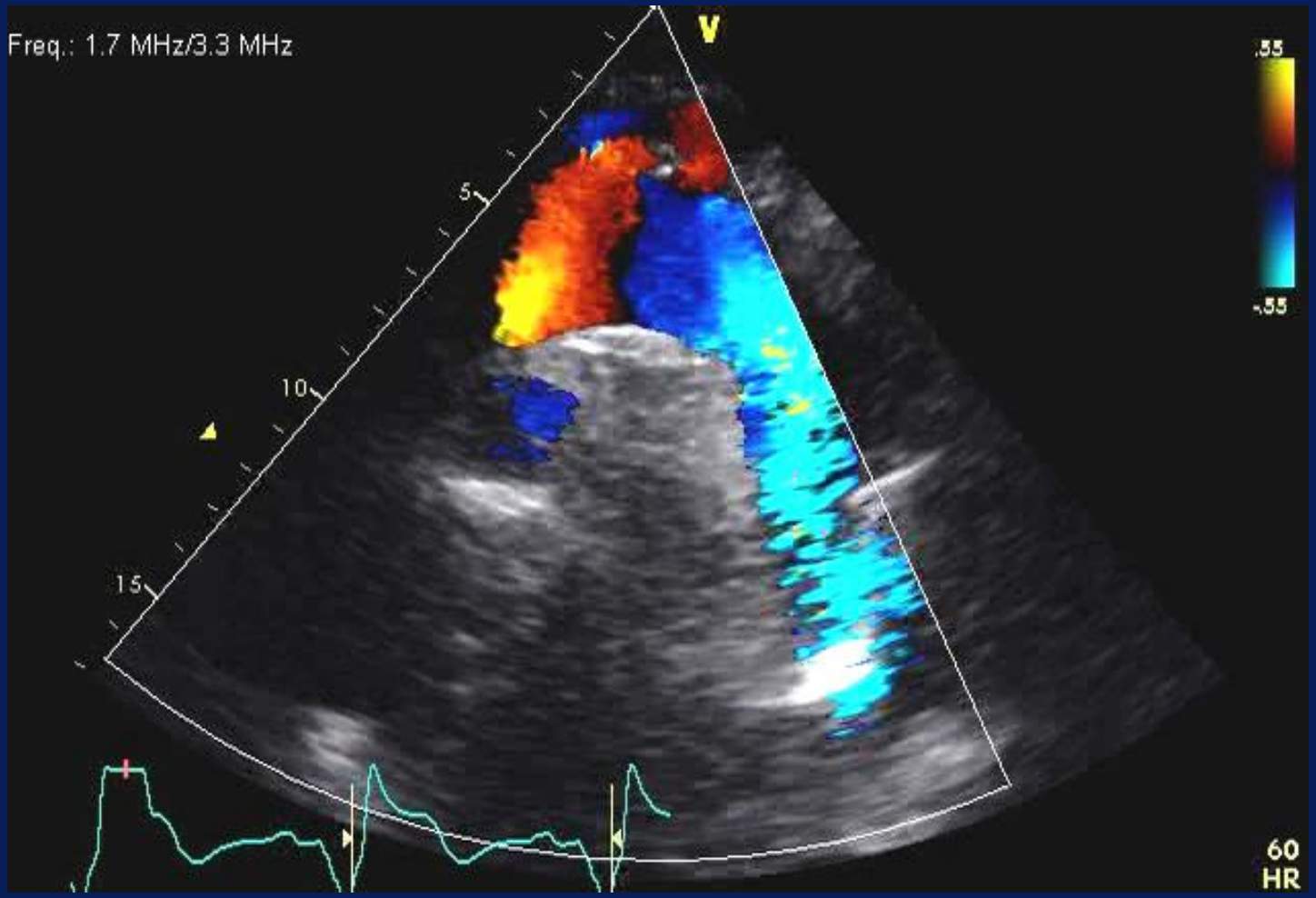
Descending aorta: Reversal TVI = 24 cm

Abdominal aorta: PW Doppler

? Diastolic flow reversals



Descending aortic eddy flow



Aortic Regurgitation (AR)
Evaluation by 2-D and Doppler Echo

- Echocardiography remains the imaging modality of choice for the diagnosis of the mechanism and the quantitation of severity of AR
- Careful application of the concepts of the continuity equation are needed for accurate quantitation of AR
- Quantitation of AR is the sum of all 2-D and Doppler data, not a single parameter