ASE American Society of Echocardiography

Workshop
Quantitative Echocardiography

Practical tips for good clinical practice

Anderson: Intra-cardiac Pressures & Continuity Equation

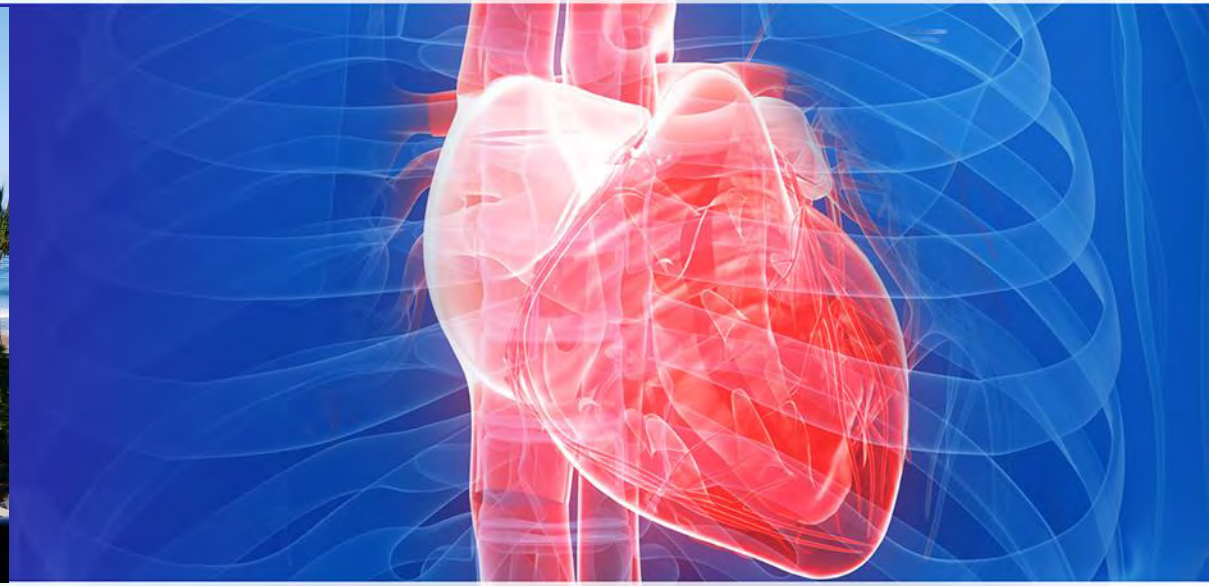
Zimmerman : MR quantification and Diastolic Function

Oh : Diastology and Hemodynamic Cases

MAYO CLINIC

Quantitative Cases

Hemodynamics and Diastology



Jae K. Oh, MD

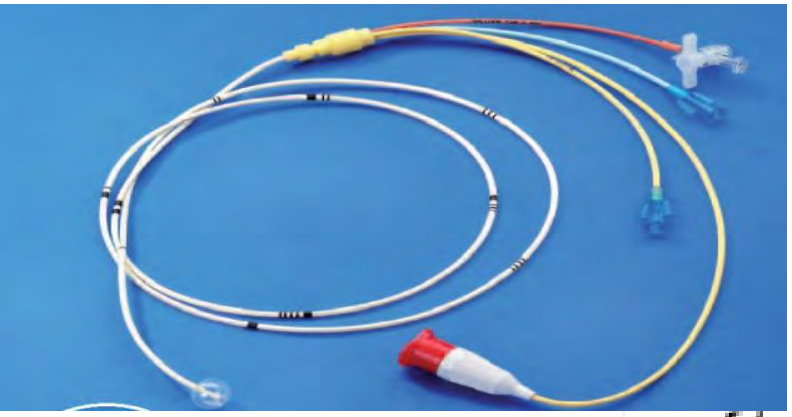
Jan 20th, 2020

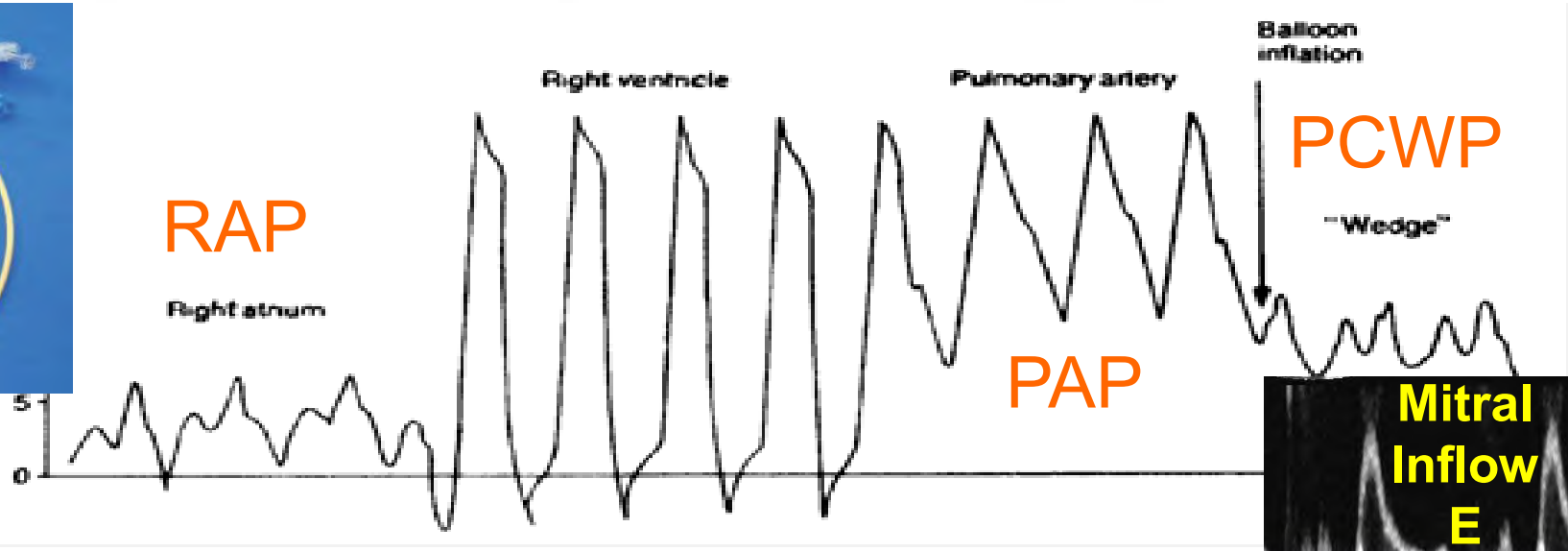
Editorial

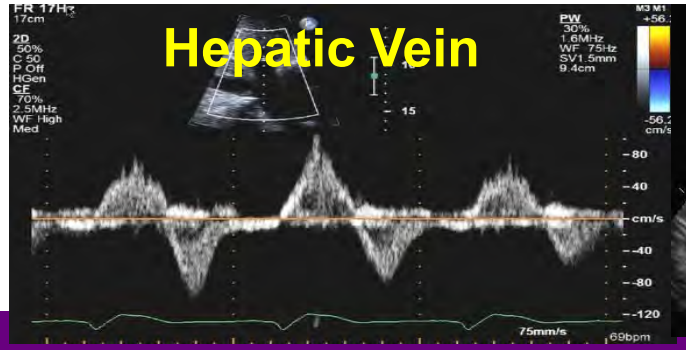
Echocardiography as a Noninvasive Swan-Ganz Catheter

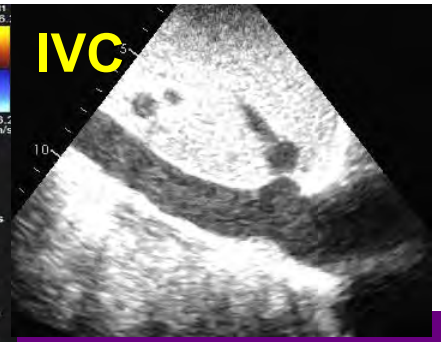
Jae K. Oh, MD

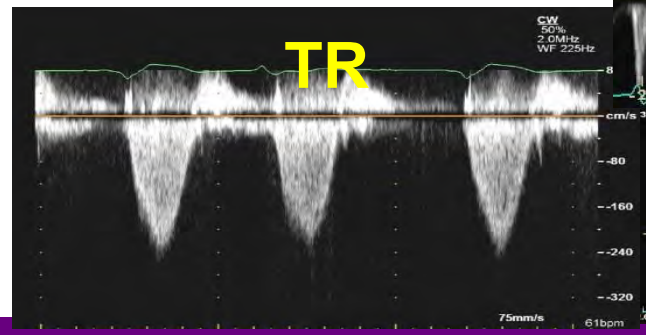
E/e' = PAWP

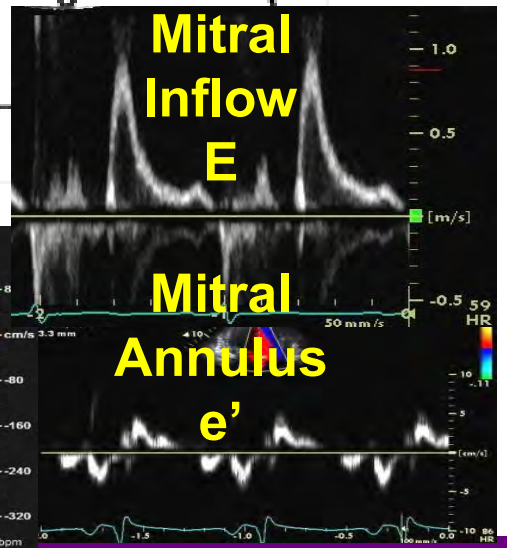










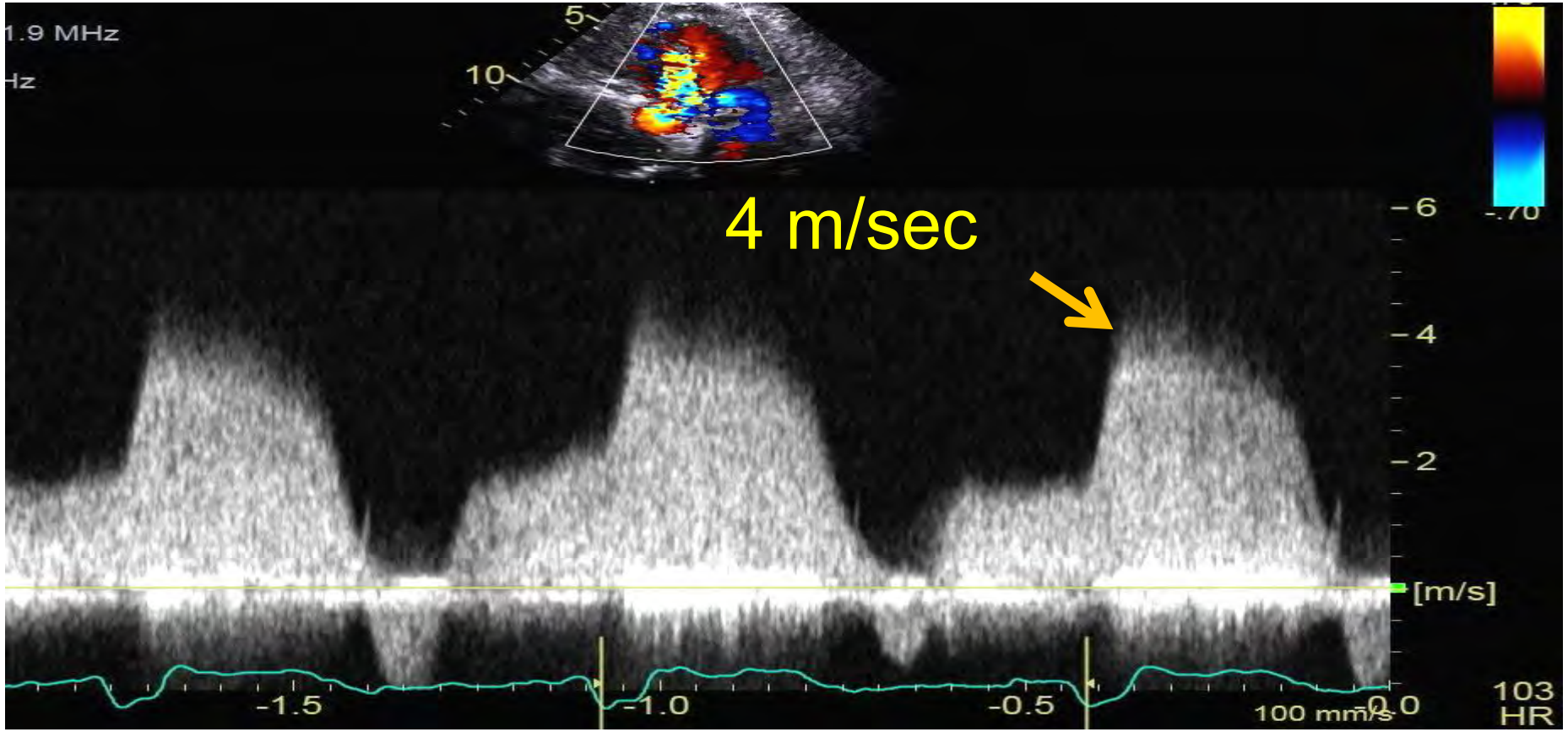


Oh Circulation June 2005

Right Heart Hemodynamics
TV, PV and Hepatic Vein Doppler Tracings
Velocity, Configuration and Density

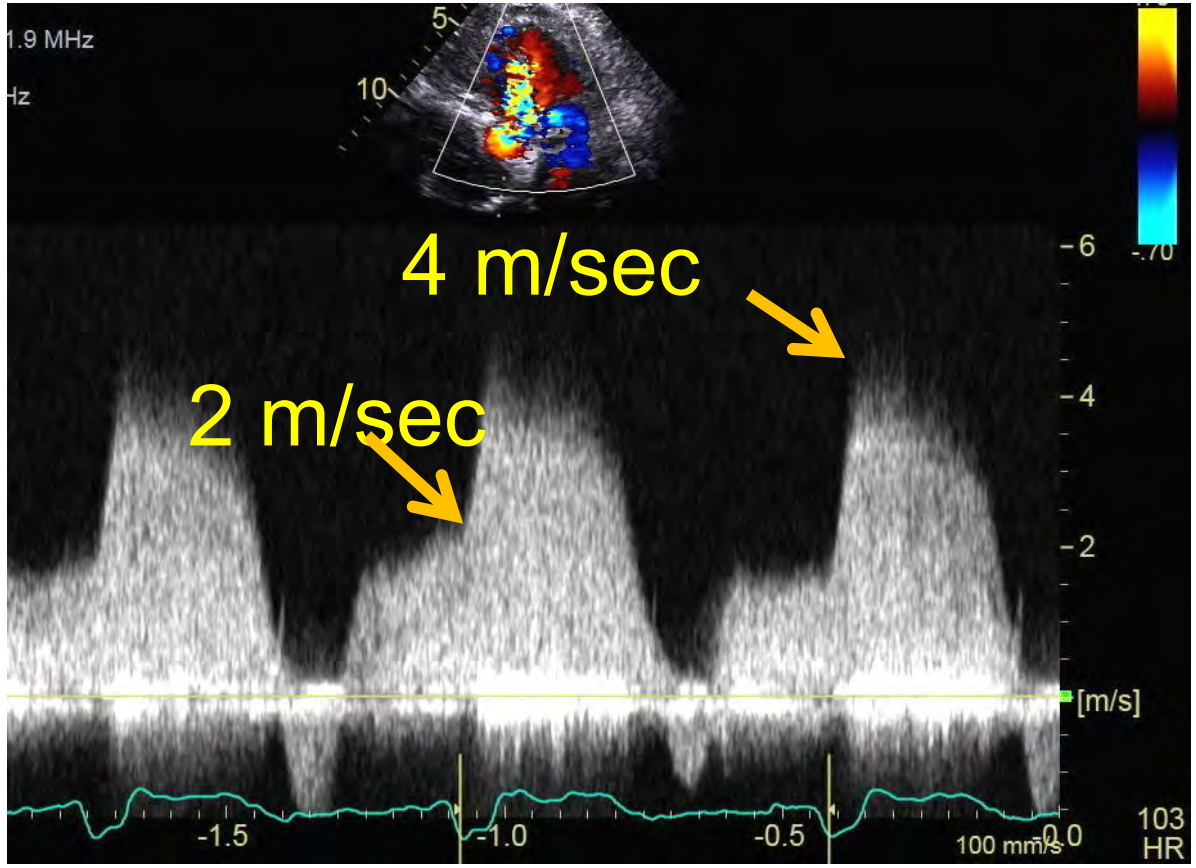
Case to Start

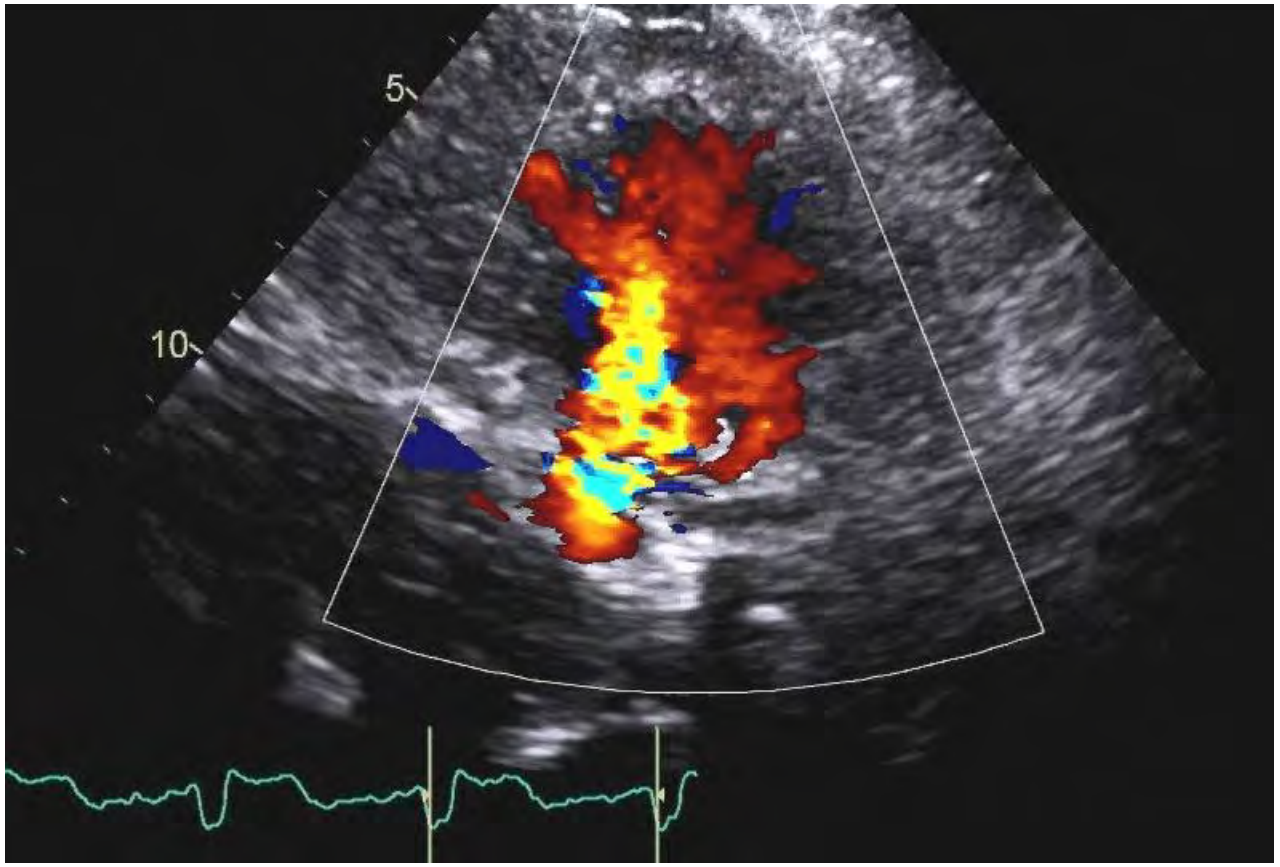
67 yo man with posterior infarct with following Doppler. Diagnosis ?



Case to Start

67 yo man with posterior infarct with following Doppler and color flow imaging. Blood pressure = 114/74 mmHg
Estimate RV systolic pressure?

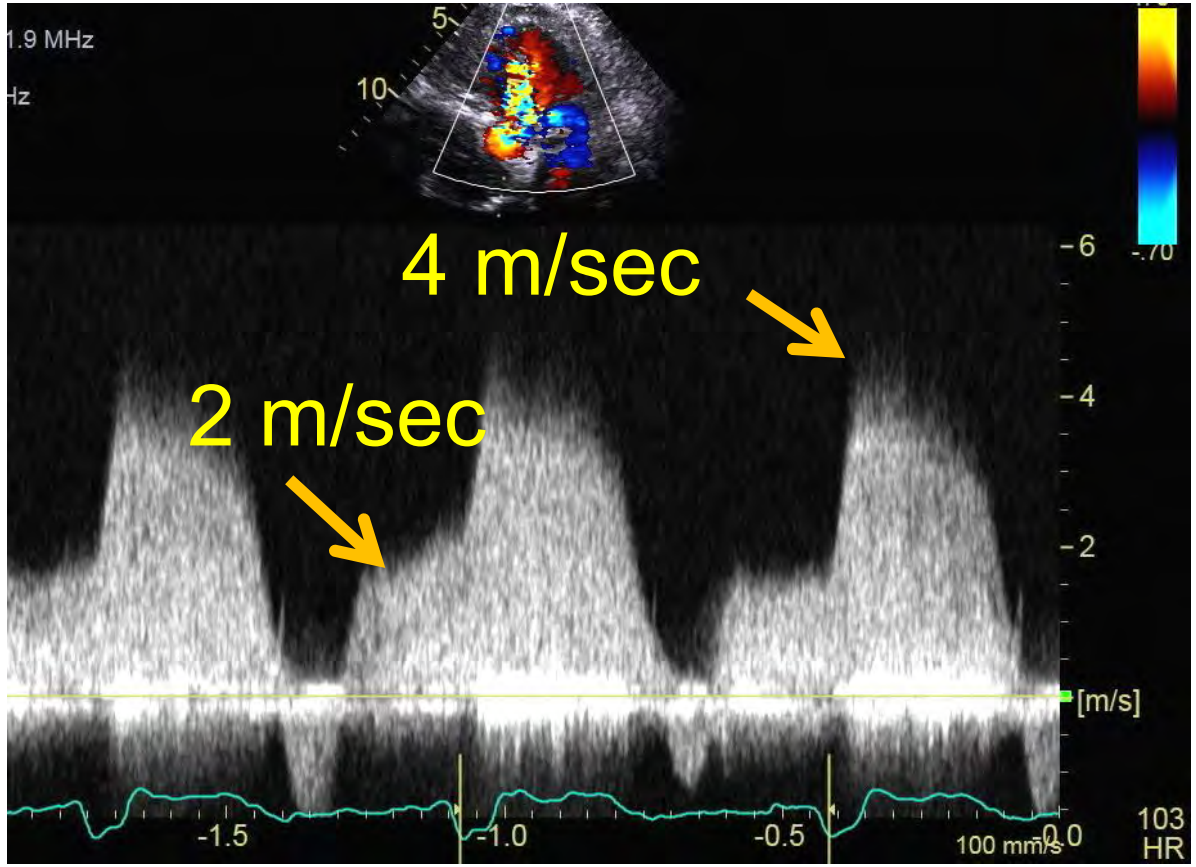


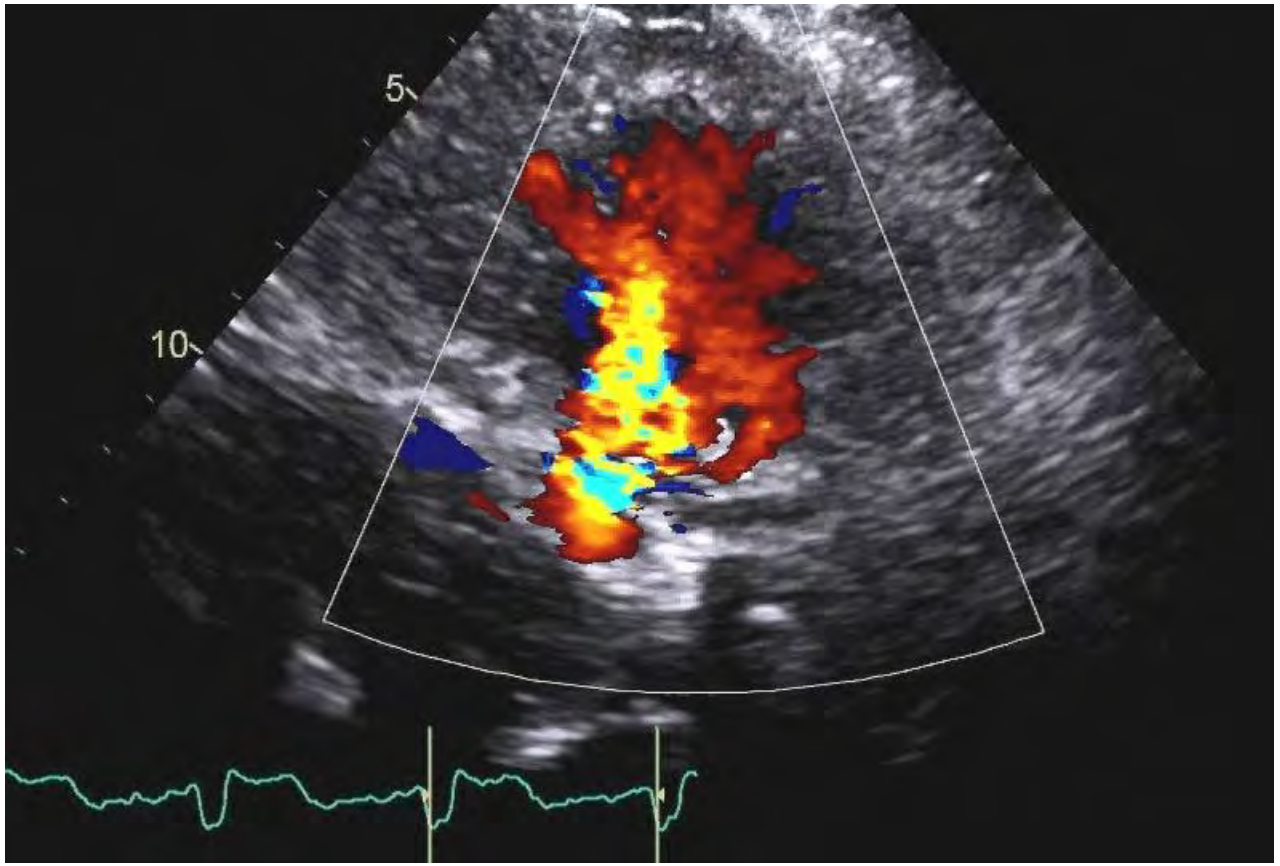


1= 64 (4 x 4^2) 2= 50 (114 – 64) 3= 98 (114-16) 4= 58 (74 -16)

Pressure Grad = 4 x Velocity^2

67 yo man with posterior infarct with following Doppler and color flow imaging. Blood pressure = 114/74 mmHg Estimate RV systolic pressure?



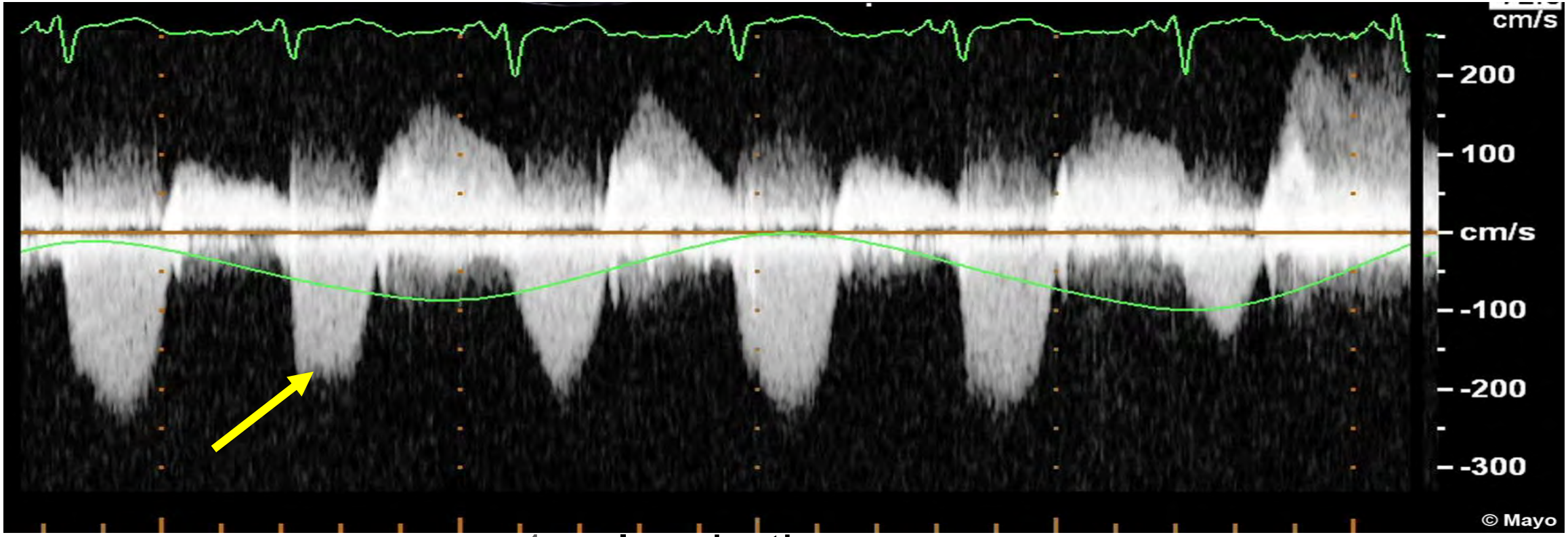


1= 64 (4 x 4^2) 2= 50 (114 – 64) 3= 98 (114-16) 4= 58 (74 -16)

Systolic BP – (4 x 4^2)

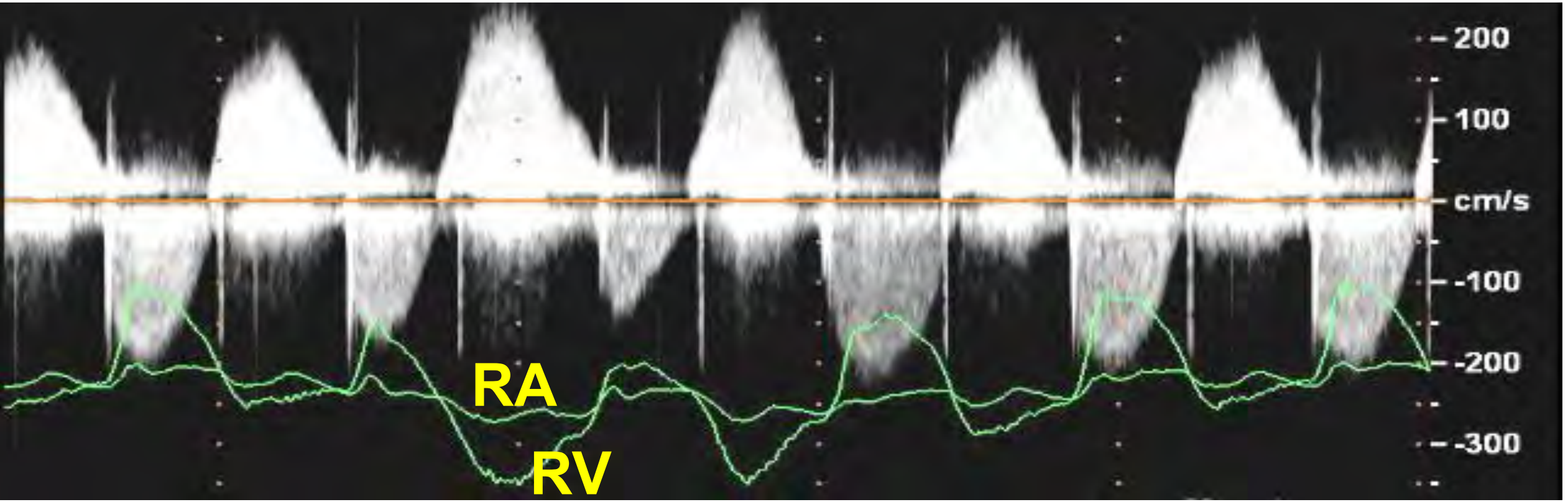
Case #1

Heart Failure after TV replacement
CW Doppler across the TV prosthesis
Which respiratory phase does the arrow indicates?

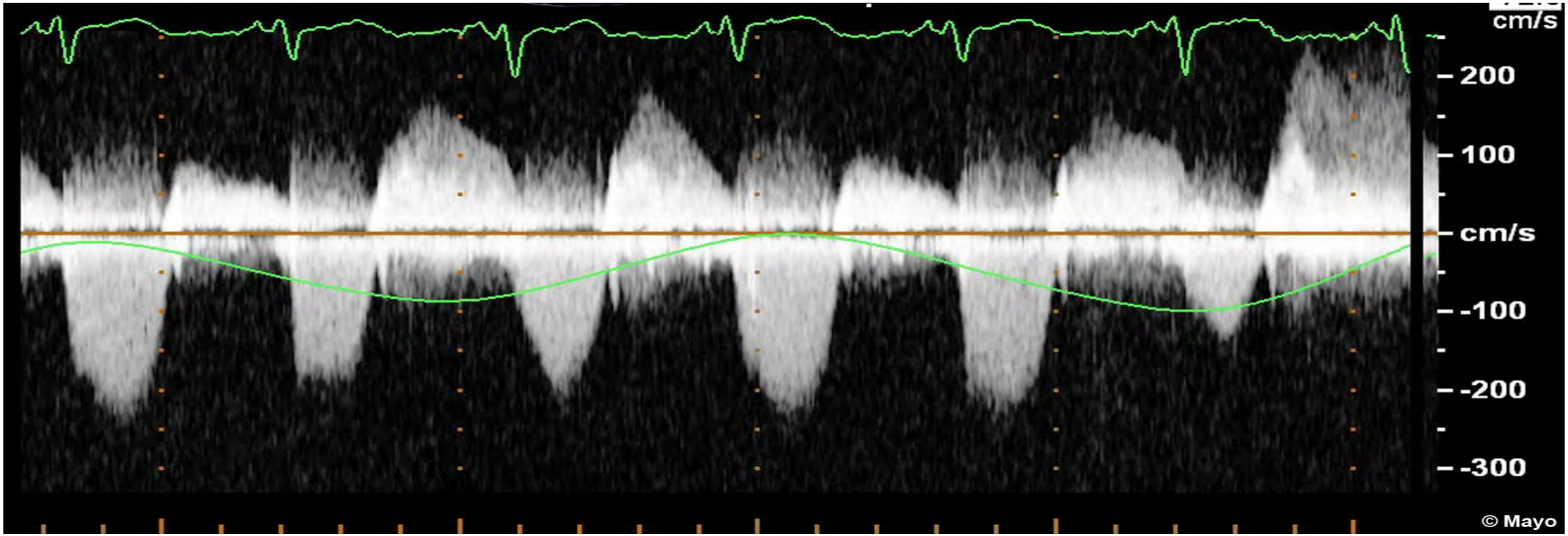


1. Inspiration
2. Expiration
3. Valsalva

Insp Exp

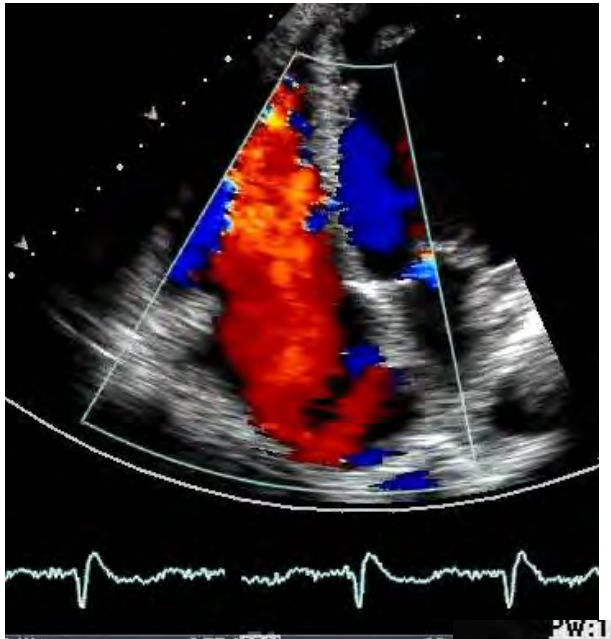


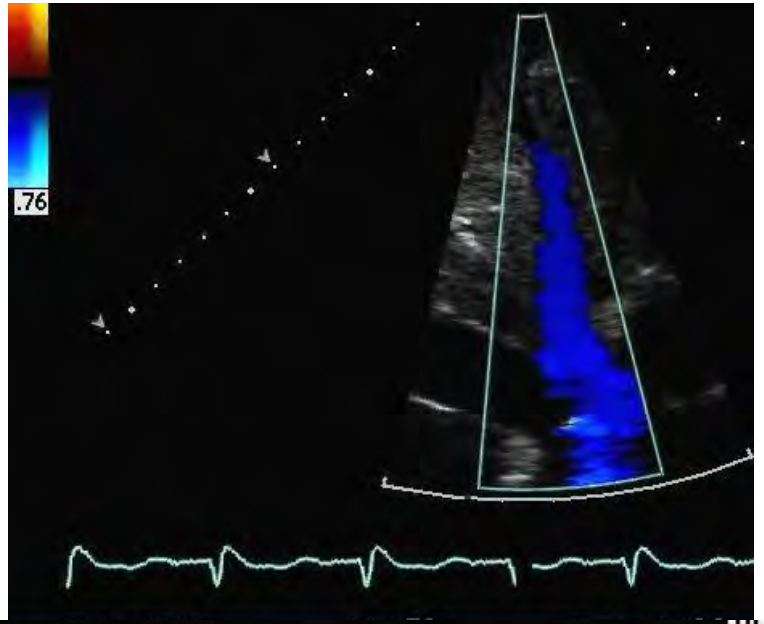
Heart Failure after TV replacement
CW Doppler across the TV prosthesis
Diagnosis?

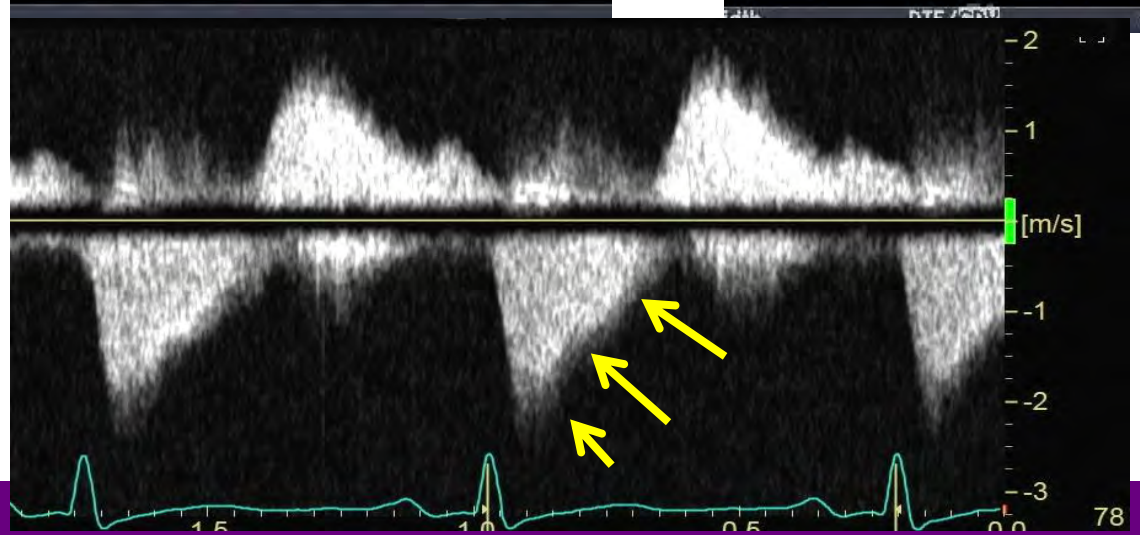


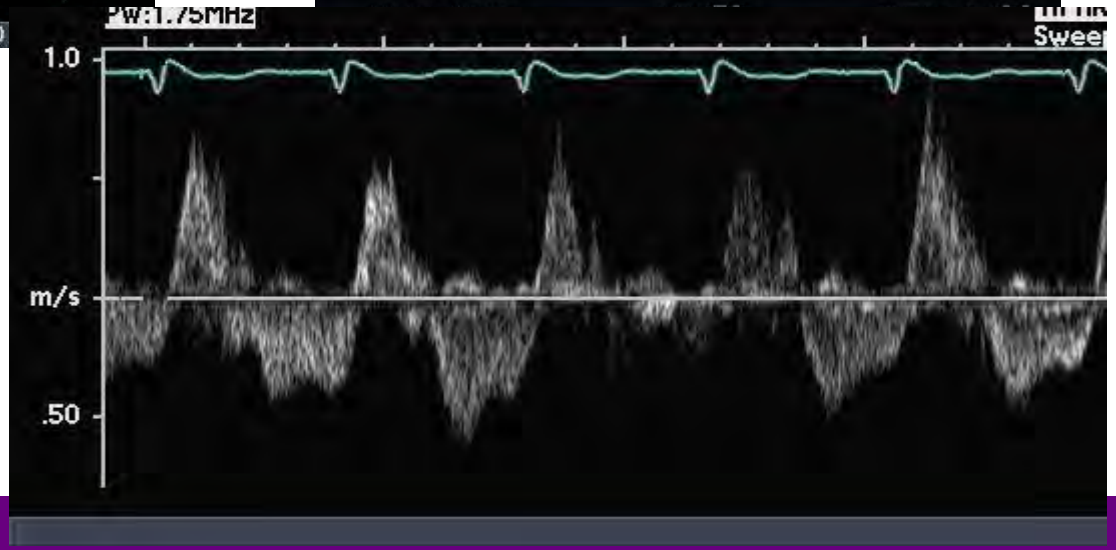
1. TV obstruction
2. Severe TR
3. Increased RA pressure

Severe TR

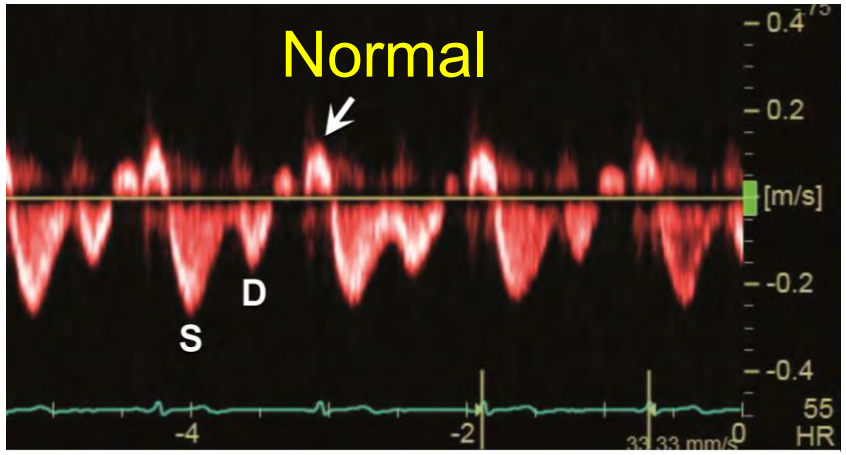


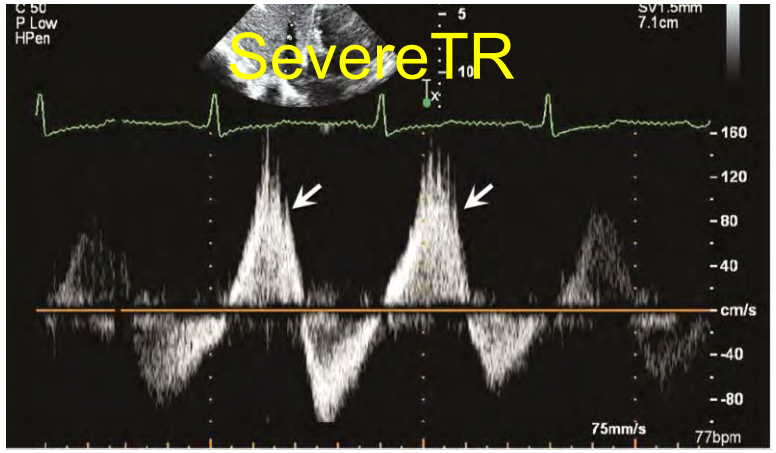


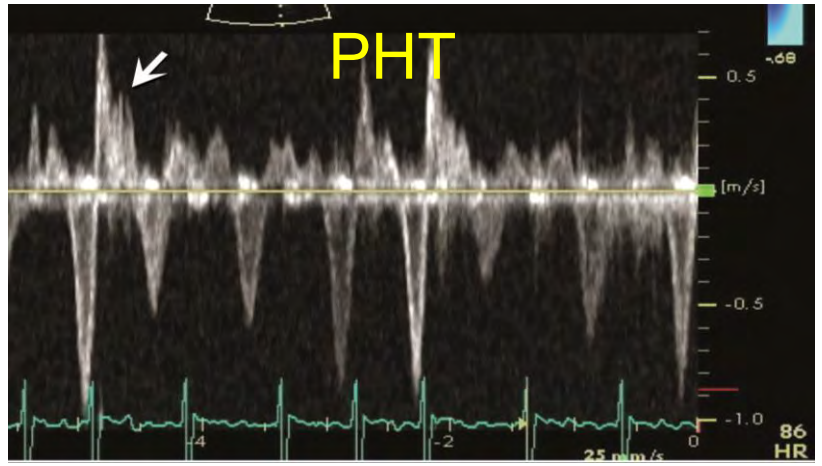


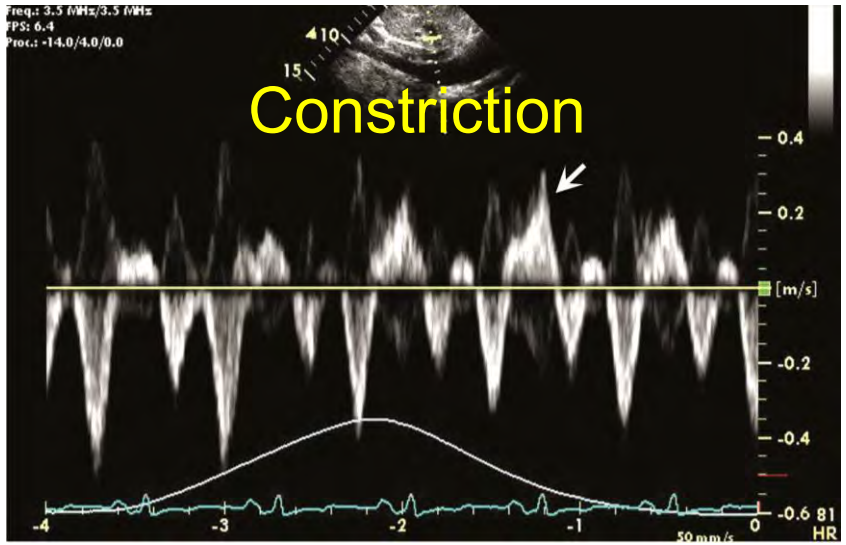


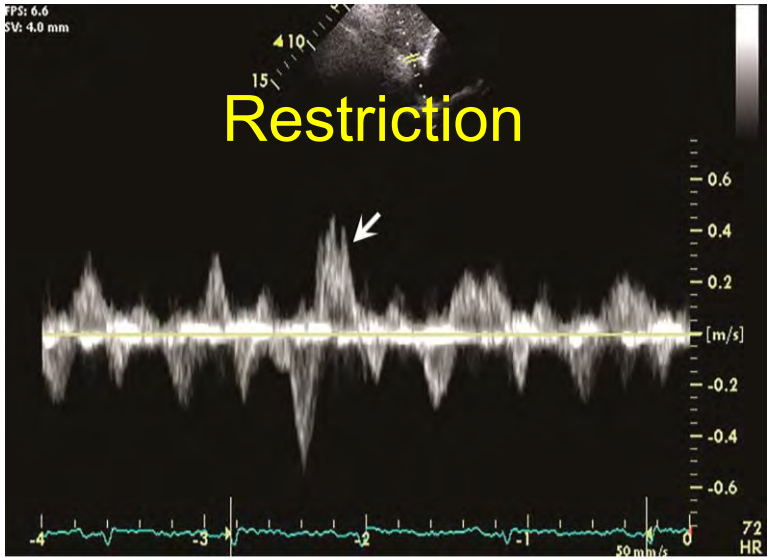
Hepatic Vein Doppler Tracings

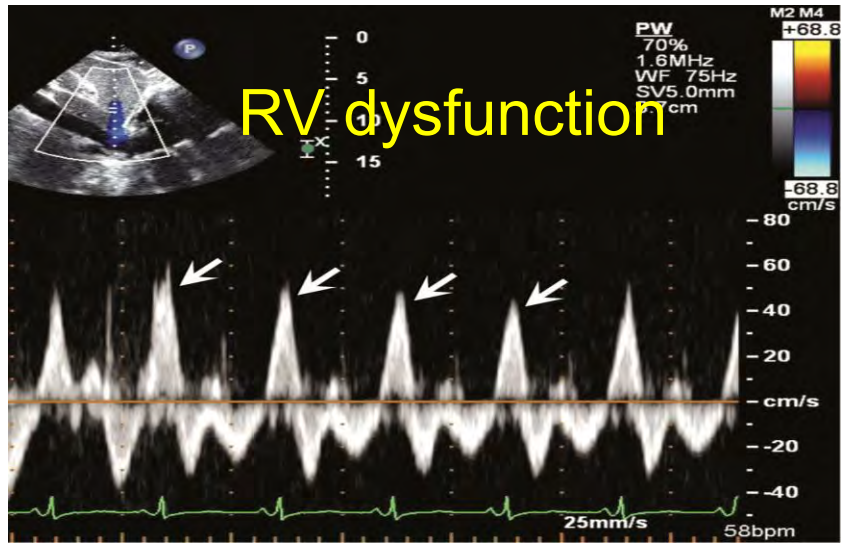






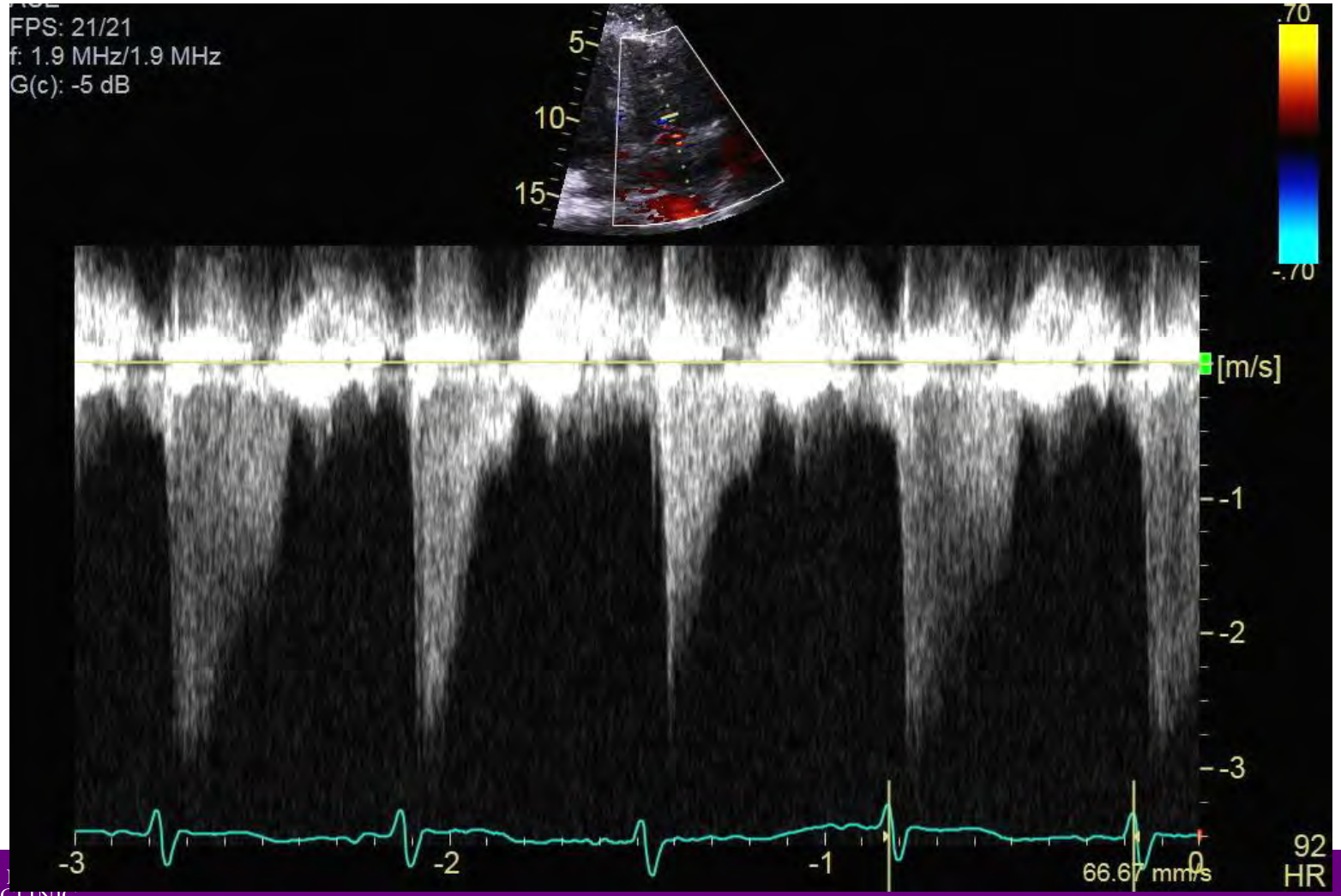






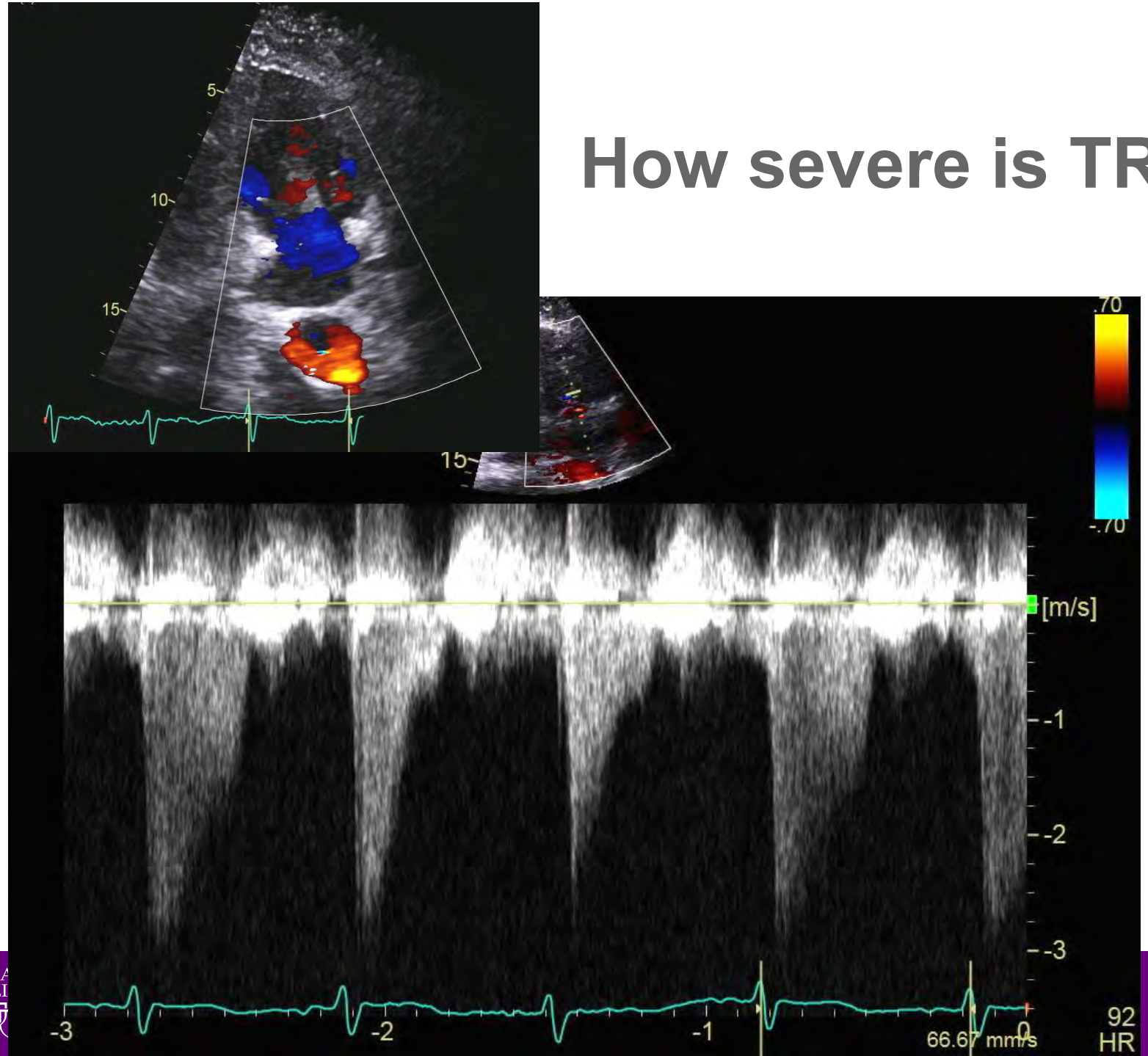
Case #2

What does this CW Doppler show? 70 year old with TIPS procedure

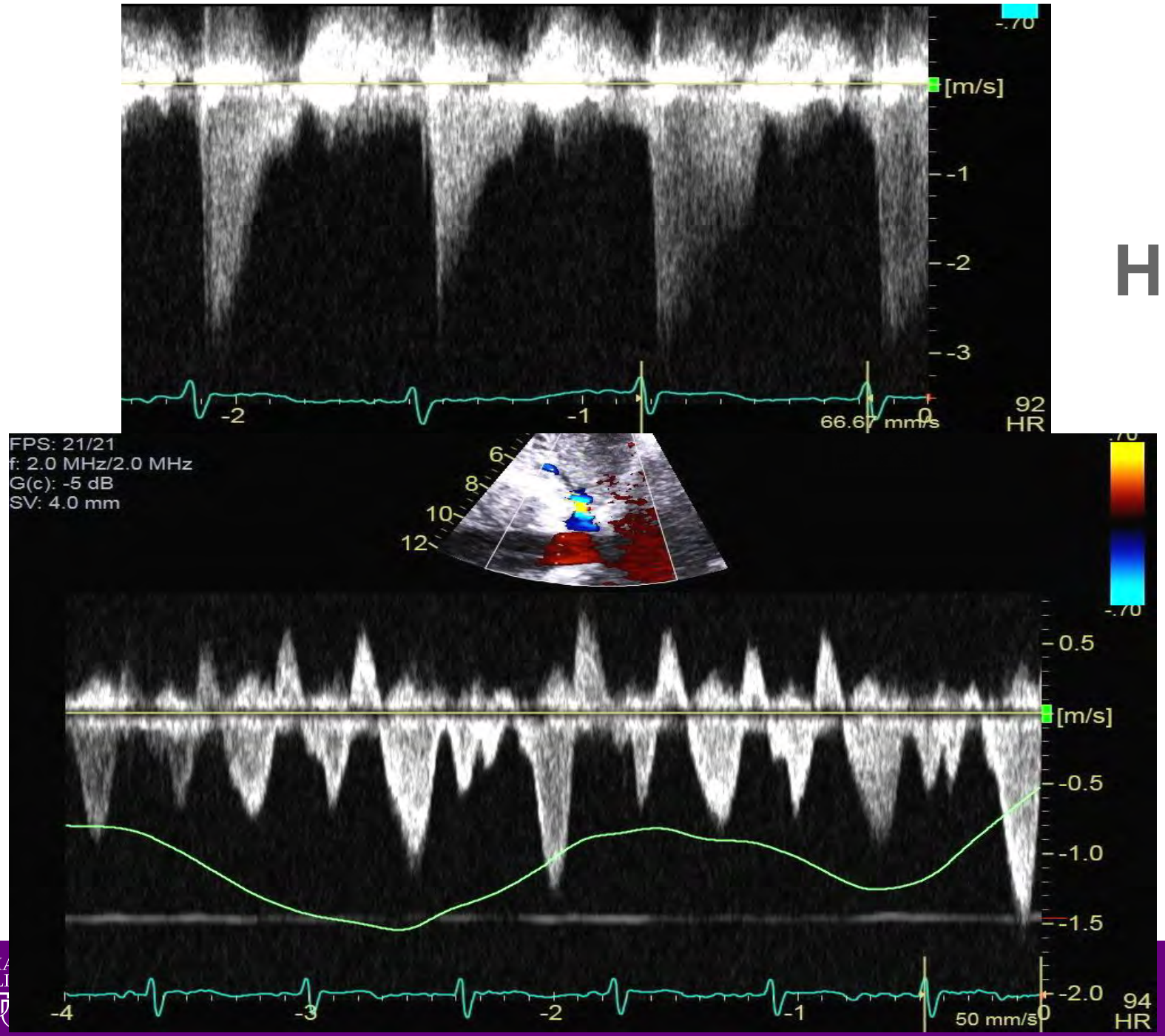


1. Tricuspid Regurgitation
2. Subaortic Stenosis
3. Mitral Regurgitation
4. LVOT Obstruction

How severe is TR?



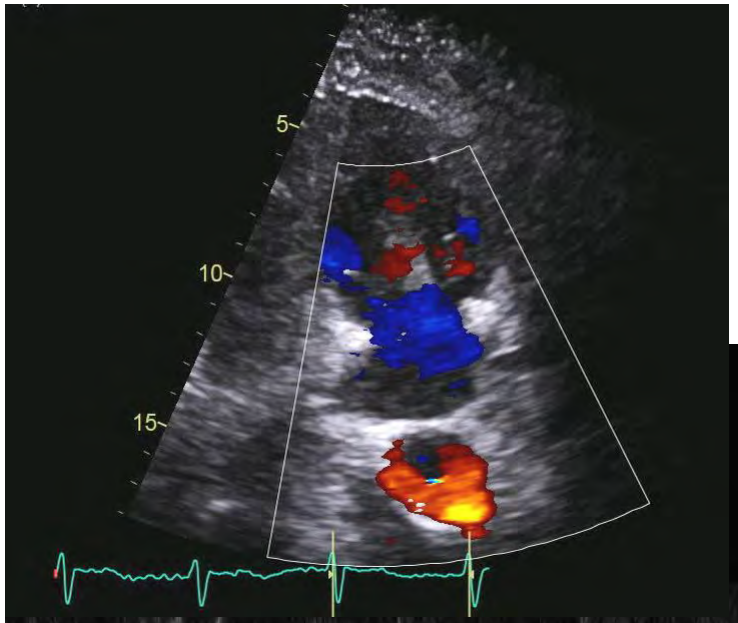
1. Mild
2. Moderate
3. Severe
4. Not certain

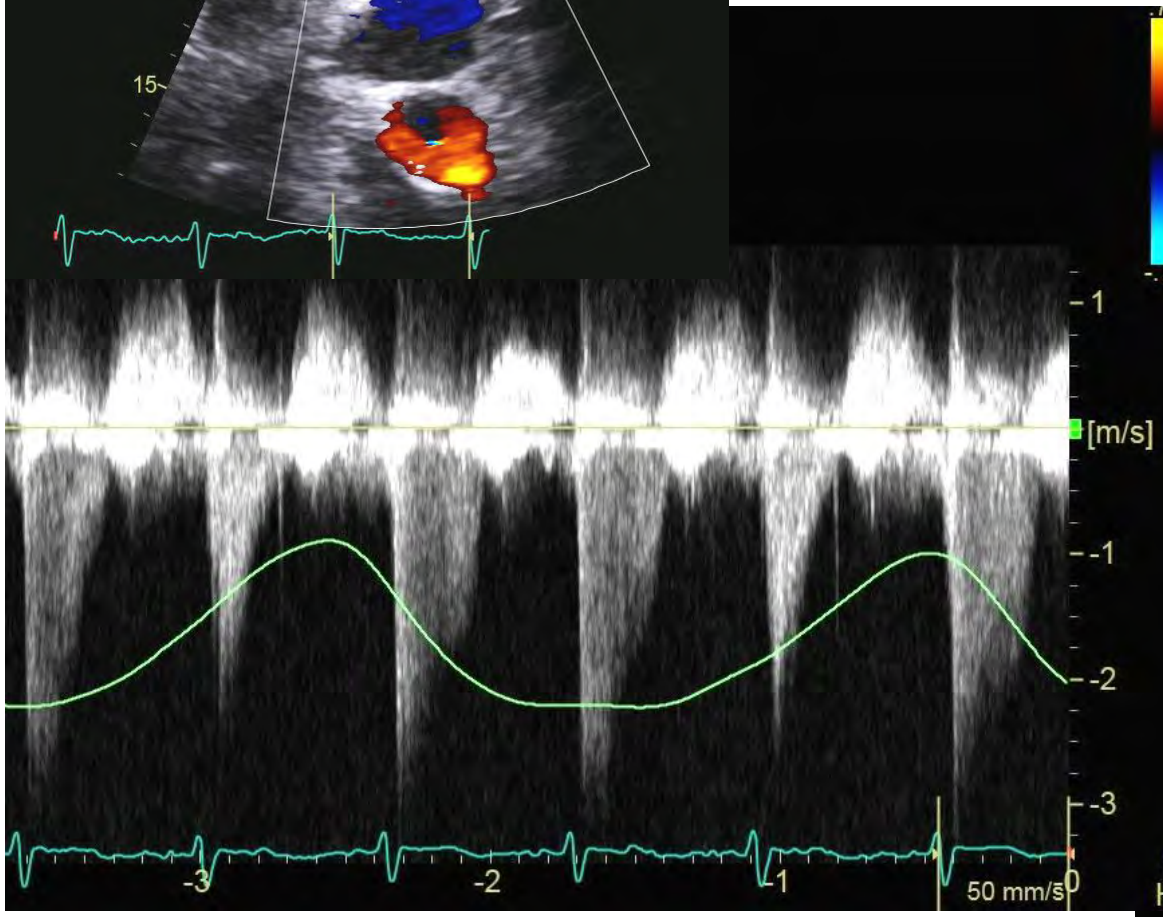


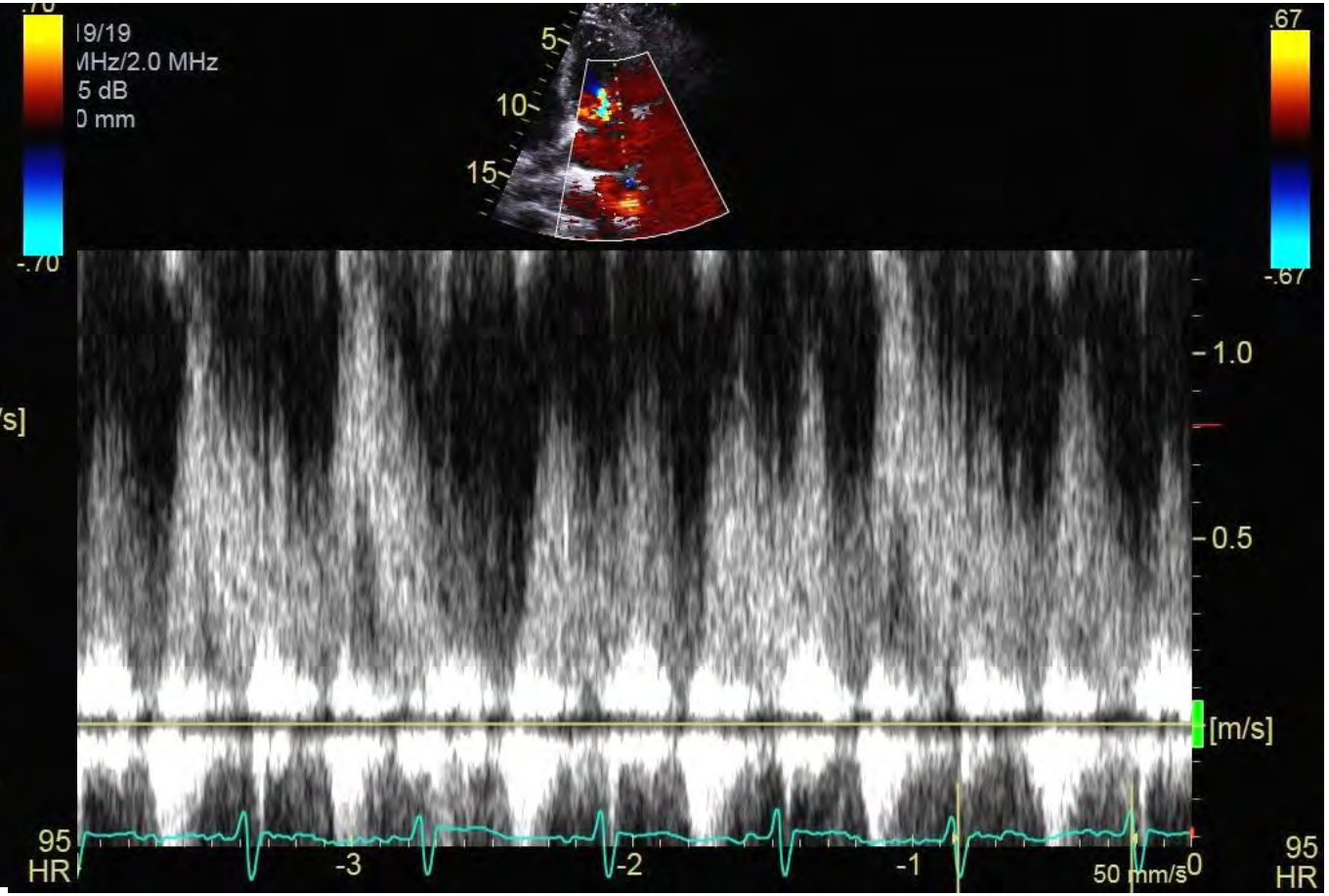
How severe is TR?

1. Mild
2. Moderate
3. Severe
4. Not certain

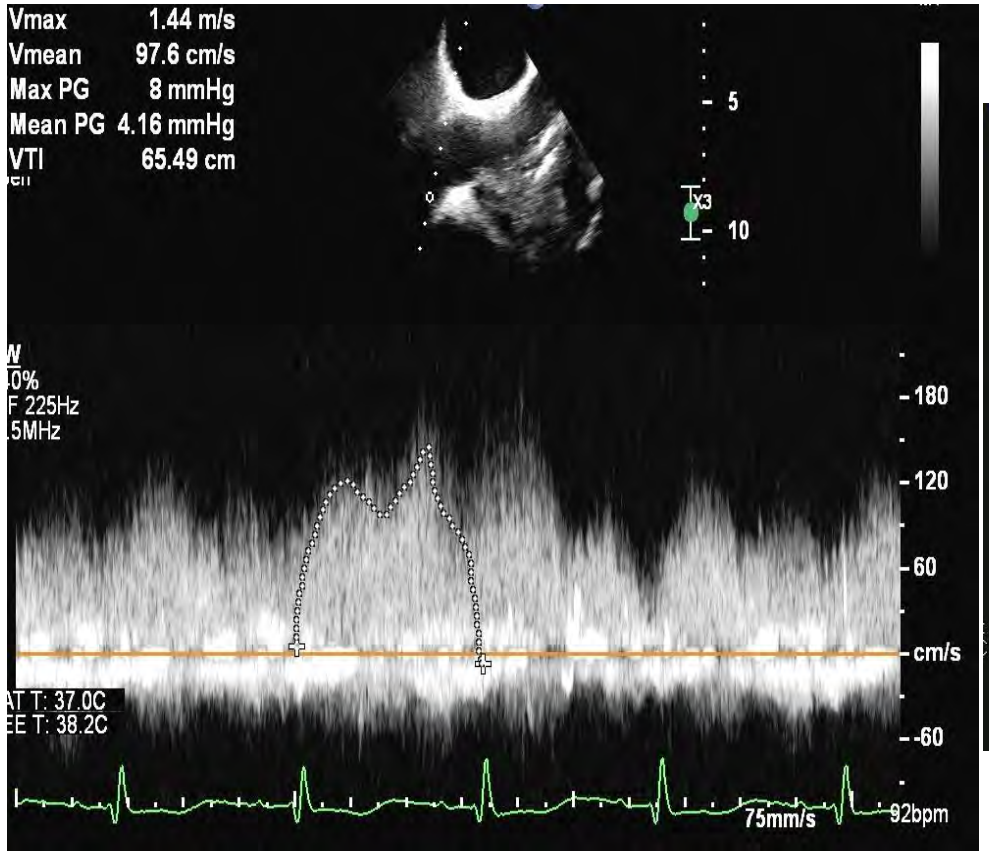
TR and IVC Doppler tracings

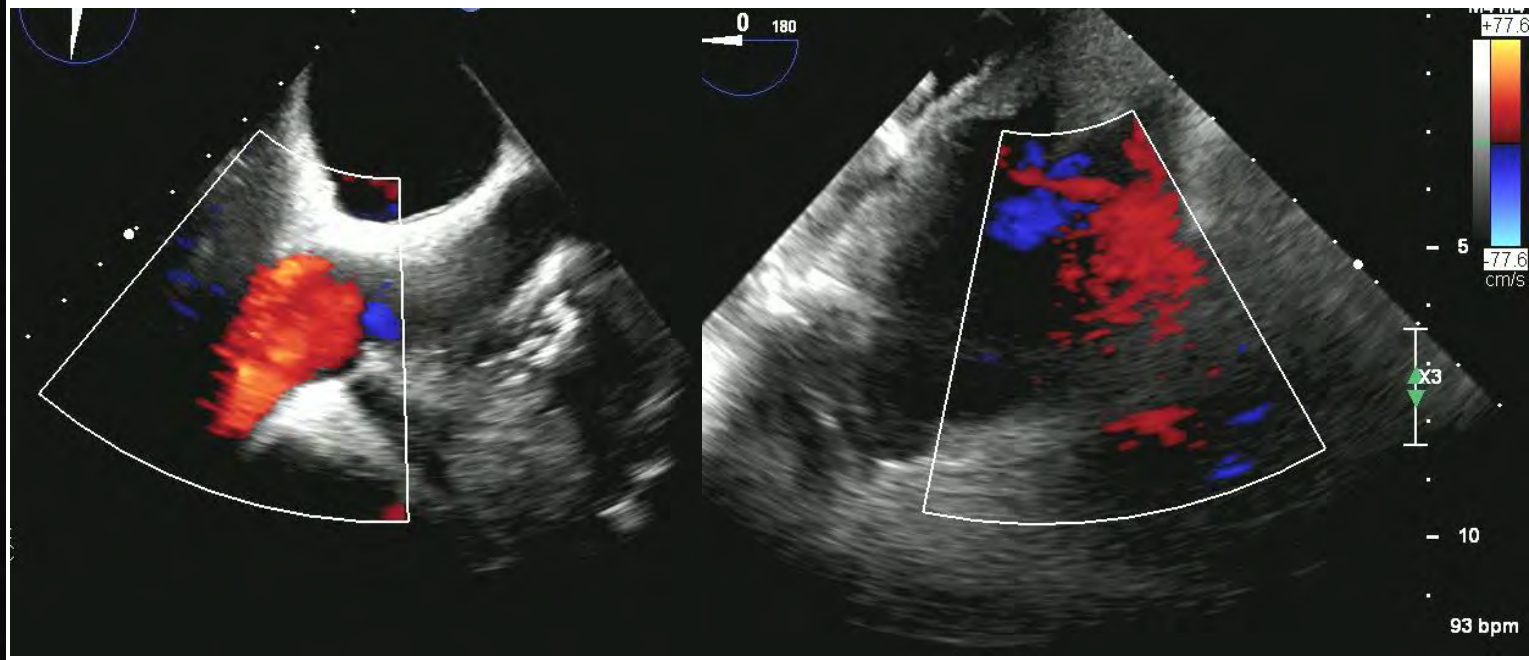






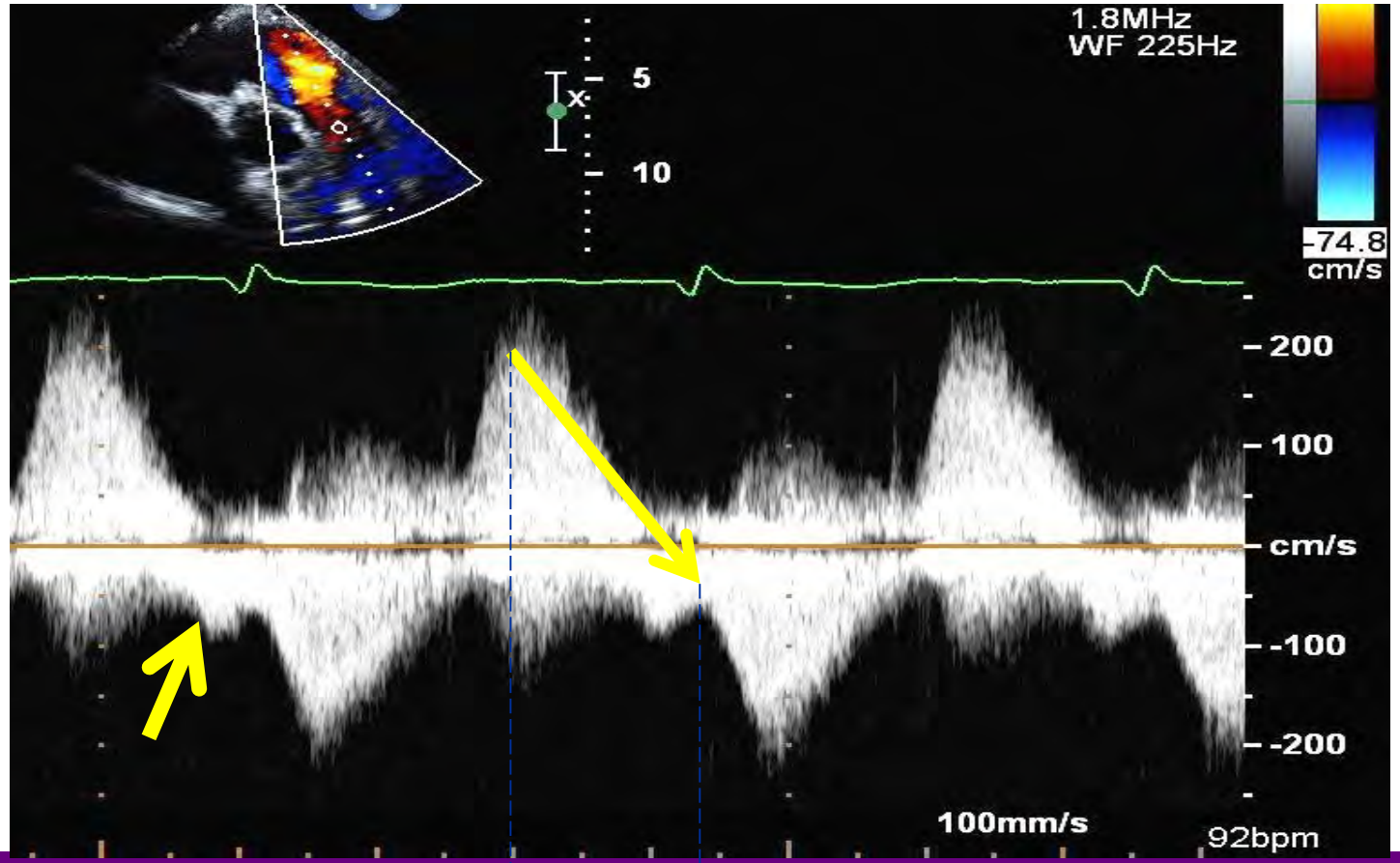
Increased flow from IVC and mild TR TEE





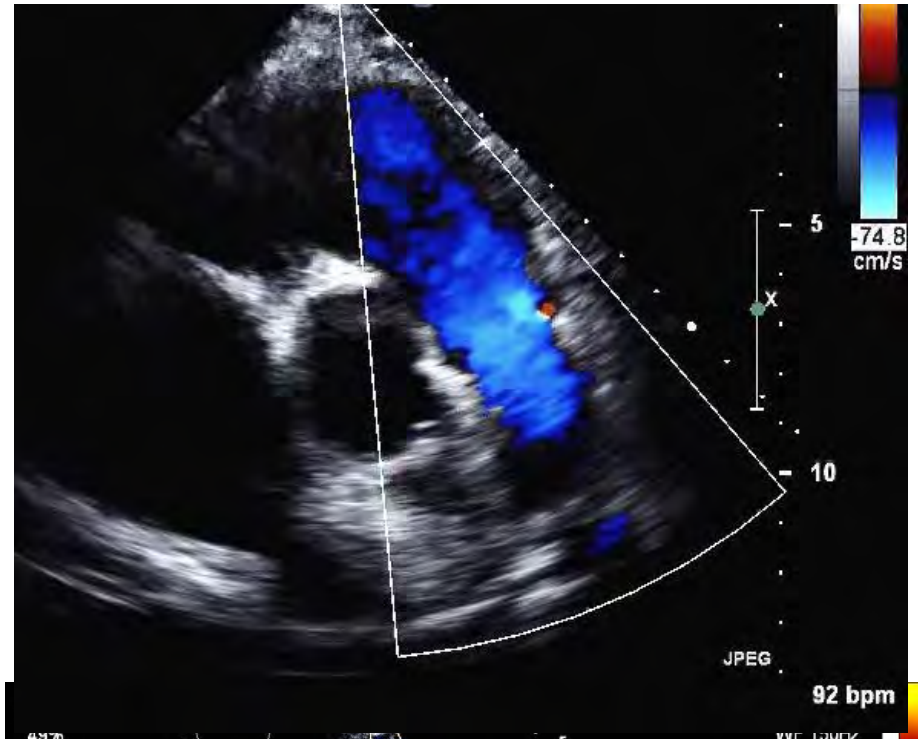
Case #3

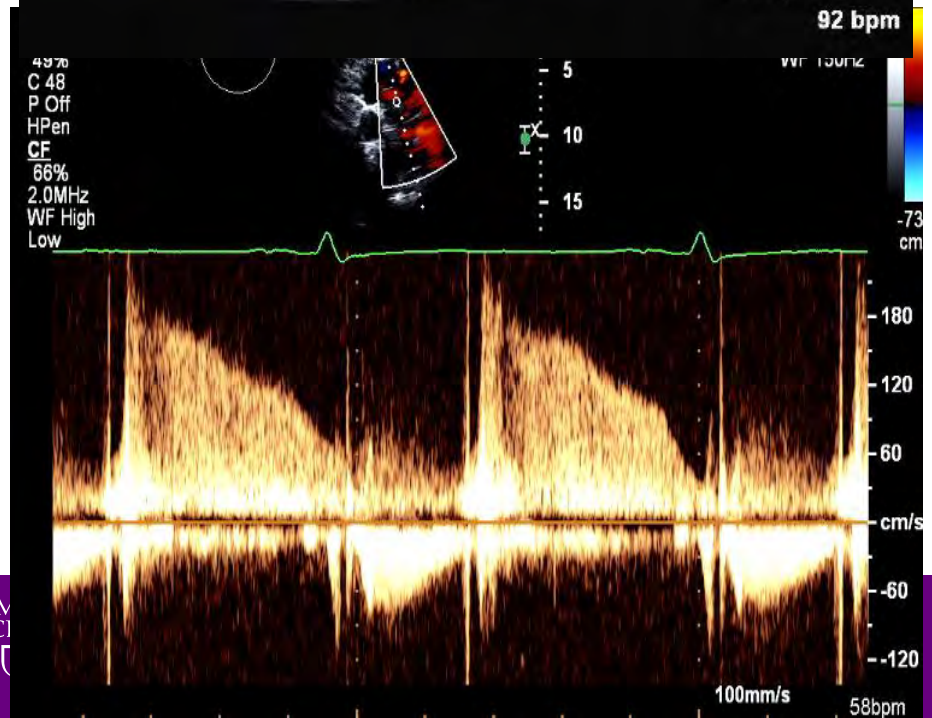
CW Across the PV Diagnosis ?

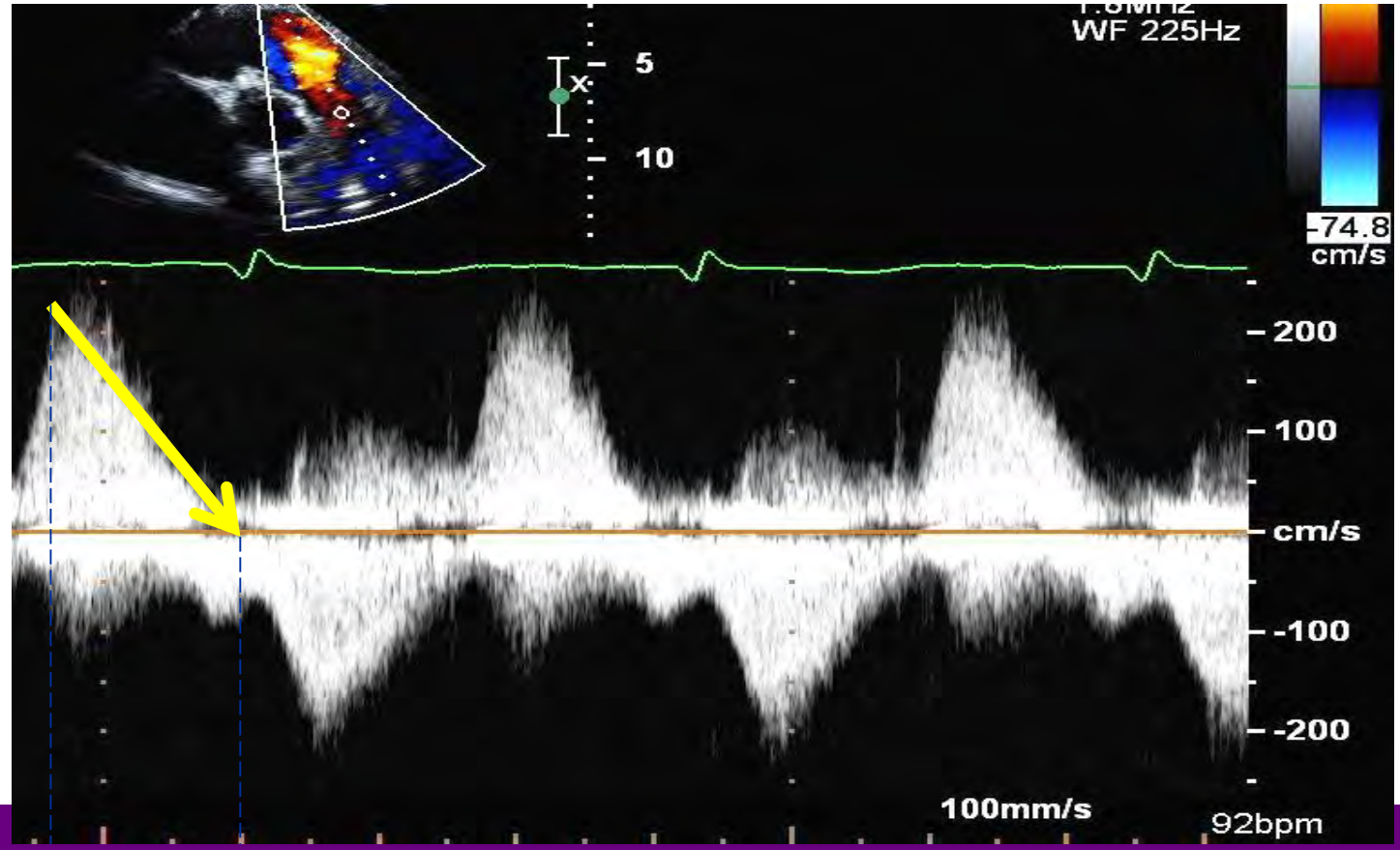


300 msec

Pulmonary Regurgitation

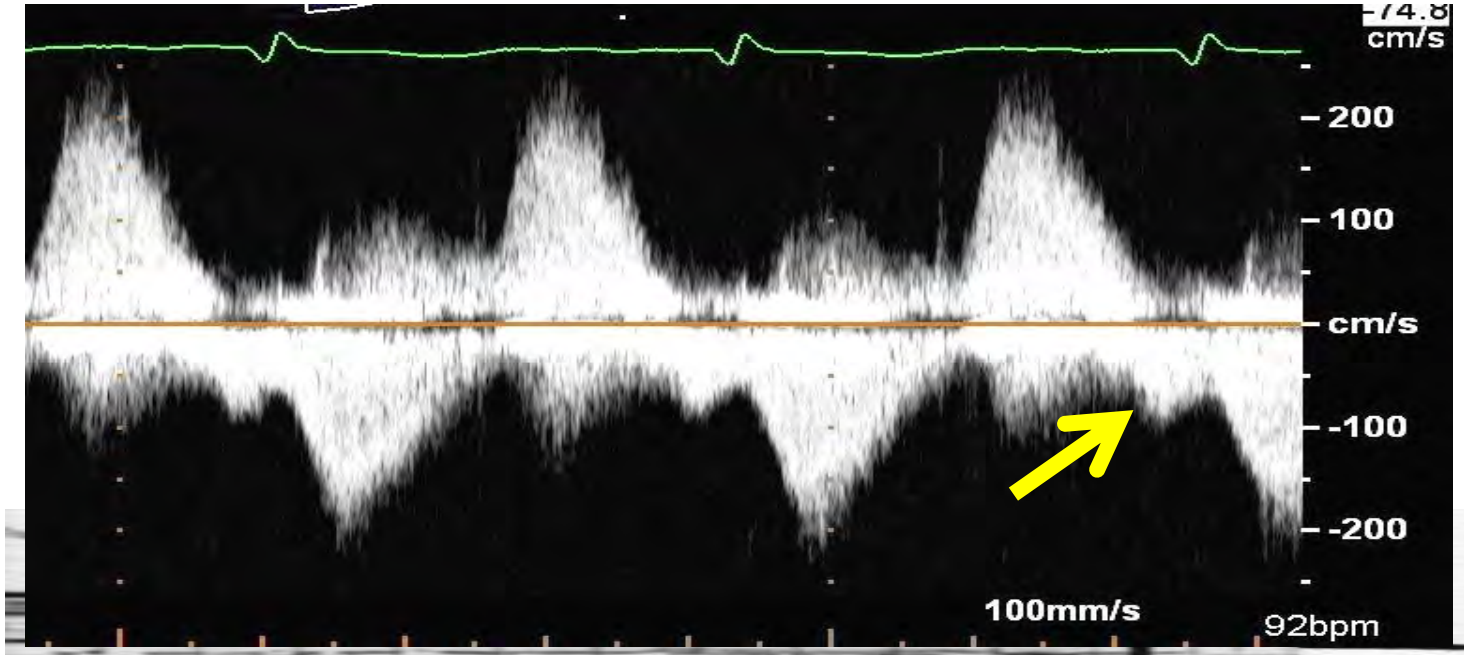


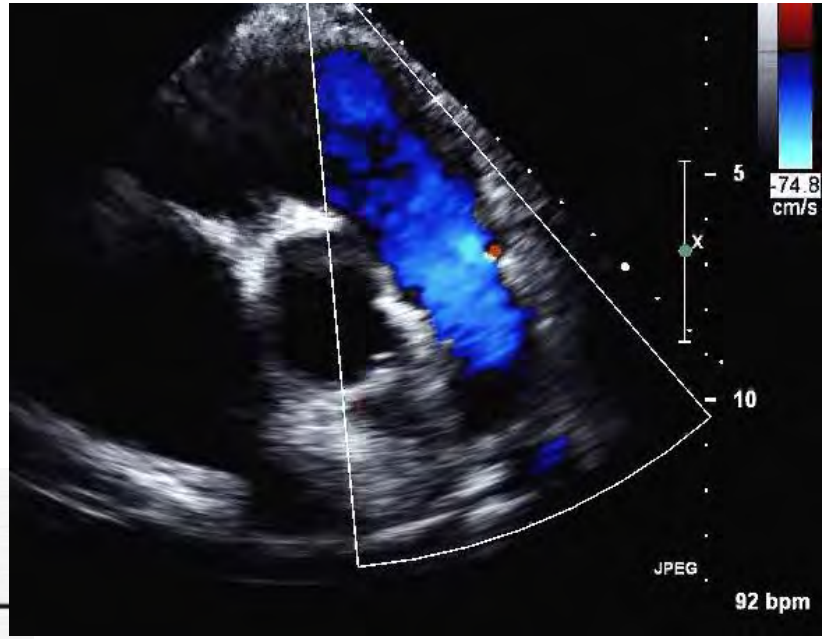


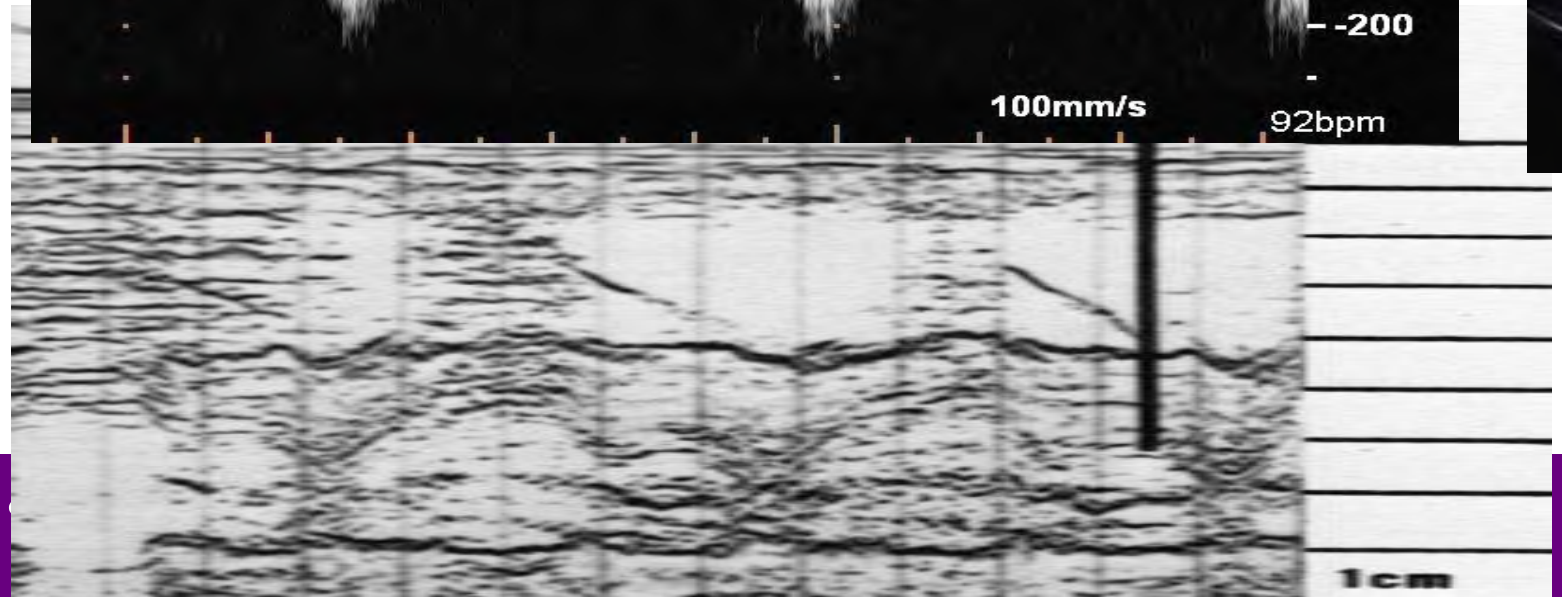


300 msec

Short PHT of Pulmonary Regurgitation
Diastolic Opening of the PV



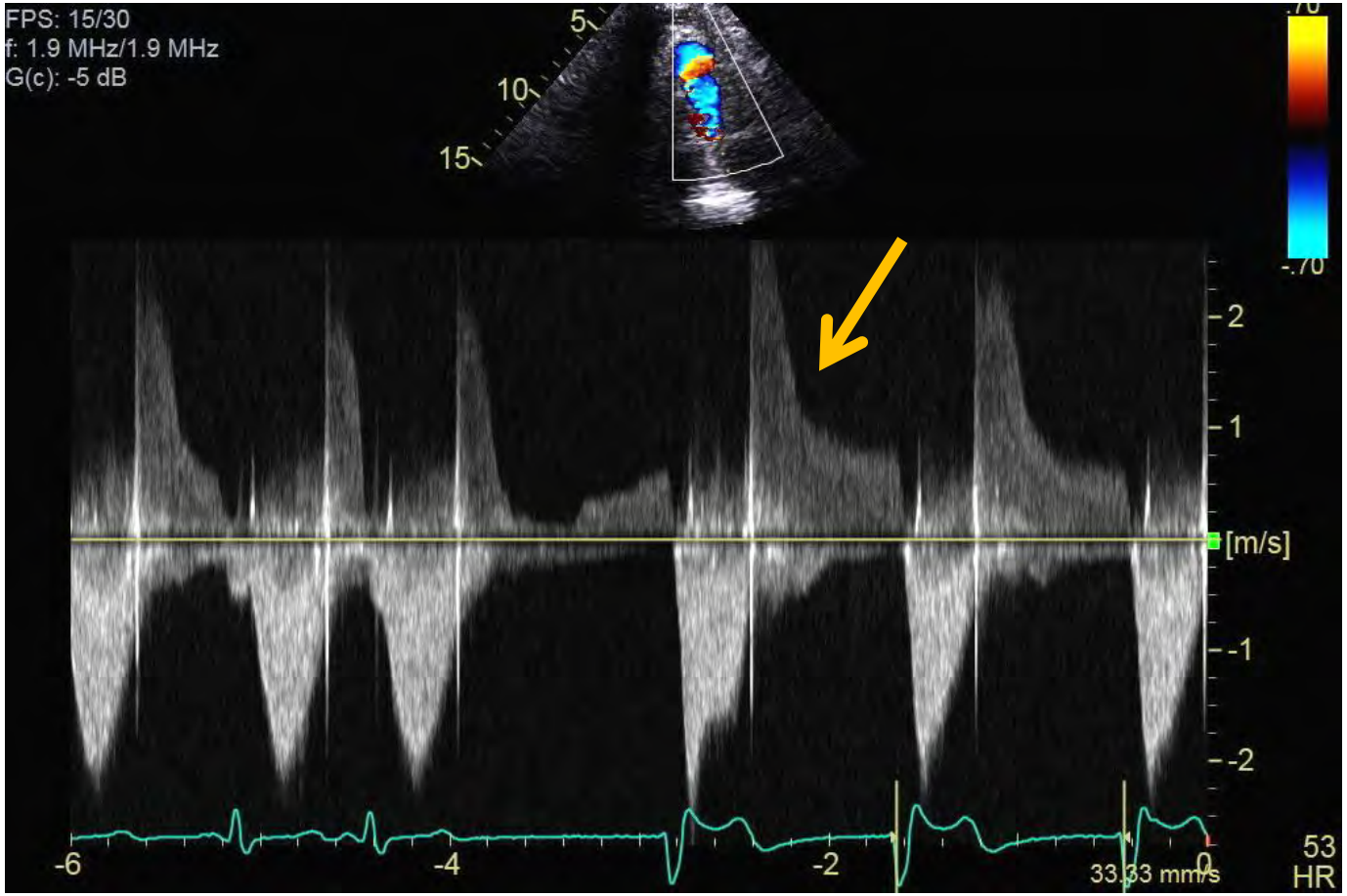




- Severe Pul Regurgitation
- Restrictive CM
- Constriction

Case #4

CW Doppler Recording of the pulmonary valve Short DT from Increased RV diastolic pressure

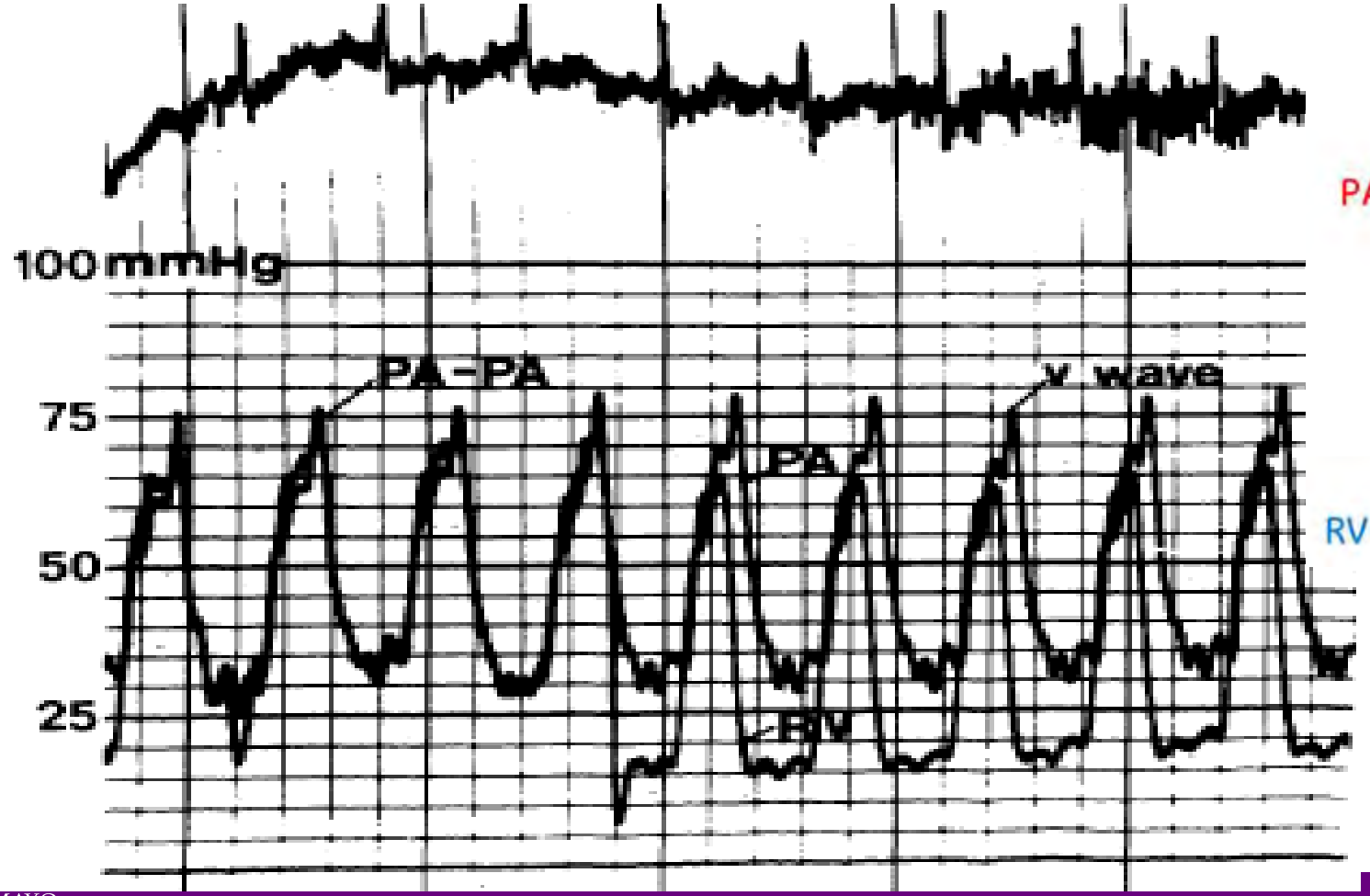


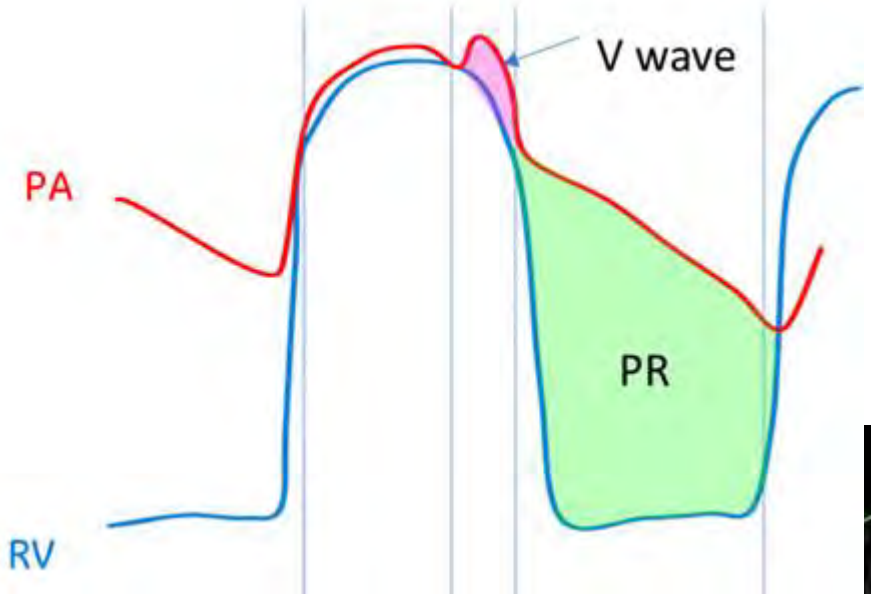
Case #5

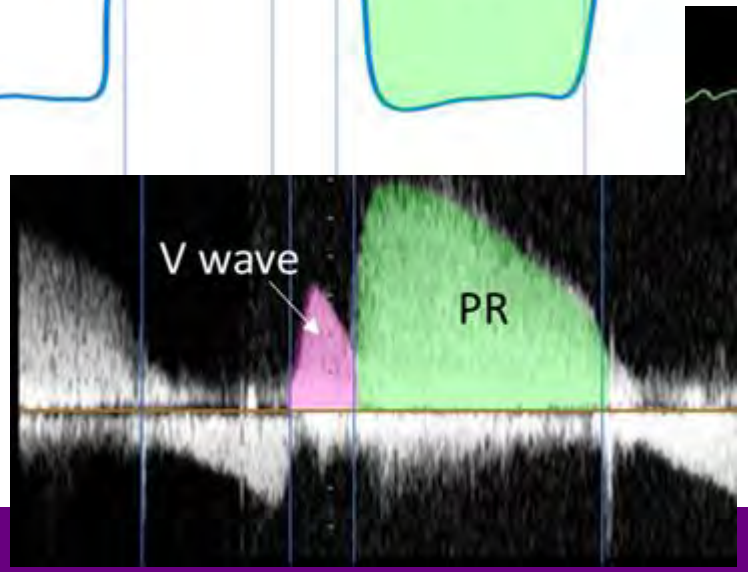
CW Doppler recording of PV
Early closure of PV

Pulmonary arterial V waves in mitral regurgitation: clinical and experimental observations

RICHARD GROSE, M.D., JANET STRAIN, M.D., AND MICHAEL V. COHEN, M.D.







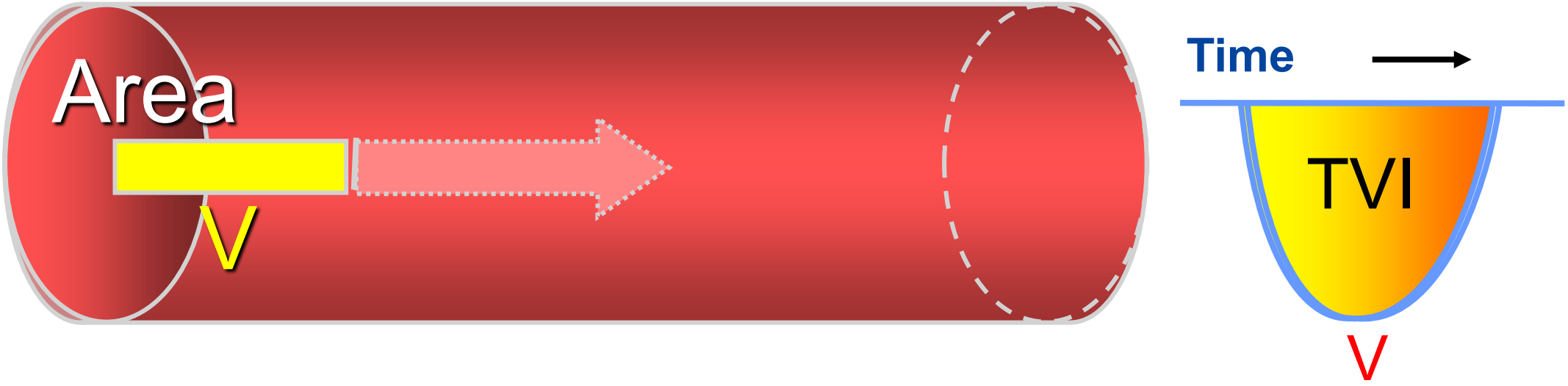
Circulation 1984

Left Side Hemodynamics

Doppler Hemodynamic Formulae

- **Hydraulic orifice formula**
  - Flow rate = Area x Velocity
  - Volume = Area x Time velocity integral (TVI)
- **Pressure gradient = 4 x velocity^2 = (2 x velocity)^2**
- **Pressure half time (PHT) = 0.29x DT**
  - MVA = 220 /PHT
- **Continuity equation and PISA**
  - AVA = LVOT area x LVOT tvi / AV tvi
  - ERO = 6.28 x radius^2 x Aliasing vel / MR vel

Hydraulic Orifice Formula



Flow Rate(mL/sec)= Area × Velocity

Volume (cm^3 or mL) = Area × TVI

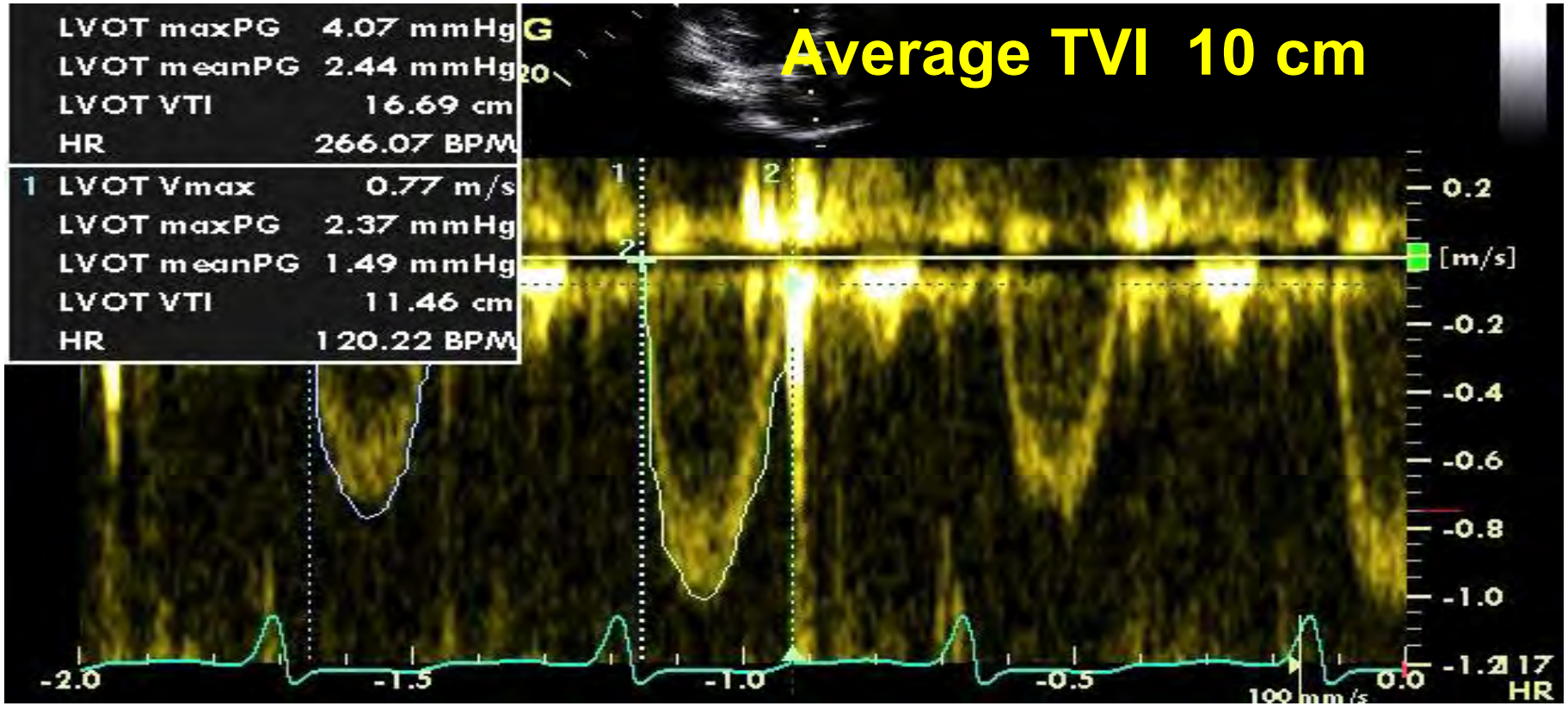
TVI = time velocity integral

Applications of Stroke Volume Calculation
SV = Area x Flow TVI

1. SV index = SV/ BSA (35 mL/ m^2 as the cut-off)
2. Cardiac output = SV x Heart Rate
3. Qp / Qs = (RVOT area x RVOT tvi) / (LVOT area x LVOT tvi)
4. Continuity equation
   - AVA = (Stroke volume) / Aortic valve tvi)
   - Mitral Regurgitation volume = LV SV – LVOT SV
5. PISA (using Flow Rate)
   - MV ERO = MR flow rate / MR tvi

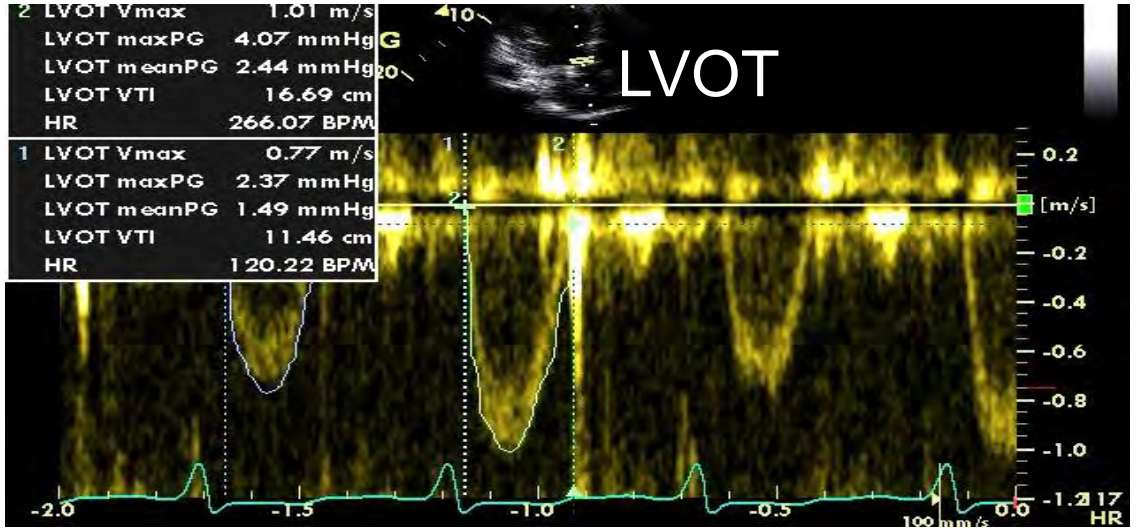
Case #6

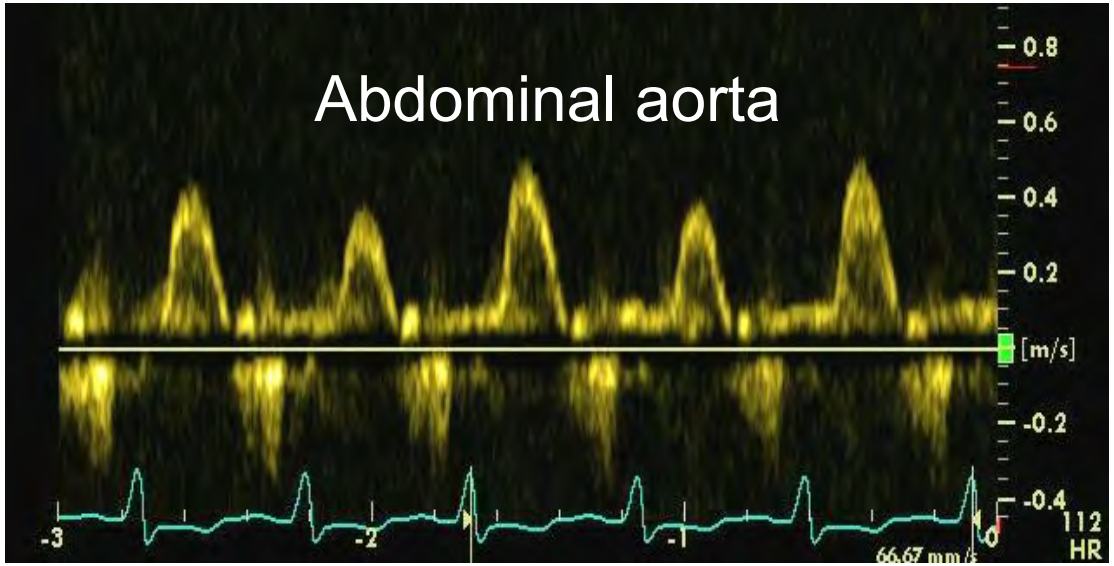
PW Doppler recording from LVOT
What is the underlying condition?

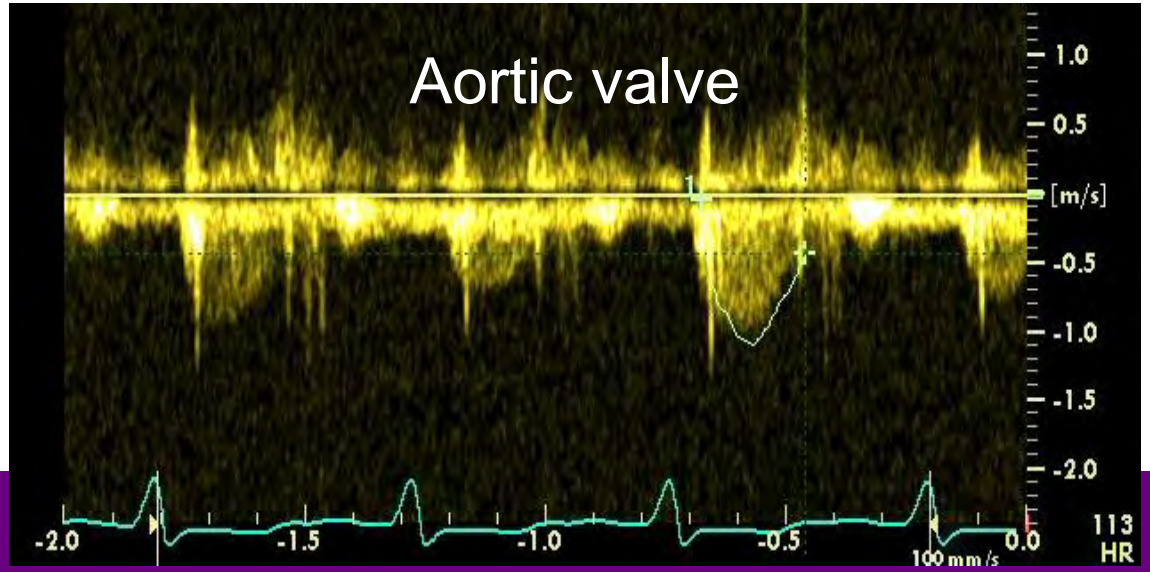


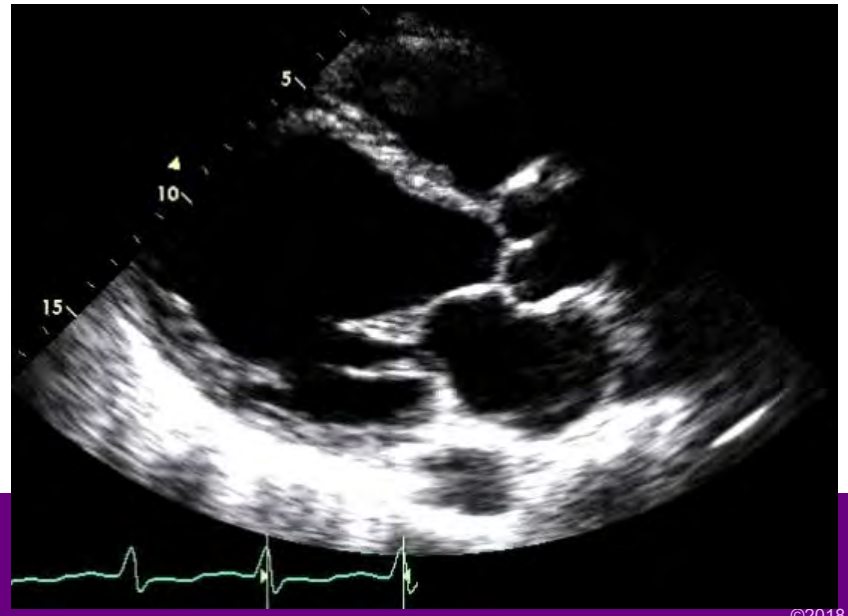
1= Constriction 2=Tamponade 3=LVEF 10% 4=LVOT alternans

Pulsus Alternans: Severe LV Dysfunction

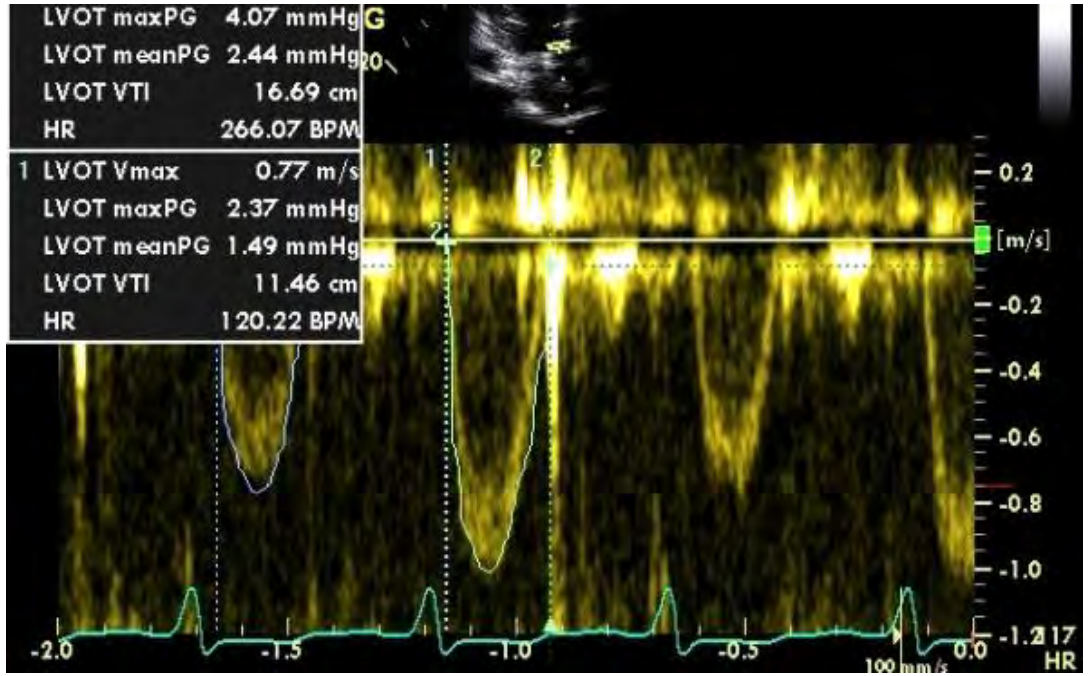




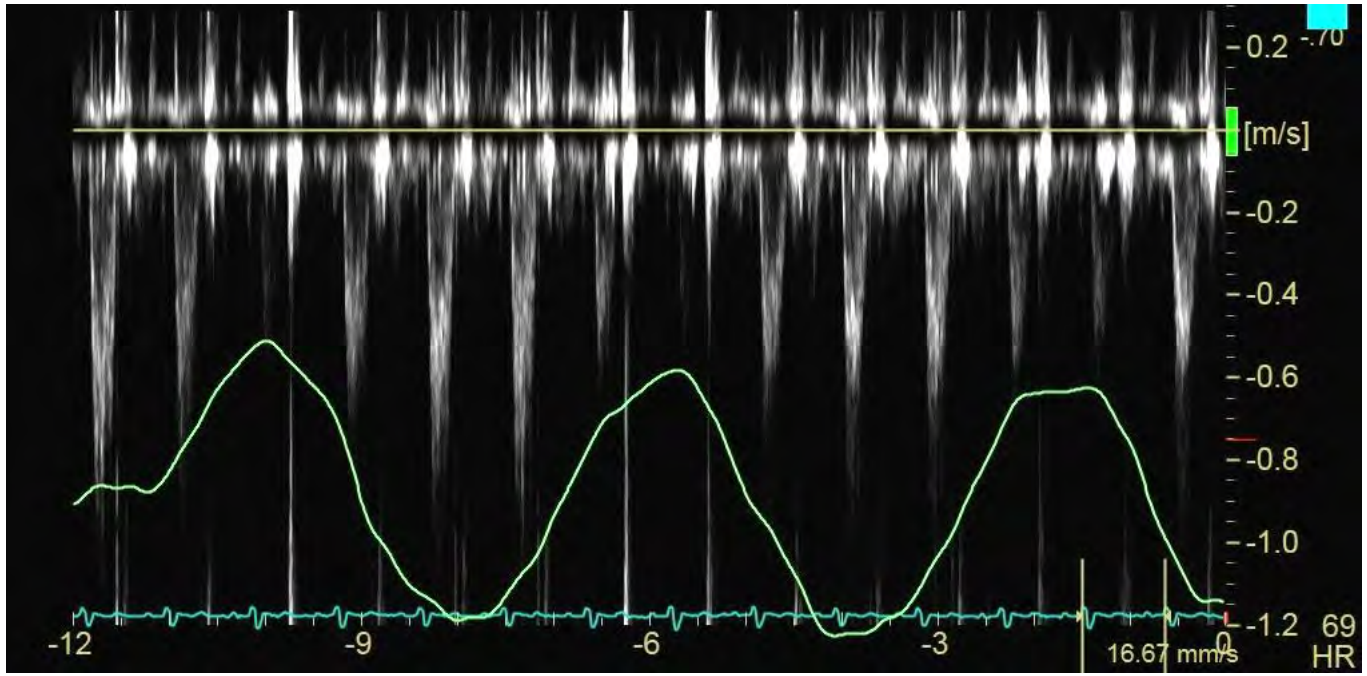




LVOT TVI and Velocity are Proportional to Stroke Volume

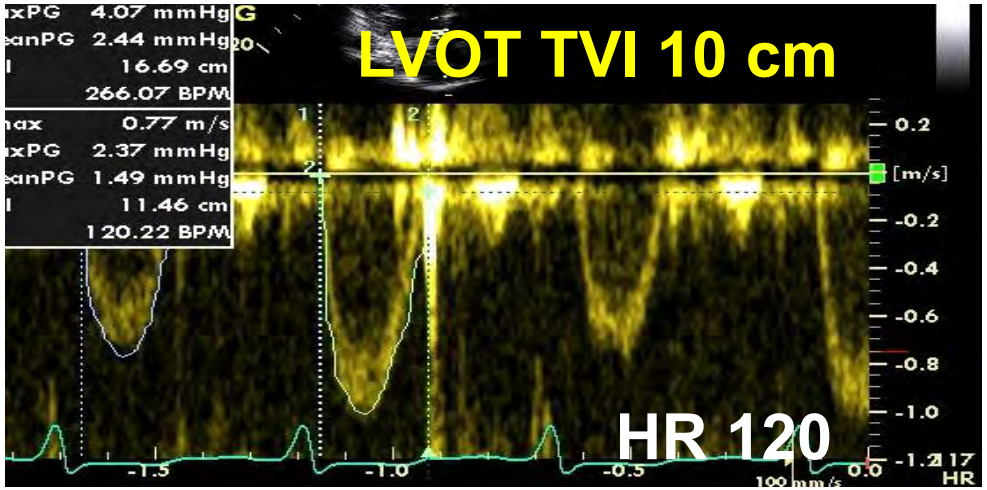


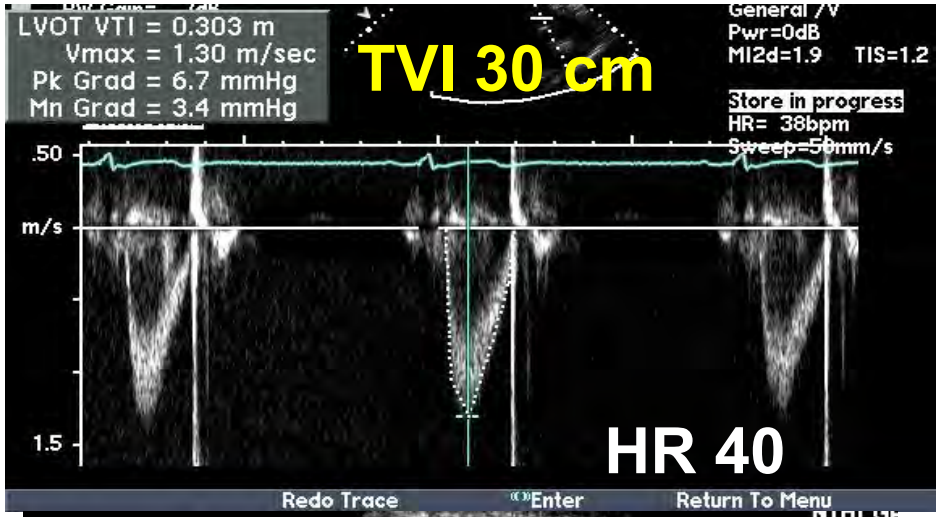
Pulsus Alternans

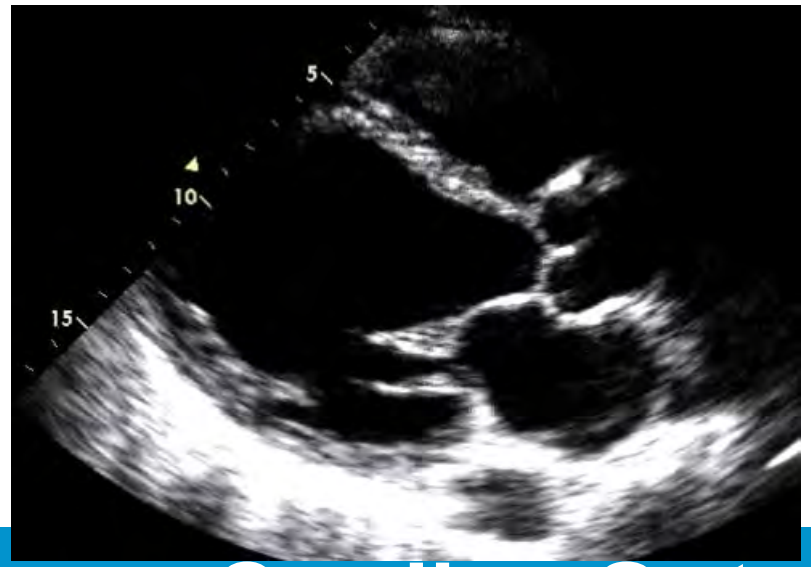


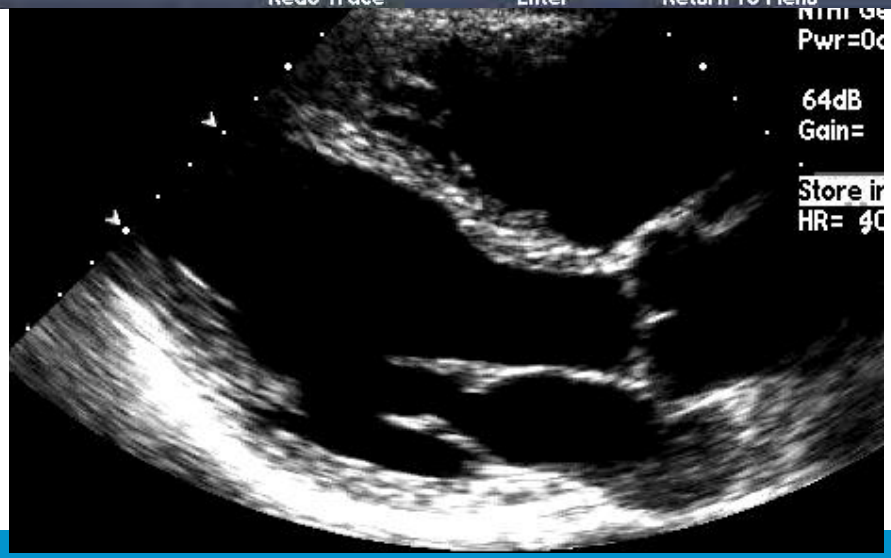
Pulsus Paradoxus

Pulsus Alternans Treated in 60 yo man with DCM







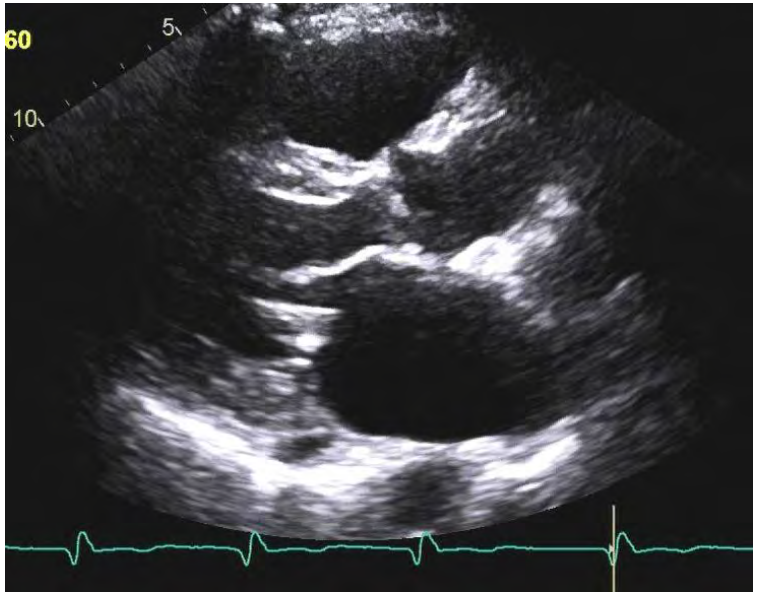


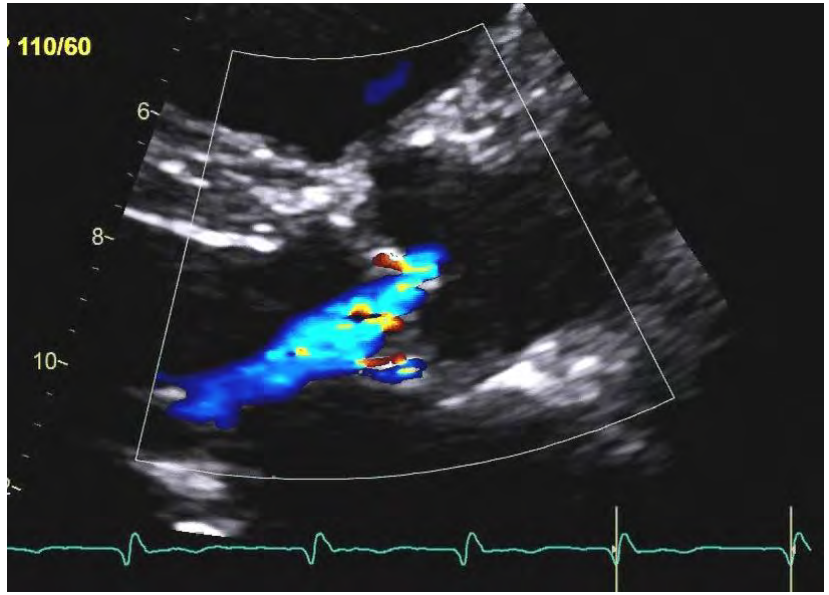
Cardiac Output is improved by

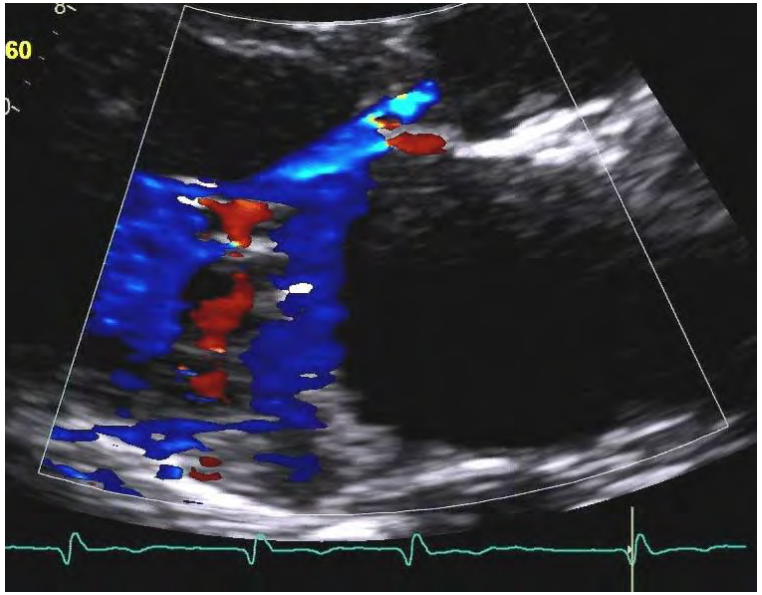
1= x1 2= x2 3= x3 4= x4

Case #7

Calculate Mitral and Aortic Regurgitant Volume
From LVOT, RVOT and Mitral Inflow volume

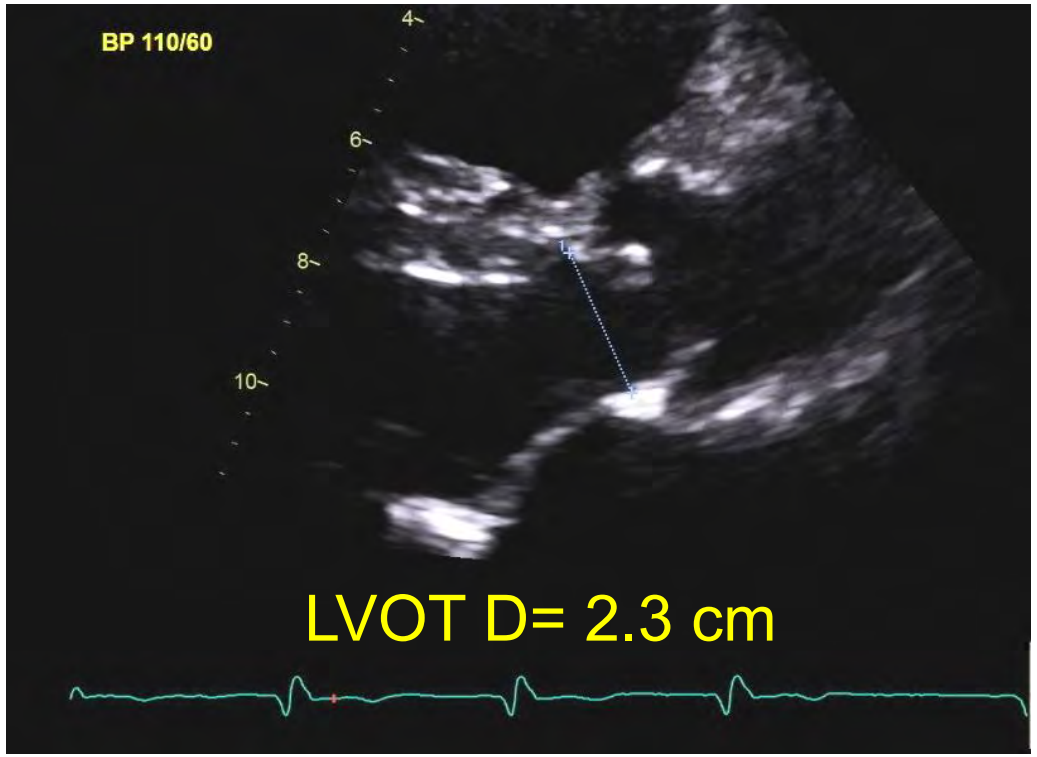


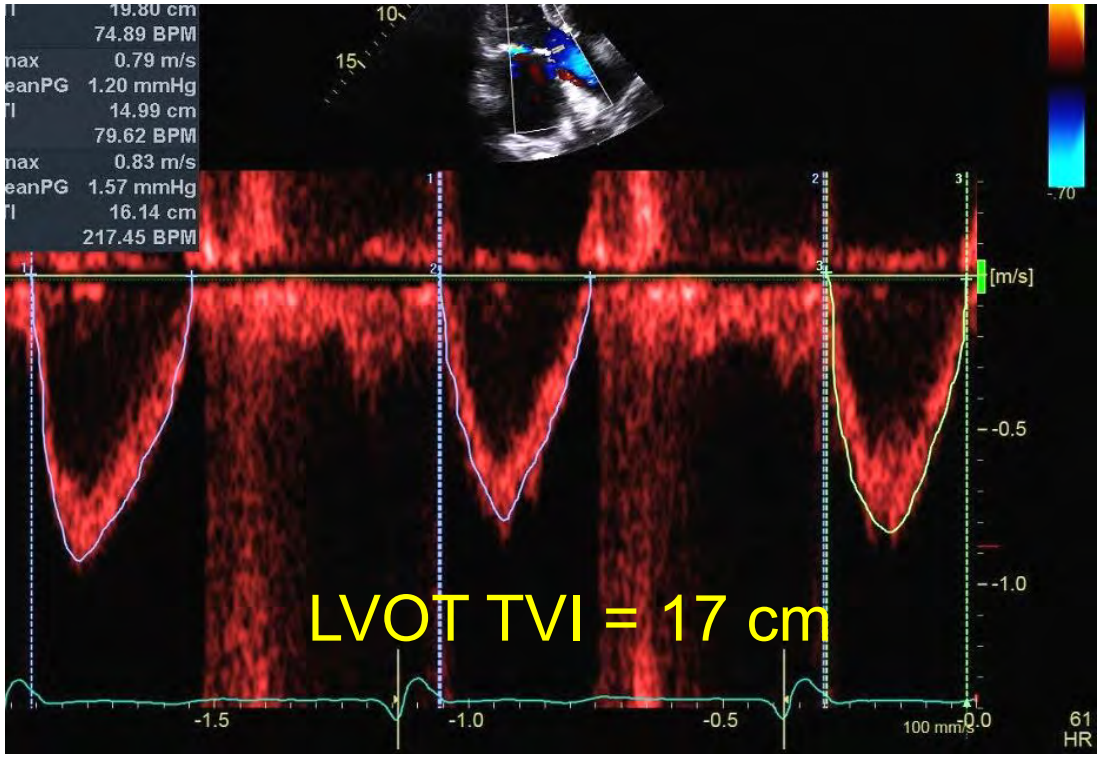




LVOT Stroke Volume

LVOT SV = AR volume + Systemic SV (RVOT SV)



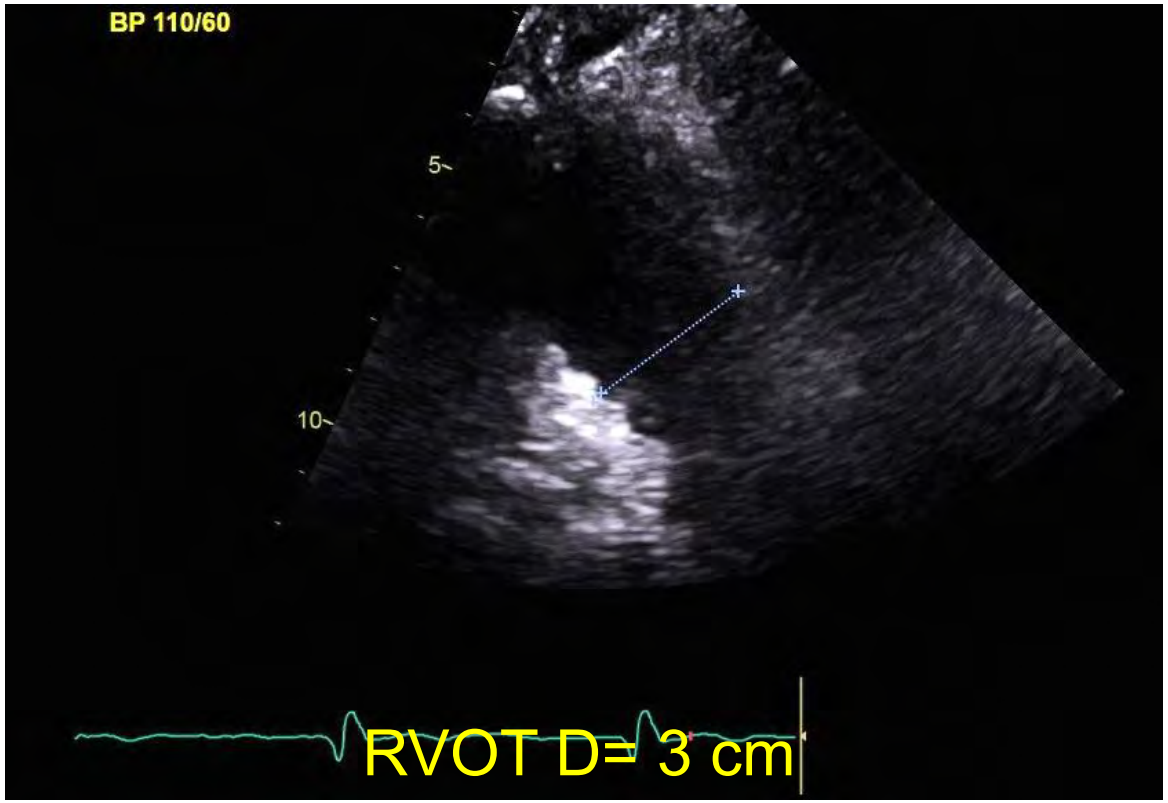


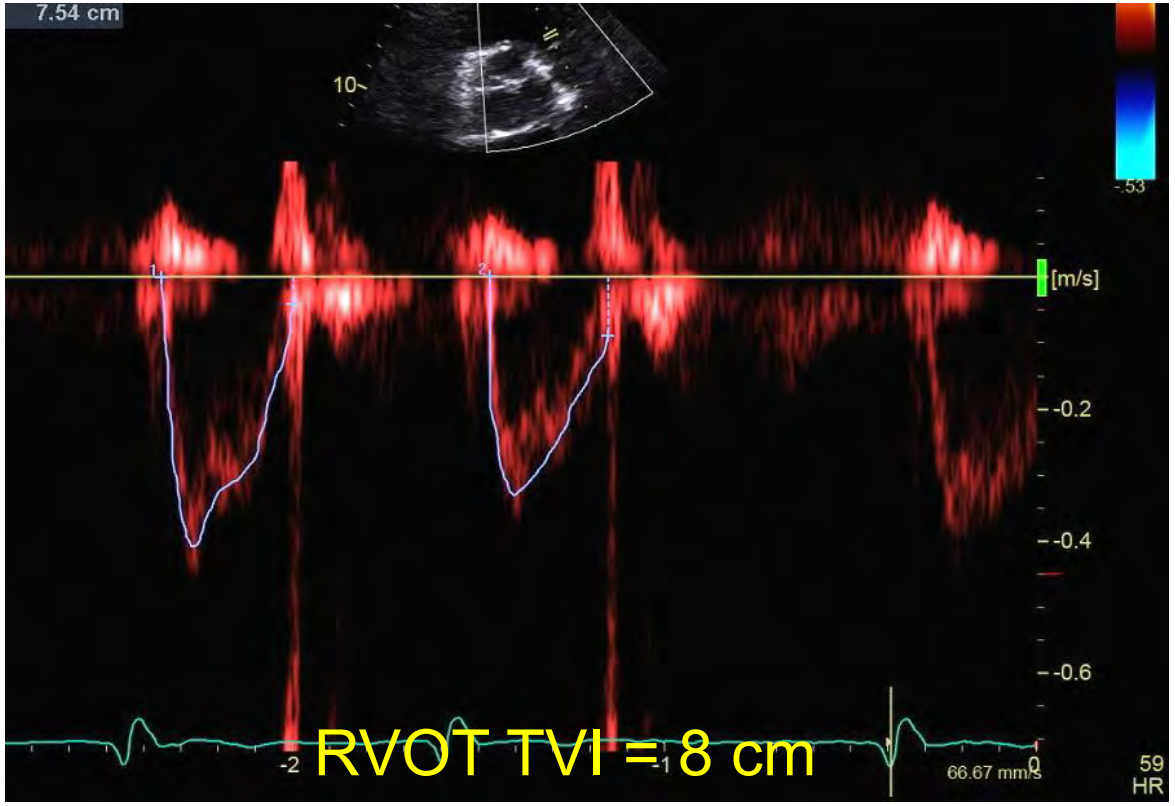
LVOT SV =$(2.3)^2$ x 0.785 x 17 = 71 mL

AR volume = LVOT SV – RVOT SV

AR volume = LVOT SV – RVOT SV

RVOT Stroke Volume





RV SV = $(3)^2$ x 0.785 x 8 = 53 mL

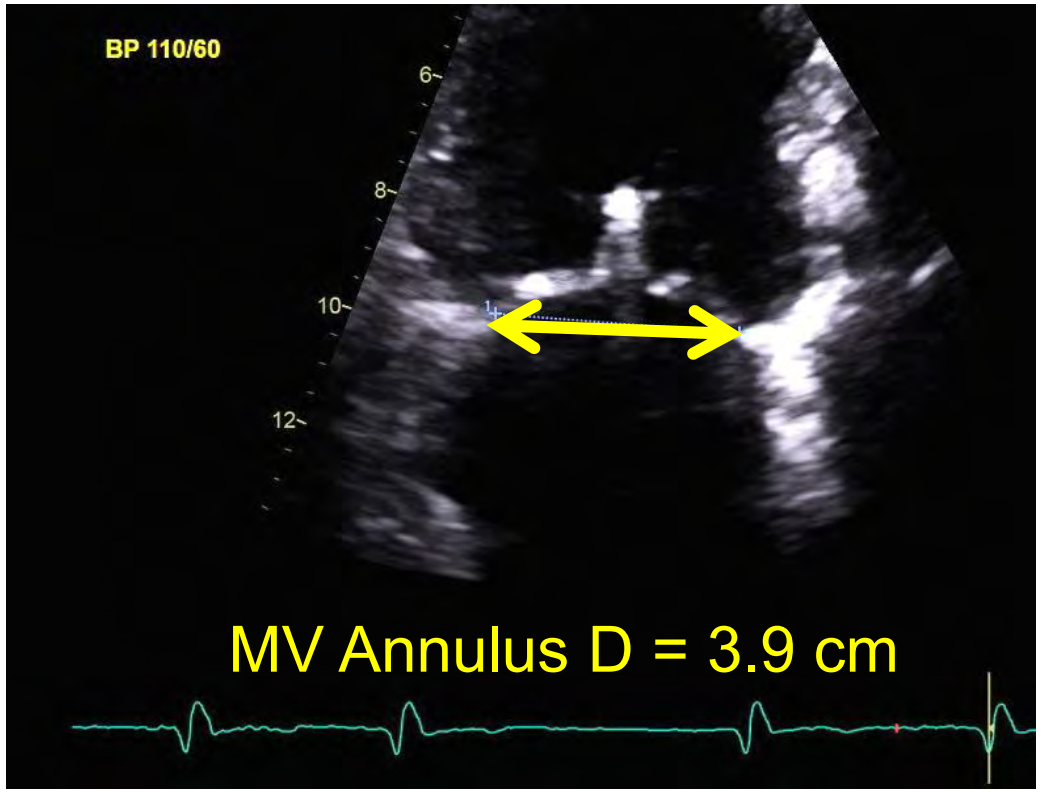
AR volume =LVOT SV - Systemic SV (RVOT SV)

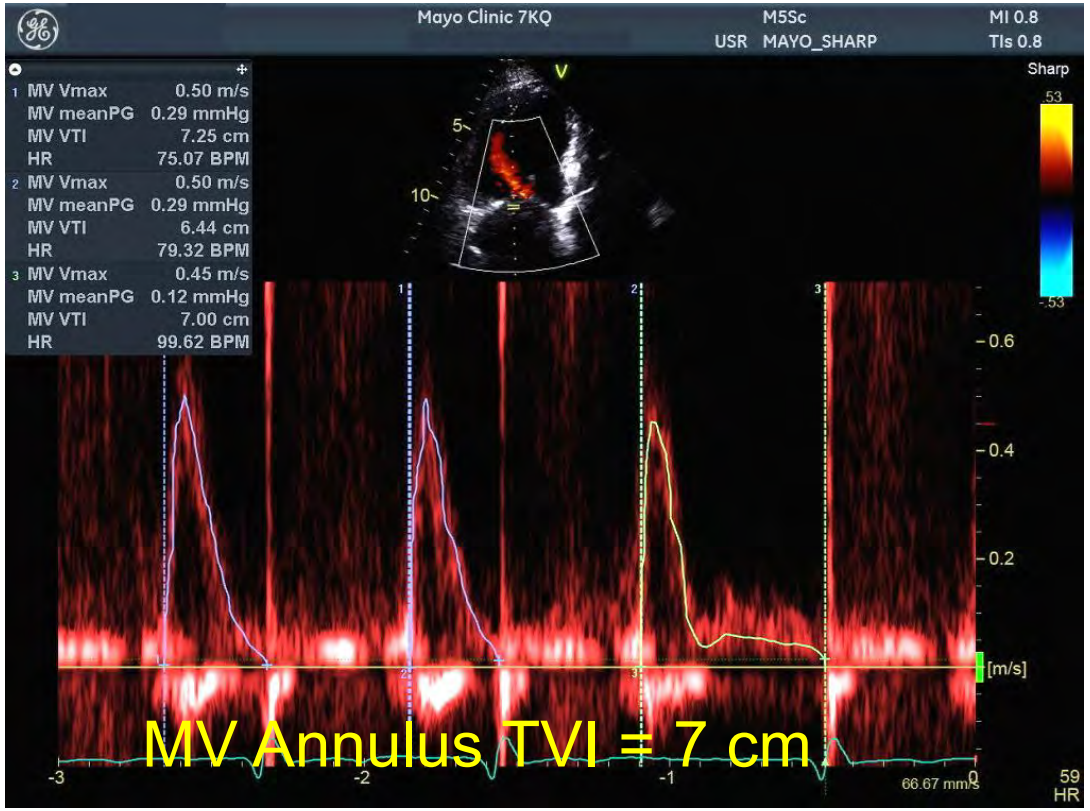
AR volume =71 mL - 53 mL

AR volume = 18 mL

MV Inflow Volume

$(3.9)^2$ x 0.785 x 7 = 83 mL





Diastole to LV= Mitral Inflow + AR volume

Systole Out of LV = MR + LVOT

Mitral Inflow + AR = MR + LVOT SV

MR Volume = Mitral Inflow + AR - LVOT SV

= Mitral inflow +AR – (AR + RVOT) = Mitral inflow – RVOT = 83 – 53 =30 mL

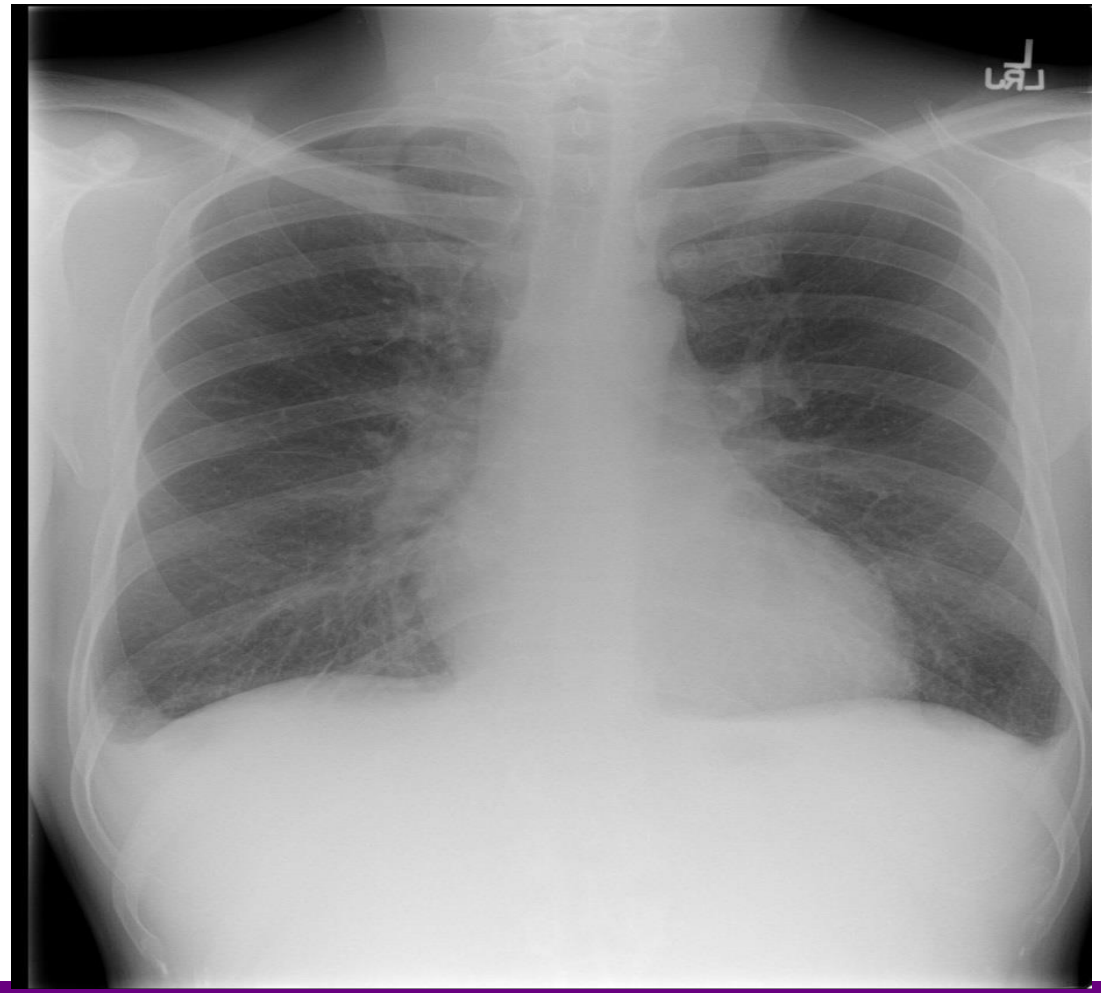
LVOT SV = AR volume + RVOT SV

Case #8

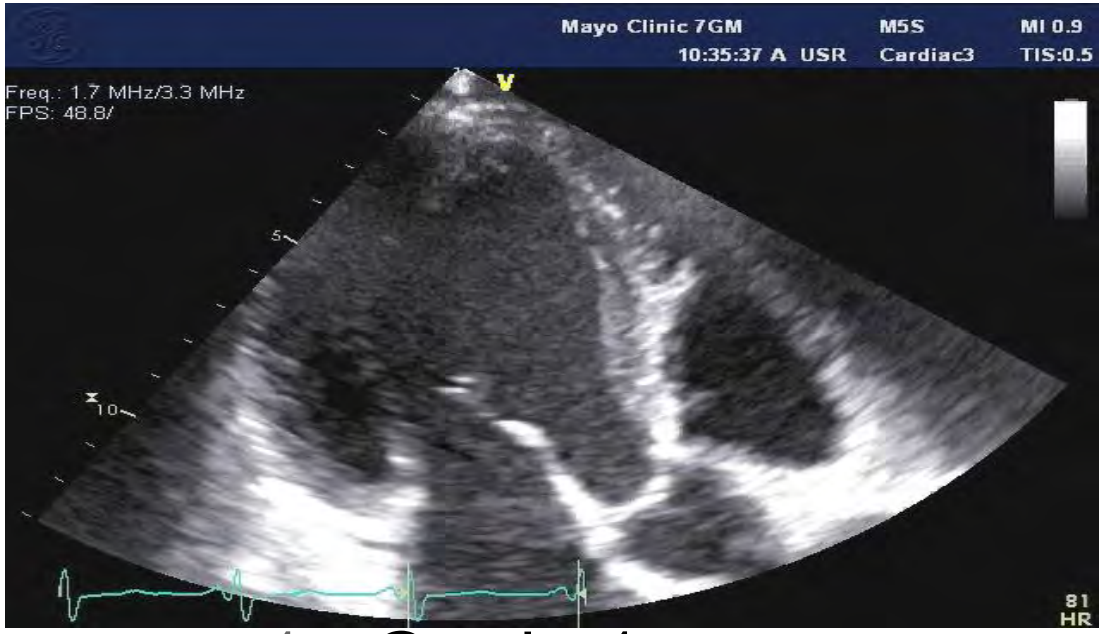
42 year old man with dyspnea

- Gradual onset of chest tightness and dyspnea
- Seen in the ED
- Chest CT negative except for bilateral pleural effusion
- Sent for cardiology evaluation
- Physical Examination
  - HR 90 BPM, JVP 7 cm
  - Increased S2 intensity with GR 1/6 systolic murmur
  - Mild pitting edema

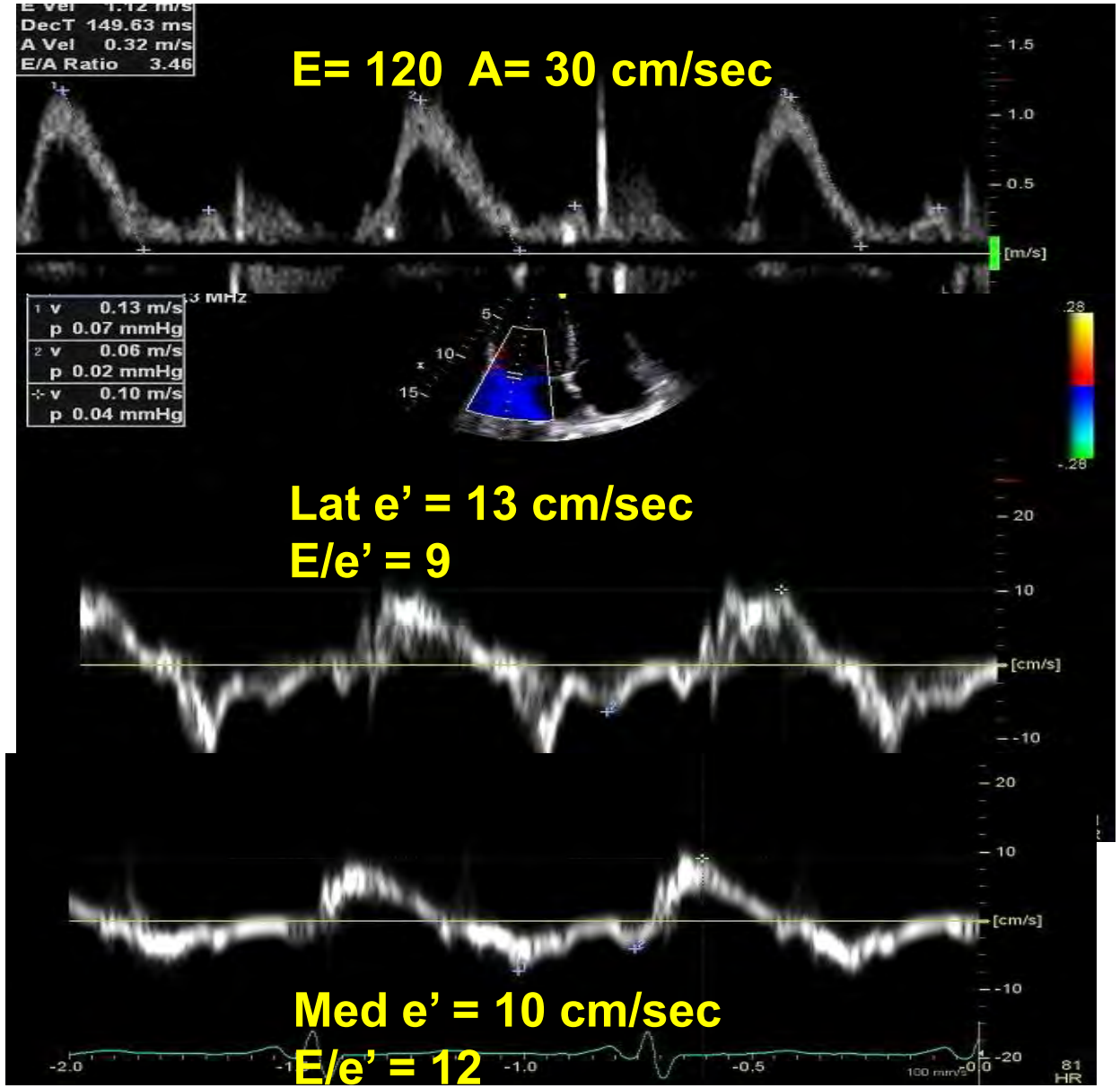
42 year old man with dyspnea



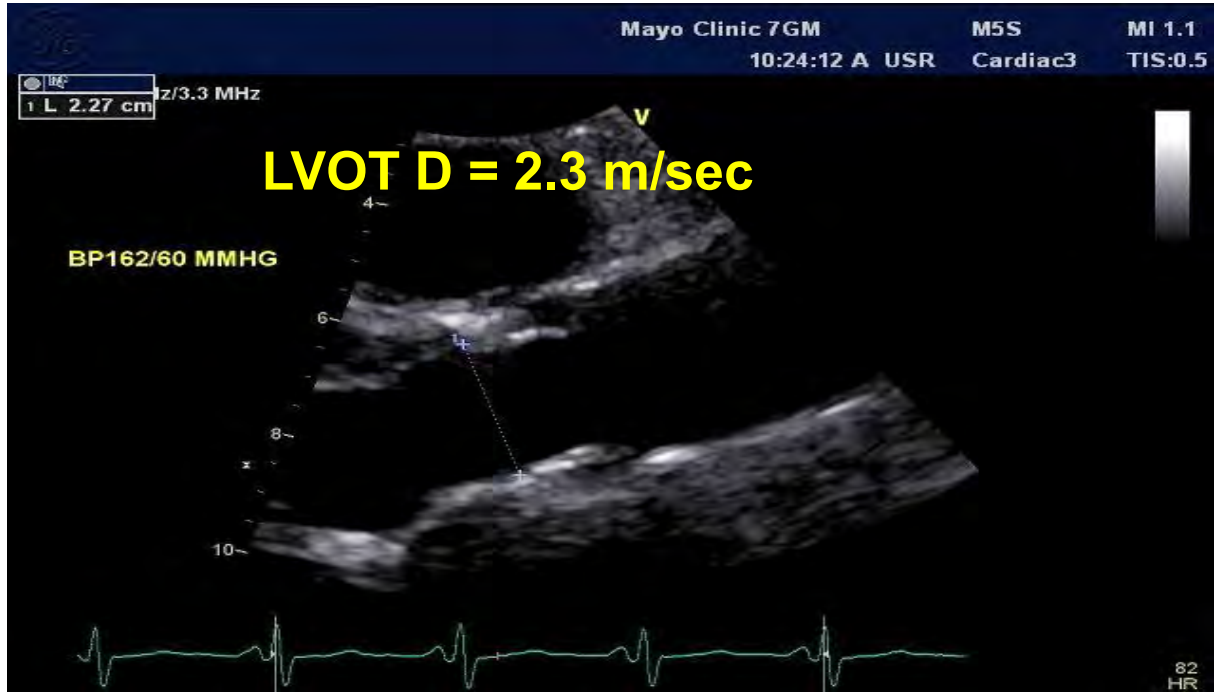
42 year old man with dyspnea
What is his diastolic function?

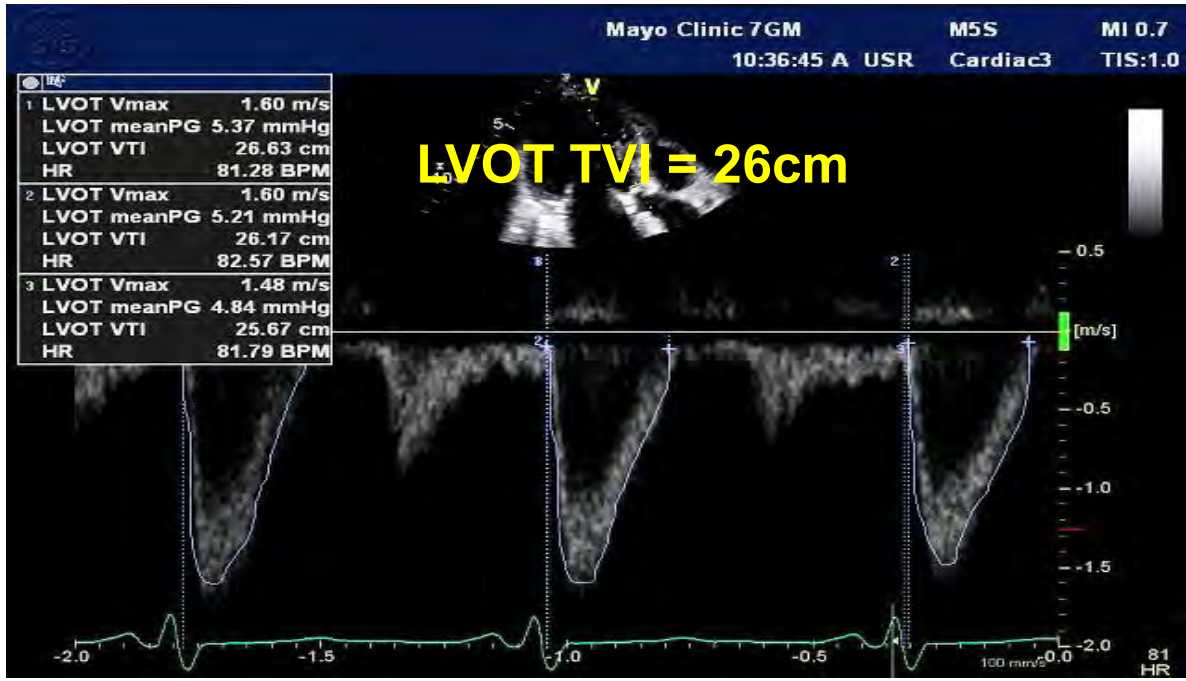


1. Grade 1
2. Grade 2
3. Grade 3
4. Normal
5. Constriction



42 year old man with dyspnea





$SV = (2.3)^2 \times 0.785 \times 26 = 108$ mL

$CO = SV \times HR = 108 \times 80 = 8.6$ L

$CI = CO/BSA = 8.6 / 1.93 = 4.48$ L/m^2

What is the most common cause of HF seen in this 42 year old man?

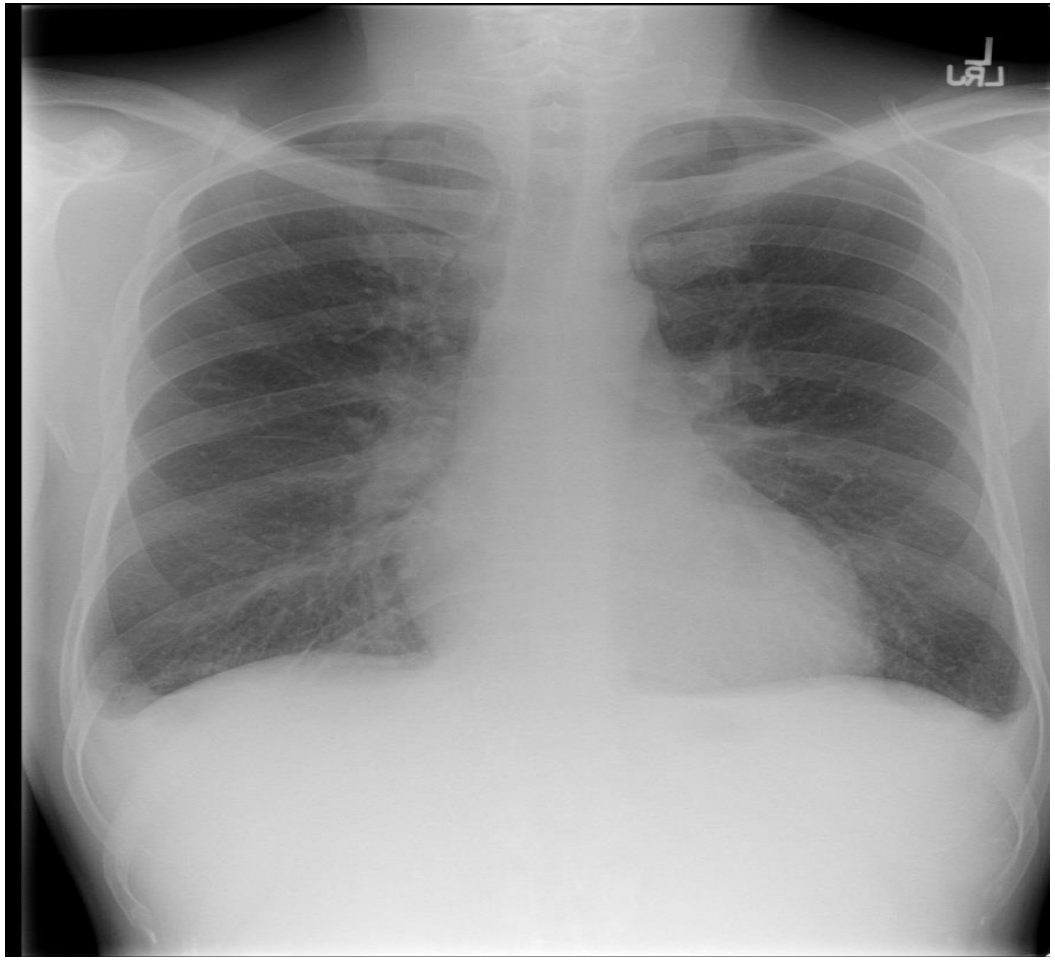
$SV = (2.3)^2 \times 0.785 \times 26 = 108$ mL

$CO = SV \times HR = 108 \times 80 = 8.6$ L

$CI = CO/BSA = 8.6 / 1.93 = 4.48$ L/m^2

1. Shunt
2. Obesity
3. Liver Disease
4. Pheochromocytoma

42 year old man with high output HF
Before and after treatment (Thyrotoxicosis)



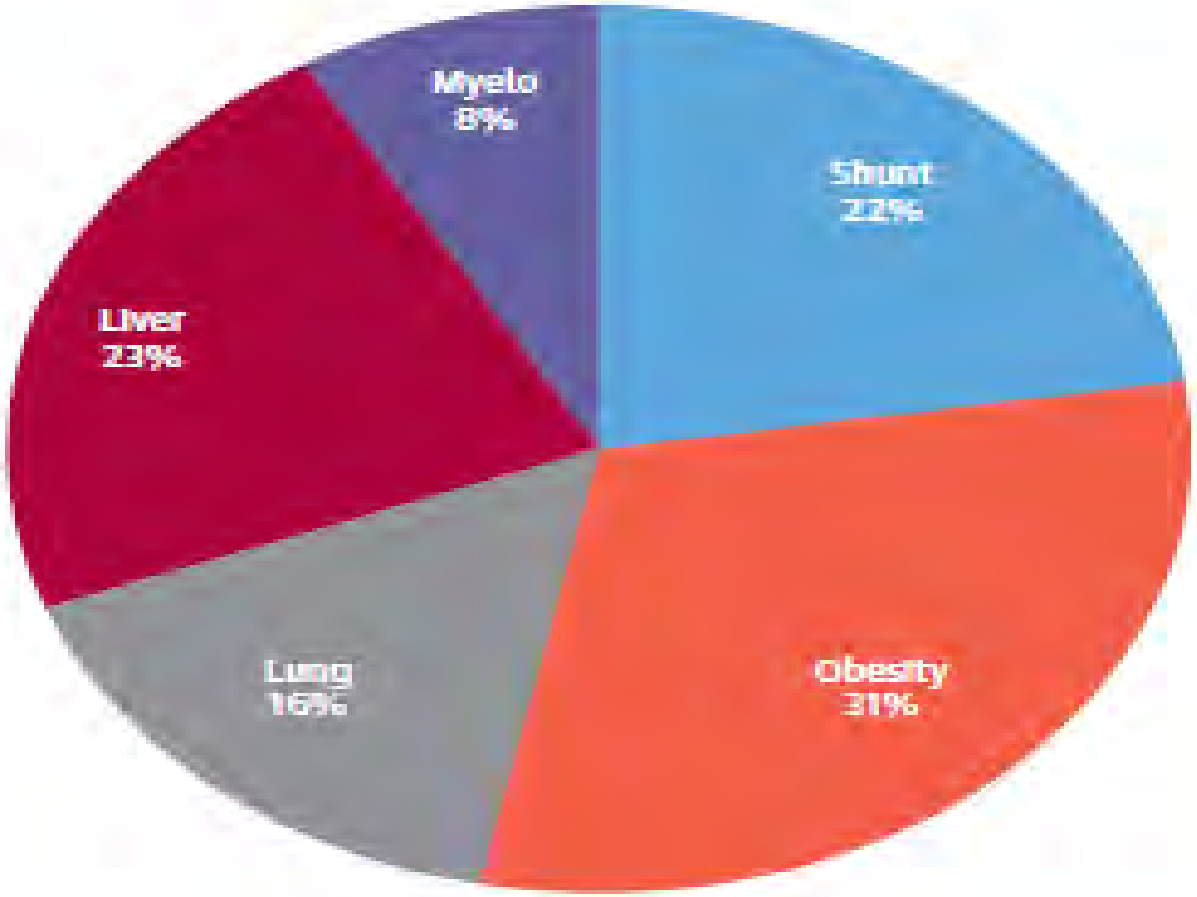
42 year old man with HF Summary

High-Output Heart Failure

A 15-Year Experience

JACC 2016

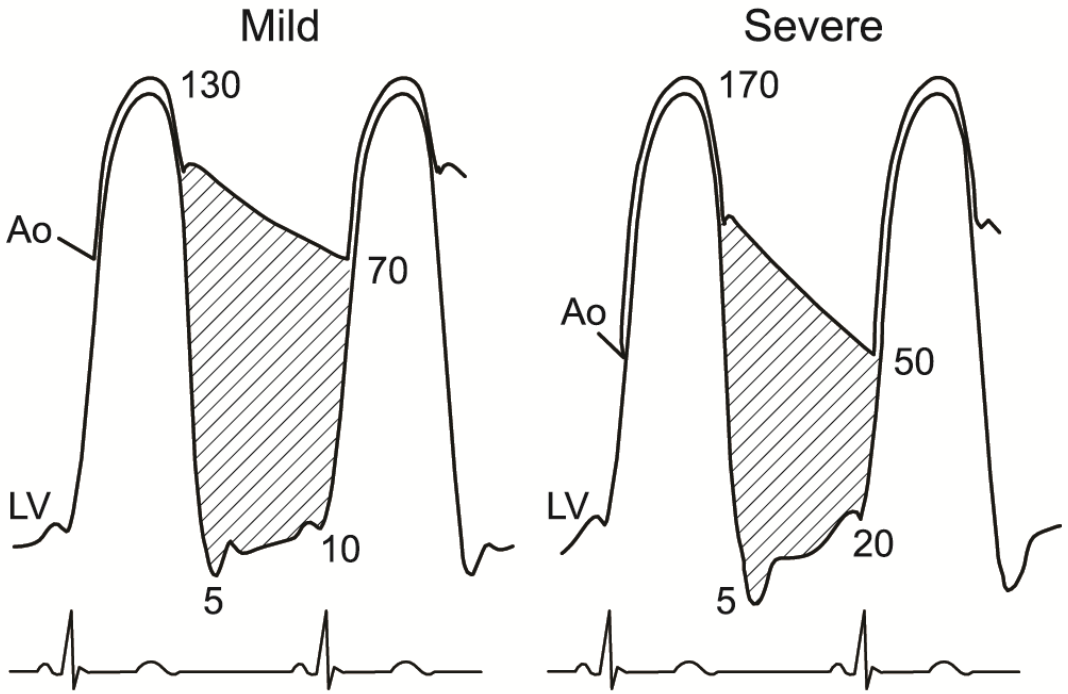
Yogesh N.V. Reddy, MD, Vojtech Melenovsky, MD, PhD, Margaret M. Redfield, MD, Rick A. Nishimura, MD, Barry A. Borlaug, MD



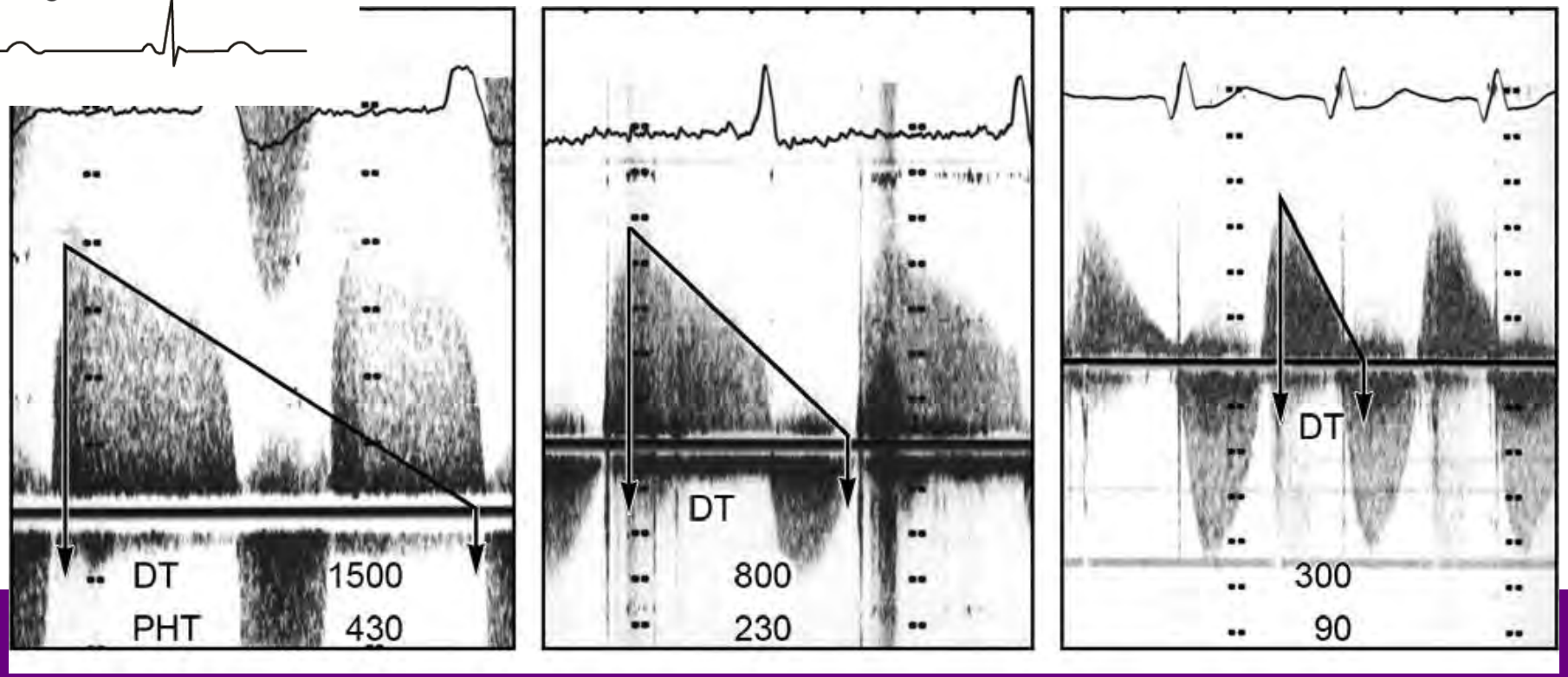
- CI > 4.0 L/m^2
- Obesity
- Shunt
- Liver Disease
- Diastolic function can be normal

Use of Pressure Half-time

- Mitral Valve Stenosis (Native Valve)
  - Longer with more severe MS (MVA = 220 /PHT)
  - Indirect measure
- Mitral Prosthetic Valve with Peak Velocity > 2 m/sec
  - Severe MR or High Output with PHT < 130 msec
- Aortic Valve Regurgitation
  - Shorter with more severe AR (Not specific)
  - Indirect
- RV diastolic pressure elevation (Severe PR/TR/Constriction)
  - Shorter with higher and more rapid elevation
  - Indirect

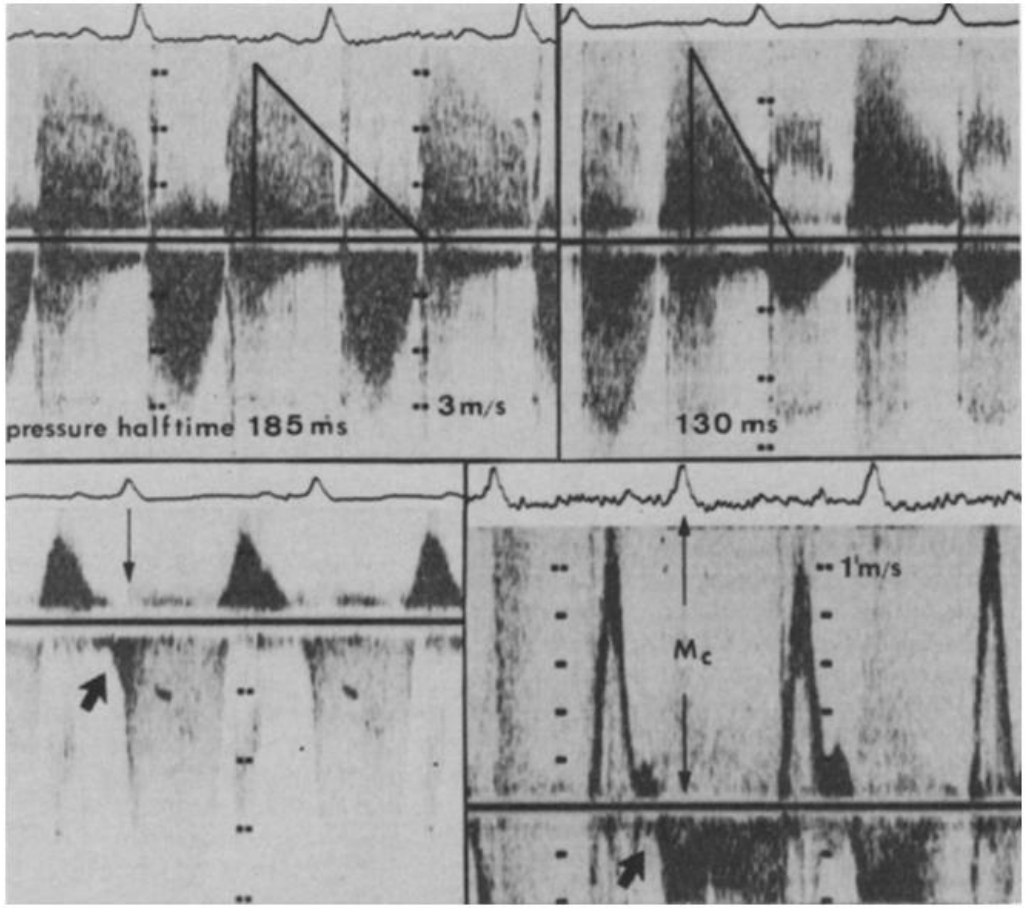


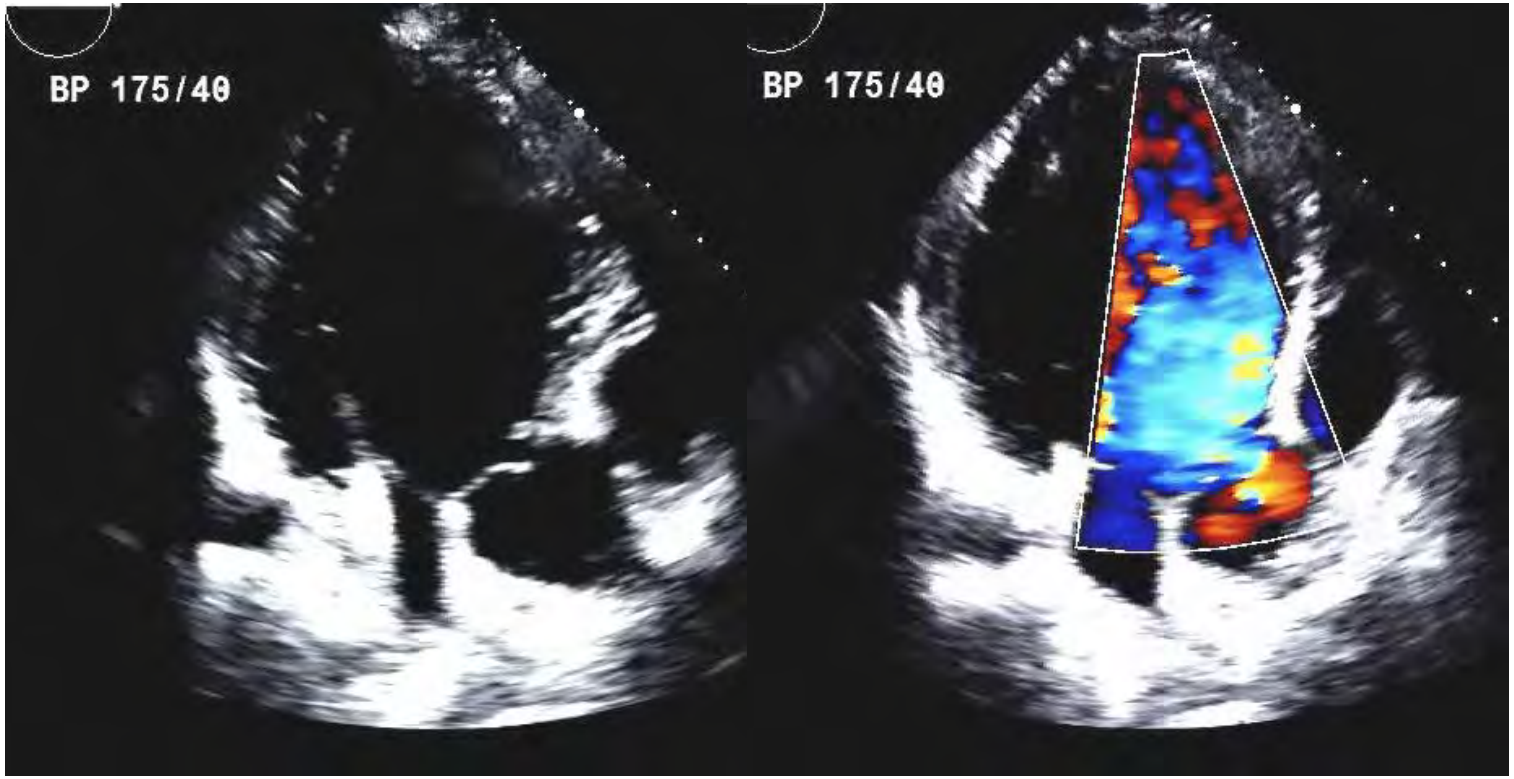
Aortic Regurgitation Pressure Half-time Severe < 200 msec



Characteristic Doppler Echocardiographic Pattern of Mitral Inflow Velocity in Severe Aortic Regurgitation

JAE K. OH, MD, FACC, LIV K. HATLE, MD, LAWRENCE J. SINAK, MD,
JAMES B. SEWARD, MD, FACC, A. JAMIL TAJIK, MD, FACC



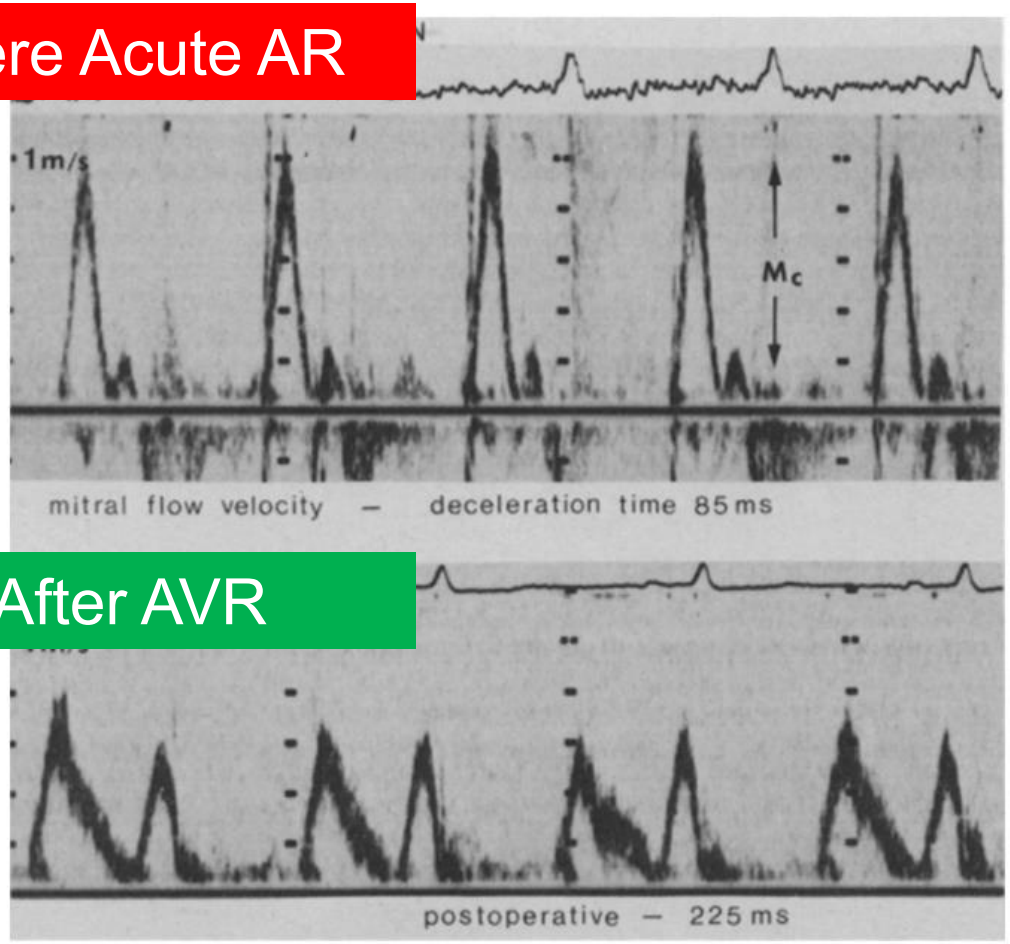


JK Oh et al JACC 1989

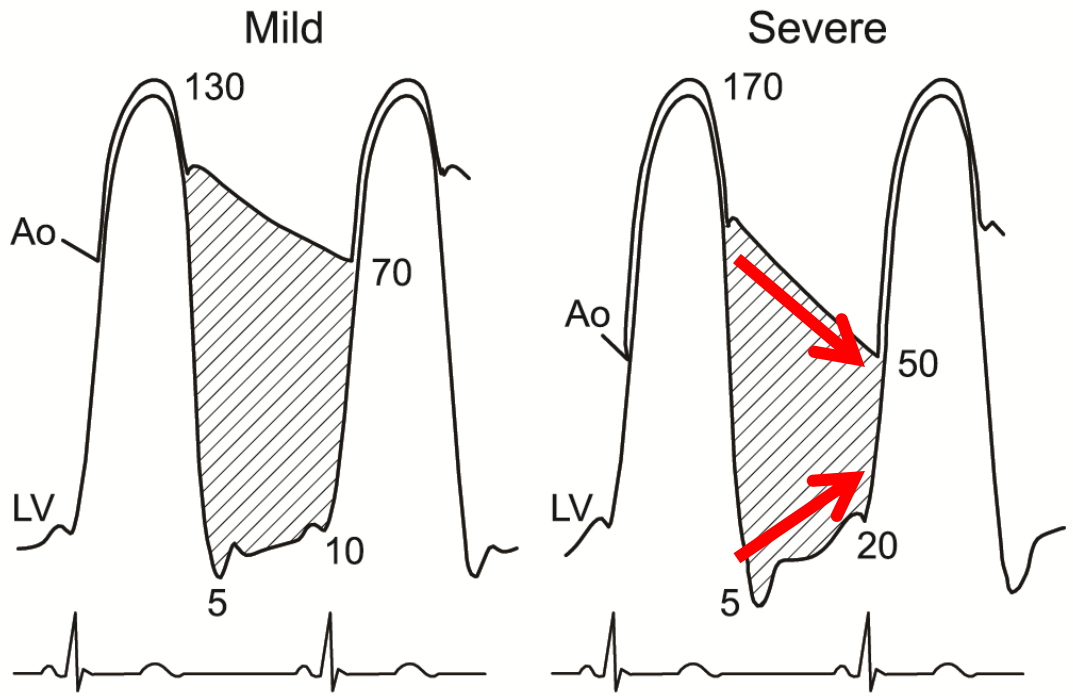
Characteristic Doppler Echocardiographic Pattern of Mitral Inflow Velocity in Severe Aortic Regurgitation

JAE K. OH, MD, FACC, LIV K. HATLE, MD, LAWRENCE J. SINAK, MD,
JAMES B. SEWARD, MD, FACC, A. JAMIL TAJIK, MD, FACC

Severe Acute AR

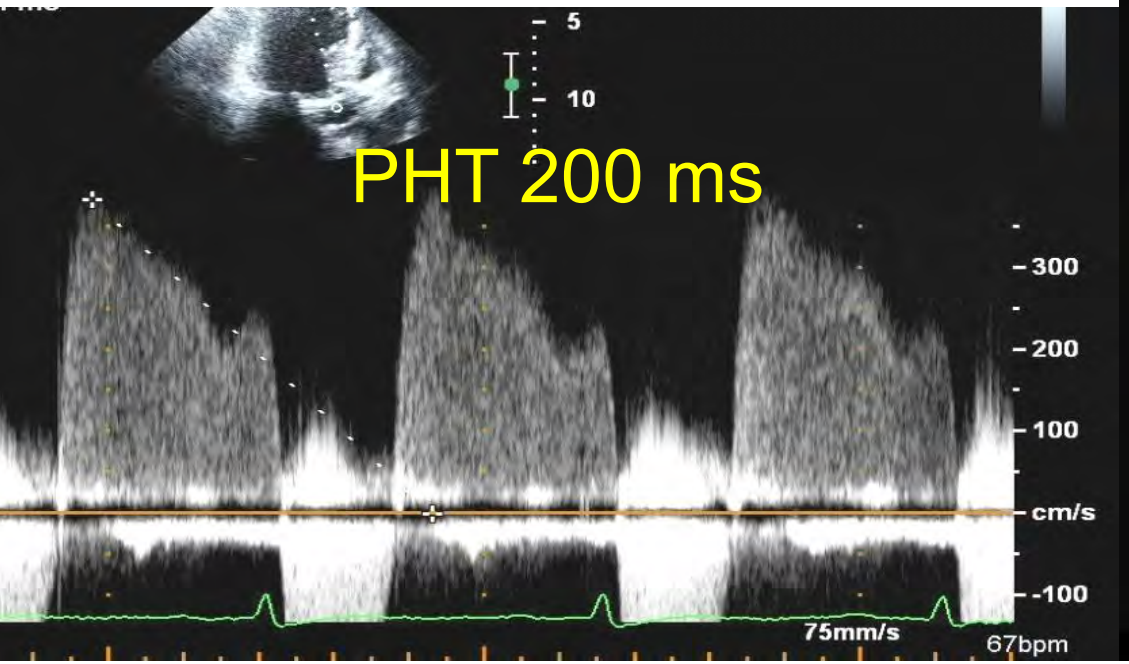


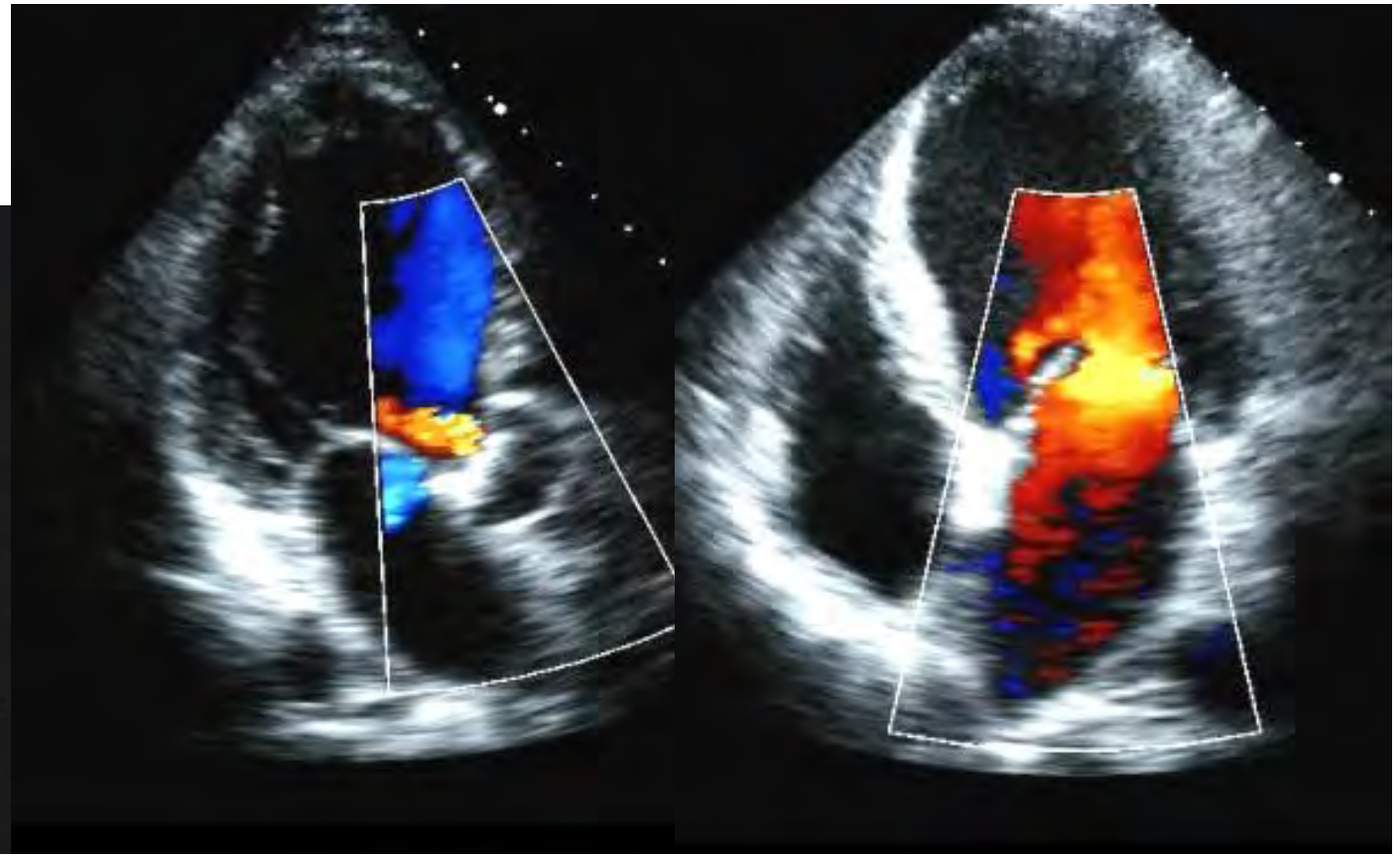
After AVR



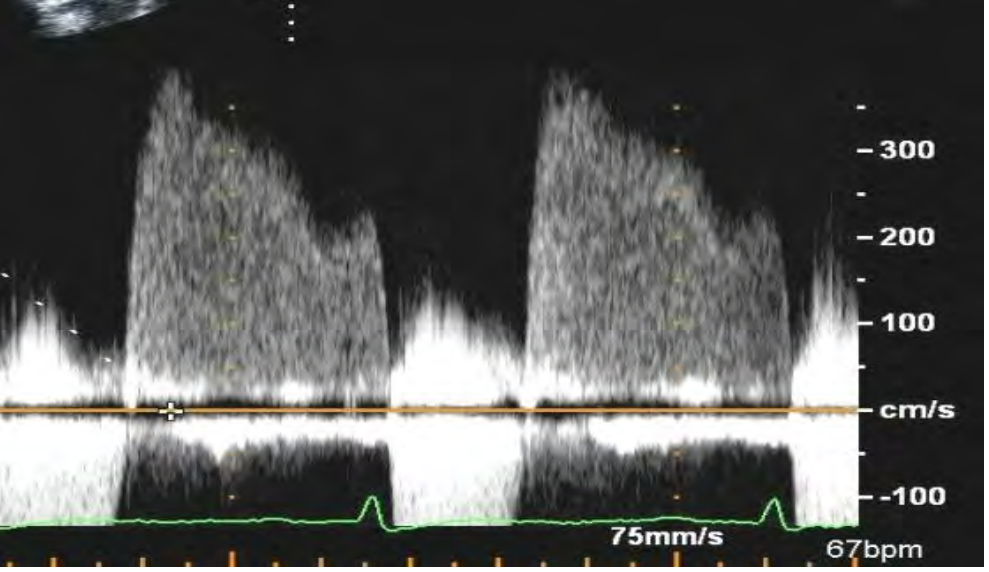
Case #9

How severe AR ?





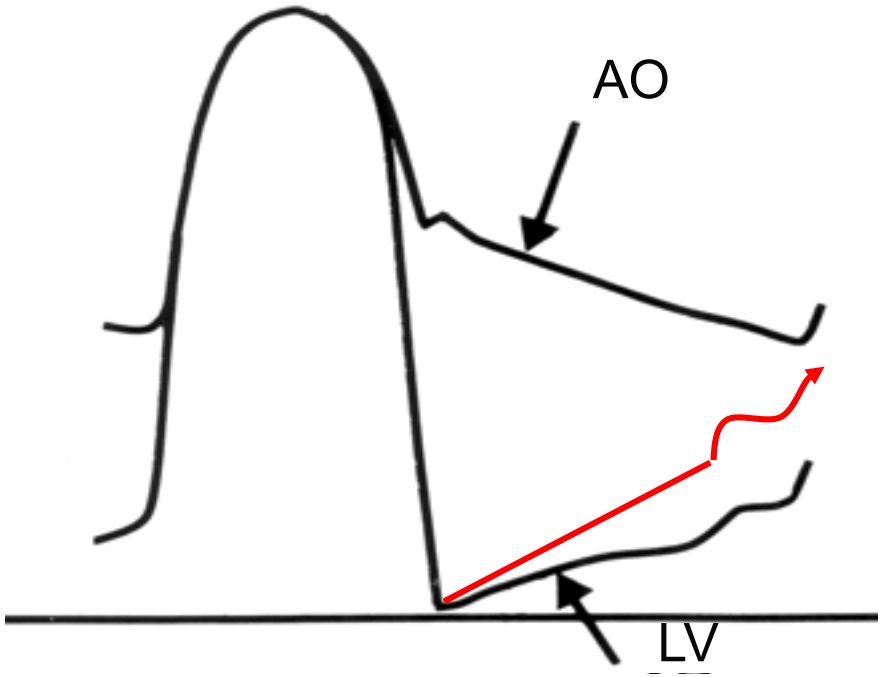
1= Mild 2= Moderate 3= Severe 4=Mild to severe



Aortic Regurgitation

Pressure ½ time

Diastolic AO-LV pressure difference



Decrease in AO pressure

Degree of AR

Systemic vasc. resist

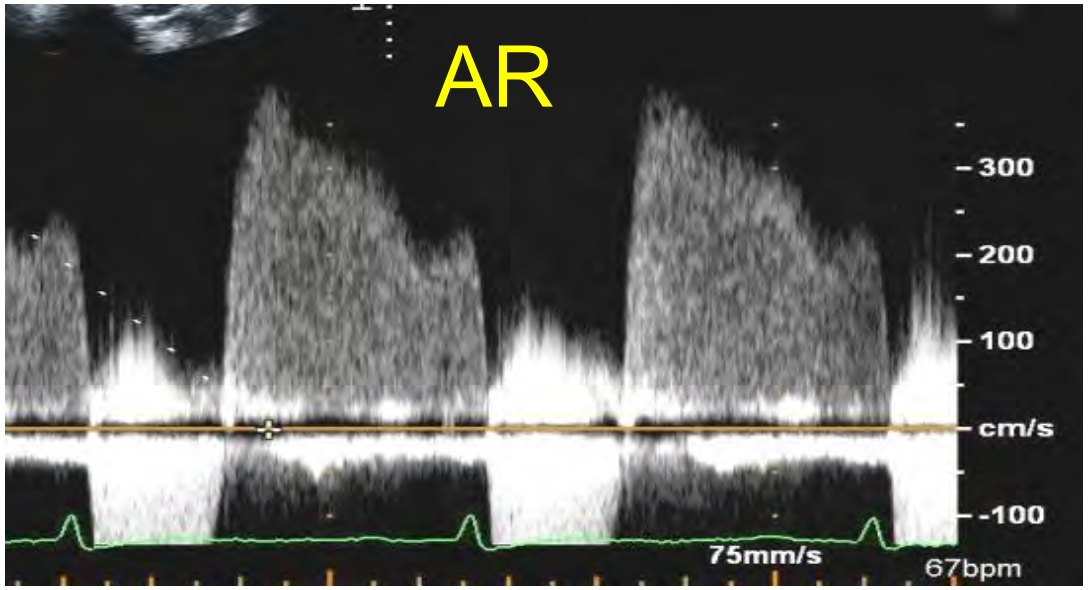
Aortic compliance

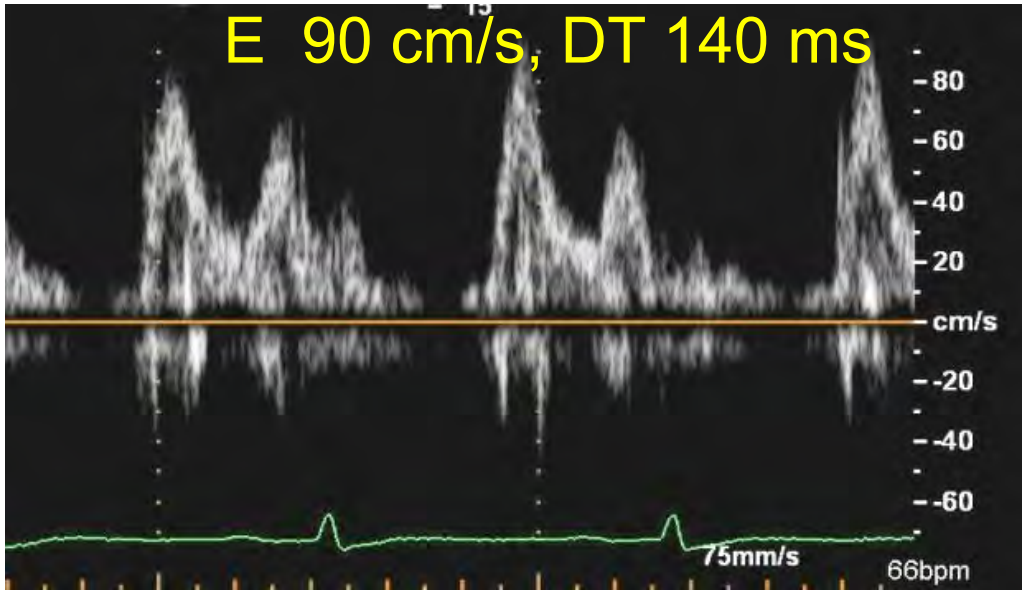
Increase in LV pressure

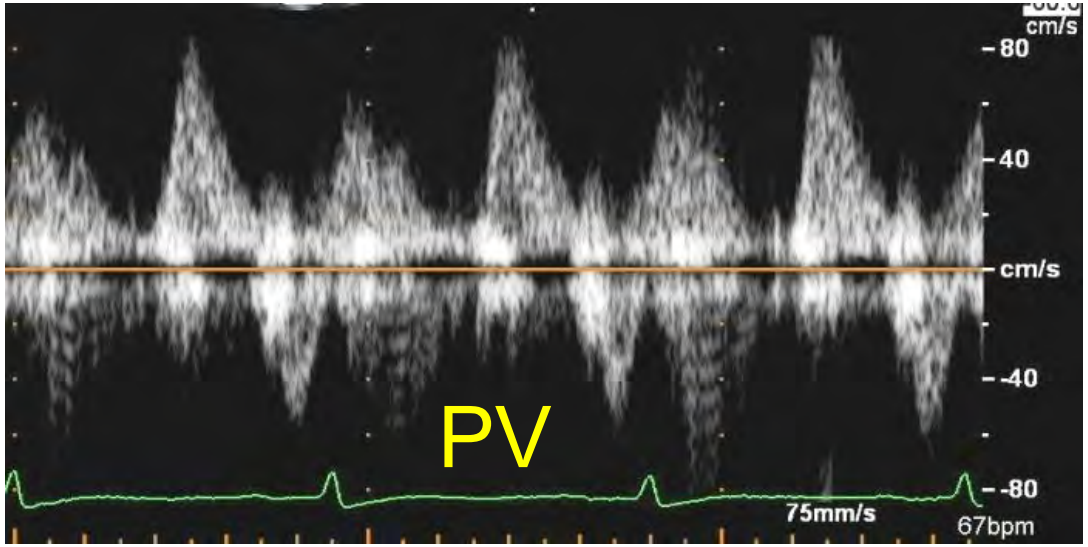
Degree of AR

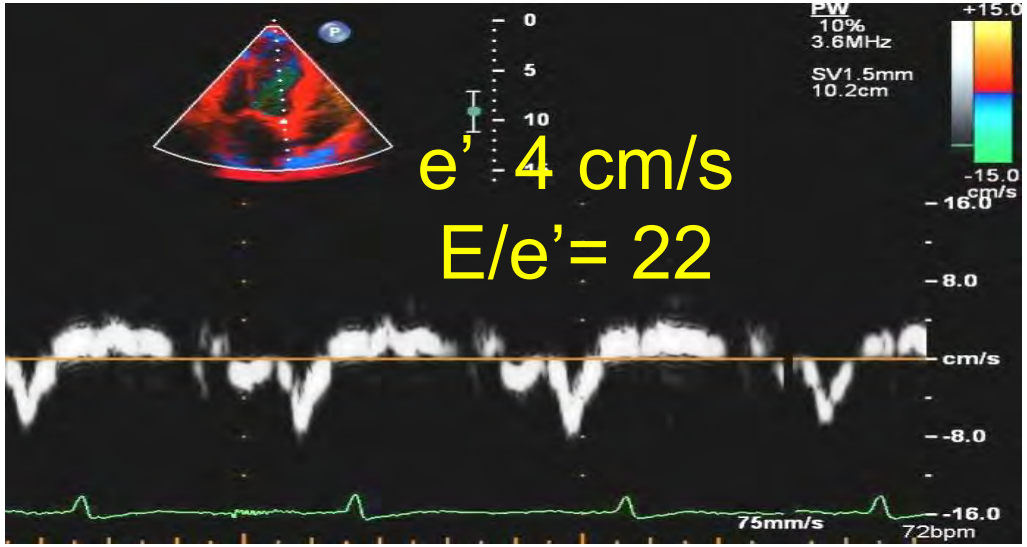
LV compliance

Increased LV filling pressure









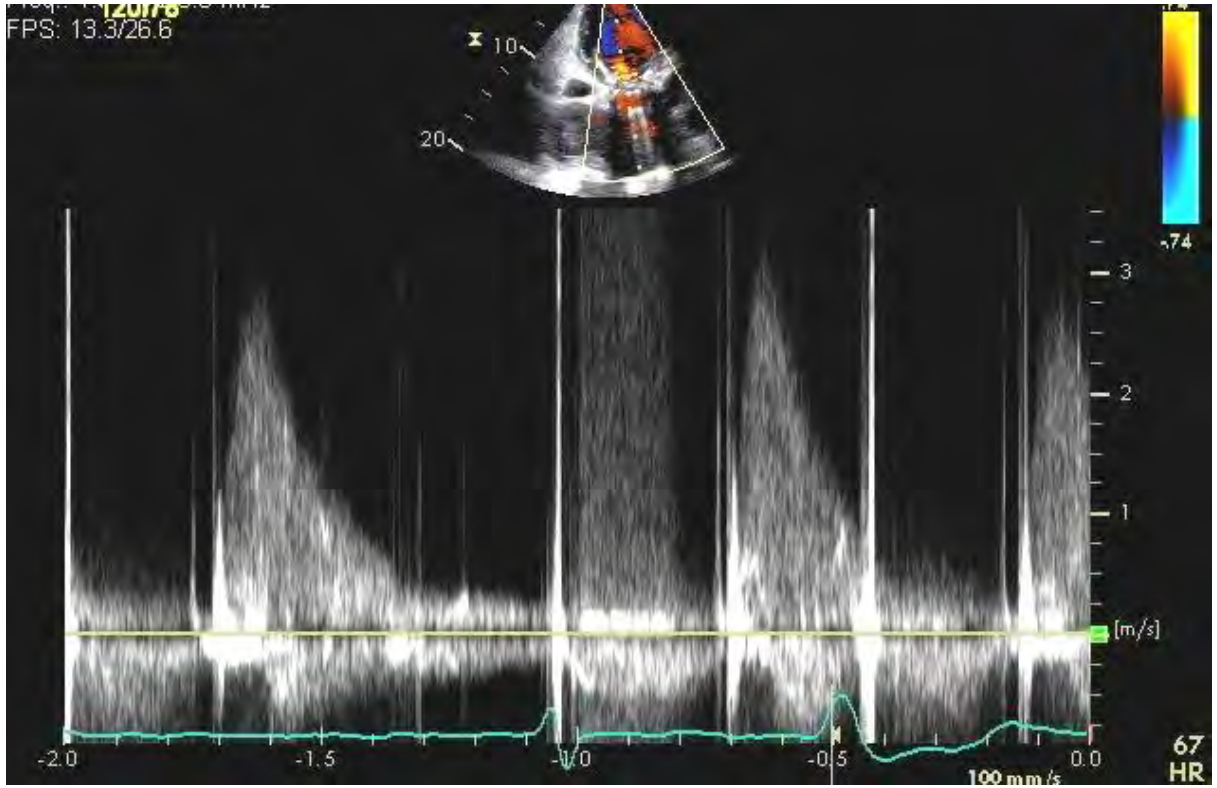
Mitral prosthetic valve dysfunction
E velocity is usually > 2 m/sec

- Obstruction or stenosis
- Severe regurgitation
- Increased flow across the MV
  - High output
  - Shunt
- Diastolic dysfunction

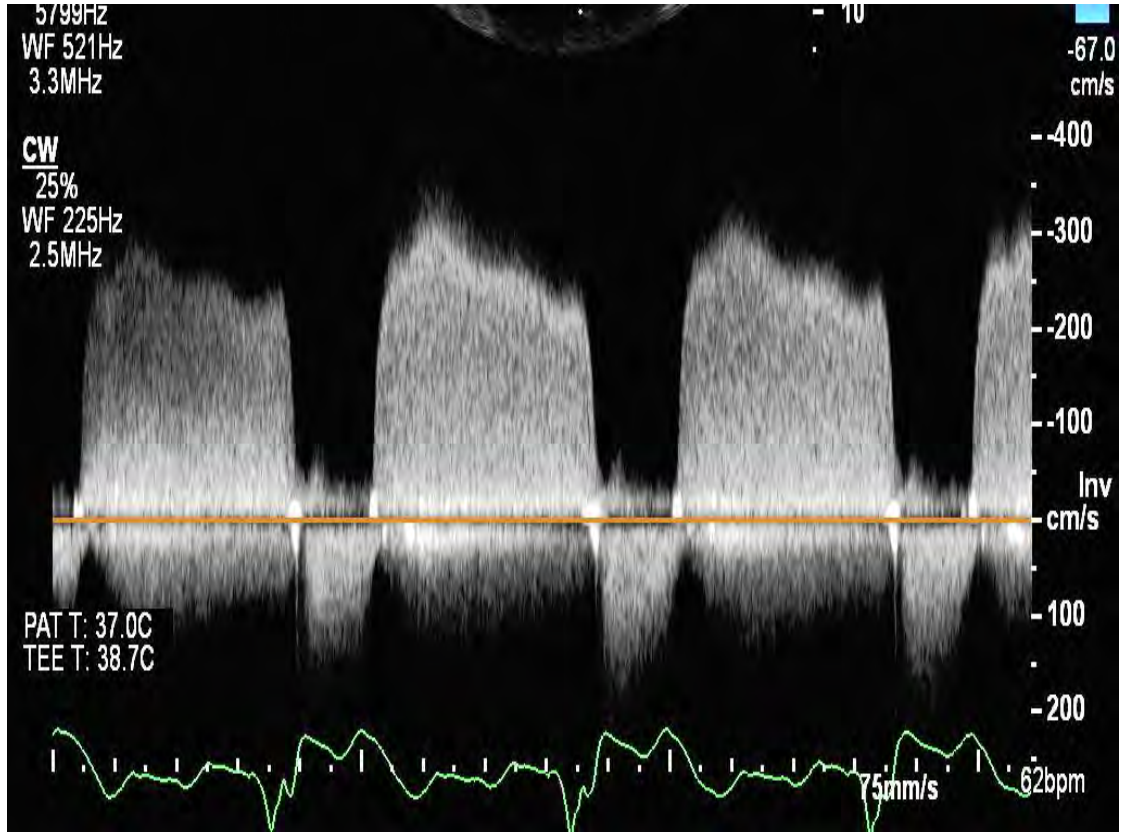
Increased mitral gradient is not always mitral stenosis

Increased E velocity in patients with MV prosthesis

E velocity = 3 m/sec



PHT 100 msec Severe MR

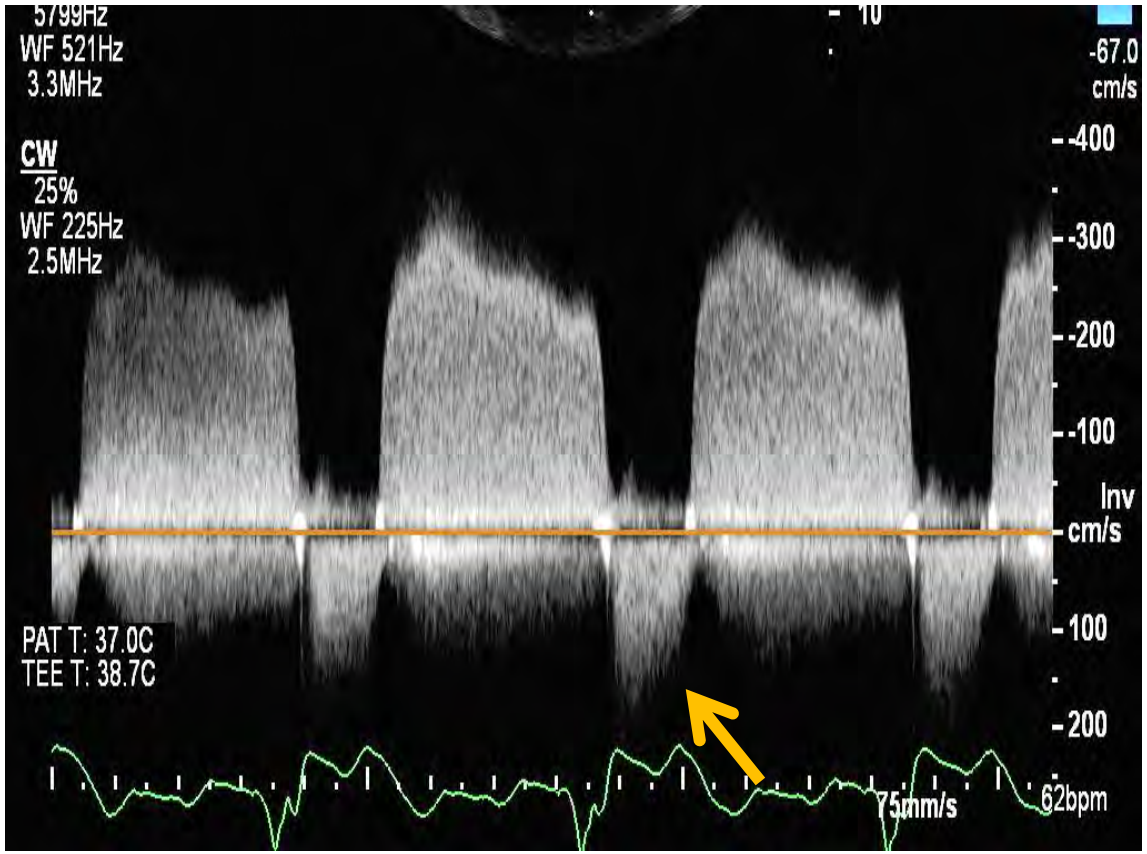


PHT 250 msec Severe obstruction

Case #10

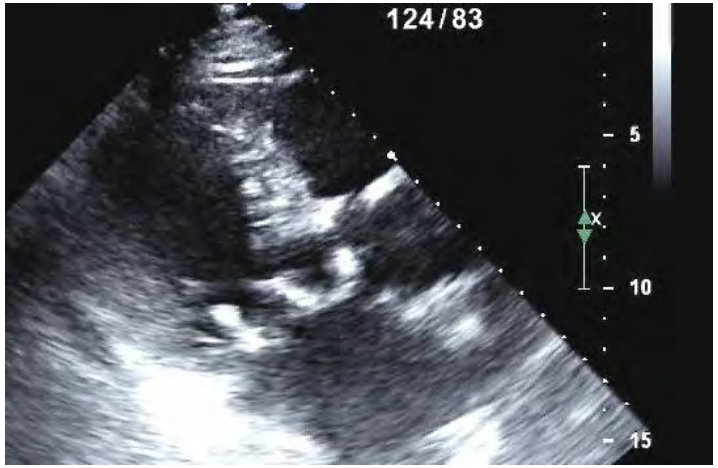
30 year old female with mitral bio-prosthesis

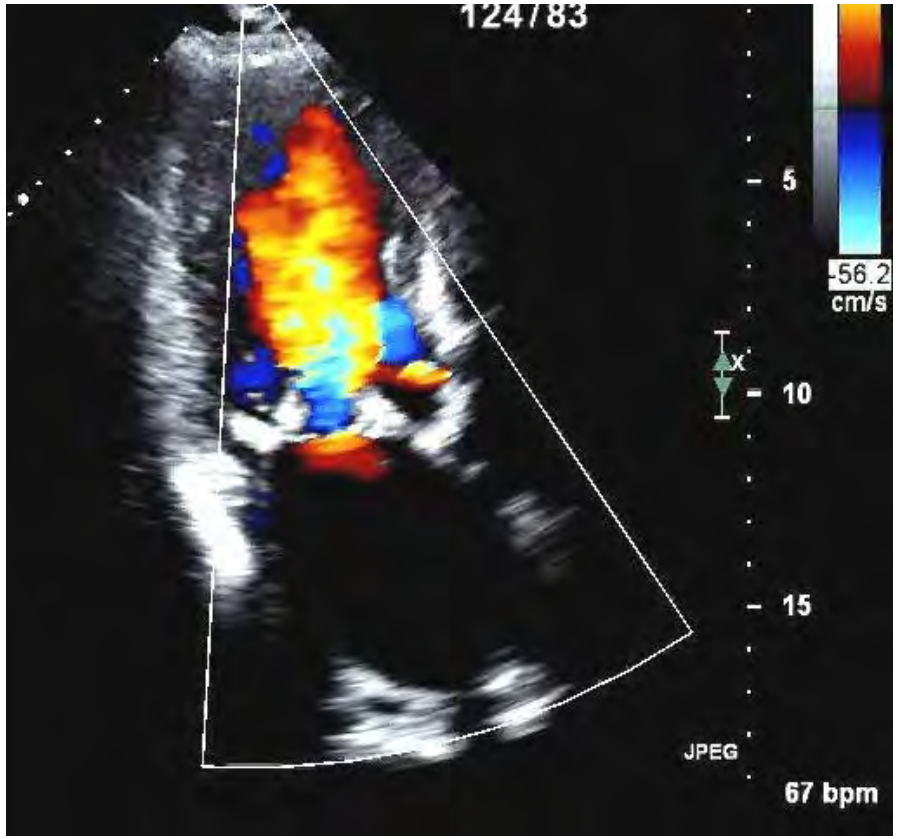
Presenting with heart failure



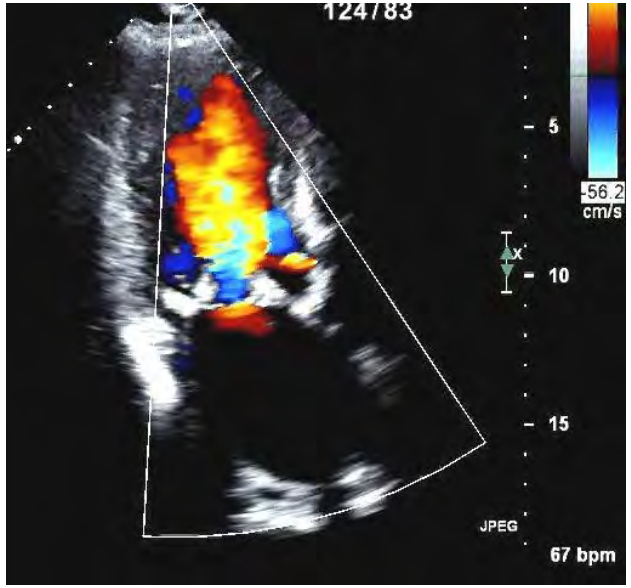
Case #11

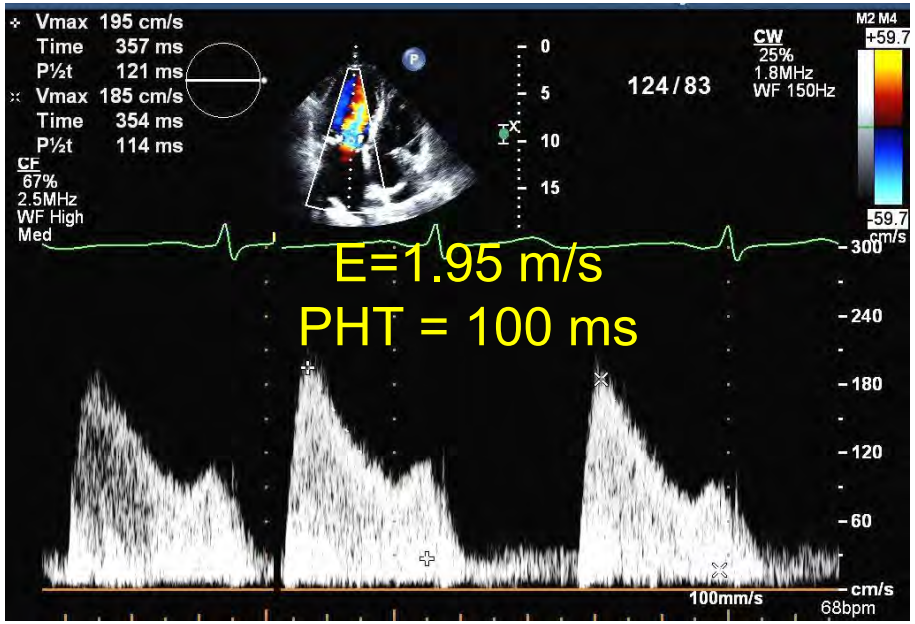
78 yo man with MVR 9 months ago (NYC)
Increasing Dyspnea

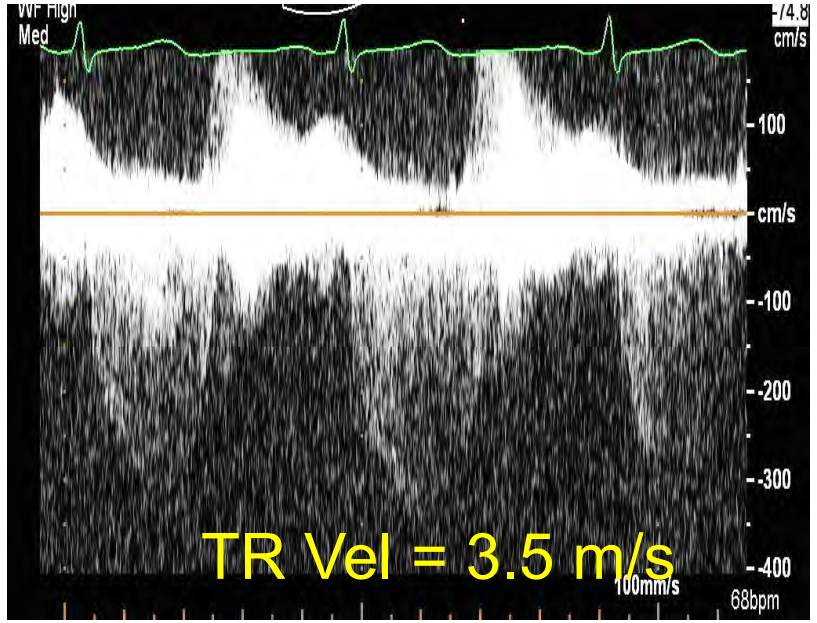




78 yo man with MVR 9 months ago (25 mm Hancock)
Increasing Dyspnea

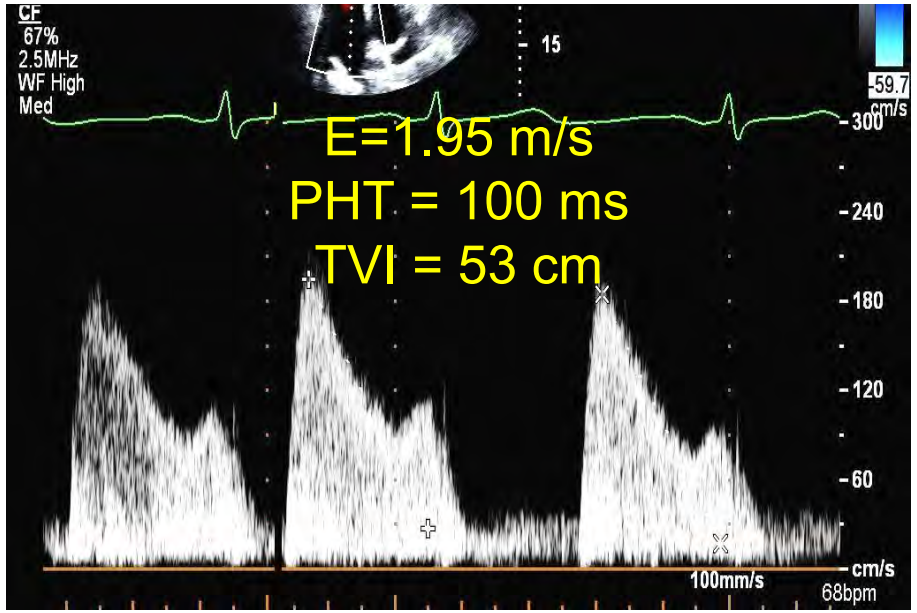


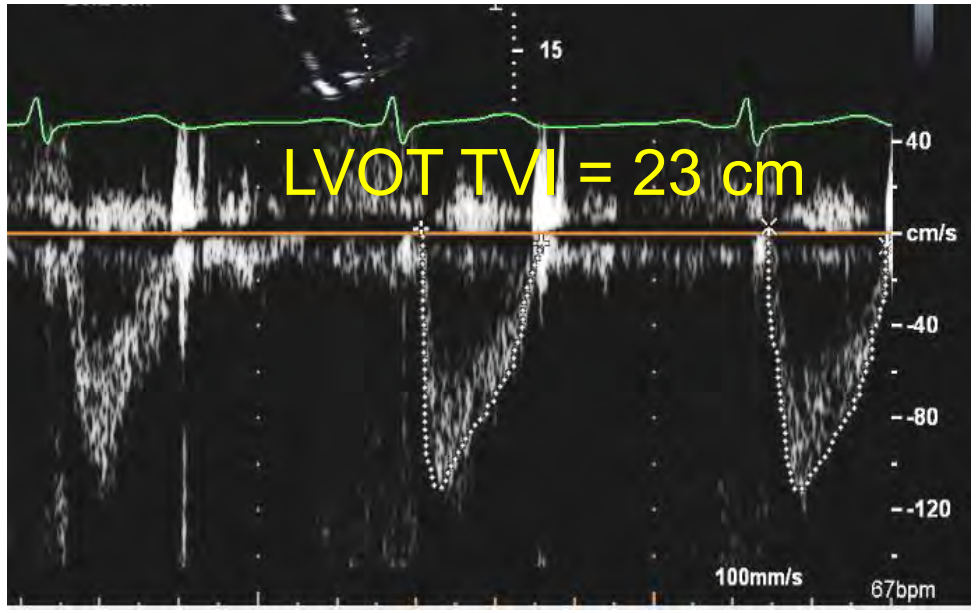




1= Normal Prosthesis and PHT. CT
2= Mitral prosthetic Obstruction. Exercise
3= Mitral Prosthetic Regurgitation. TEE
4= Normal Prosthesis. Lose weight.

78 yo man with MVR 9 months ago in NYC Increasing Dyspnea



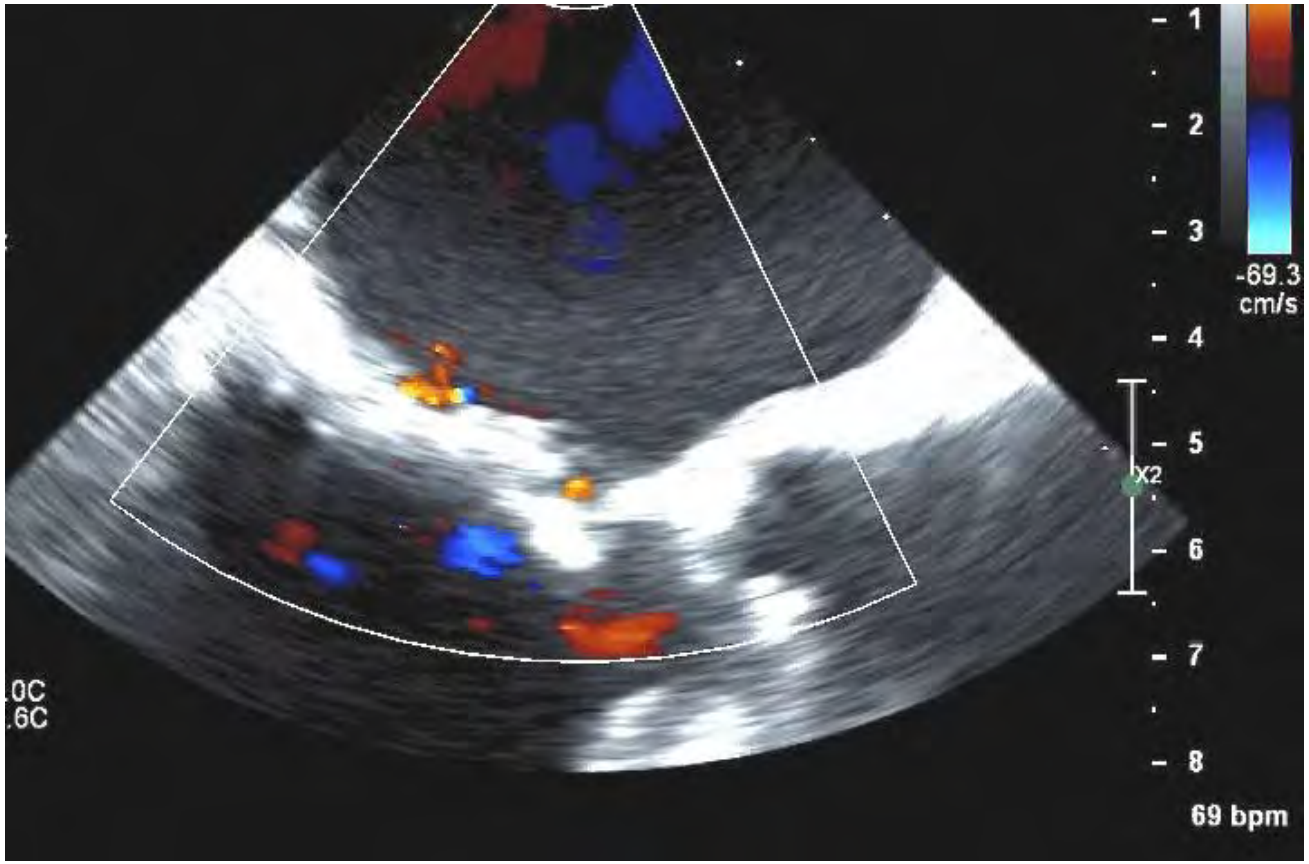


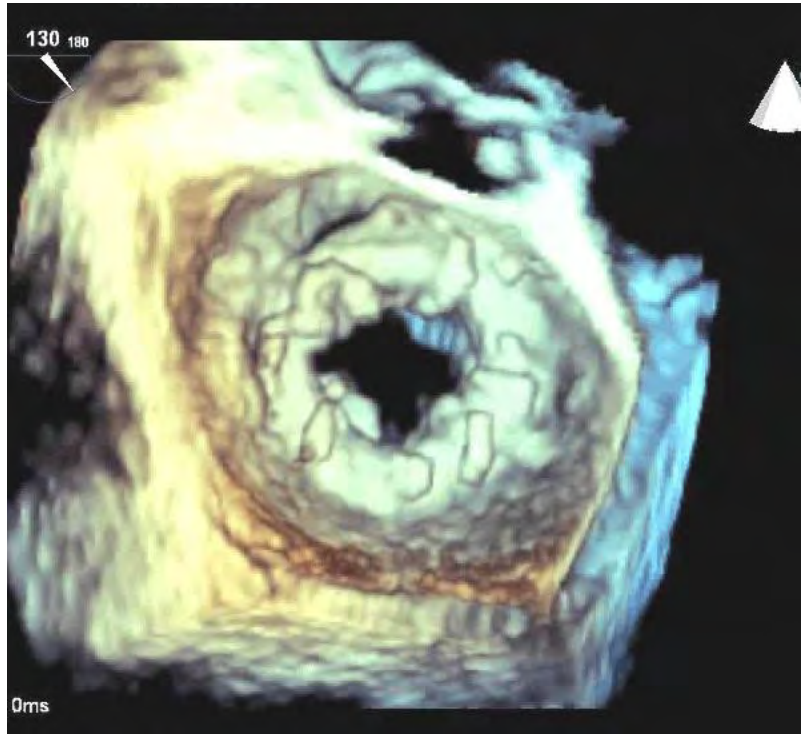
$$\frac{\text{MV TVI}}{\text{LVOT TVI}}$$

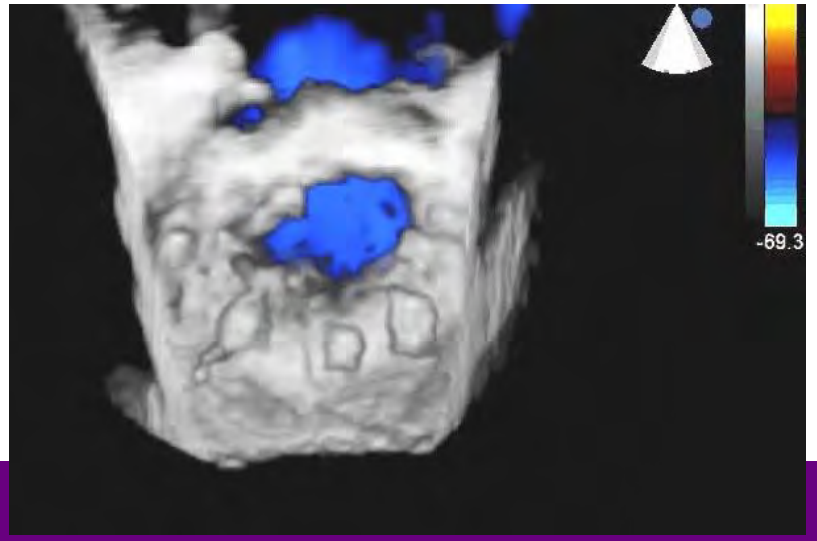
= 53/23
= 2.3

1= Normal Prosthesis and PHT. CT
2= Mitral prosthetic Obstruction. Exercise
3= Mitral Prosthetic Regurgitation. TEE
4= Normal Prosthesis. Lose weight.

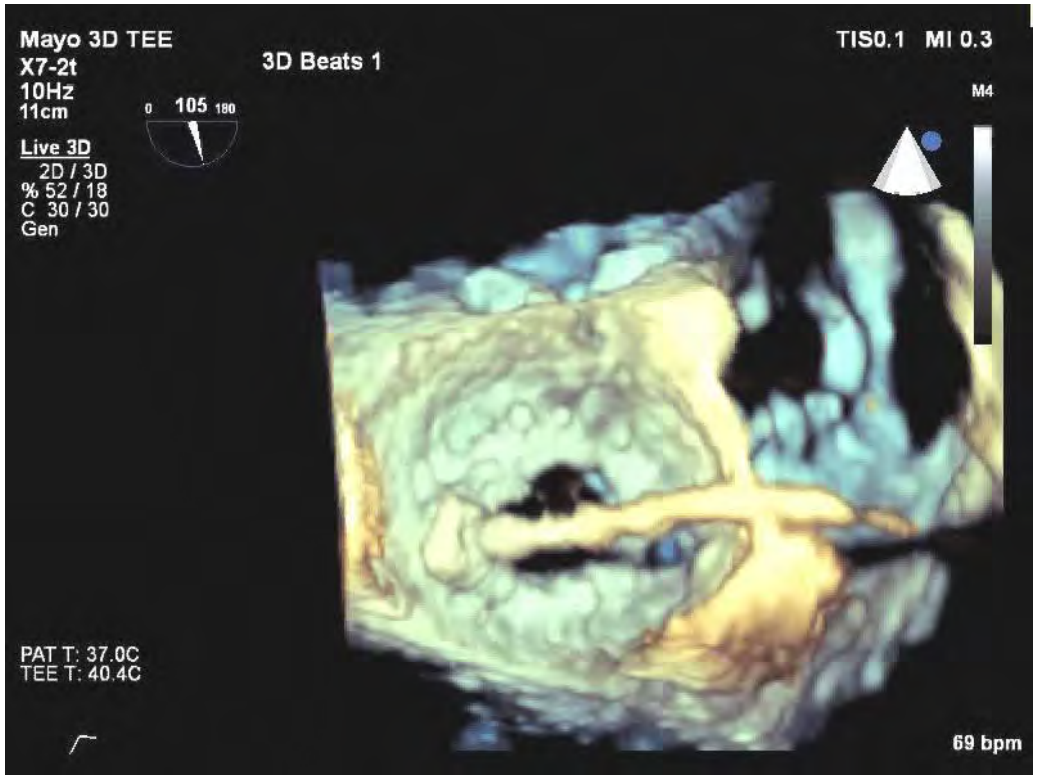
2-D and 3-D TEE Paravalvular Leak

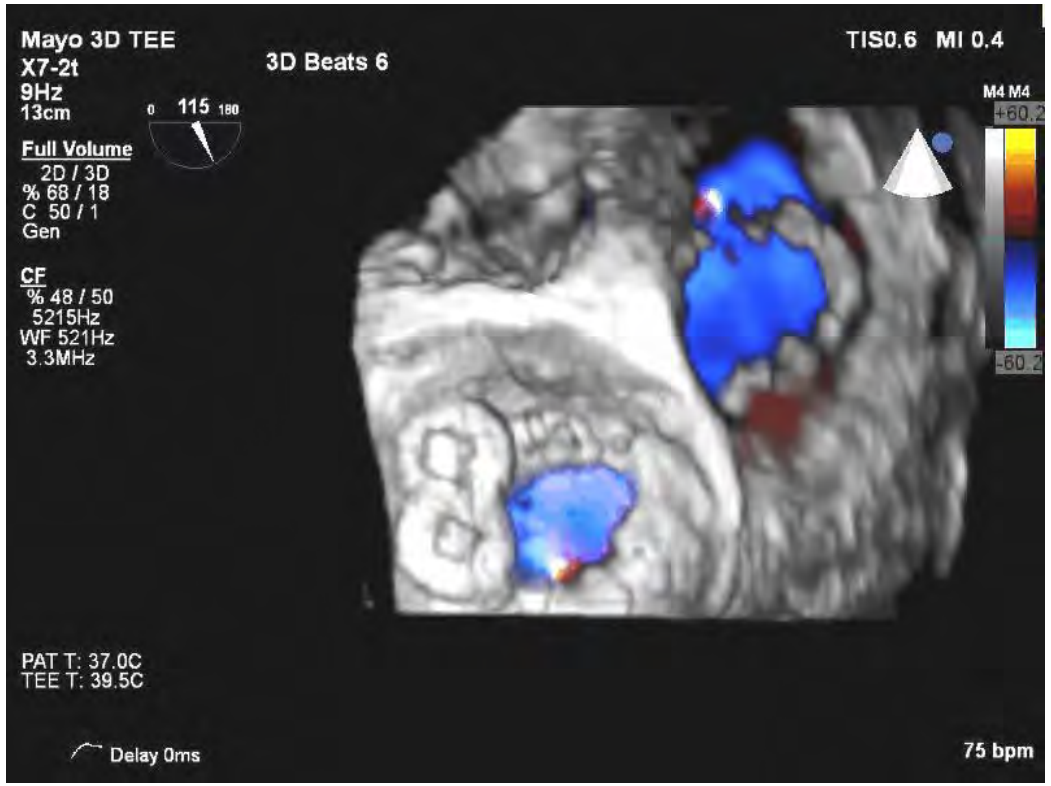






Mitral Prosthetic Paravalvular Leak Closure

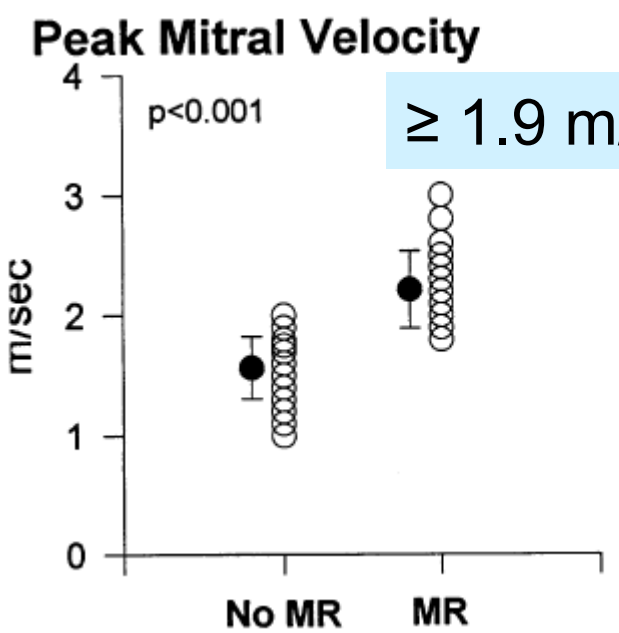


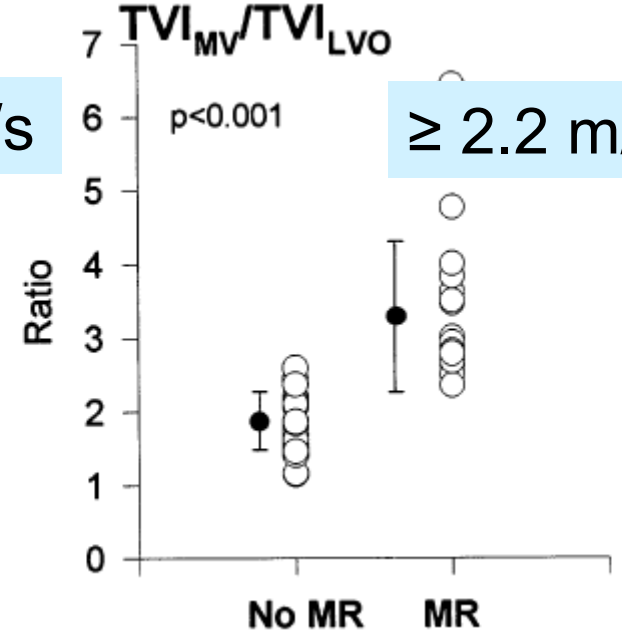


Usefulness of Transthoracic Echocardiography in Detecting Significant Prosthetic Mitral Valve Regurgitation

Leopoldo Olmos, MD, Gabriel Salazar, MD, John Barbetseas, MD, Miguel A. Quiñones, MD, and William A. Zoghbi, MD

To identify the transthoracic echo-Doppler (TTE) vari- 0.97 for both). A peak velocity of ≥1.9 m/s was 90%
ables most predictive of
(MR) of mechanical pro
esophageal echo (TEE) s
viewed in 57 patients (
years) undergoing both
eral 2-dimensional and D
from the TTE studies we
significant (moderate or
whereas mild or no MR v
univariate predictors of s
velocity of mitral inflow,
gitation velocity, isovolu
of time velocity integral
integral in the left vent
Peak mitral velocity an
predictors of significant
(area under the receiver



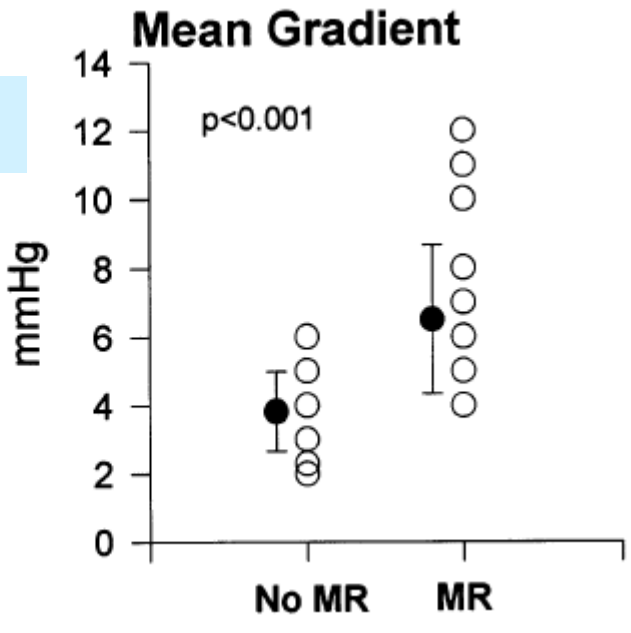


Peak Early Diastolic Velocity Rather Than Pressure Half-Time Is the Best Index of Mechanical Prosthetic Mitral Valve Function

Valerian Fernandes, MD, Leopoldo Olmos, MD, Sherif F. Nagueh, MD, Miguel A. Quiñones, MD, and William A. Zoghbi, MD

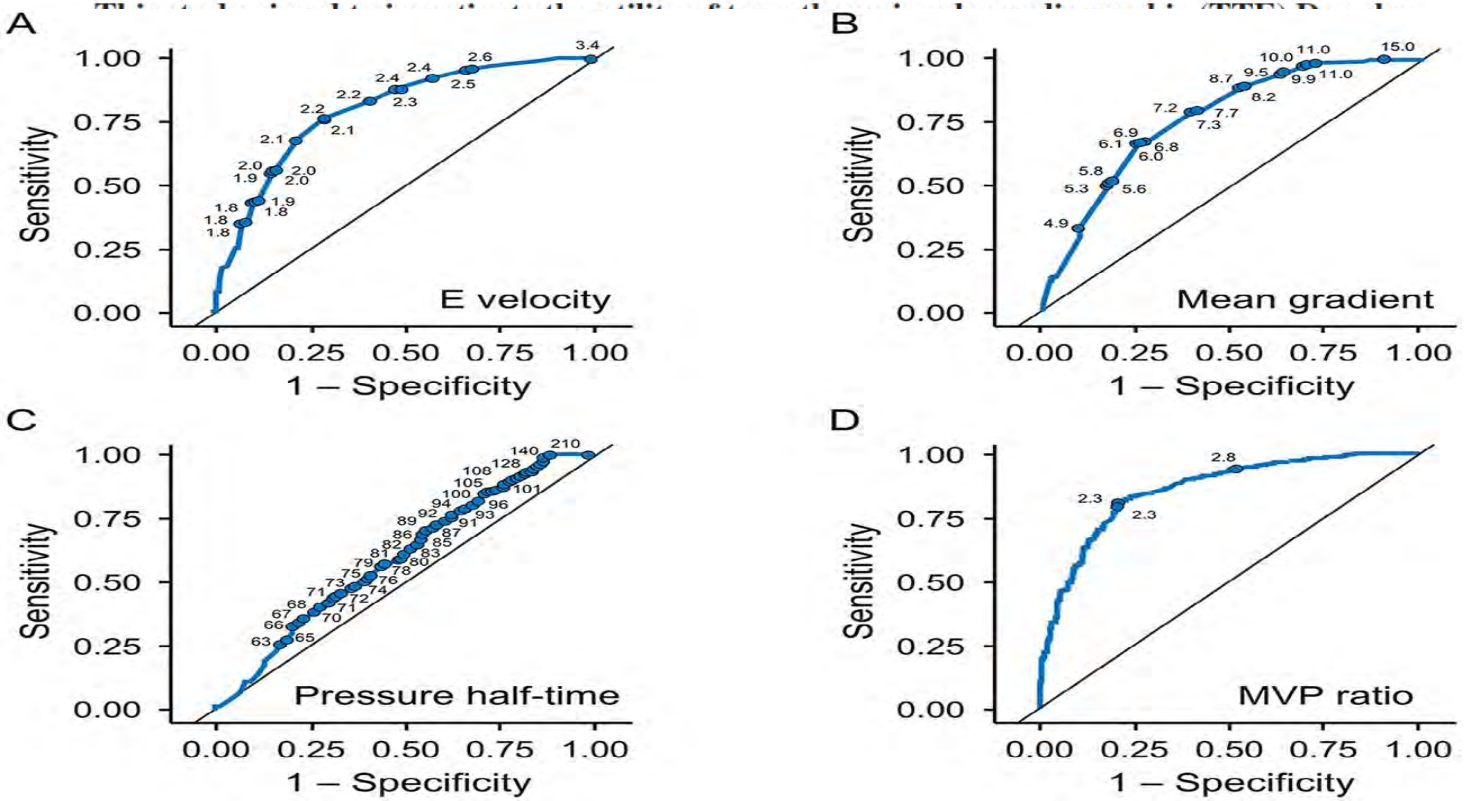
Reliable screening of mechanical prosthetic mitral valve pressure half-time (PHT) readily identified PMV obstruc-
Logistic models in-
VTI$_{lvo}$ or PHT were
dysfunction. How-
o best distinguish
urgitant valves. A
/VTI$_{lvo}$ ratio ≥2.2
f valves when PHT
5% when PHT was
elocity <1.9 m/s,
<130 ms had a
e of 98%. Thus, TTE
ning parameters of
atients for further
2002 by Excerpta

002;89:704–710)



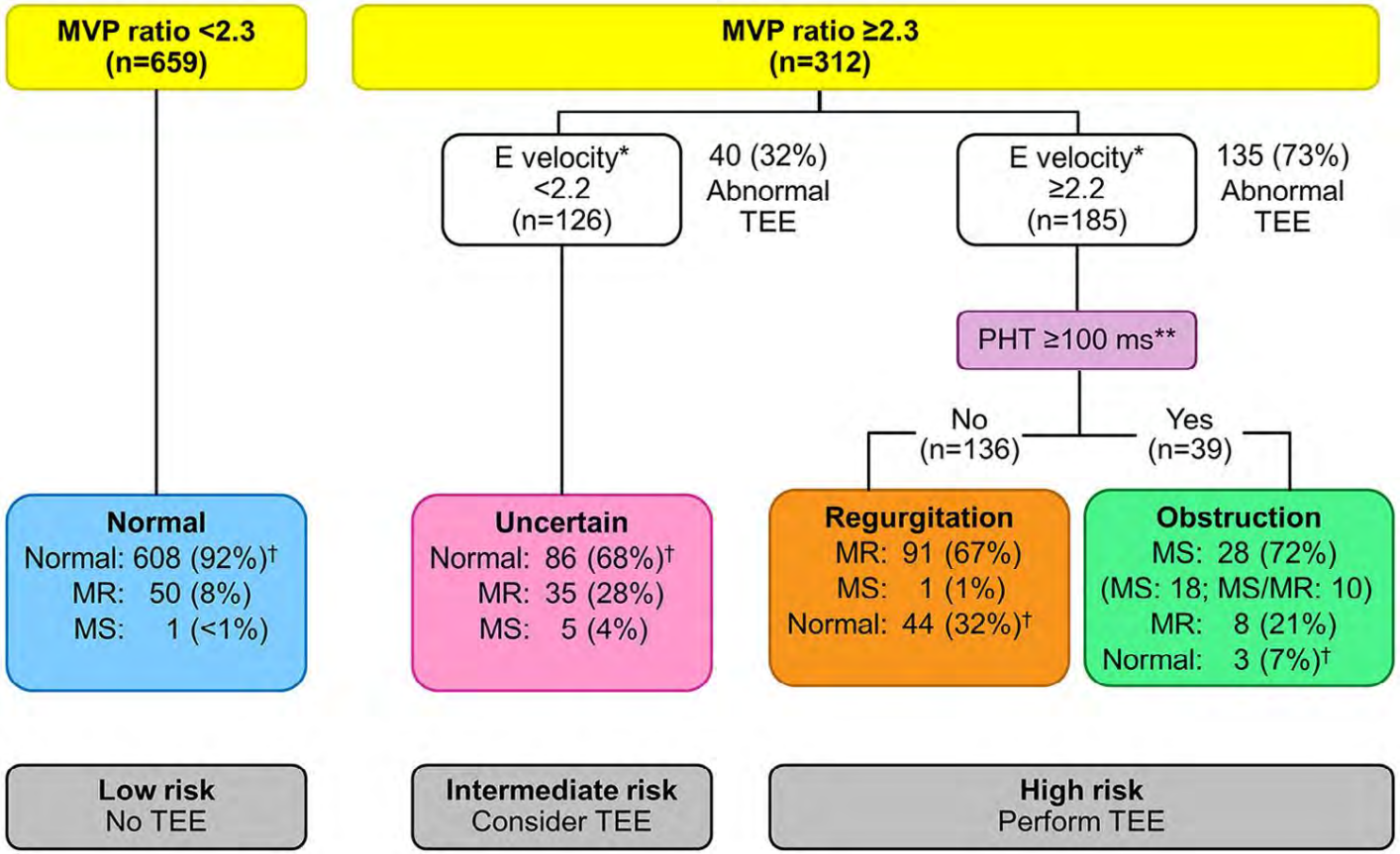
Usefulness of Mitral Valve Prosthetic or Bioprosthetic Time Velocity Index Ratio to Detect Prosthetic or Bioprosthetic Mitral Valve Dysfunction

Sushil Allen Luis, MBBS[a,b,*,†], Lori A. Blauwet, MD[a,†], Himabindu Samardhi, MBBS[c], Cathy West, DMU[c], Ramila A. Mehta, MS[d], Chris R. Luis, MBBS[b,c], Gregory M. Scalia, MBBS[b,c], Fletcher A. Miller Jr, MD[a], and Darryl J. Burstow, MBBS[b,c]



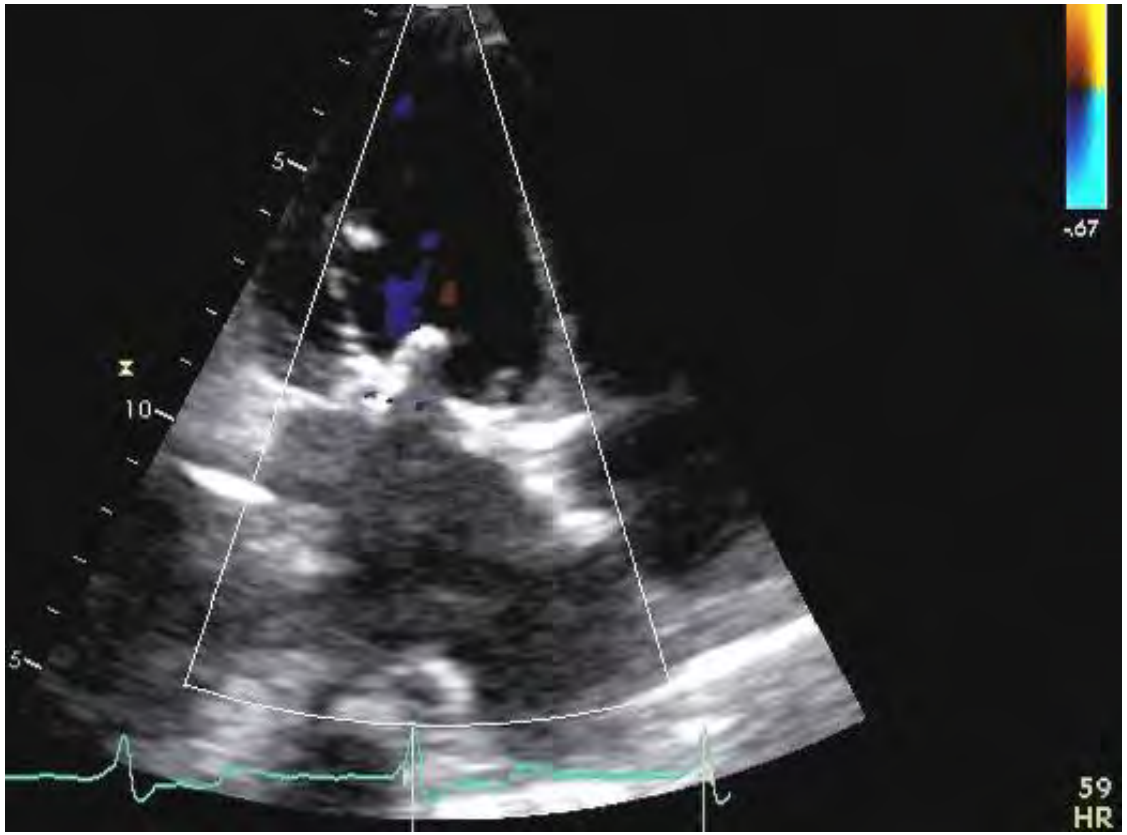
Usefulness of Mitral Valve Prosthetic or Bioprosthetic Time Velocity Index Ratio to Detect Prosthetic or Bioprosthetic Mitral Valve Dysfunction

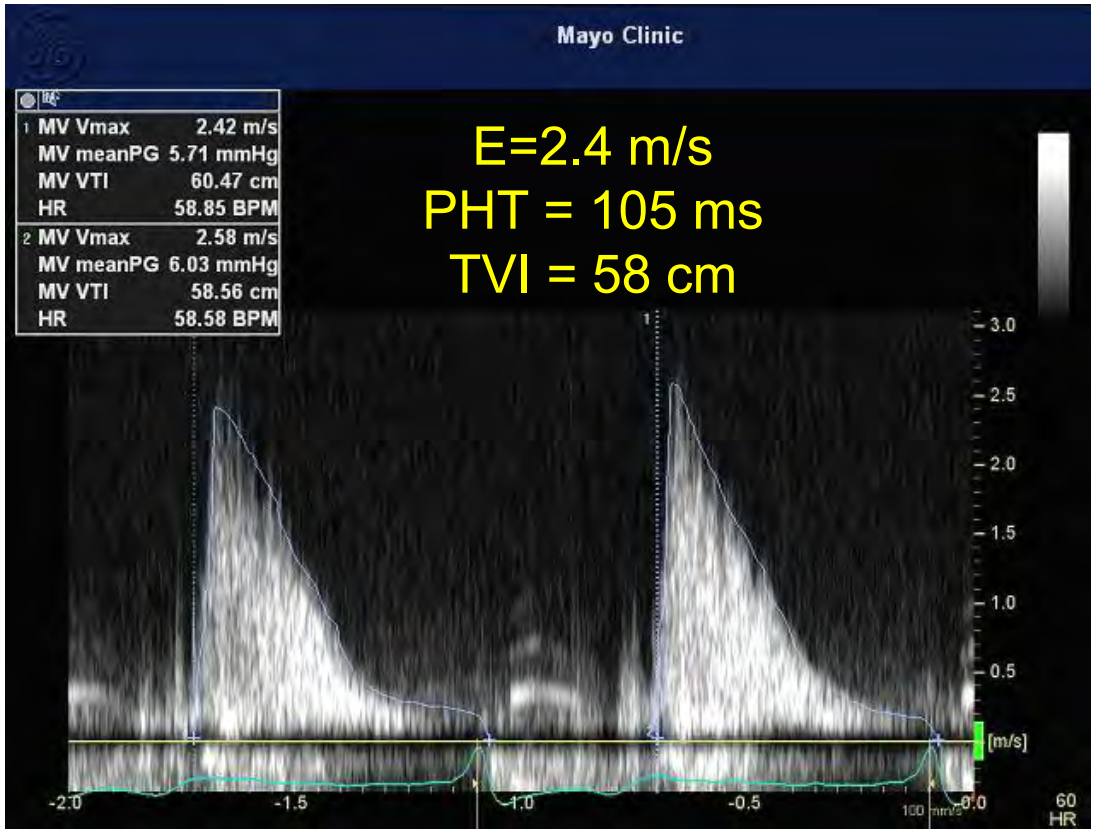
Sushil Allen Luis, MBBS[a,b,*,†], Lori A. Blauwet, MD[a,†], Himabindu Samardhi, MBBS[c], Cathy West, DMU[c], Ramila A. Mehta, MS[d], Chris R. Luis, MBBS[b,c], Gregory M. Scalia, MBBS[b,c], Fletcher A. Miller Jr, MD[a], and Darryl J. Burstow, MBBS[b,c]



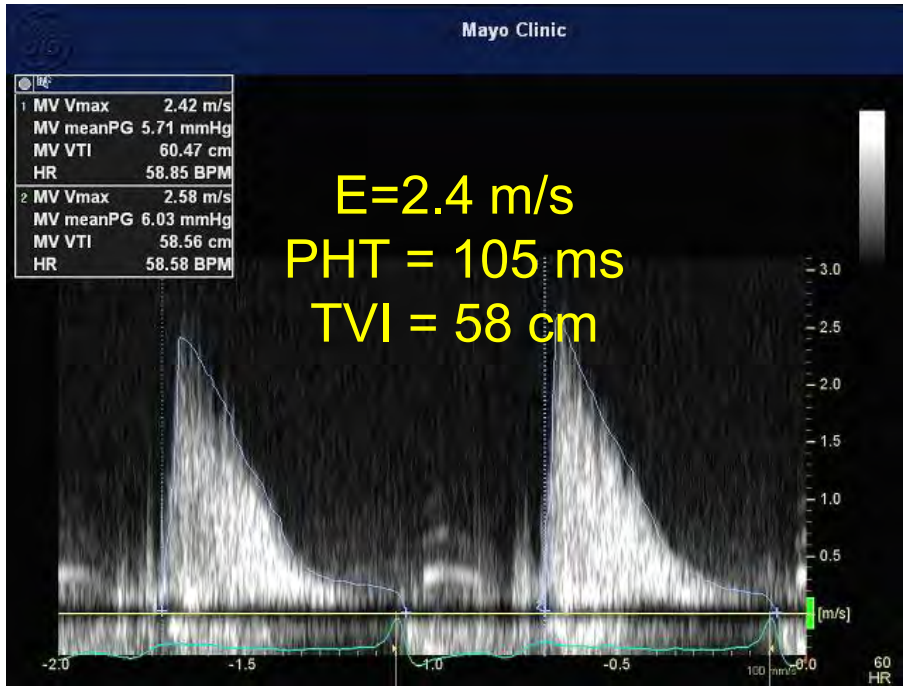
Case #12

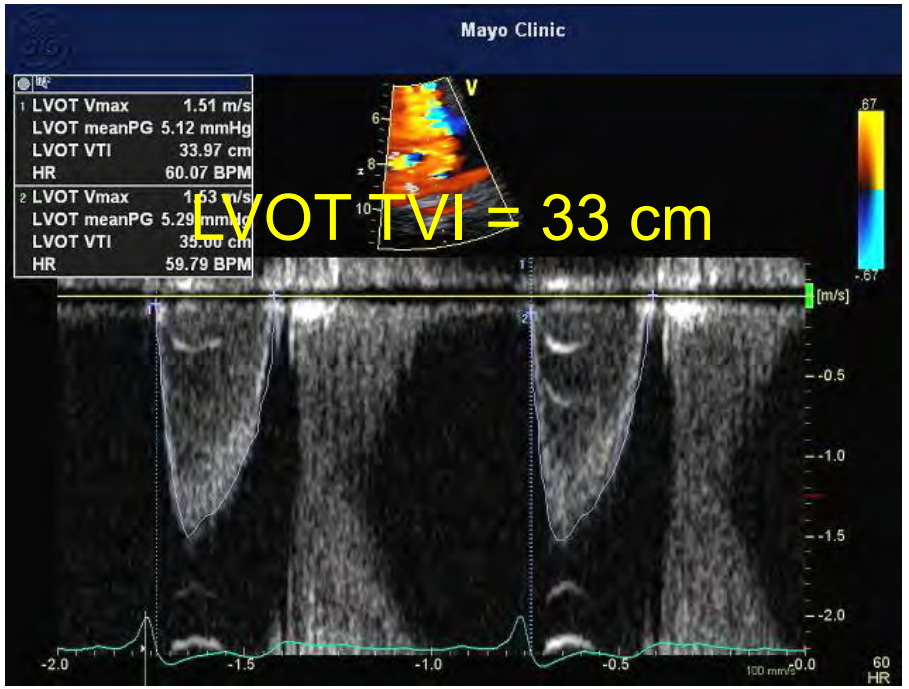
79 yo woman with 25 mm Hancock MV Prosthesis Post-op Discharge Echocardiography





79 yo woman with 25 mm Hancock MVR
Hbg 8 gm%





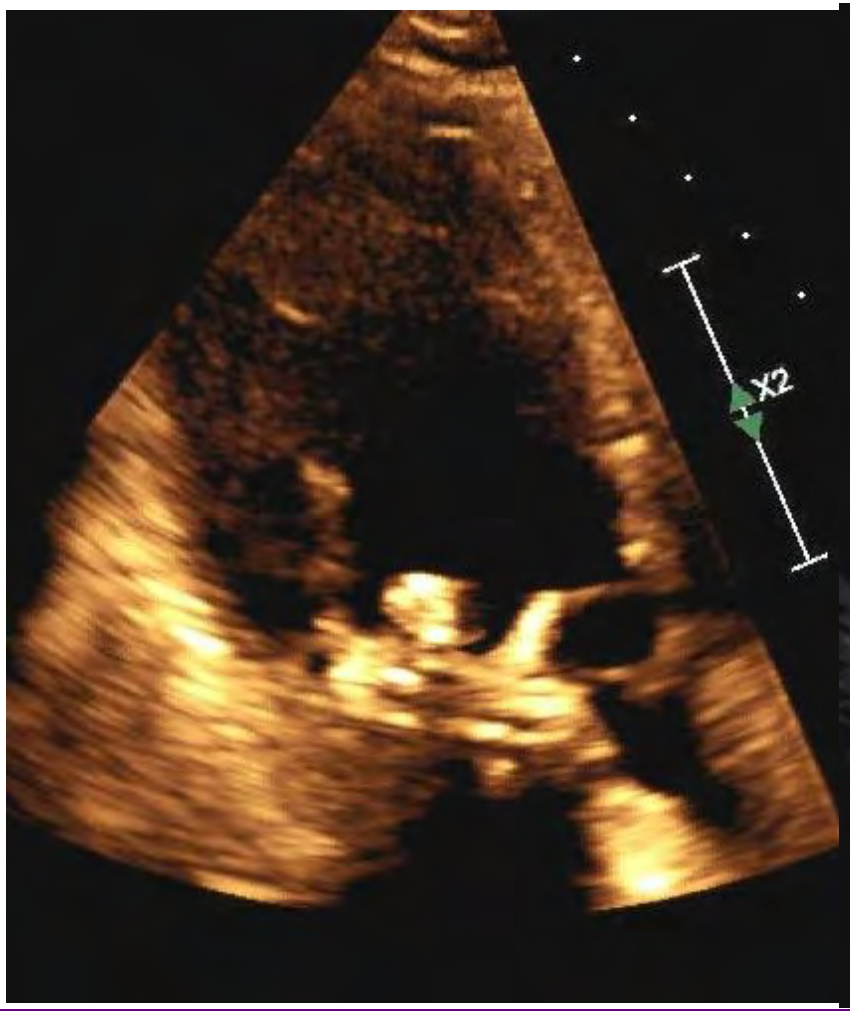
$$\frac{\text{MV TVI}}{\text{LVOT TVI}}$$

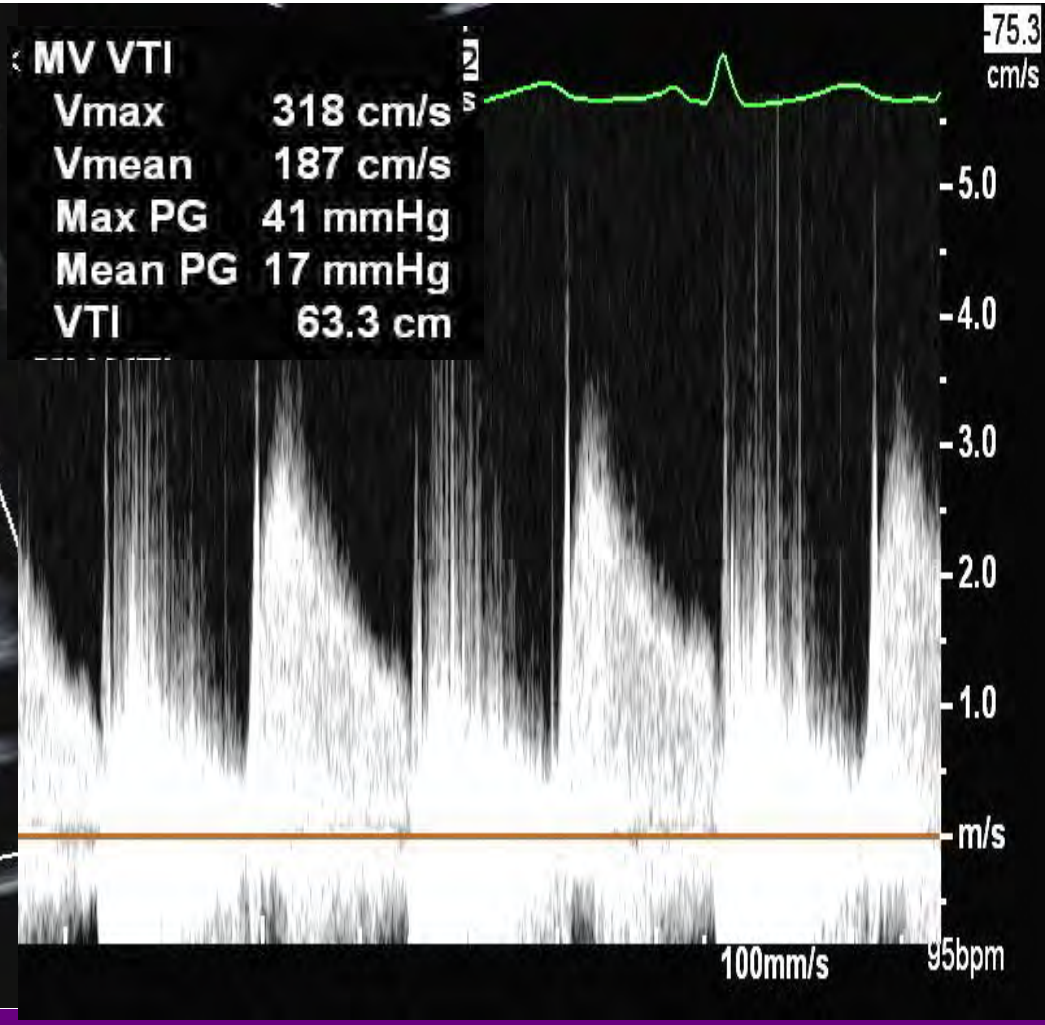
= 58/33
= 1.8

1= Normal Prosthesis and PHT. CT
2= Mitral prosthetic Obstruction. Exercise
3= Mitral Prosthetic Regurgitation. TEE
4= Normal Prosthesis.

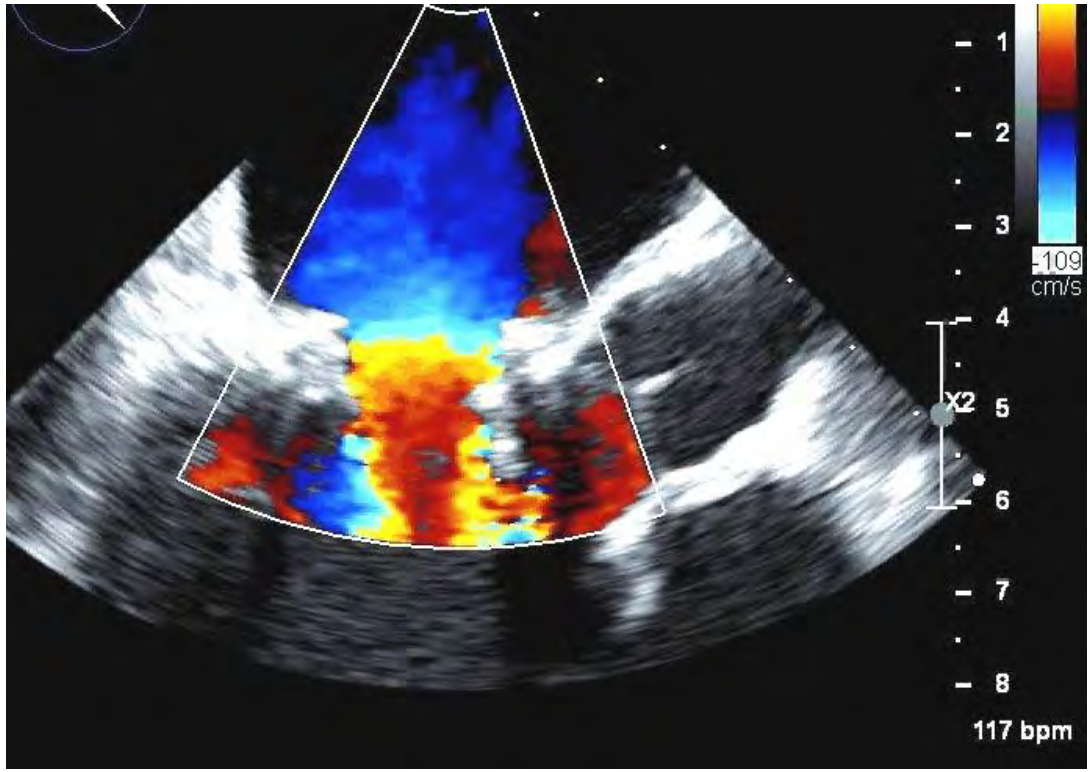
Case #13

43 yo Female from South America with MVR
Progressive dyspnea

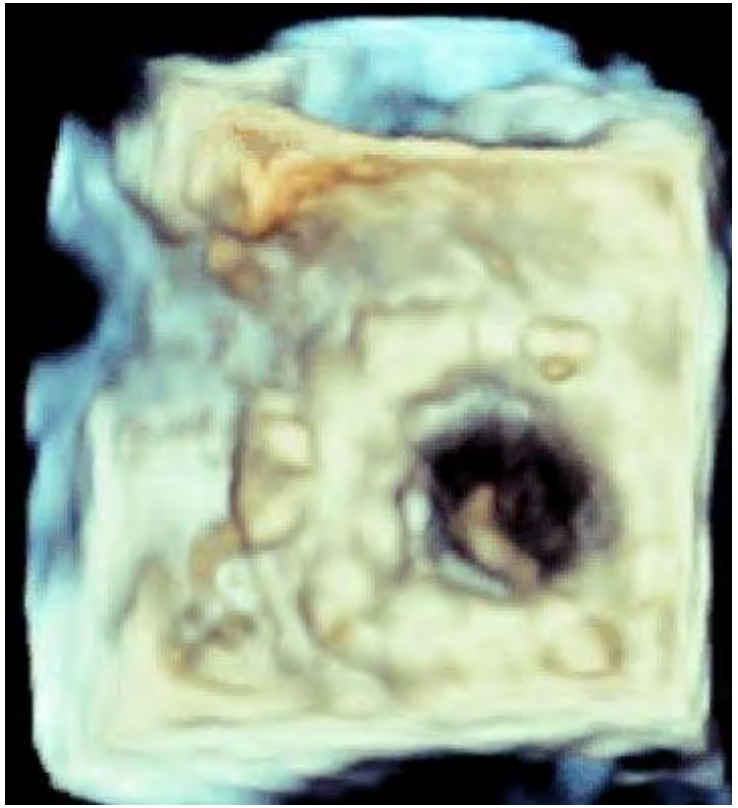


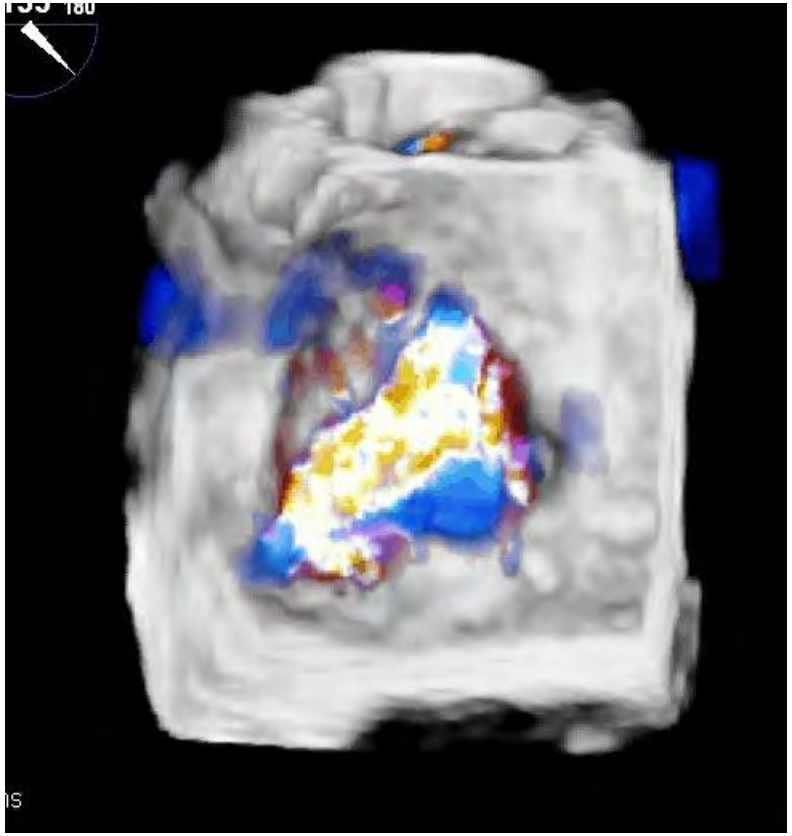


TEE



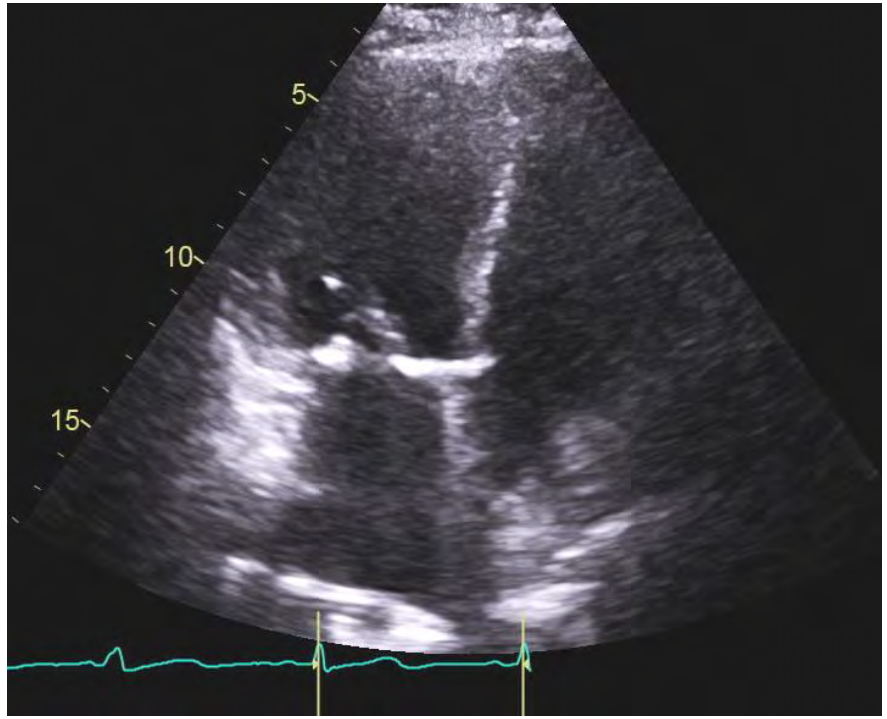
Bio-prosthetic MV Degeneration

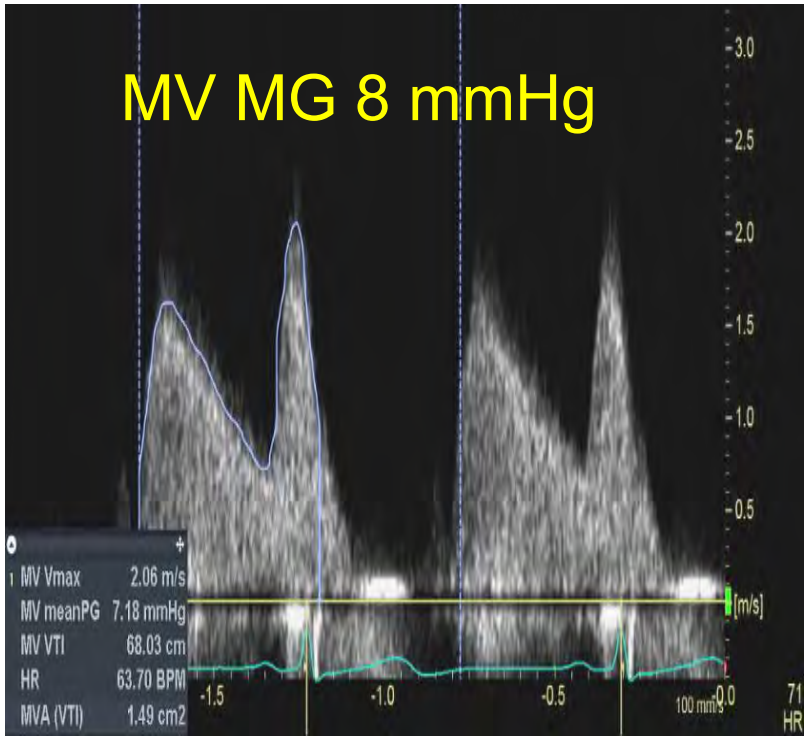


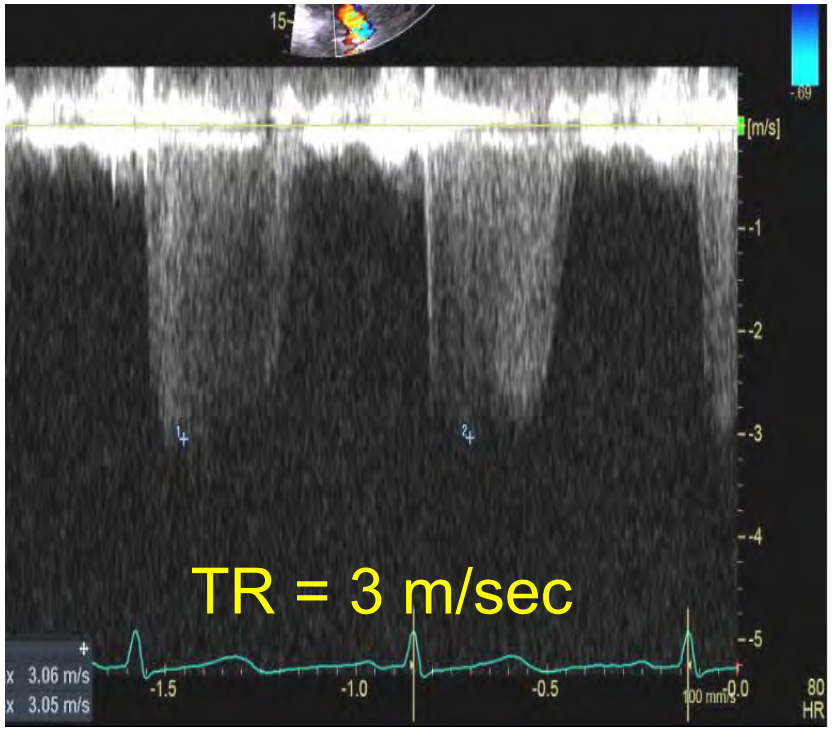


Case #15

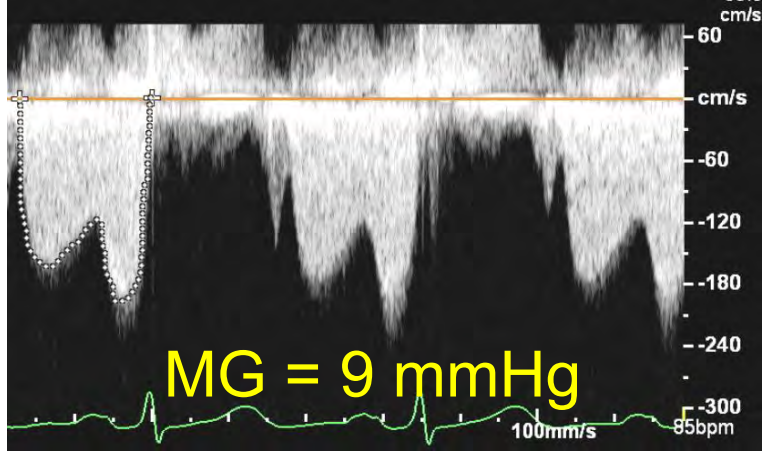
70 year old woman with hypertension and NYHA III
Mitral annulus calcification and increased gradient



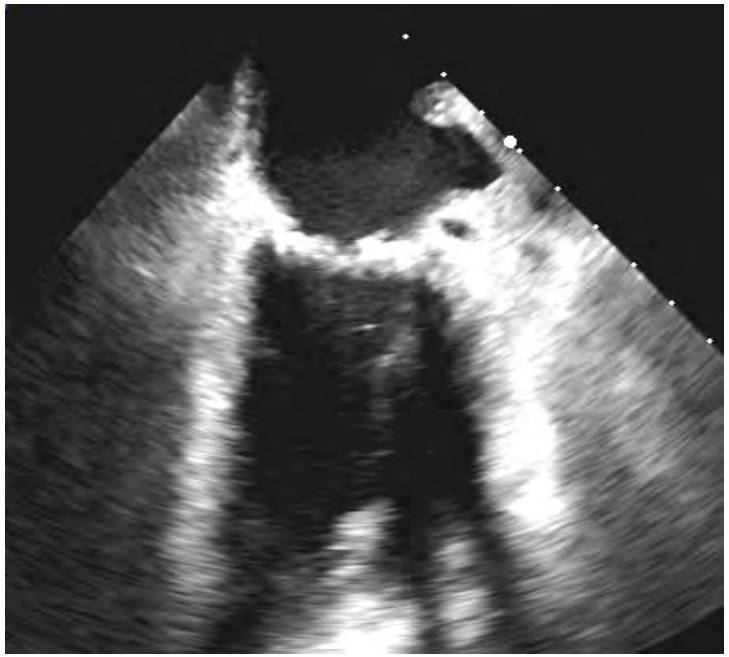


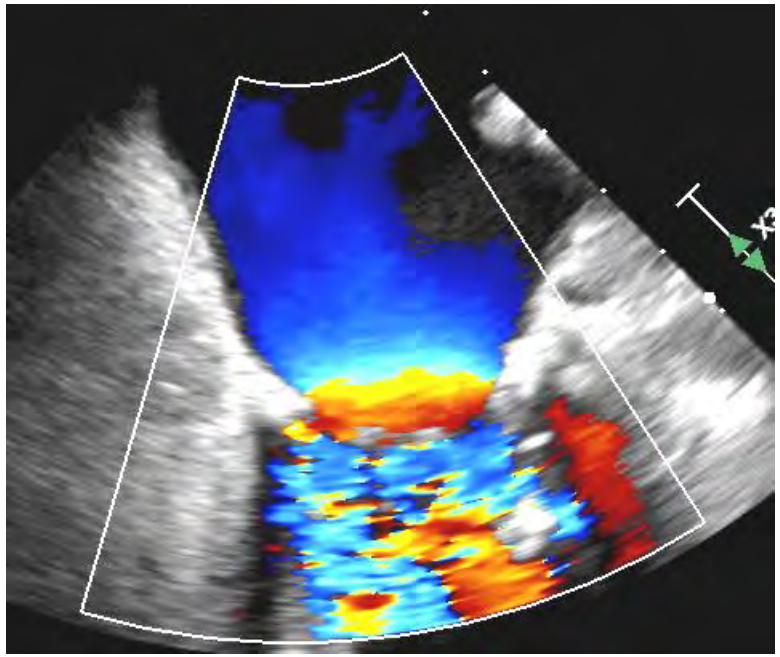


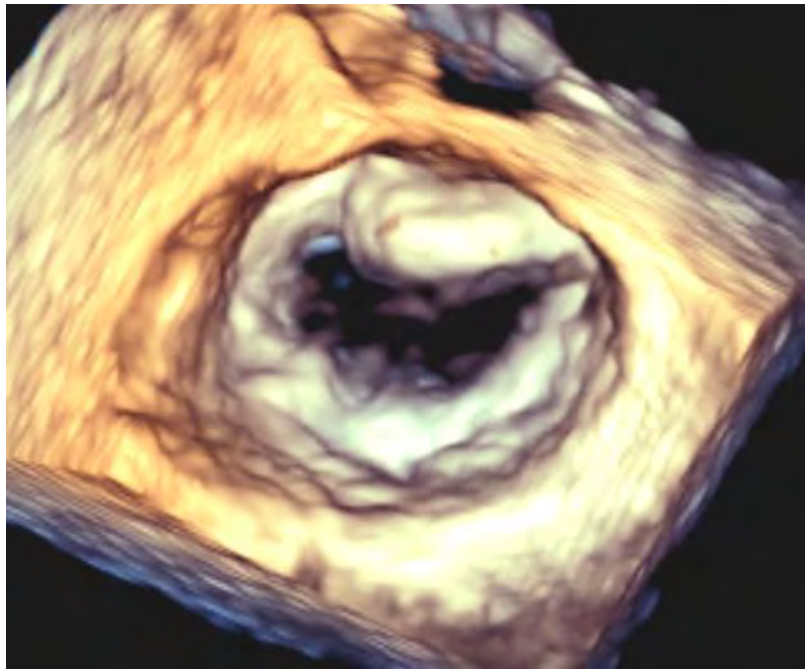
1= Severe mitral stenosis
2= Mitral annulus stenosis
3= Severe diastolic dysfunction
4= Mitral regurgitation



70 yo woman with hypertension and NYHA III
Mitral annulus calcification and stenosis



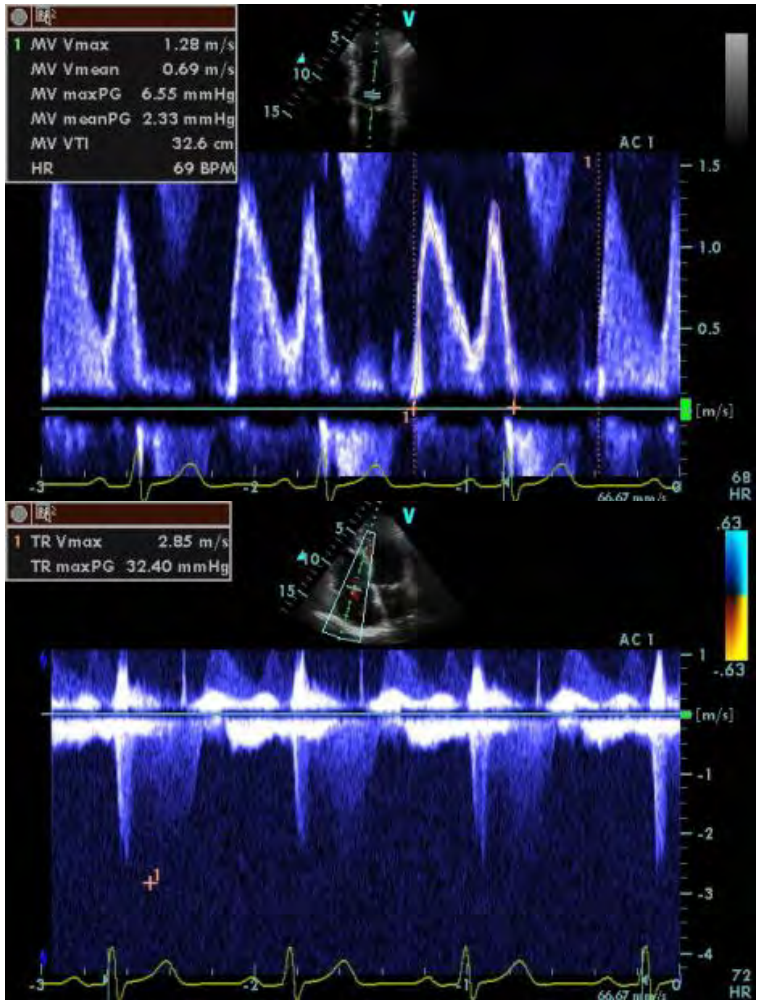


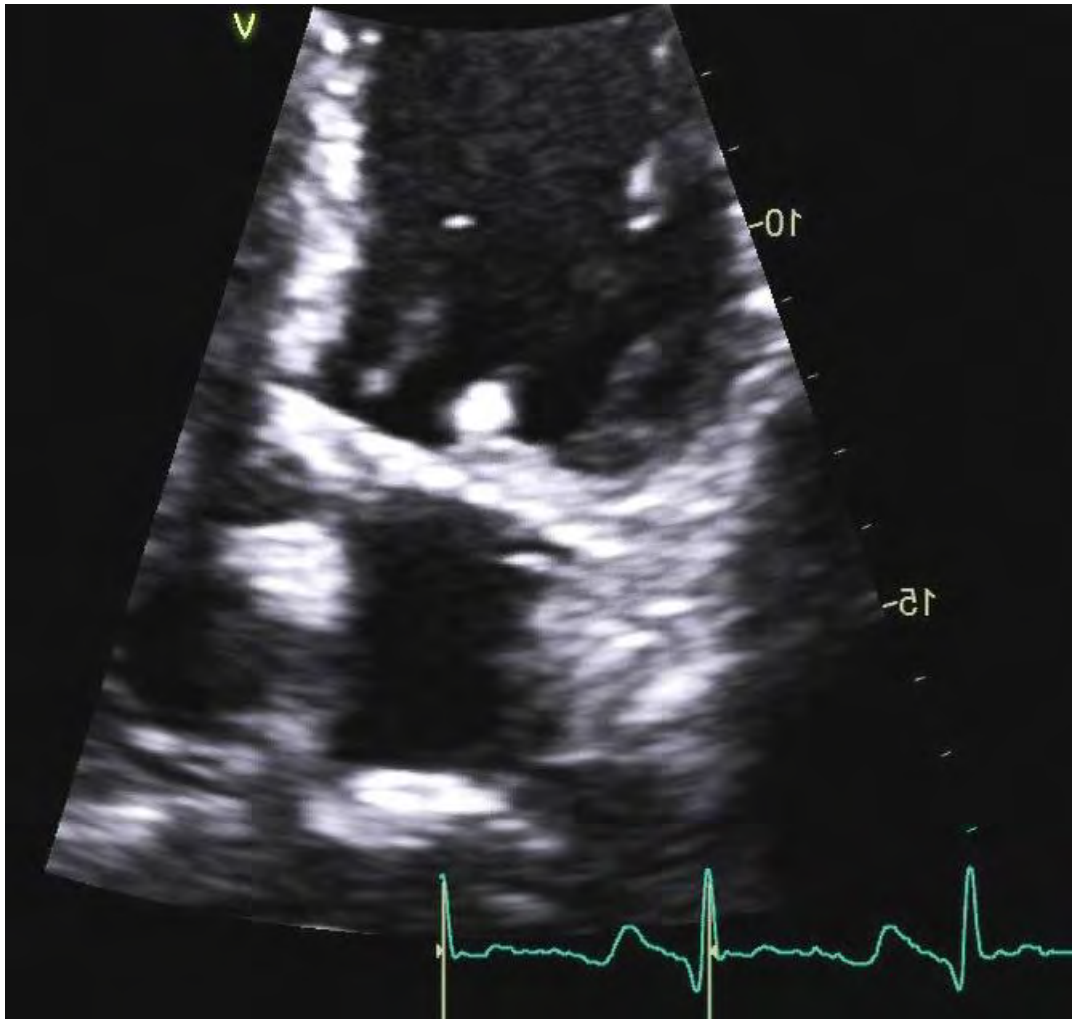


MAYO CLINIC

Case #16

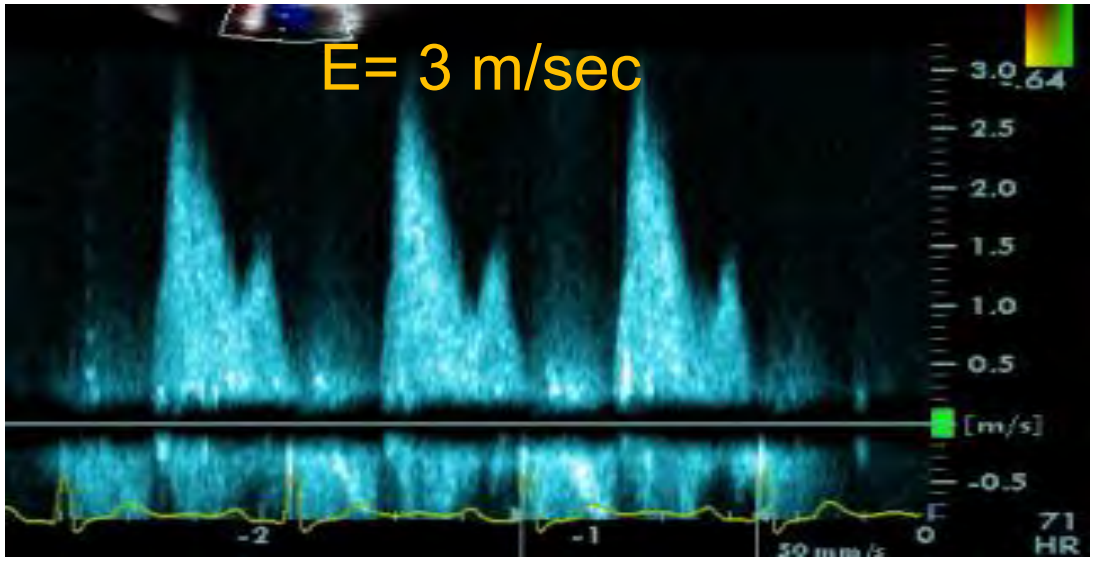
55 yo avid cyclist came to Valve Clinic
Stenotic repaired mitral valve (3 yrs ago)?

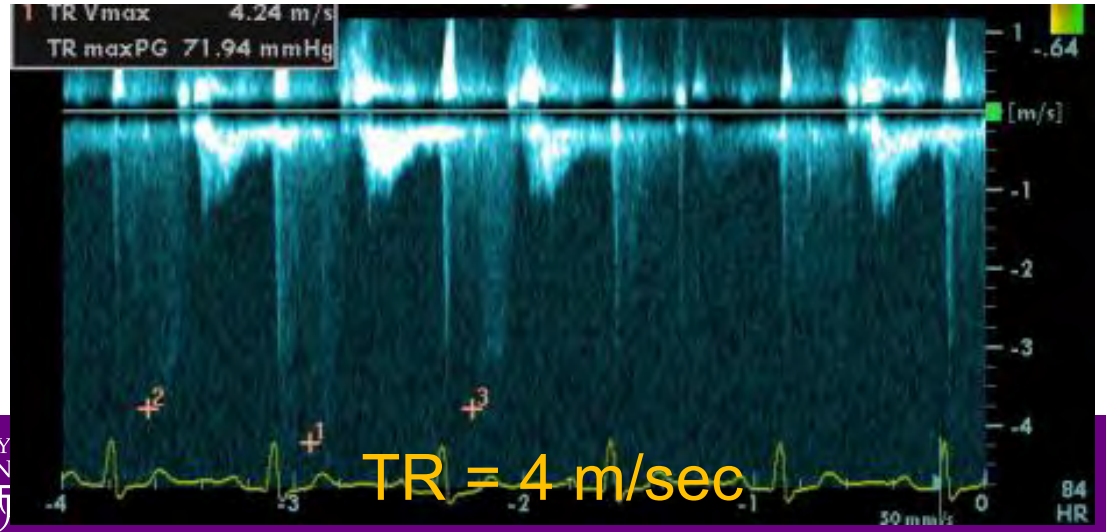


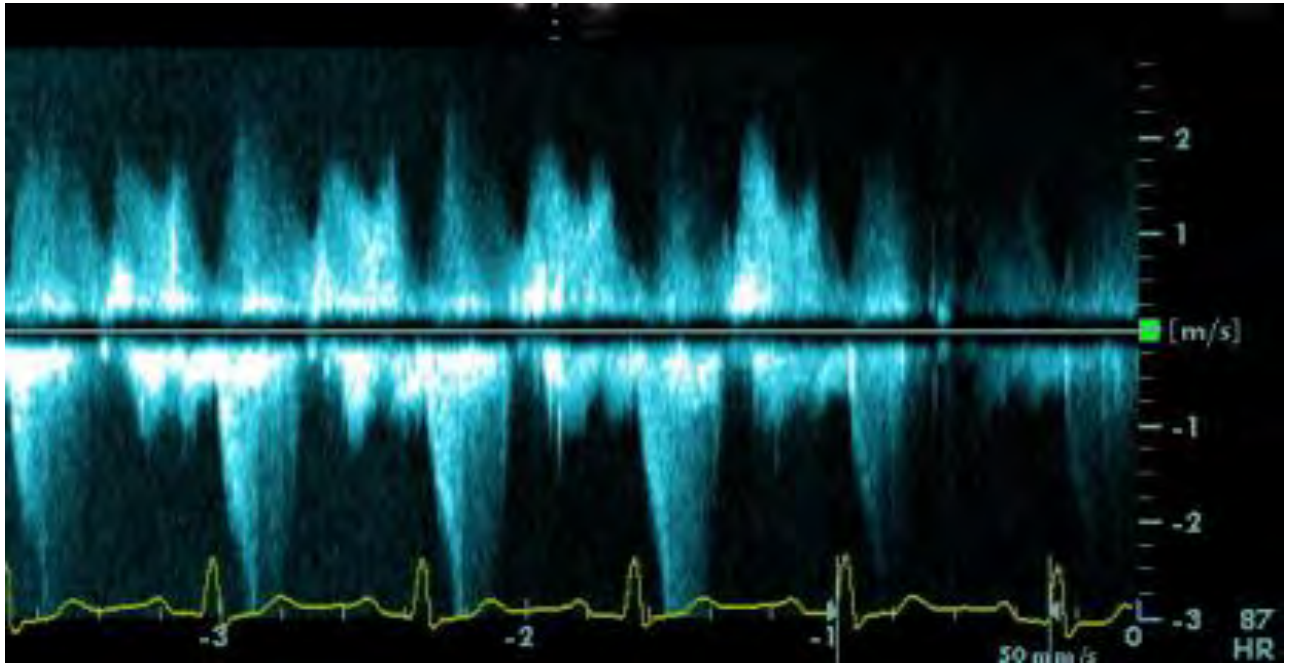


Resting Echo for SOB at HR of 120 BPM

55 yo avid cyclist came to Valve Clinic
Stenotic repaired mitral valve (3 yrs ago)?
Exercise Echo

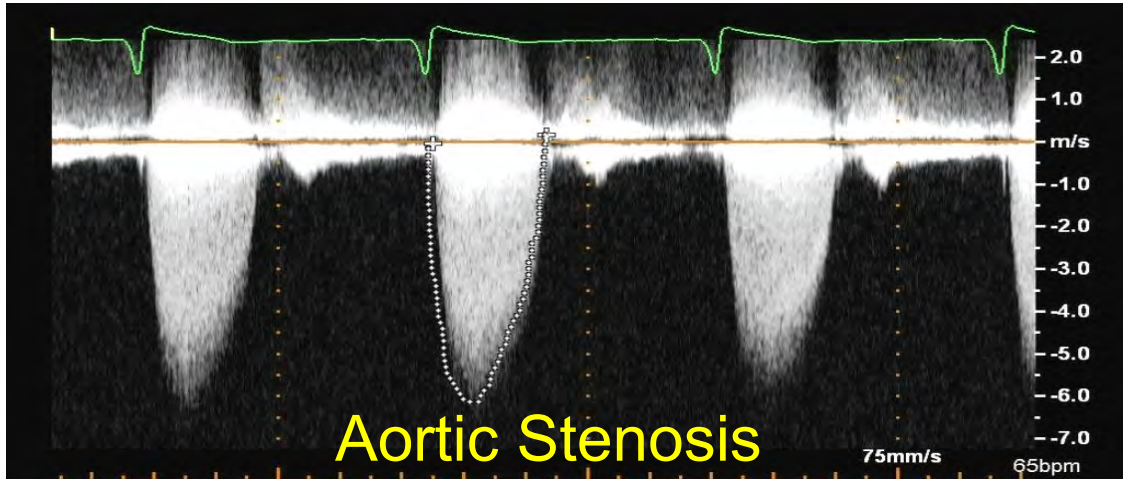




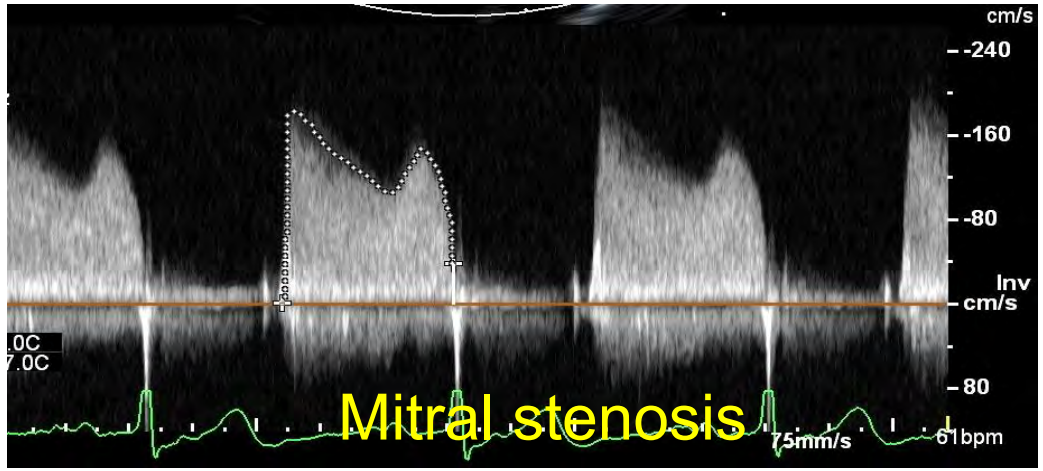


Recovery

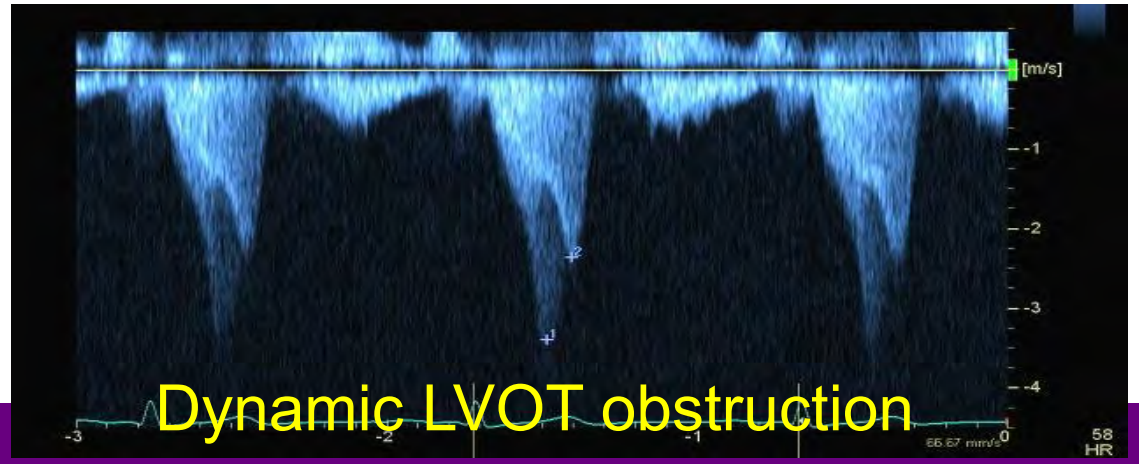
Doppler Pattern Recognition
Intracardiac Hemodynamics



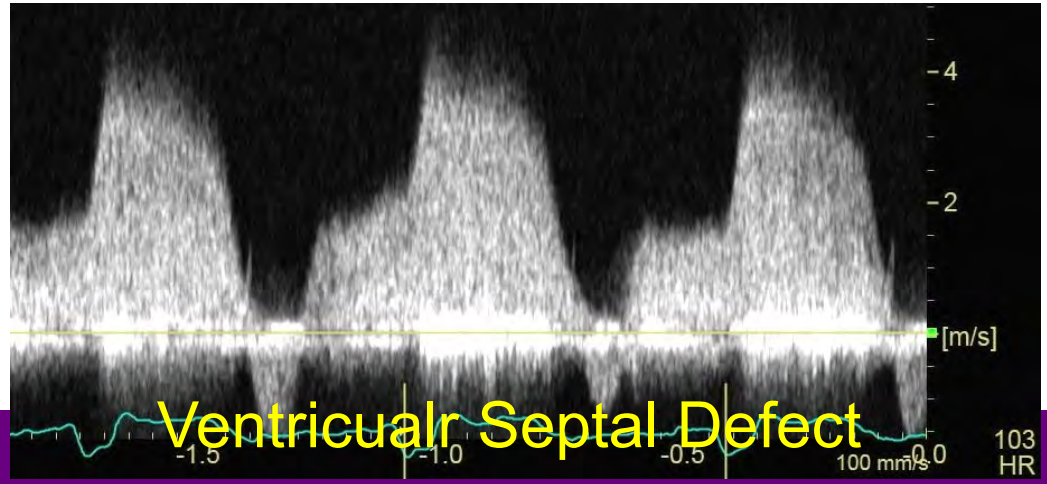
Aortic Stenosis



Mitral stenosis

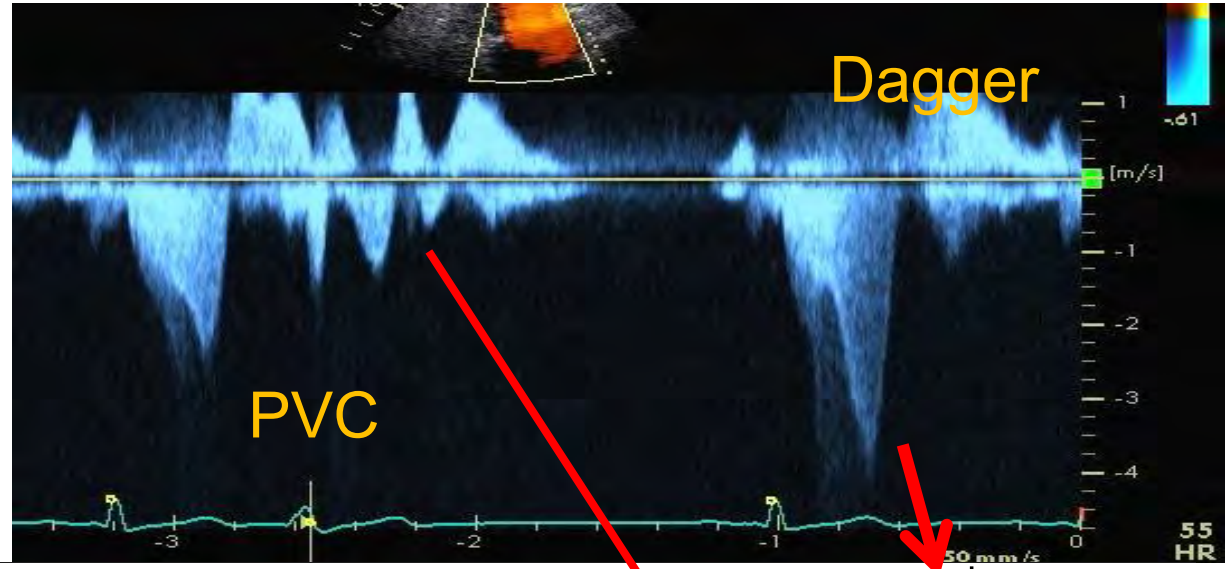


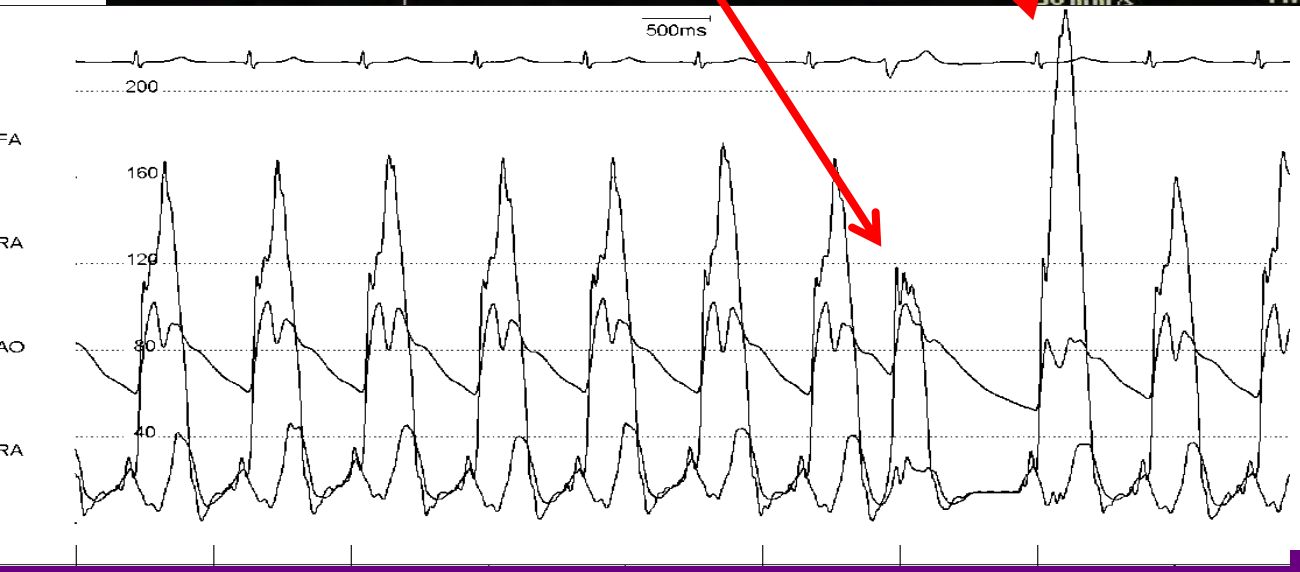
Dynamic LVOT obstruction

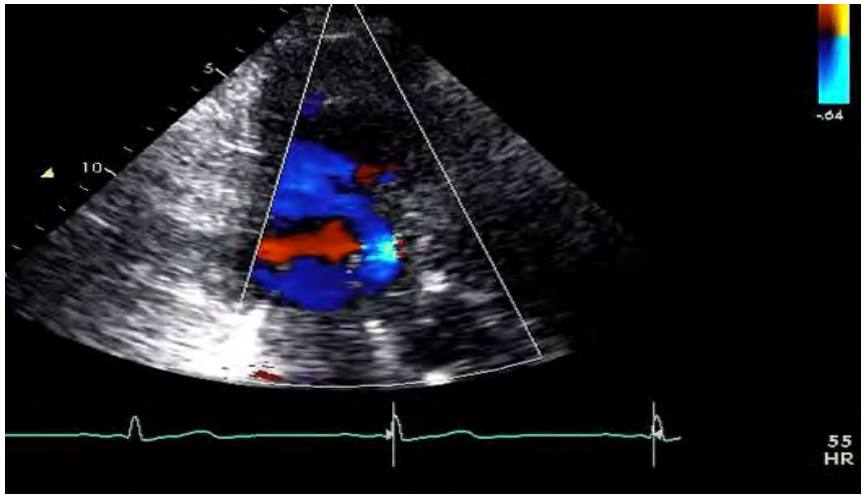


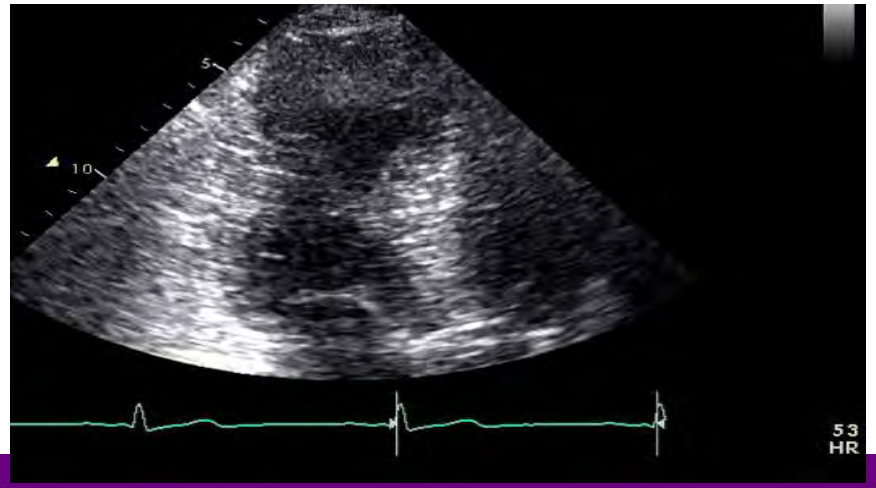
VentricualR Septal Defect

Brockenbrough-Braunwald-Morrow Sign



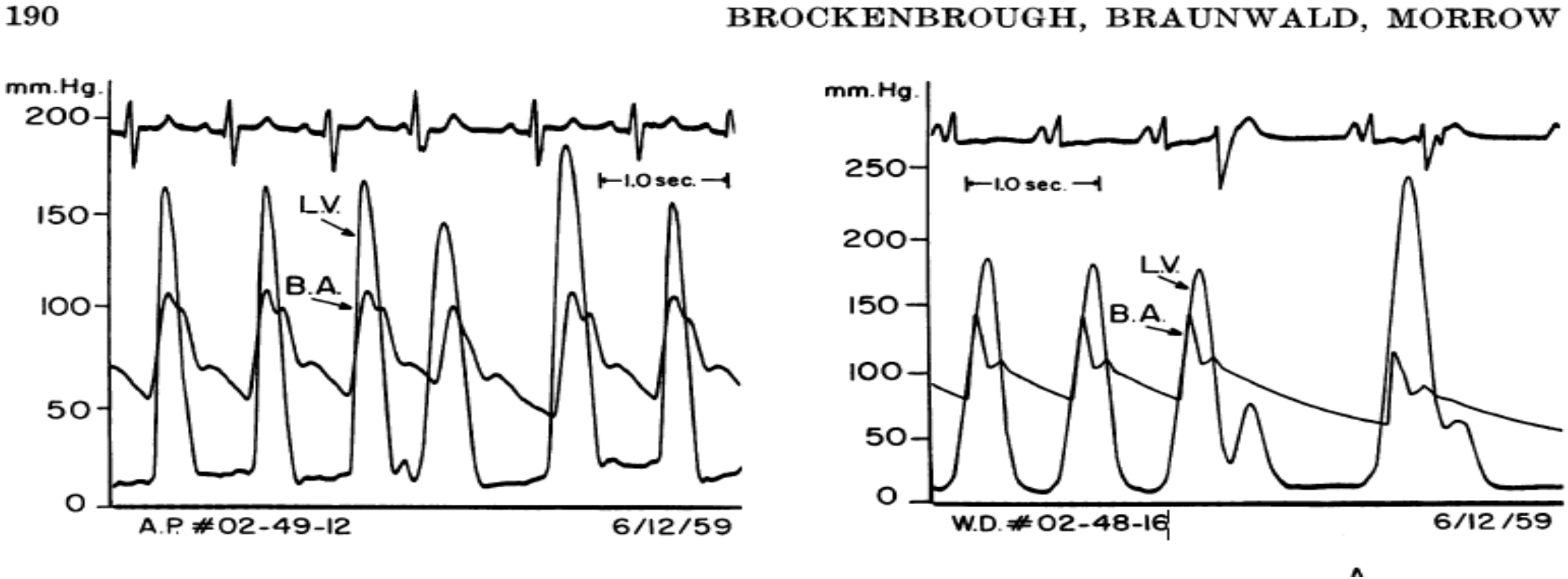






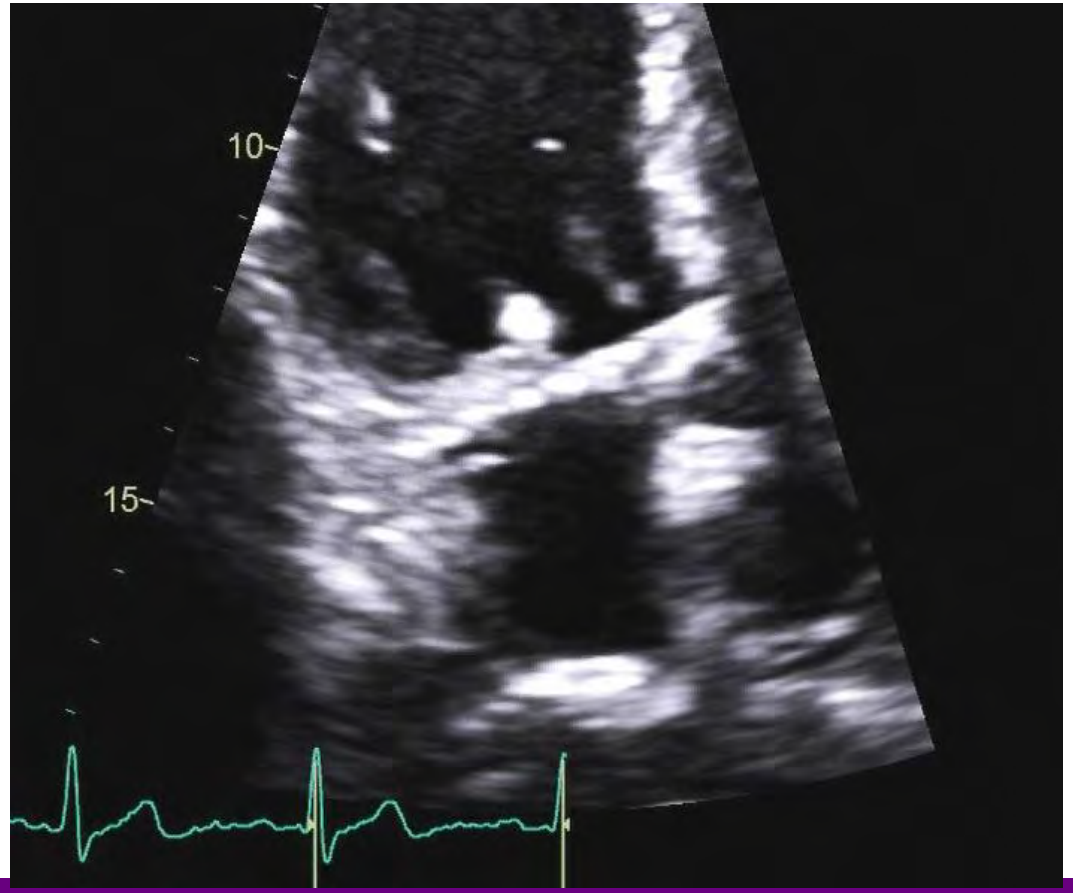
MAYO CLINIC

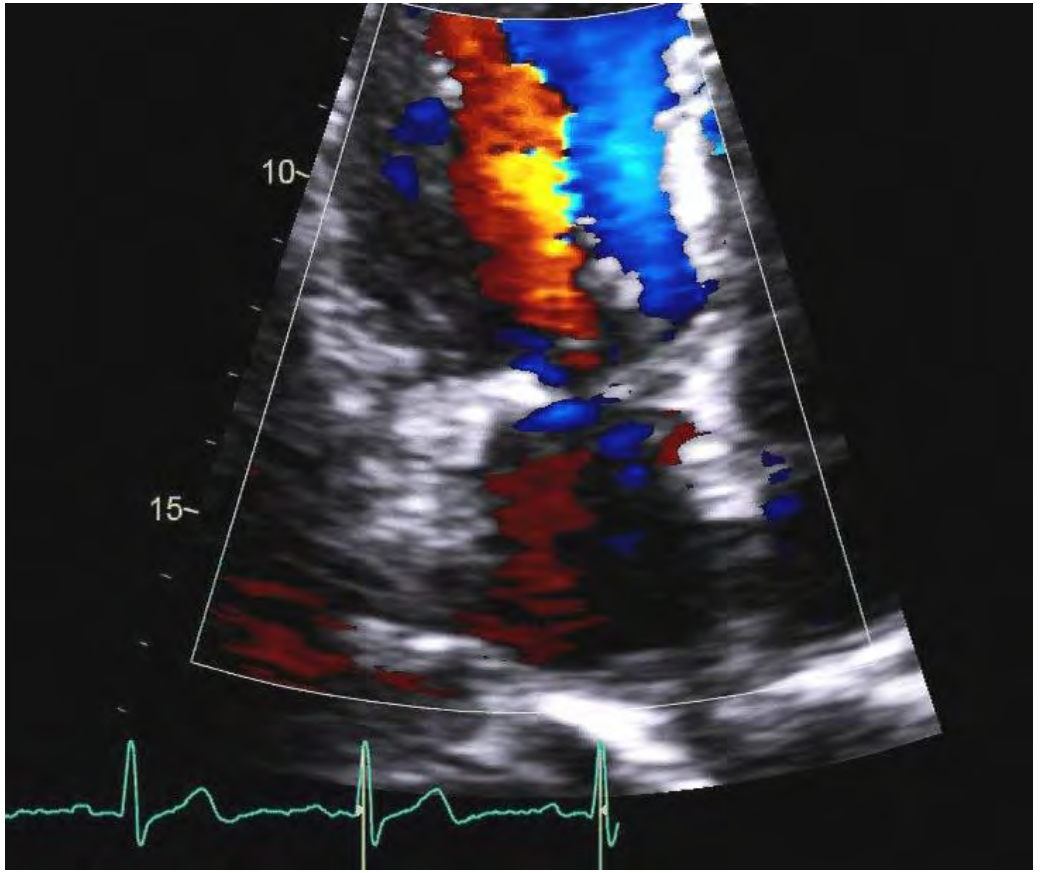
Brockenbrough-Braunwald-Morrow Sign



Circulation Feb 1961

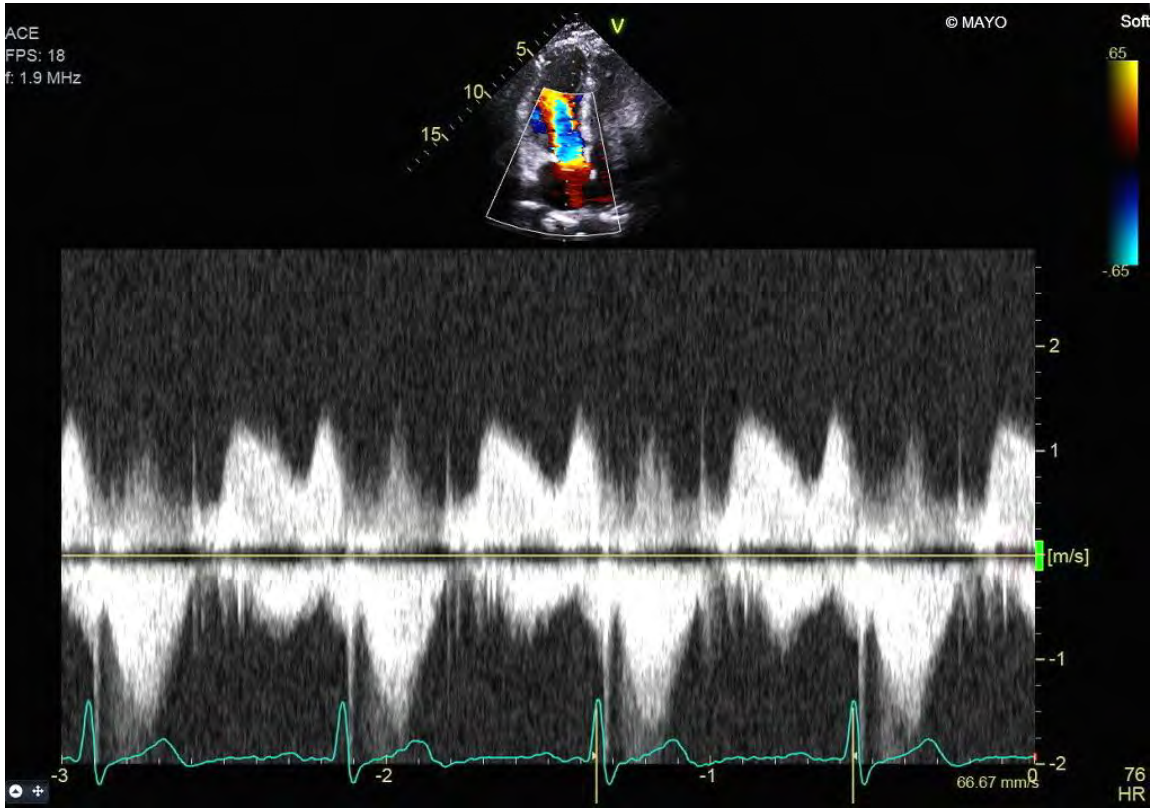
55 yo avid cyclist with exertional dyspnea after MV Repair
Repeat Resting Echo

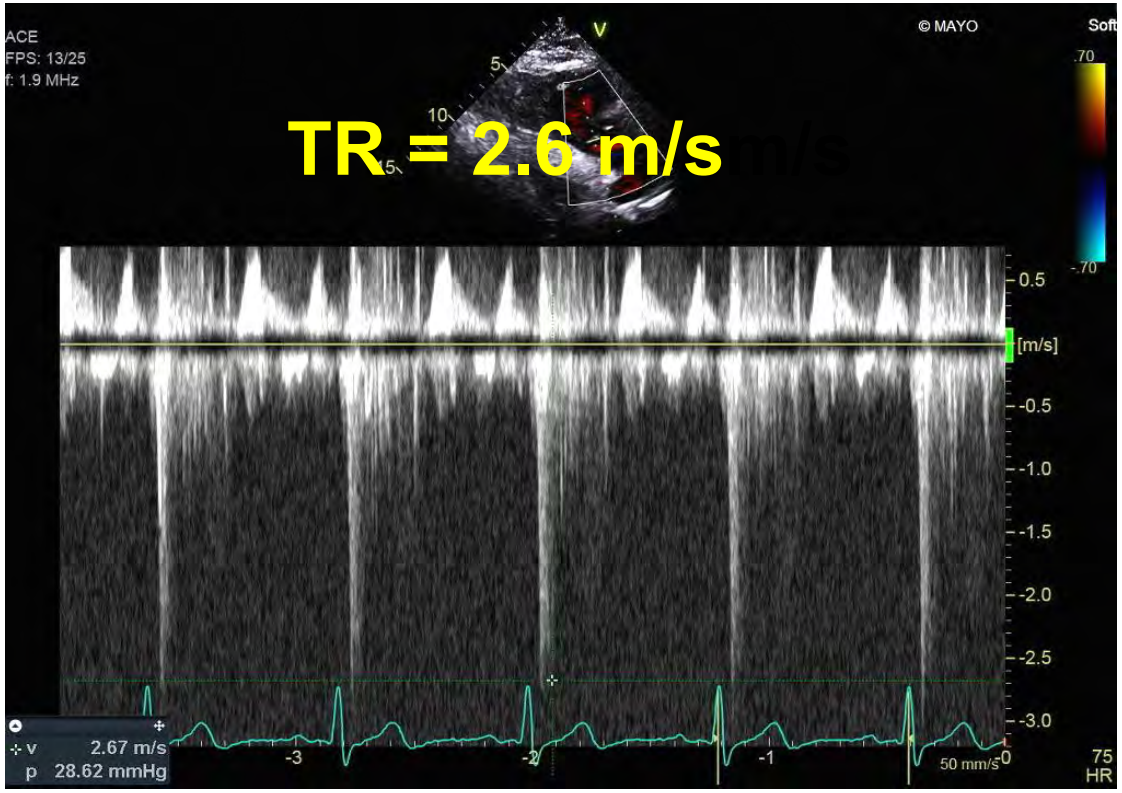




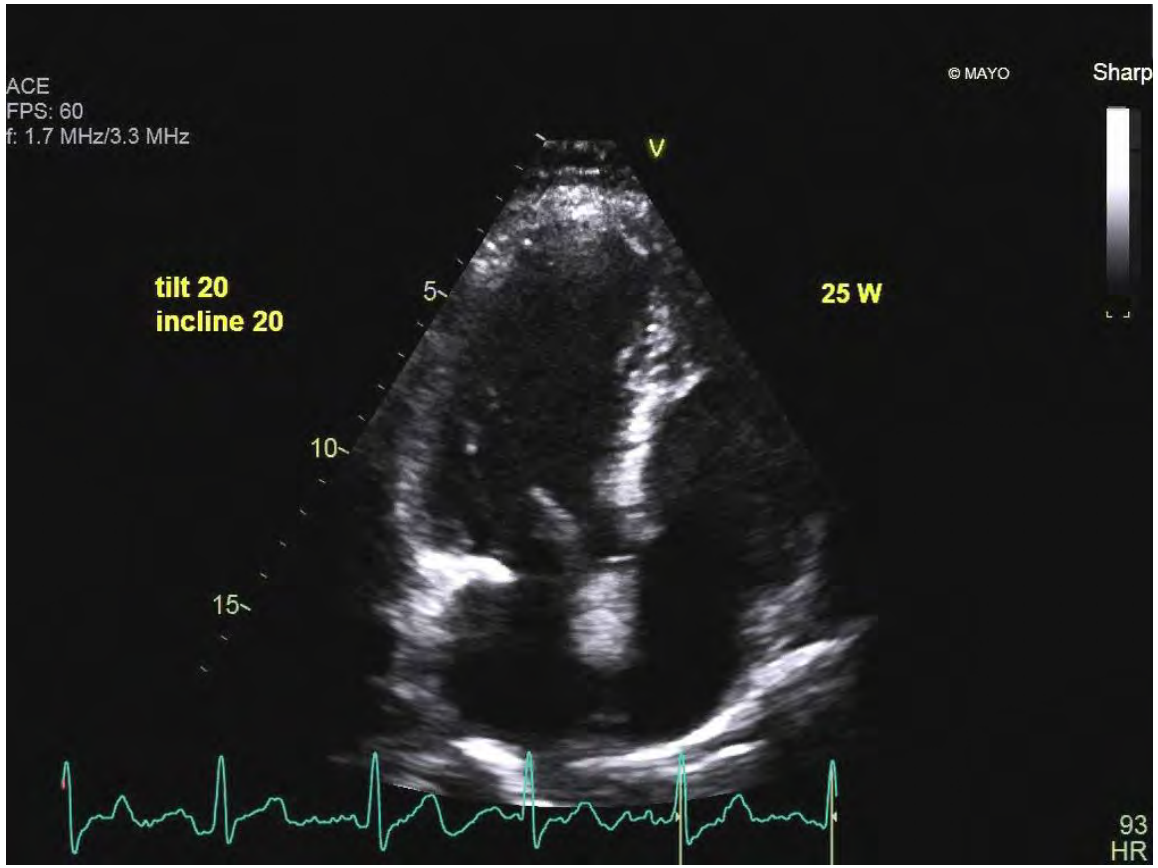
MAYO CLINIC

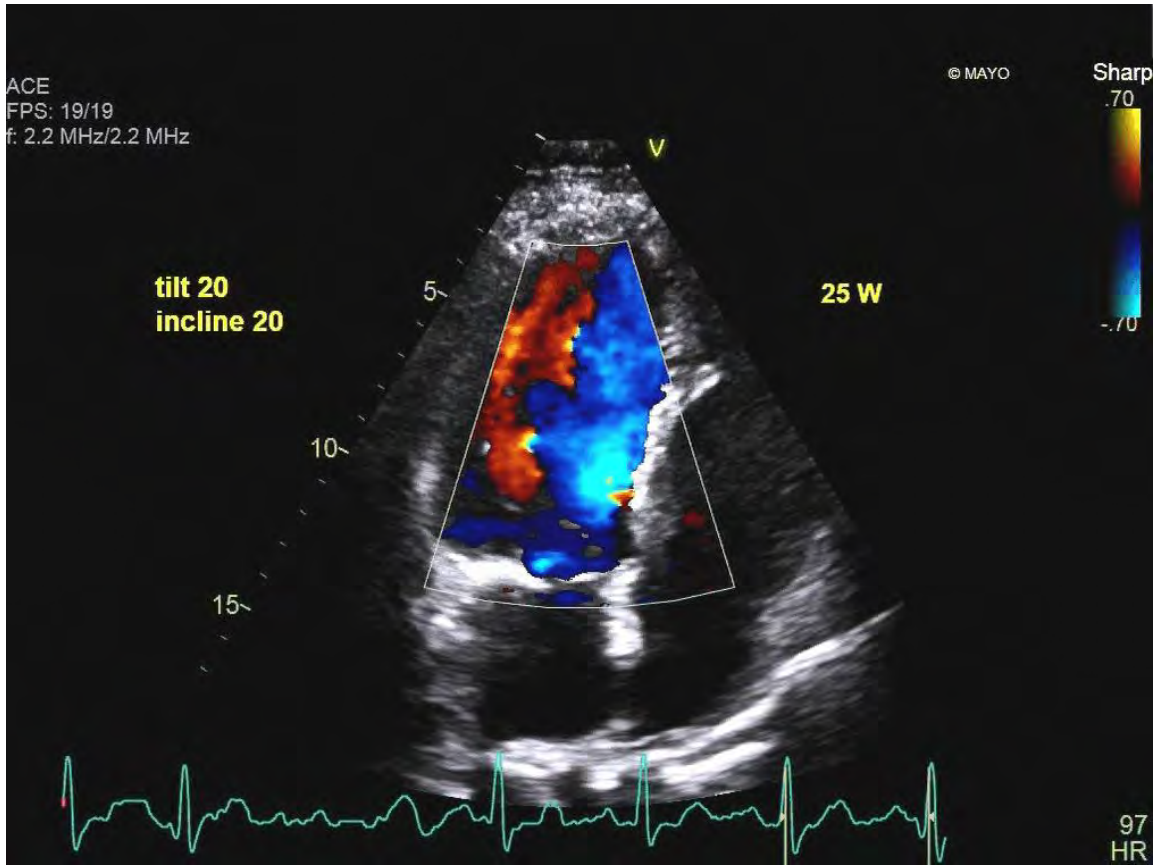
55 yo avid cyclist came to Valve Clinic
Exertional Dyspnea after MV Repair in 2015





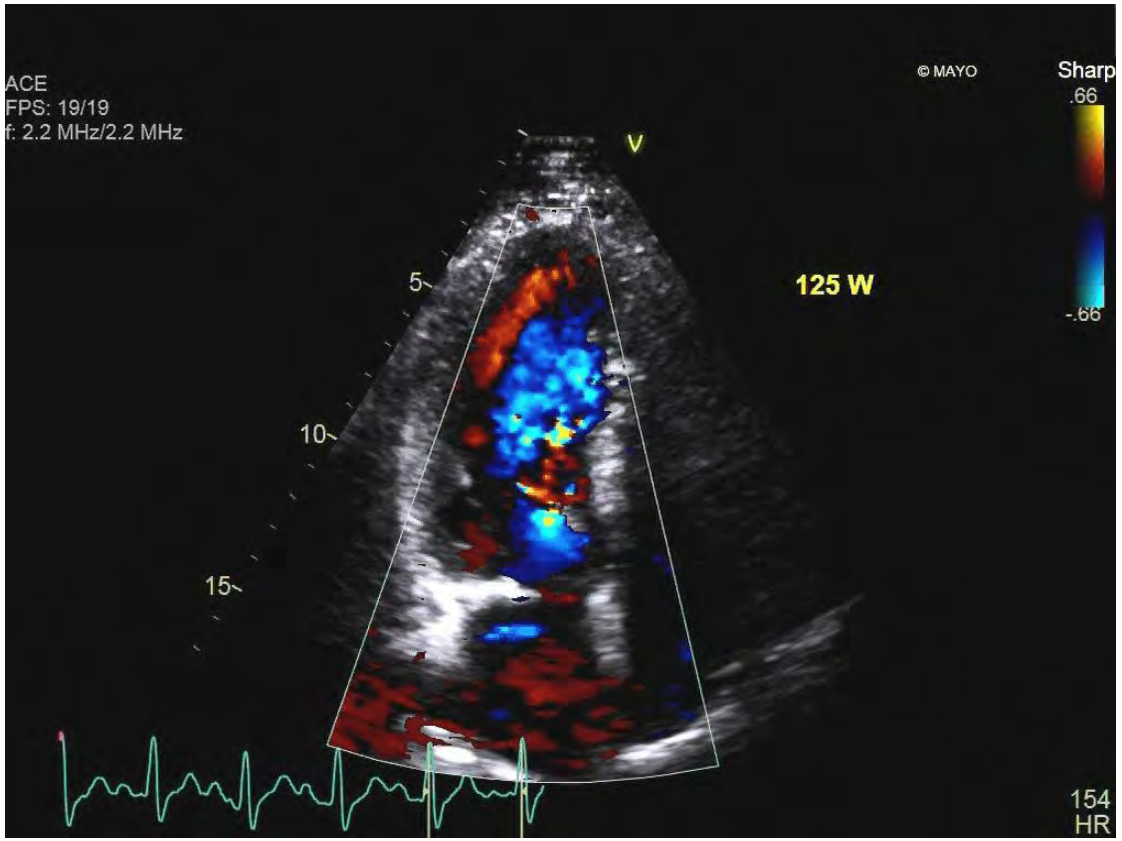
Supine Bike Exercise Echo
25W

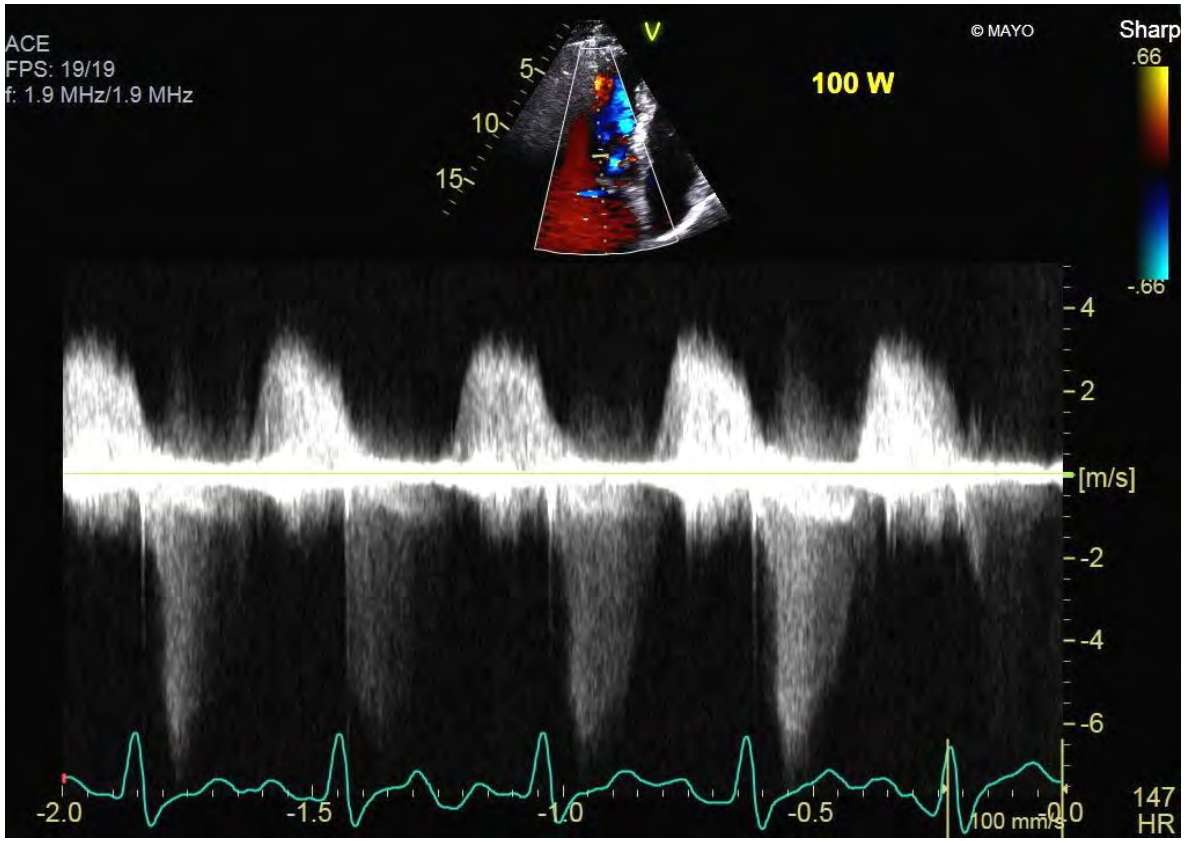




55 yo avid cyclist with exertional dyspnea
Mitral Valve Repair

Blood Pressure = 160/80 mmHg





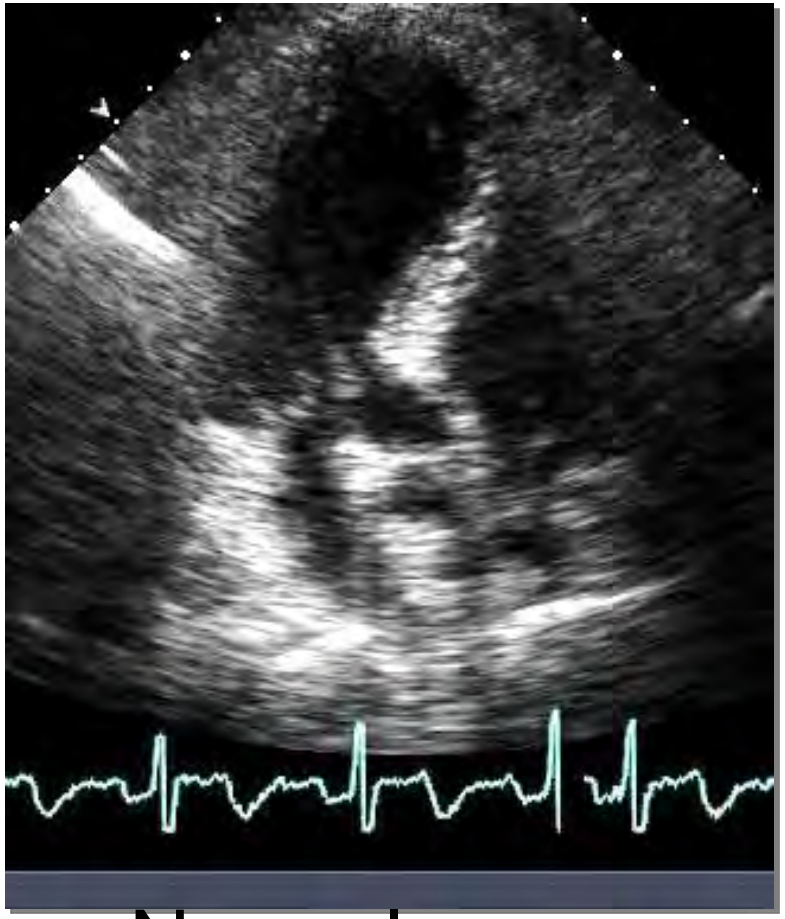
MR Velocity = 7 m/sec (200 mmHg)

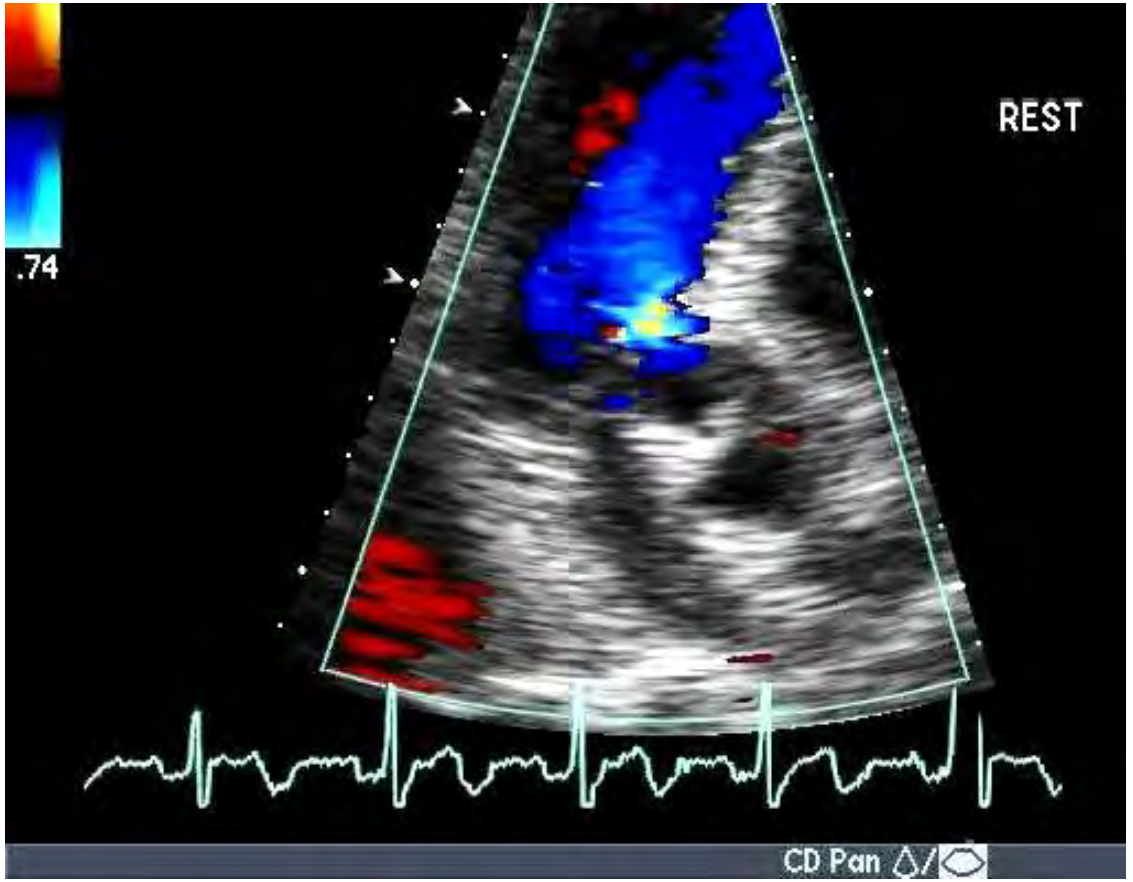
How severe is LVOT obstruction?

Case #17

82 year old man with dyspnea

Soon after treated for hypertension



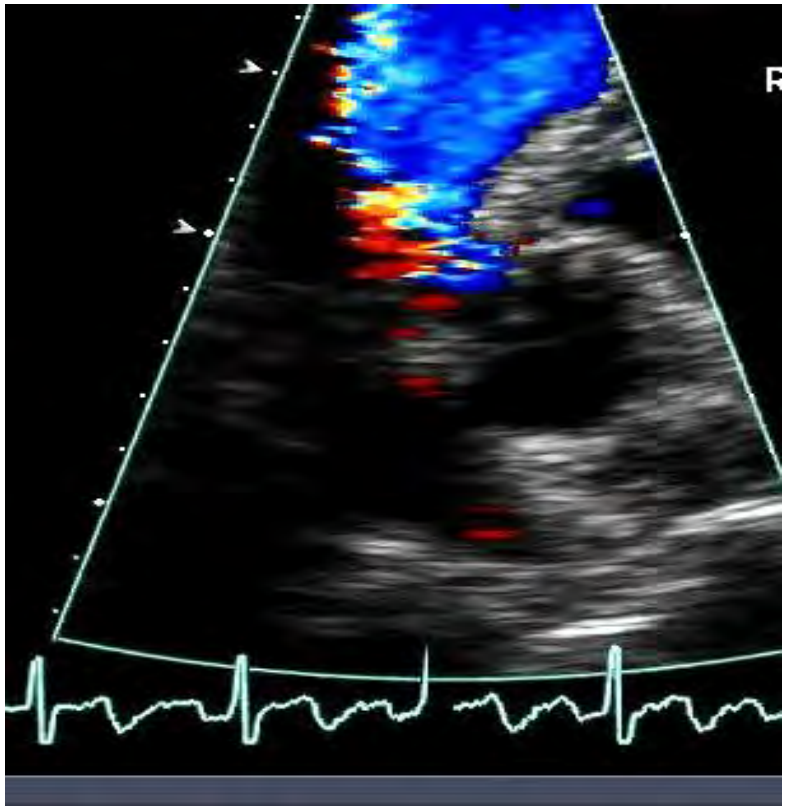


Normal coronary angiogram and stress test

Before and After Exercise

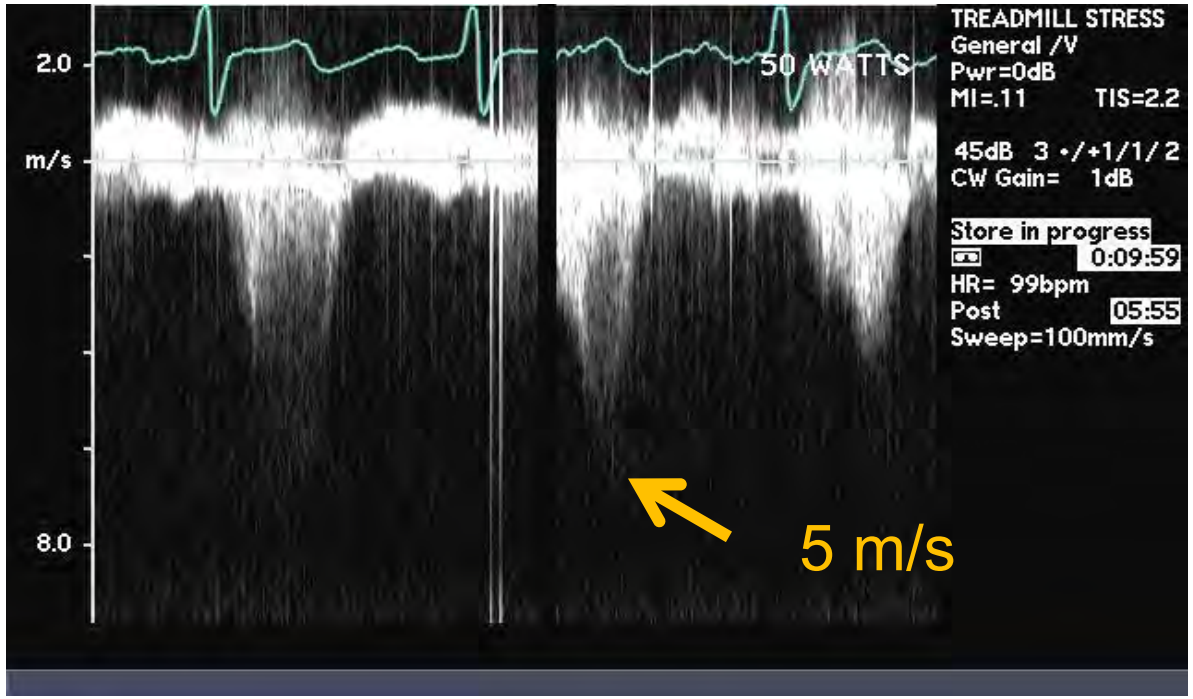
Resting

Exercise



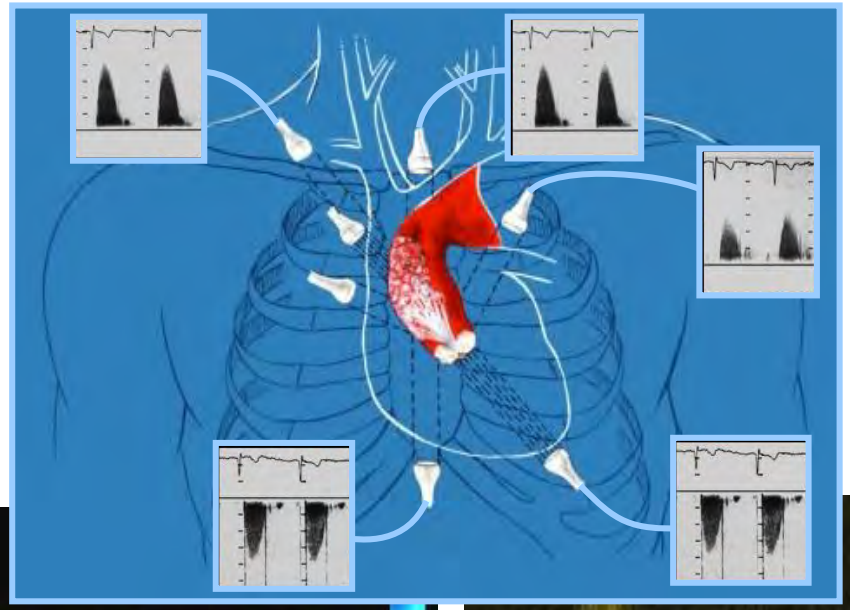
What is the mechanism ?

LVOT gradient before and after exercise

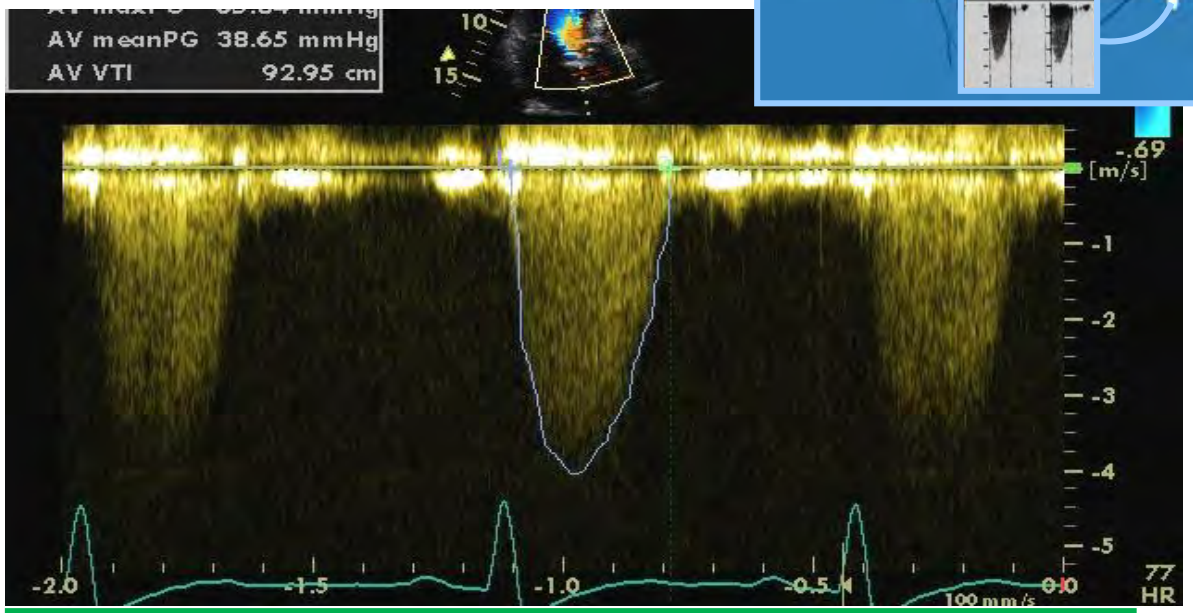


Baseline

Exercise

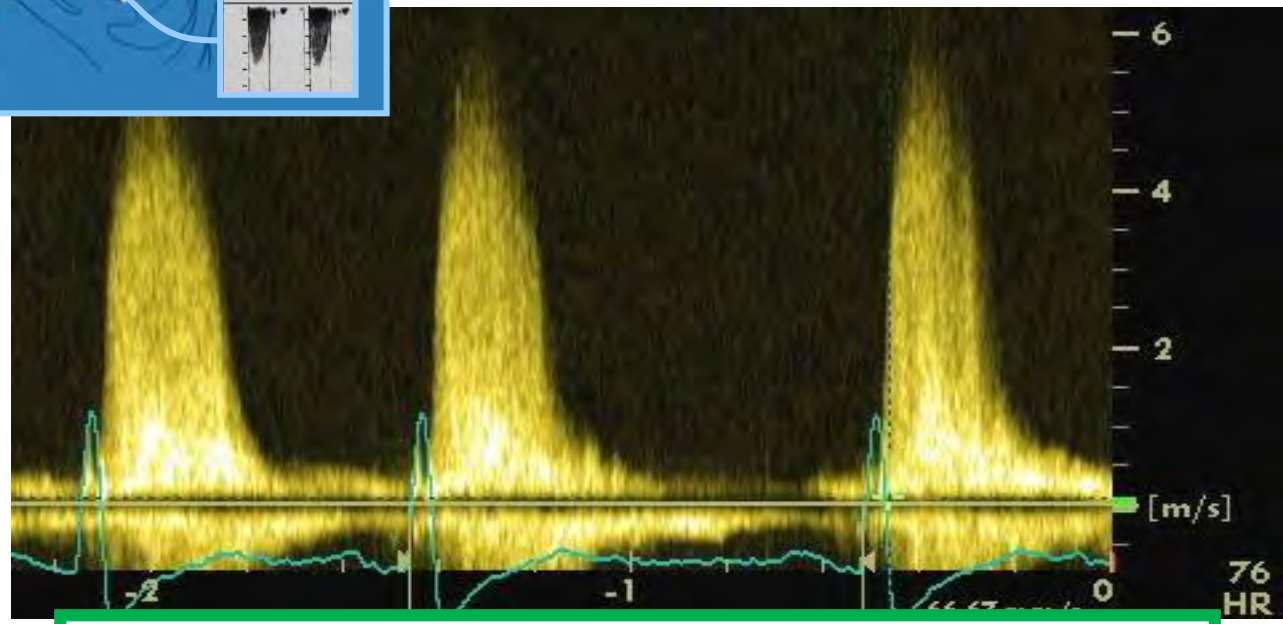


Apical Window



Peak velocity (V2) 4.1 m/s
Mean gradient 38 mmHg
EOA= 1.1 cm^2

Right Parasternal

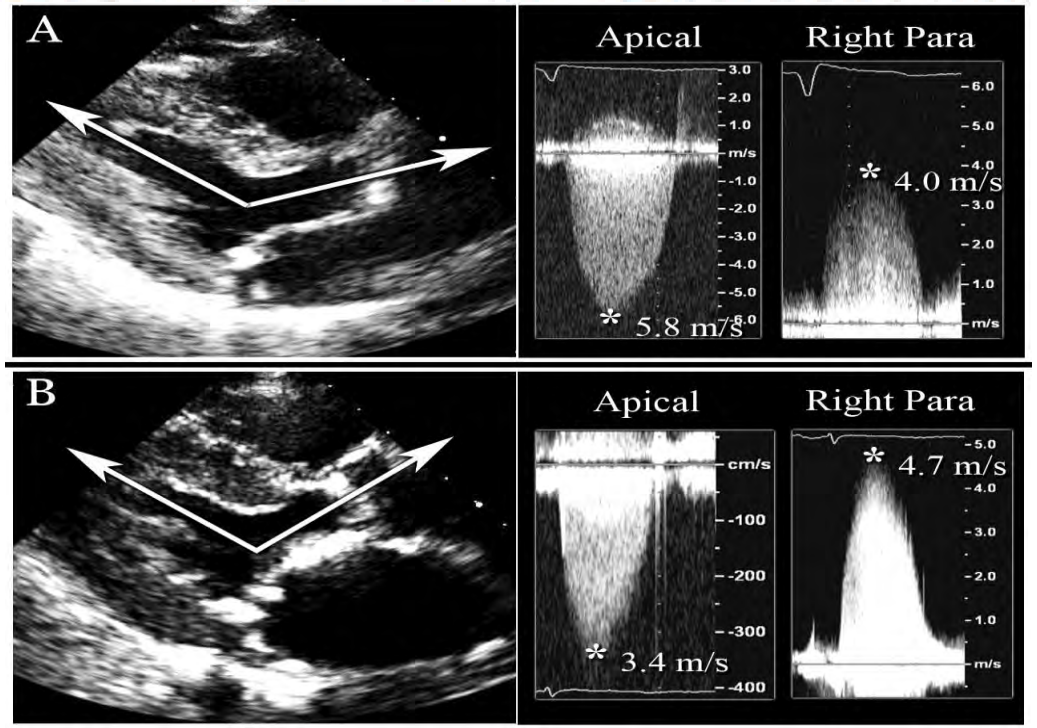


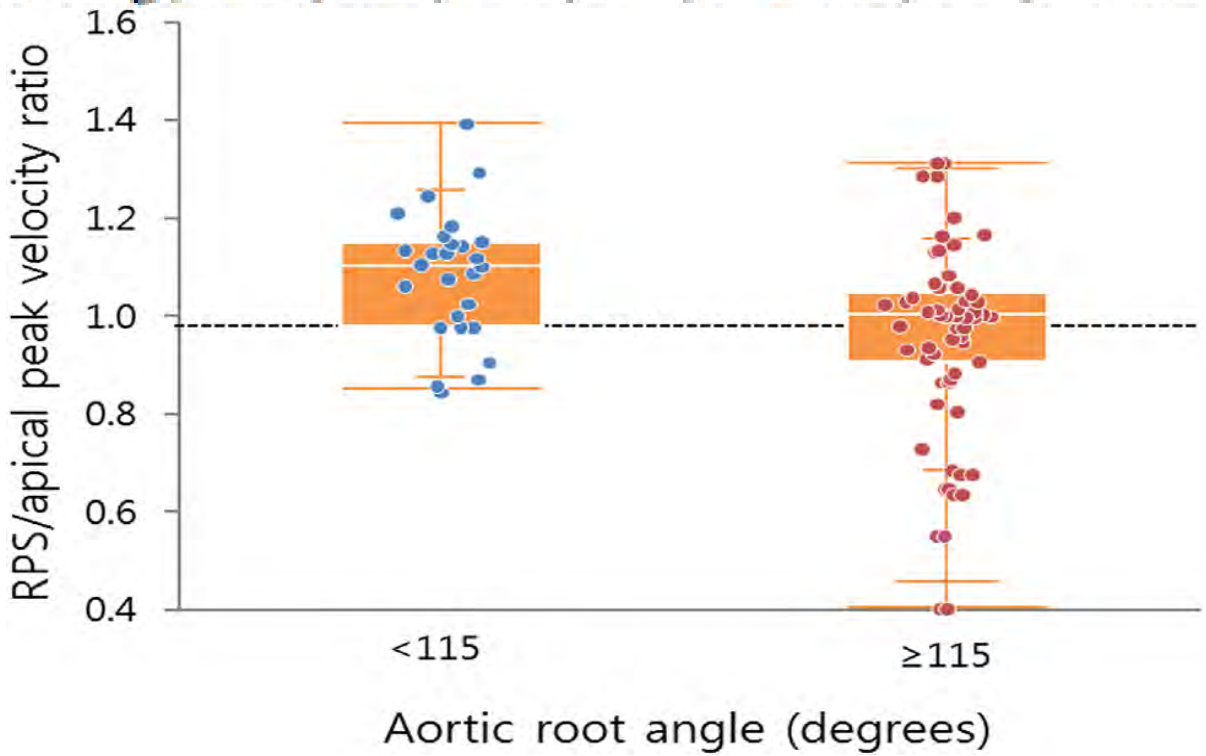
Peak velocity (V2) 6.1 m/s
Mean gradient 92 mmHg
EOA= 0.5 cm^2

Doppler Imaging in Aortic Stenosis: The Importance of the Nonapical Imaging Windows to Determine Severity in a Contemporary Cohort

JASE 2015

Jeremy J. Thaden, MD, Vuyisile T. Nkomo, MD, MPH, Kwang Je Lee, MD, PhD, and Jae K. Oh, MD, *Rochester*,

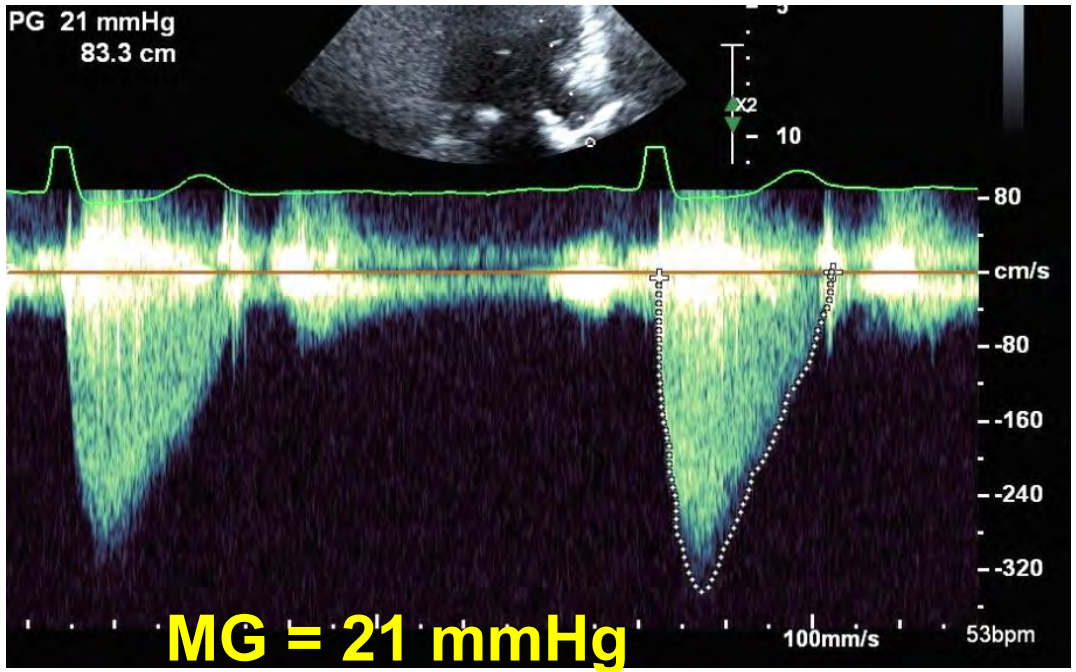




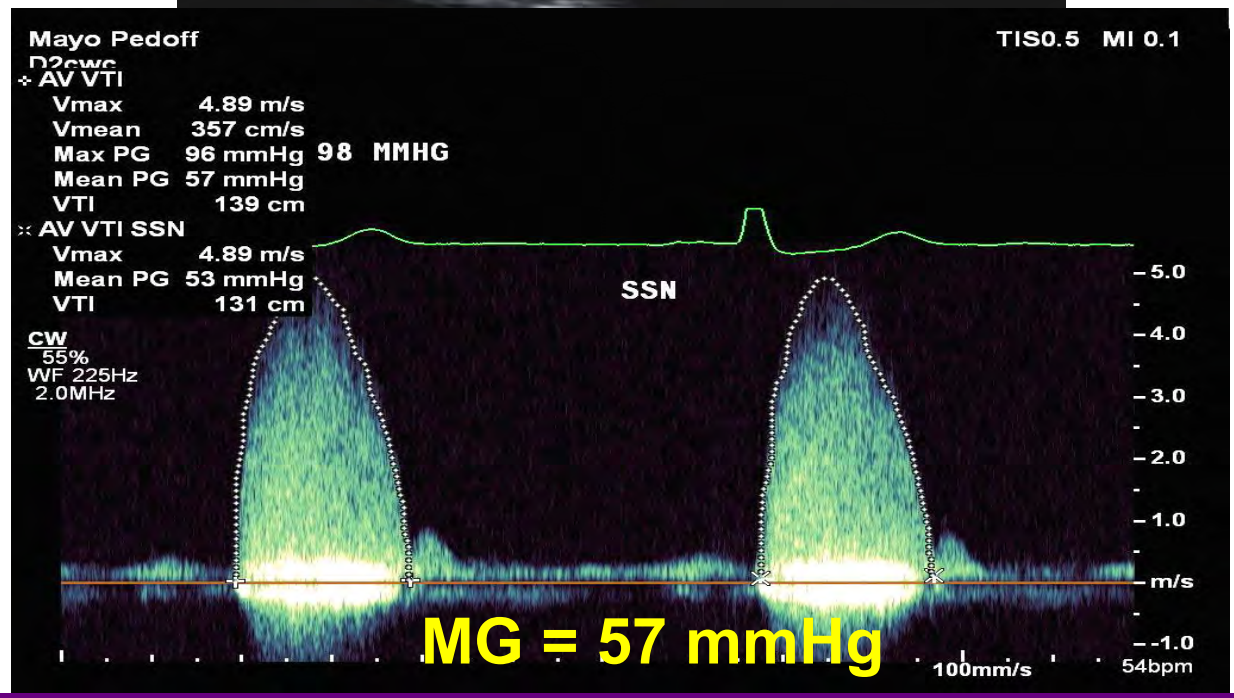
- The highest AV velocity comes from RPS in 50%
- If the angle<115 degree, it is from RPS in 67%
- AS is underestimated in 15% if only apex is used

Case #19

A caution !
76 year old man with dyspnea and murmur



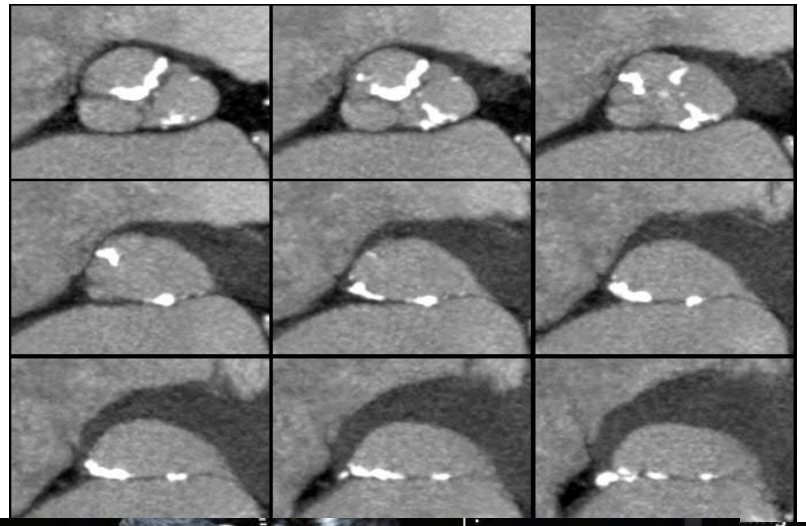
MG = 21 mmHg

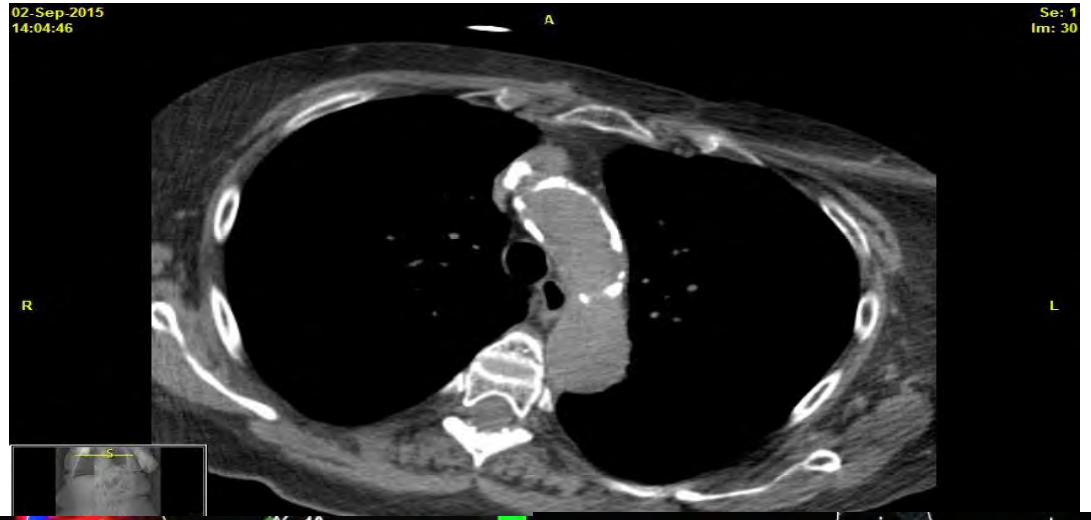


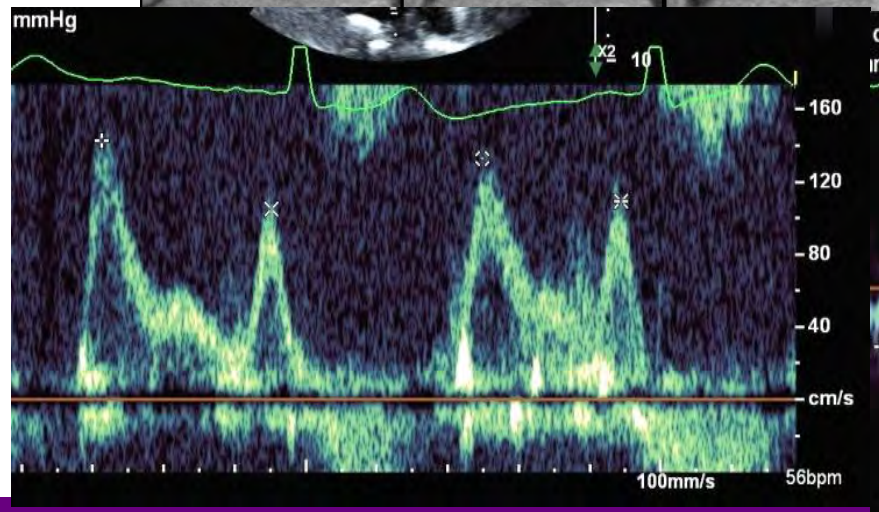
MG = 57 mmHg

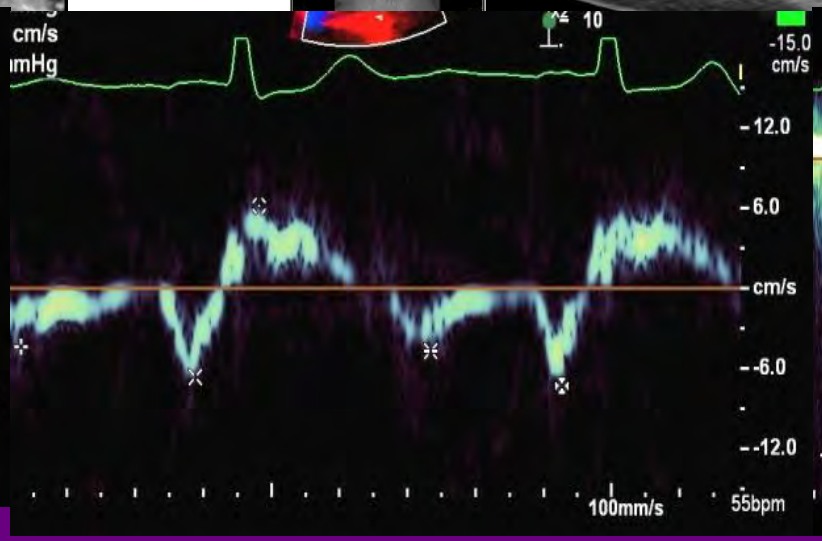
Cath MG = 20 mmHg

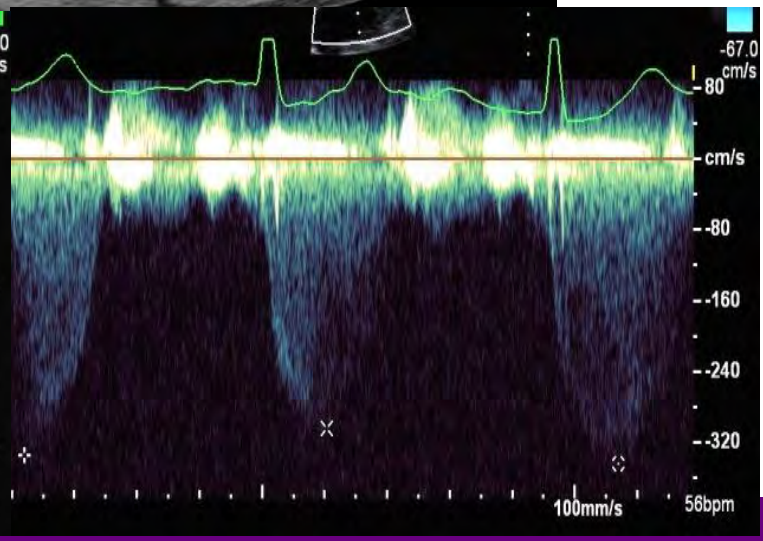
76 yo woman with dyspnea and hypertension. Moderate AS, Subclavian Art Stenosis Diastolic Dysfunction





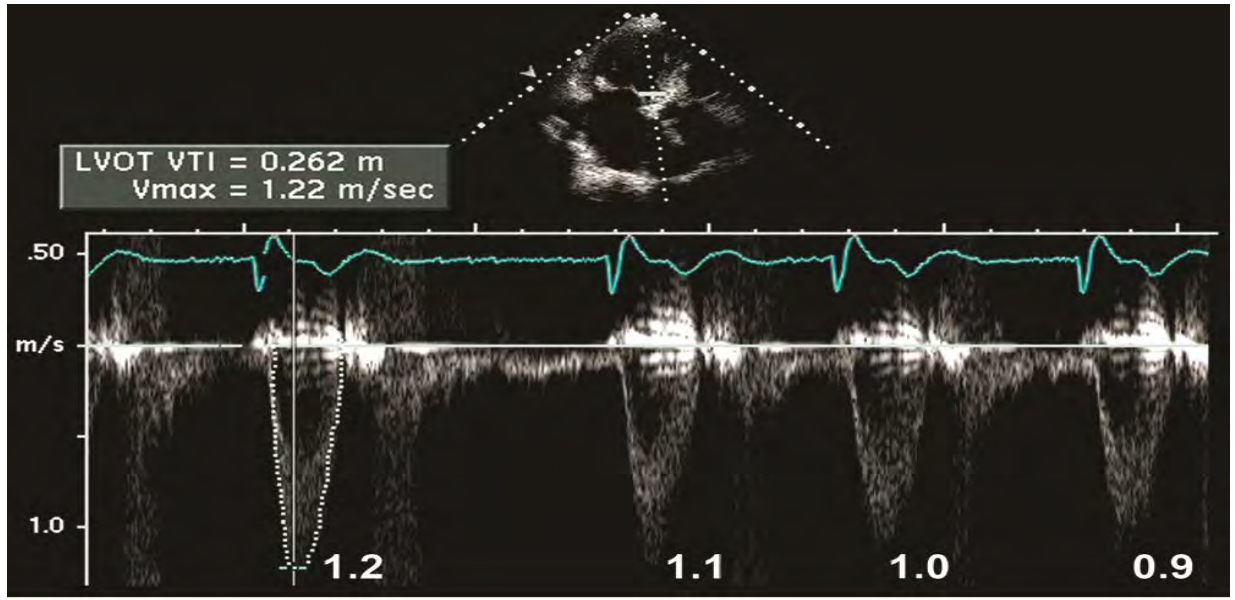


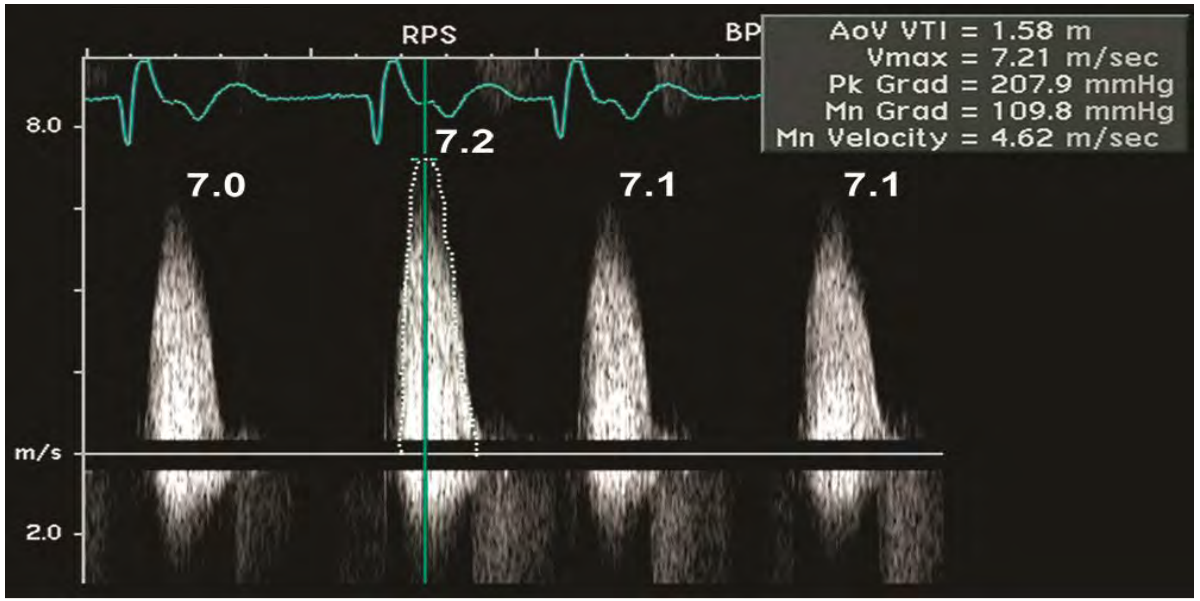




Case #20

Atrial Fibrillation and Aortic Stenosis

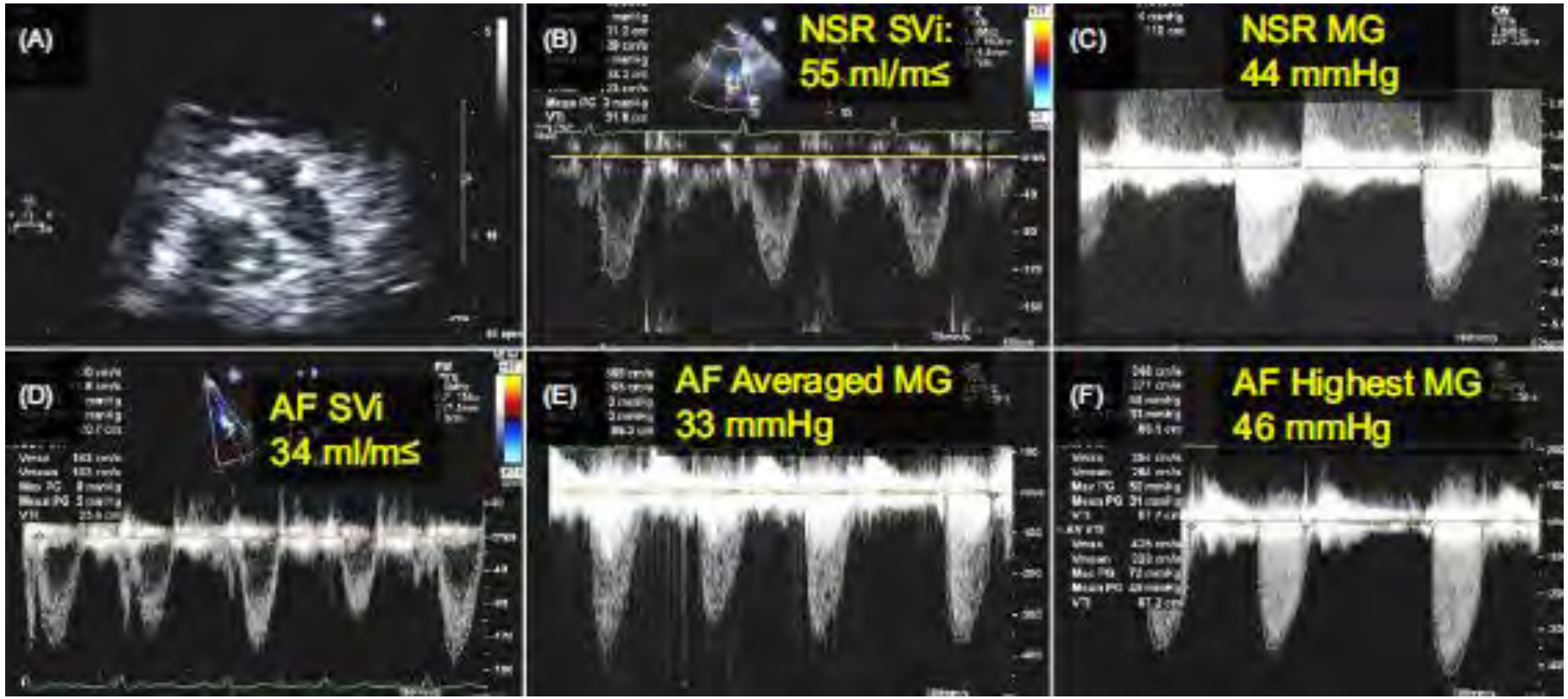




- Average 3-5 cycles for LVOT and AV
- Match up
- Just pick the highest LVOT and AV velocity

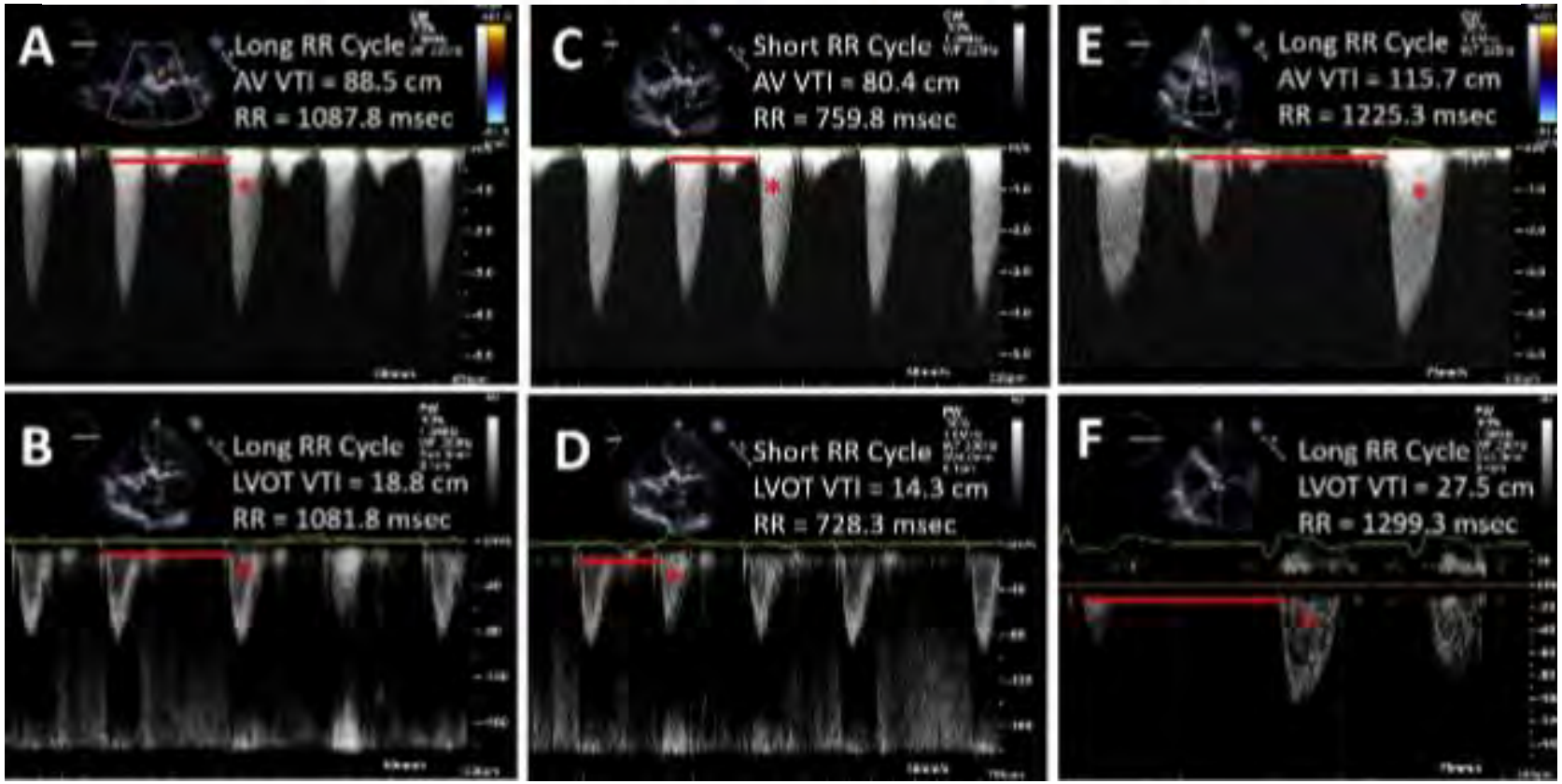
Aortic valve hemodynamics in atrial fibrillation: Should the highest Doppler signal be used to estimate severity of aortic stenosis?

Said Alsidawi MD[1] | Sana Khan MD[2] | Sorin V. Pislaru MD, PhD[2] | Vuyisile T. Nkomo MD, MPH[2]



Accuracy of the Single Cycle Length Method for Calculation of Aortic Effective Orifice Area in Irregular Heart Rhythms

Kerry A. Esquitin, MD, Omar K. Khalique, MD, Qi Liu, MD, Susheel K. Kodali, MD, Leo Marcoff, MD, Tamim M. Nazif, MD, Isaac George, MD, Torsten P. Vahl, MD, Martin B. Leon, MD, and Rebecca T. Hahn, MD, *New York, New York; and Morristown, New Jersey*



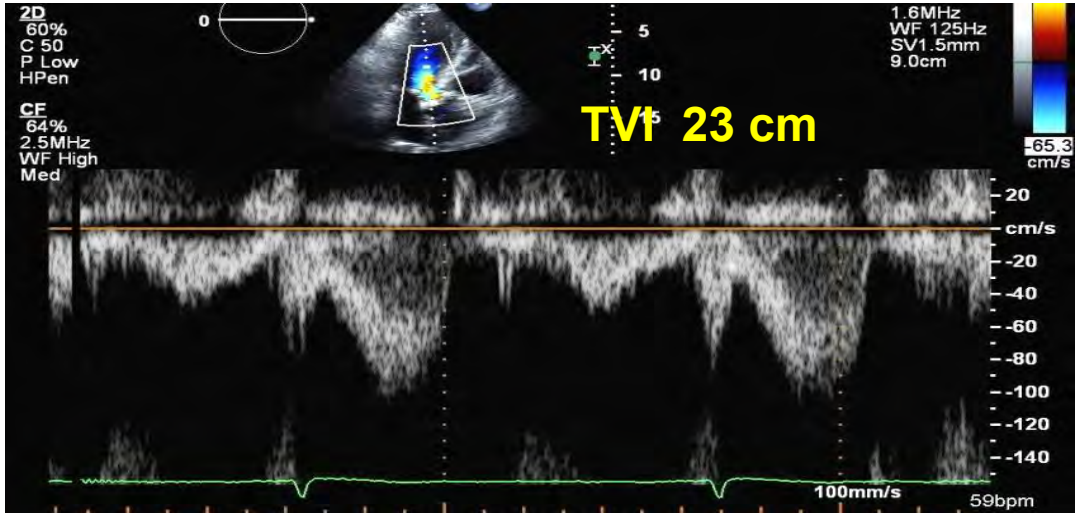
MAYO CLINIC

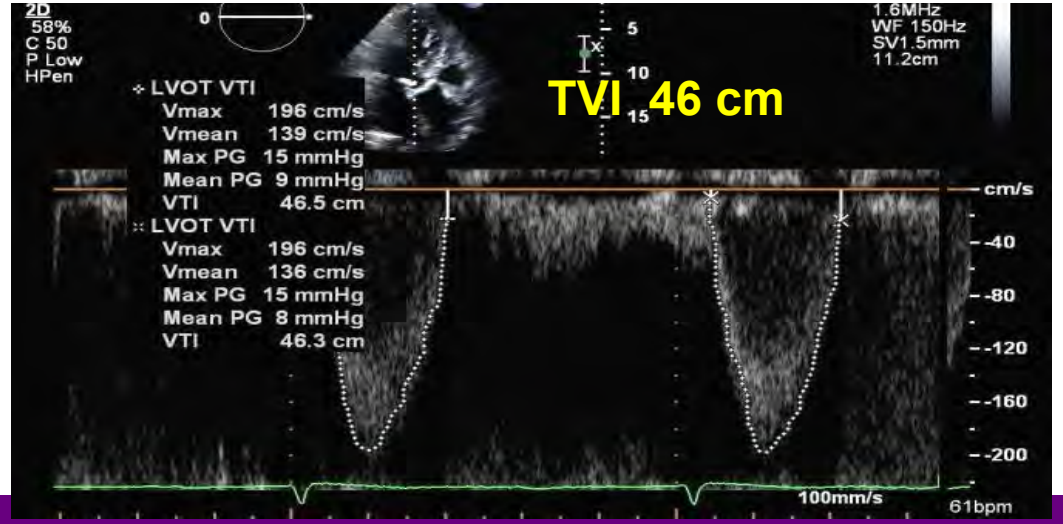
Esquitin et al. JASE 2019

Case #21

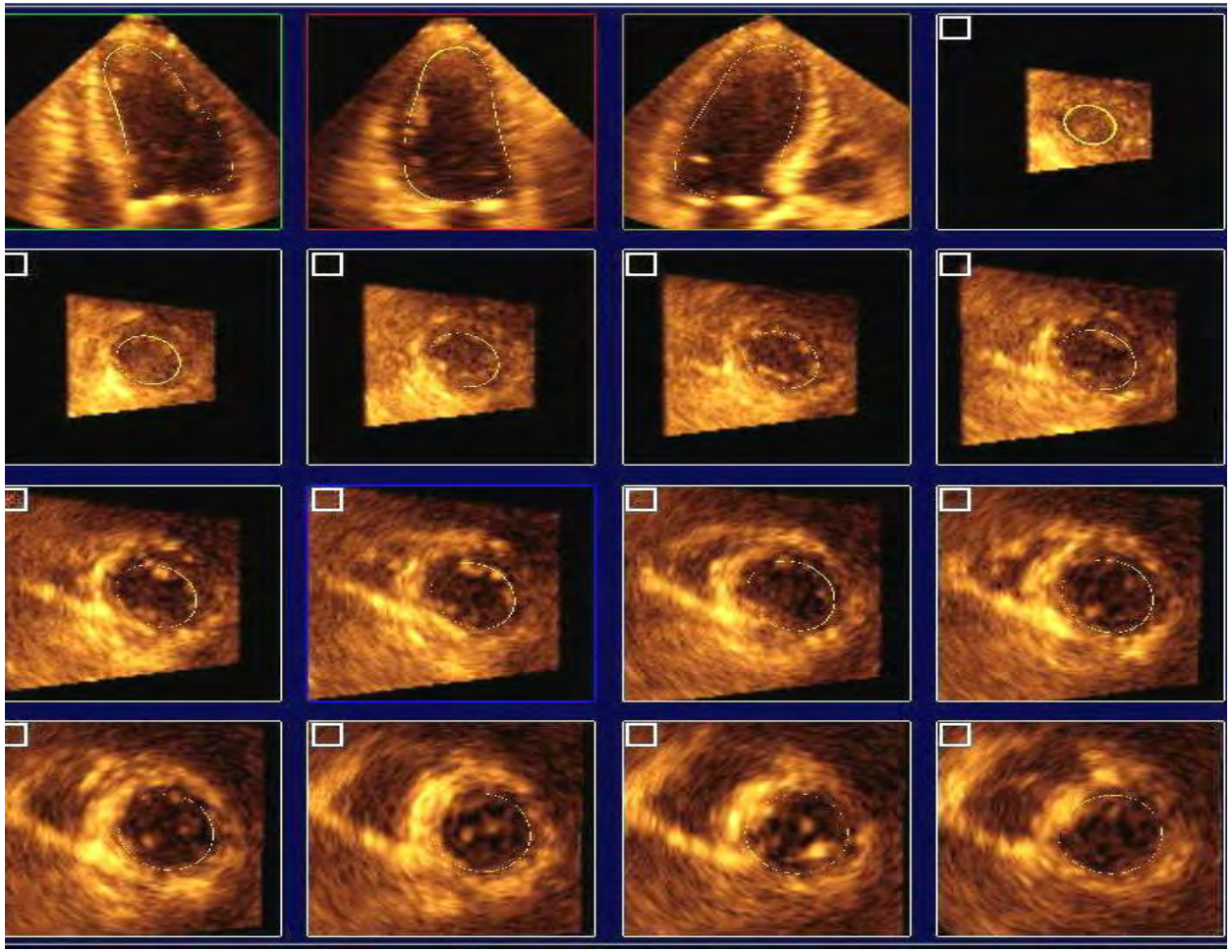
74 yo man with dyspnea and murmur

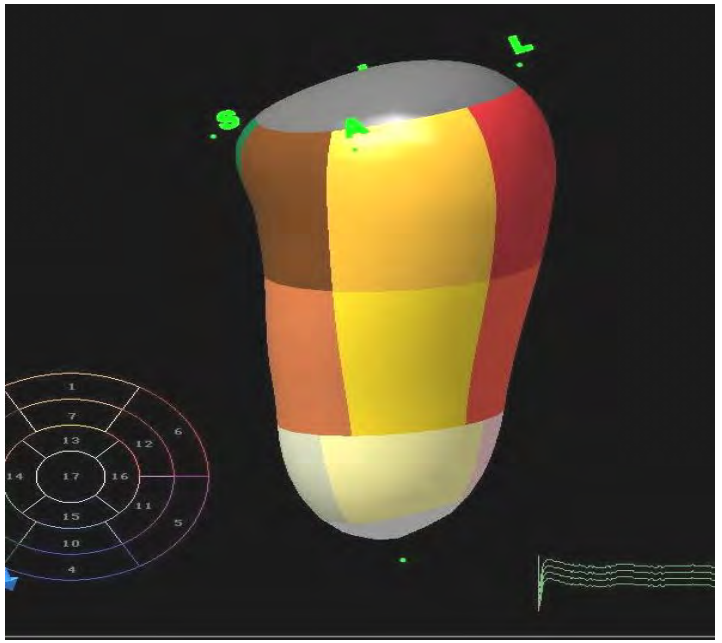
Aortic stenosis and SAM

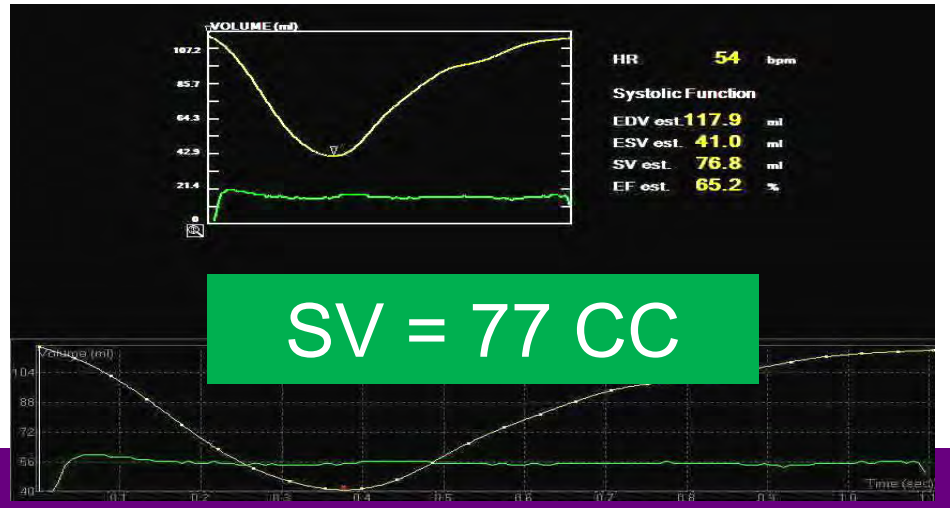




RT3DE: Stroke Volume and Aortic Stenosis

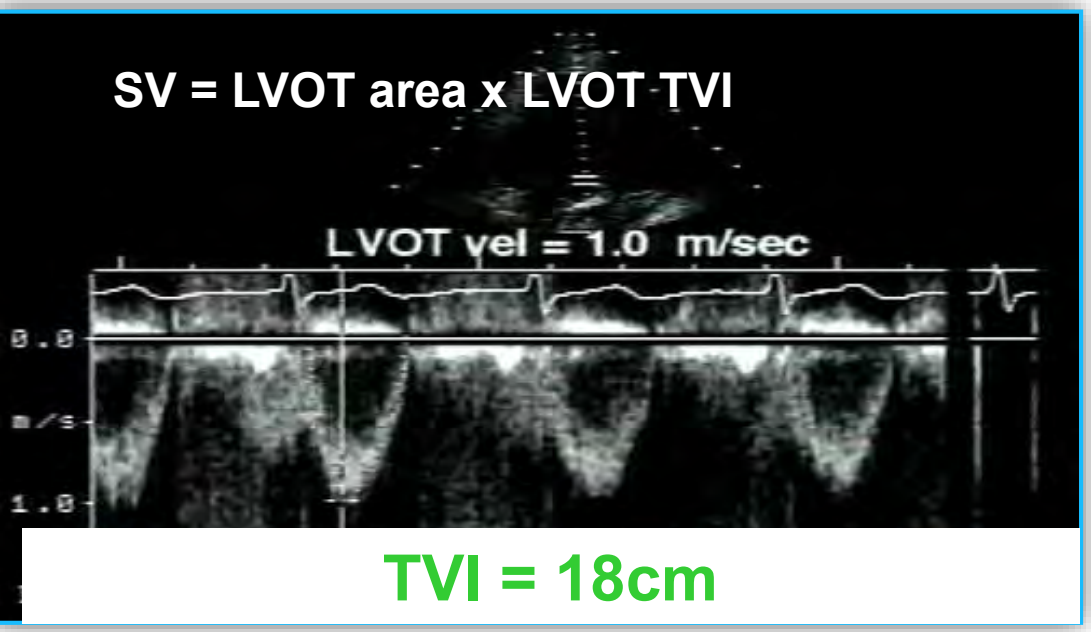




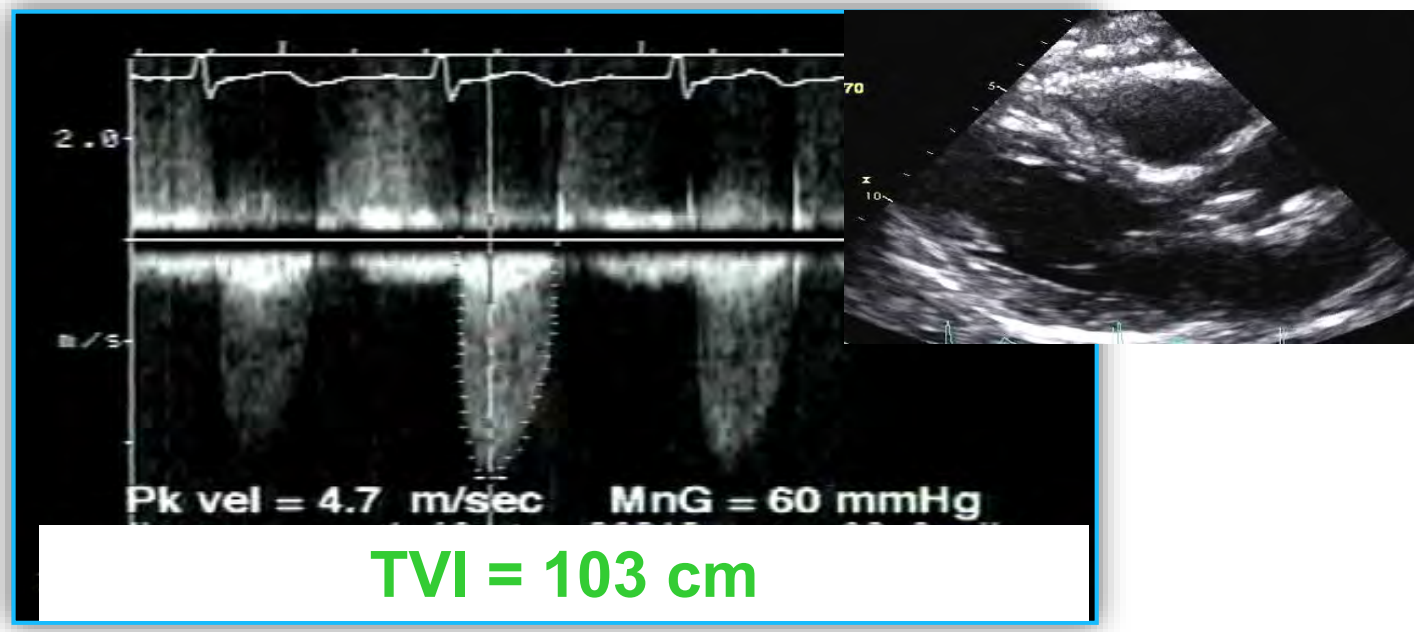


Case #22

67-Year-Old Completely Asymptomatic Man



TVI = 18cm



TVI = 103 cm

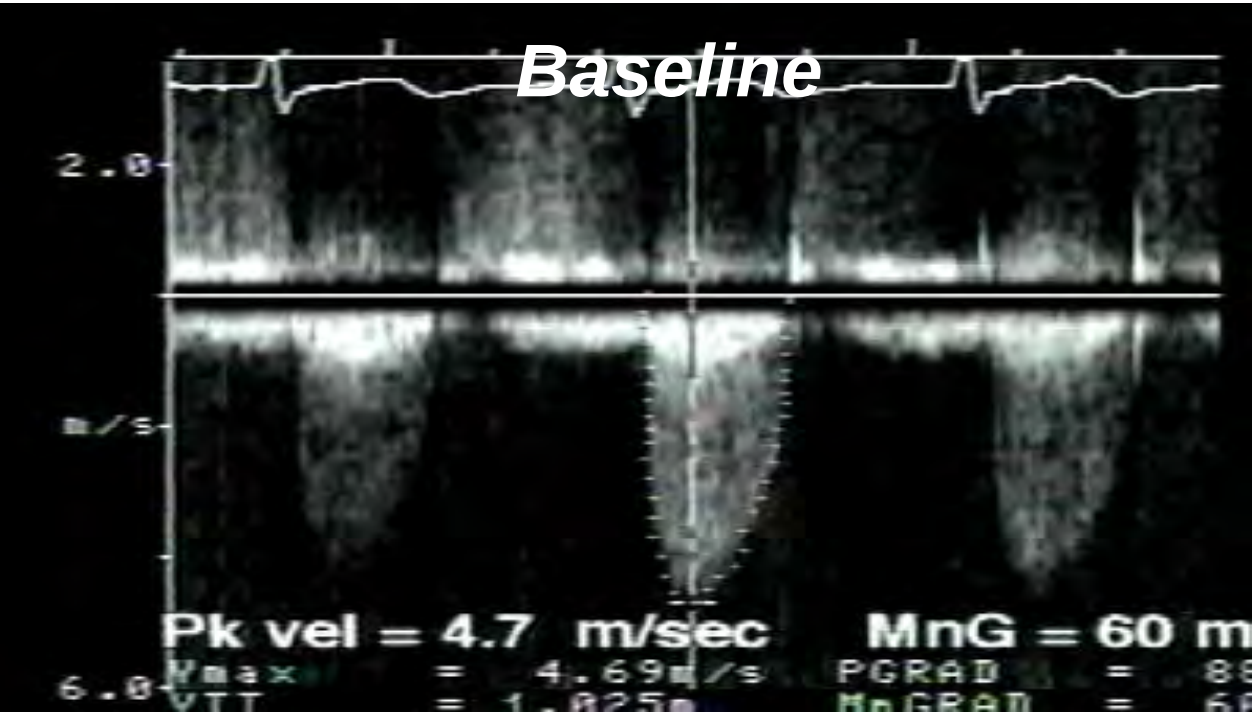
a. **Follow-up in 6 months**
b. **Cardiac catheterization**
c. **Exercise test**
d. **AVR**

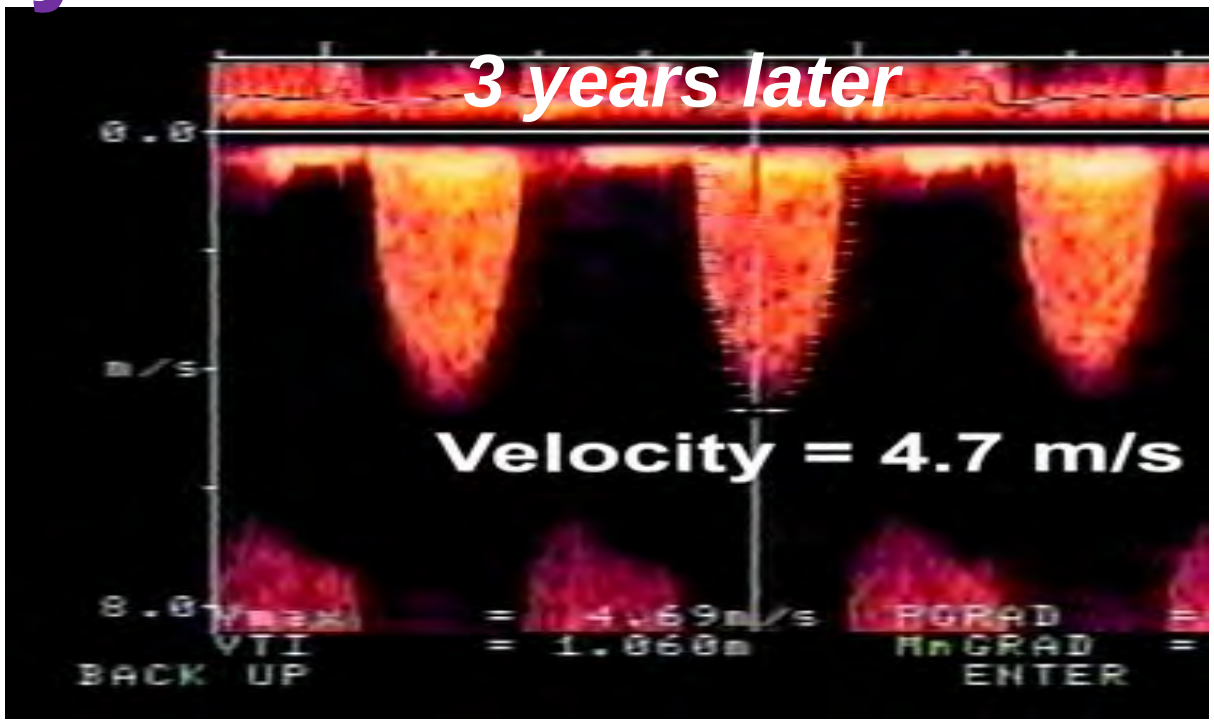
LVOT diameter 2.1 cm
AV vel = 4.7 m/sec
Mean gradient 60 mm Hg
LVOT TVI/ AV TVI =0.21 AVA =0.6 cm^2

AVA= Stroke Volume / AV TVI

MAYO CLINIC

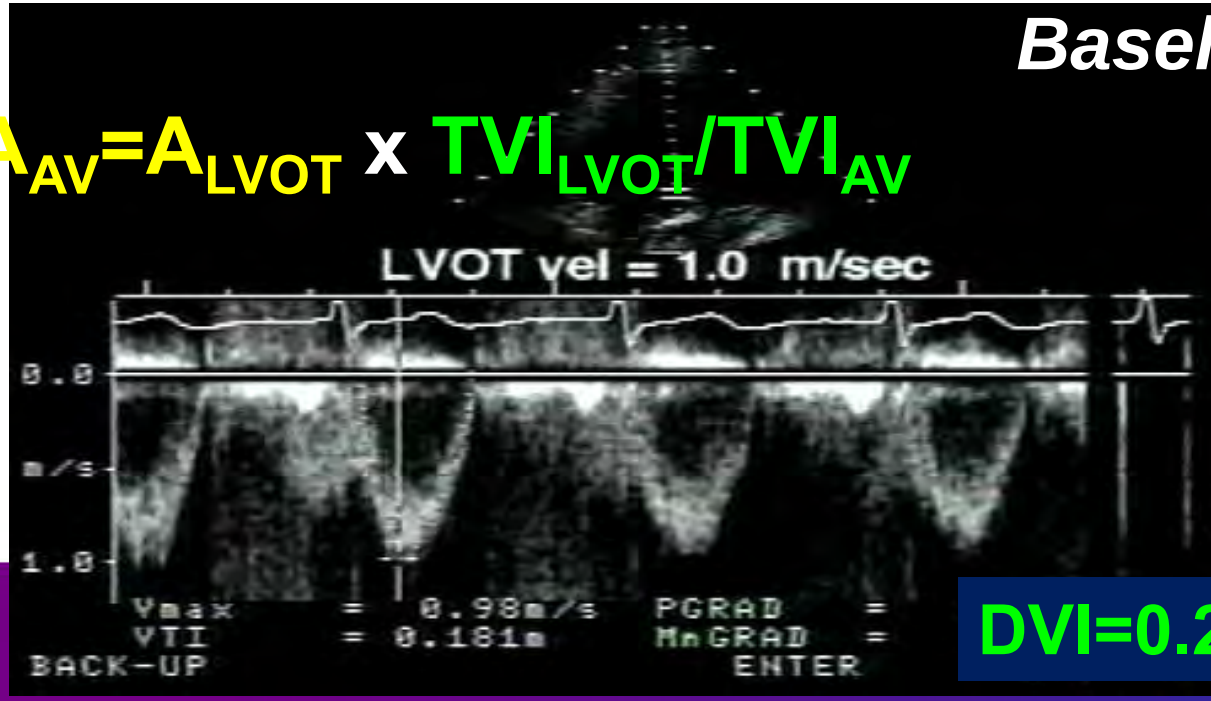
He returns 3 years later





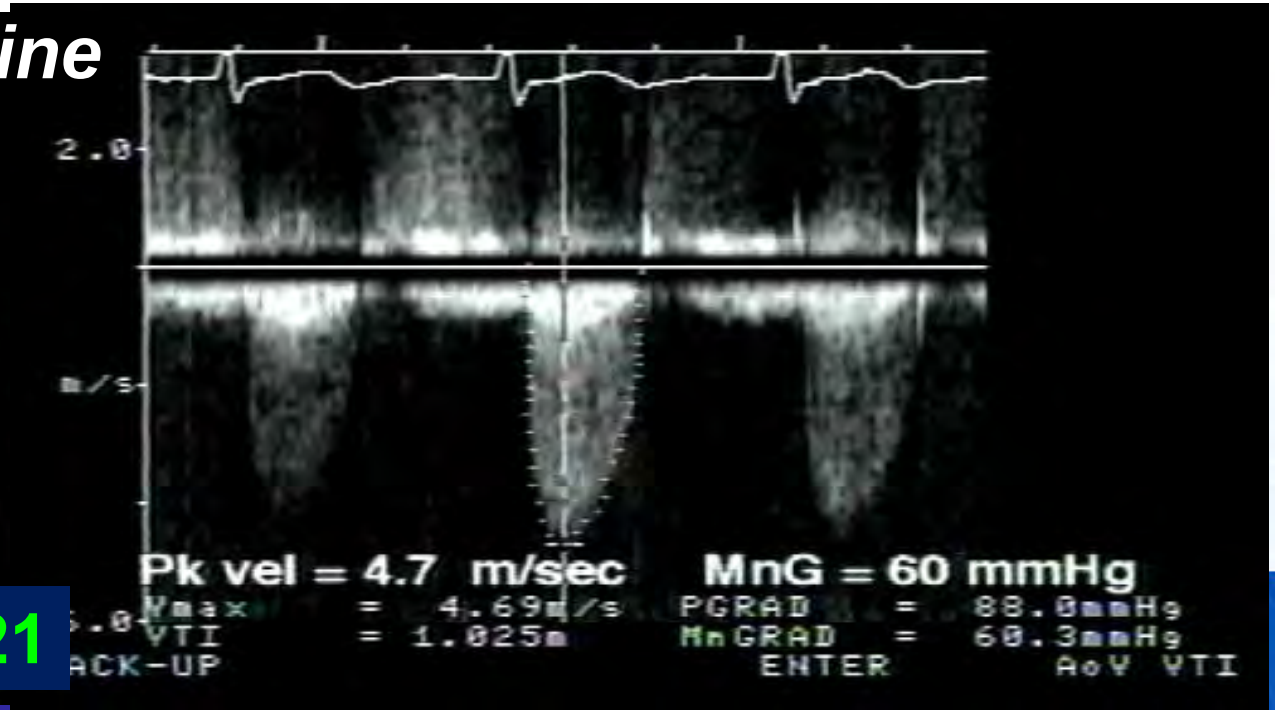
1. Follow up in 3 yrs
2. Exercise
3. Cath
4. AVR

$A_{AV}=A_{LVOT} \times TVI_{LVOT}/TVI_{AV}$

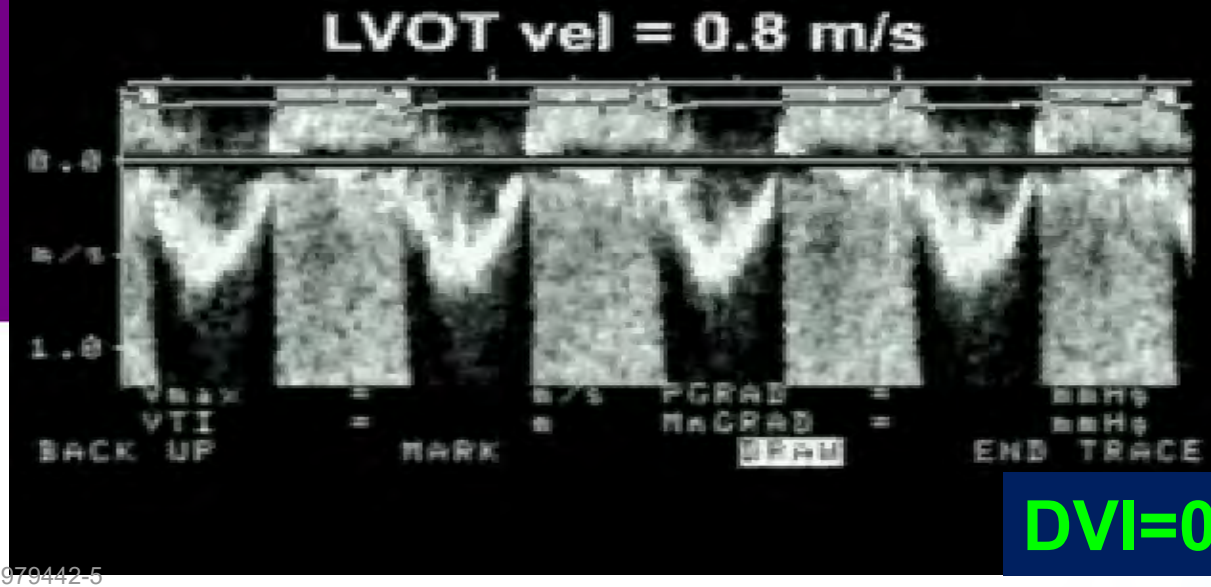


DVI=0.21

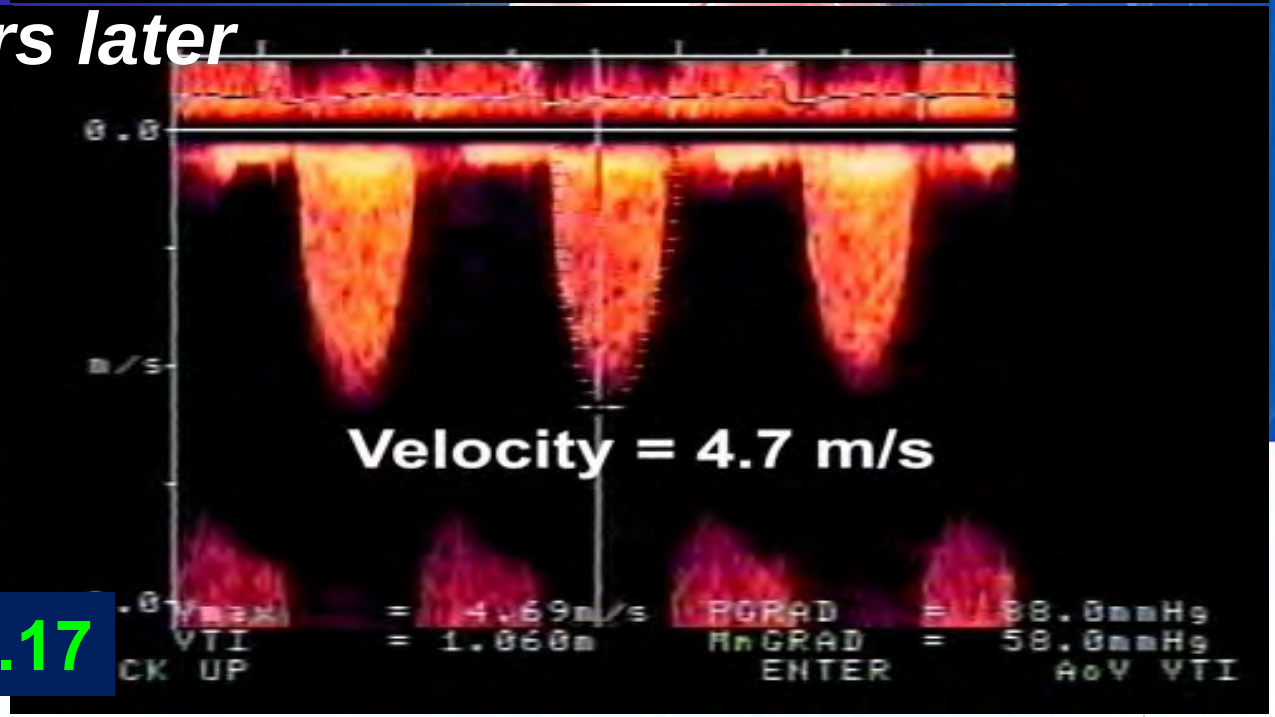
Baseline



3 years later

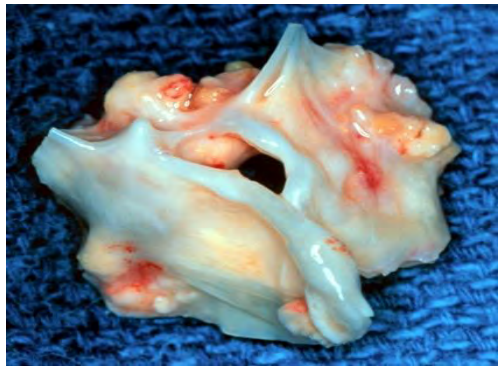


DVI=0.17



Dimensionless Velocity Index (DVI)

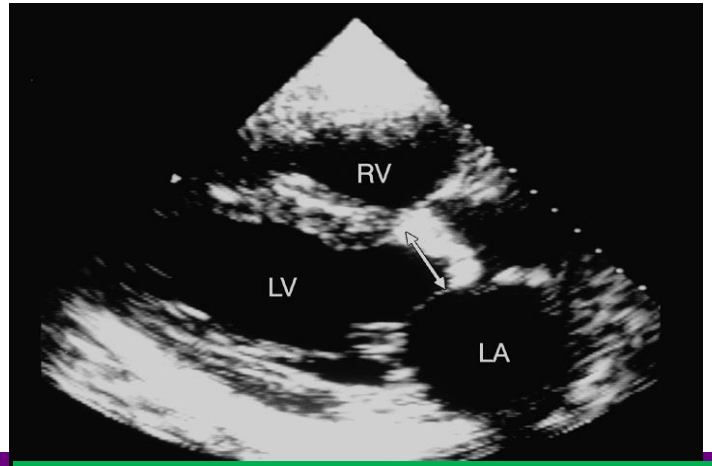
AV area



LVOT TVI

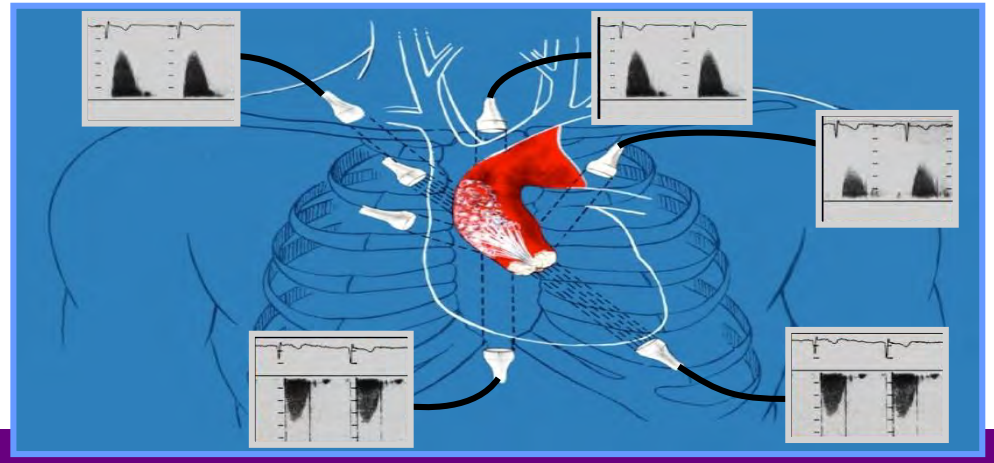
$$\frac{\text{AV area}}{\text{LVOT area}} = \frac{\text{LVOT TVI}}{\text{AV TVI}}$$

LVOT area



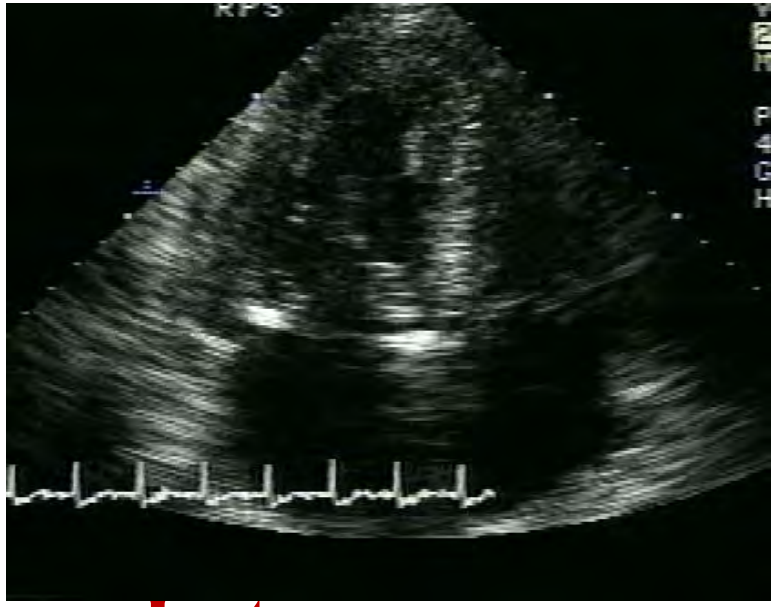
NL 3.5 – 4.0 cm^2

AV TVI

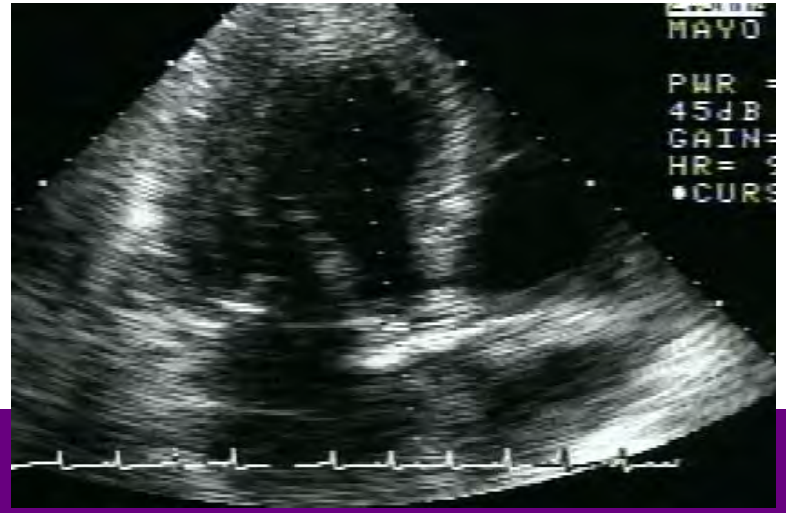


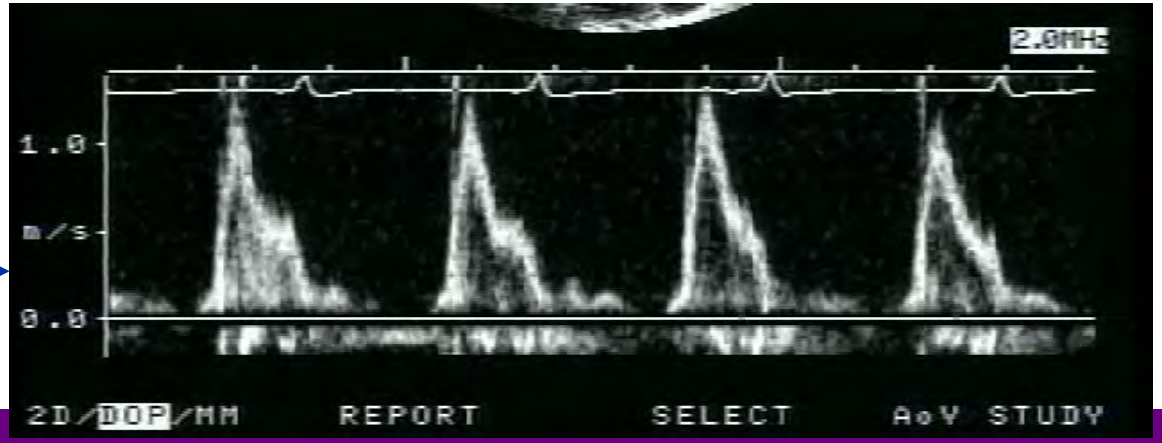
LVEF and Diastolic Function

Baseline

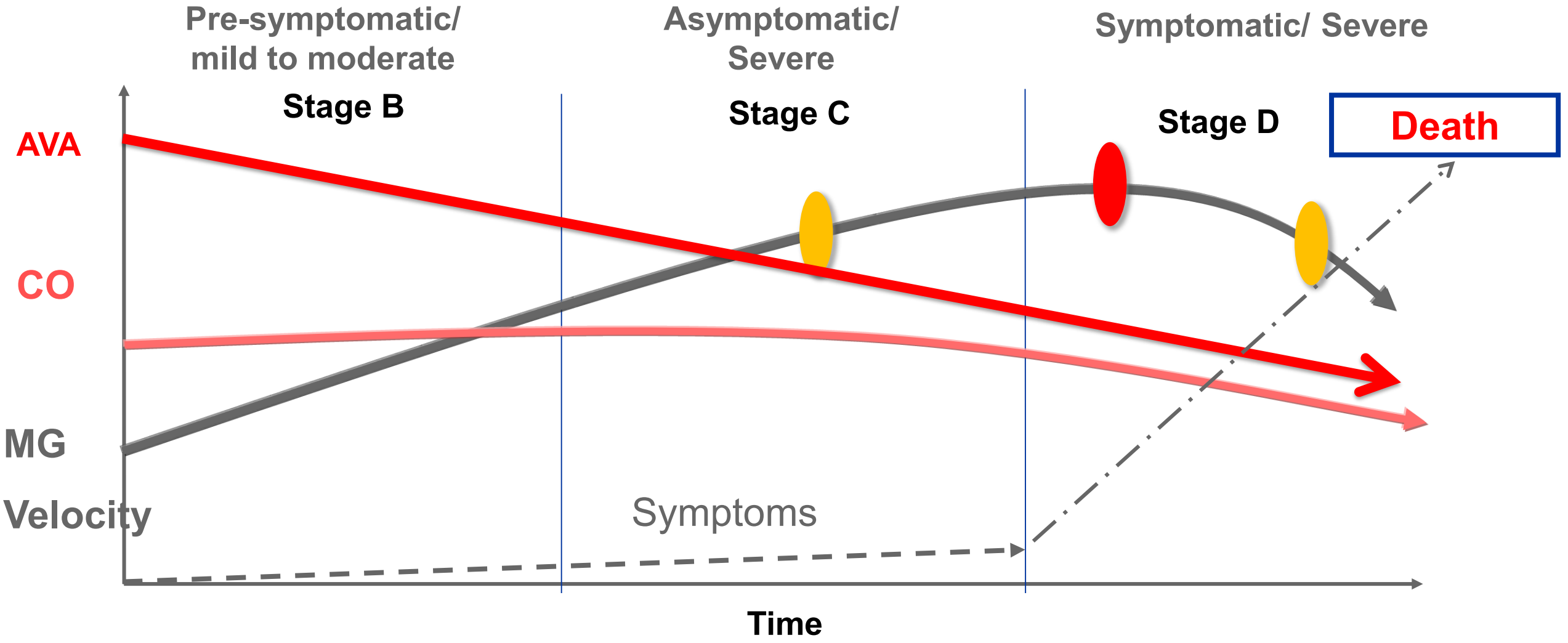


3 Years Later

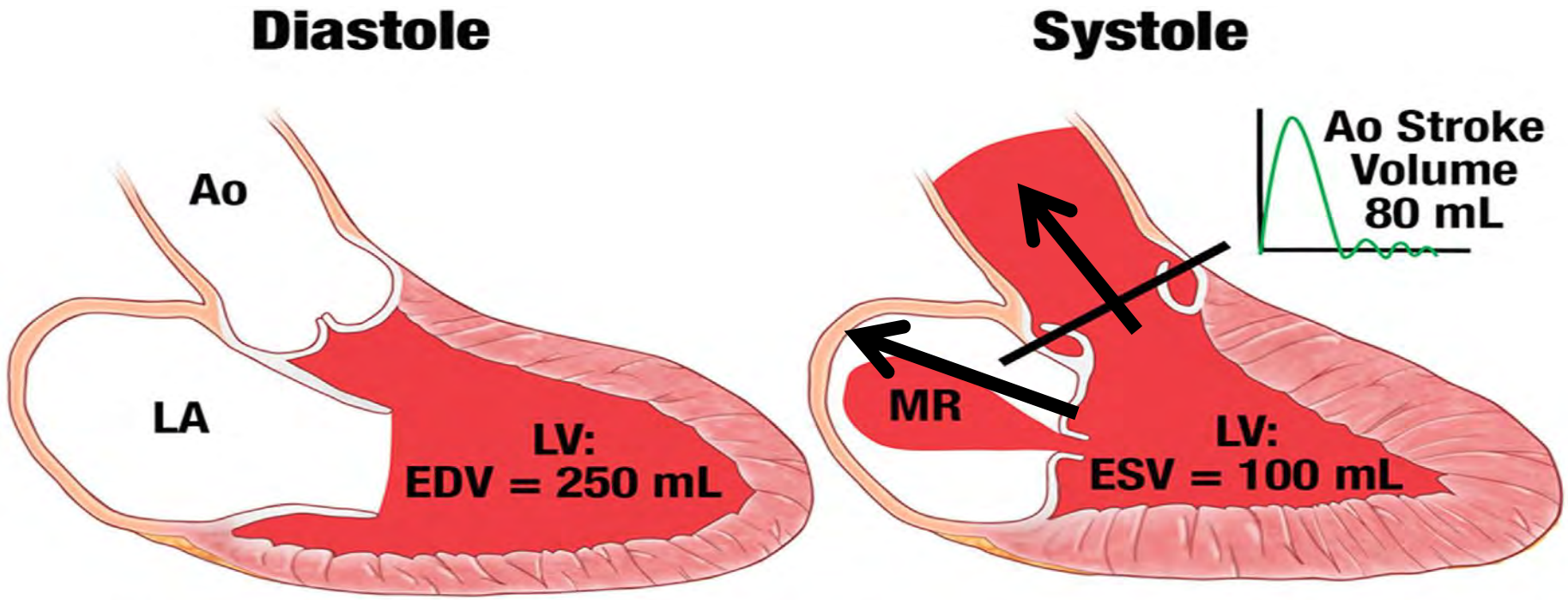




Natural History of Aortic Stenosis



LV Stroke Volume – LVOT Stroke Volume = MR Vol



LV Stroke Volume (LVSV):

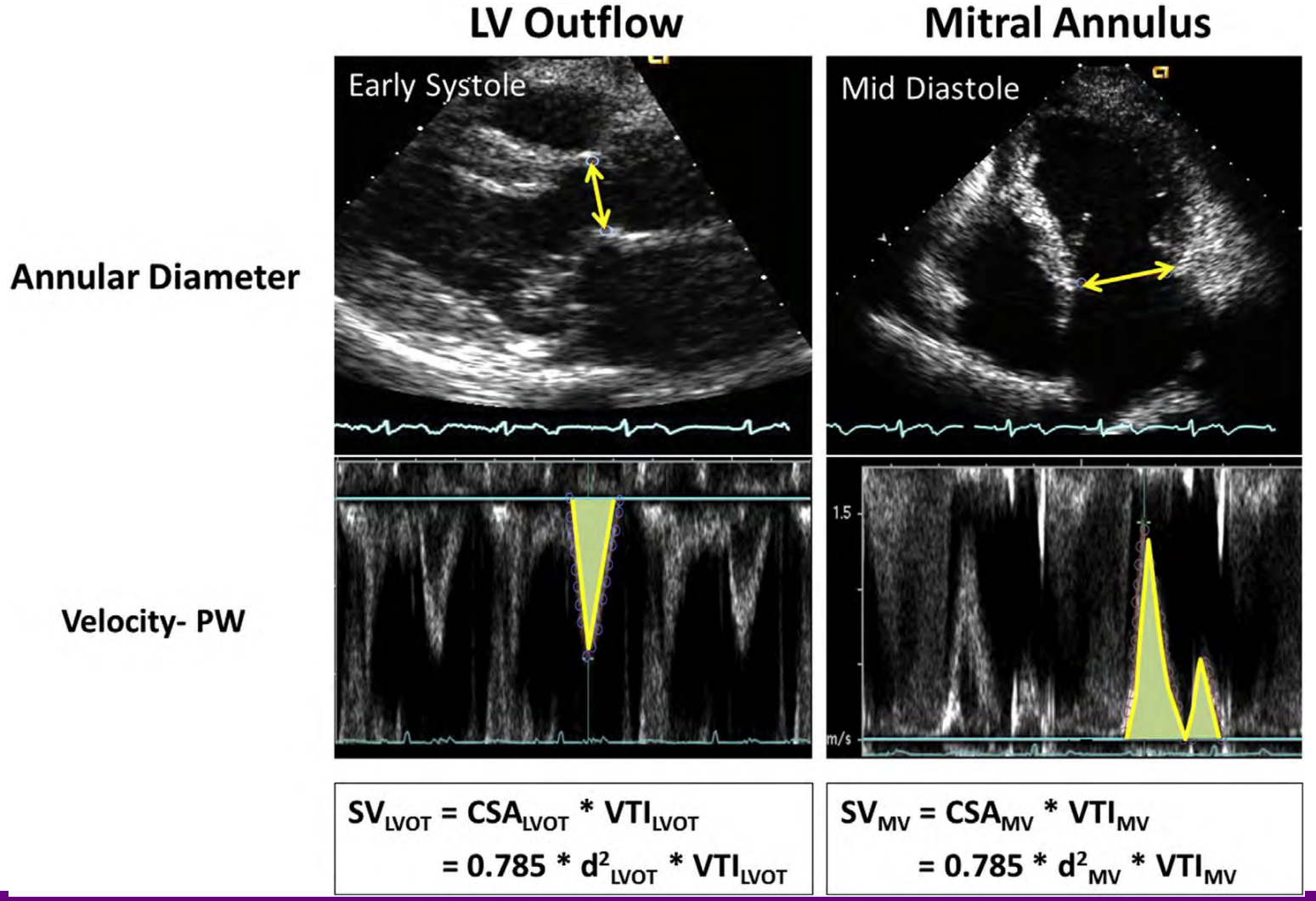
LVSV = LVEDV-LVESV
LVSV = 250 mL - 100 mL
LVSV = 150 mL

Mitral Regurgitant Volume (M RVol):

M RVol = LVSV - Ao Stroke Volume
M RVol = 150 mL - 80 mL
M RVol = 70 mL

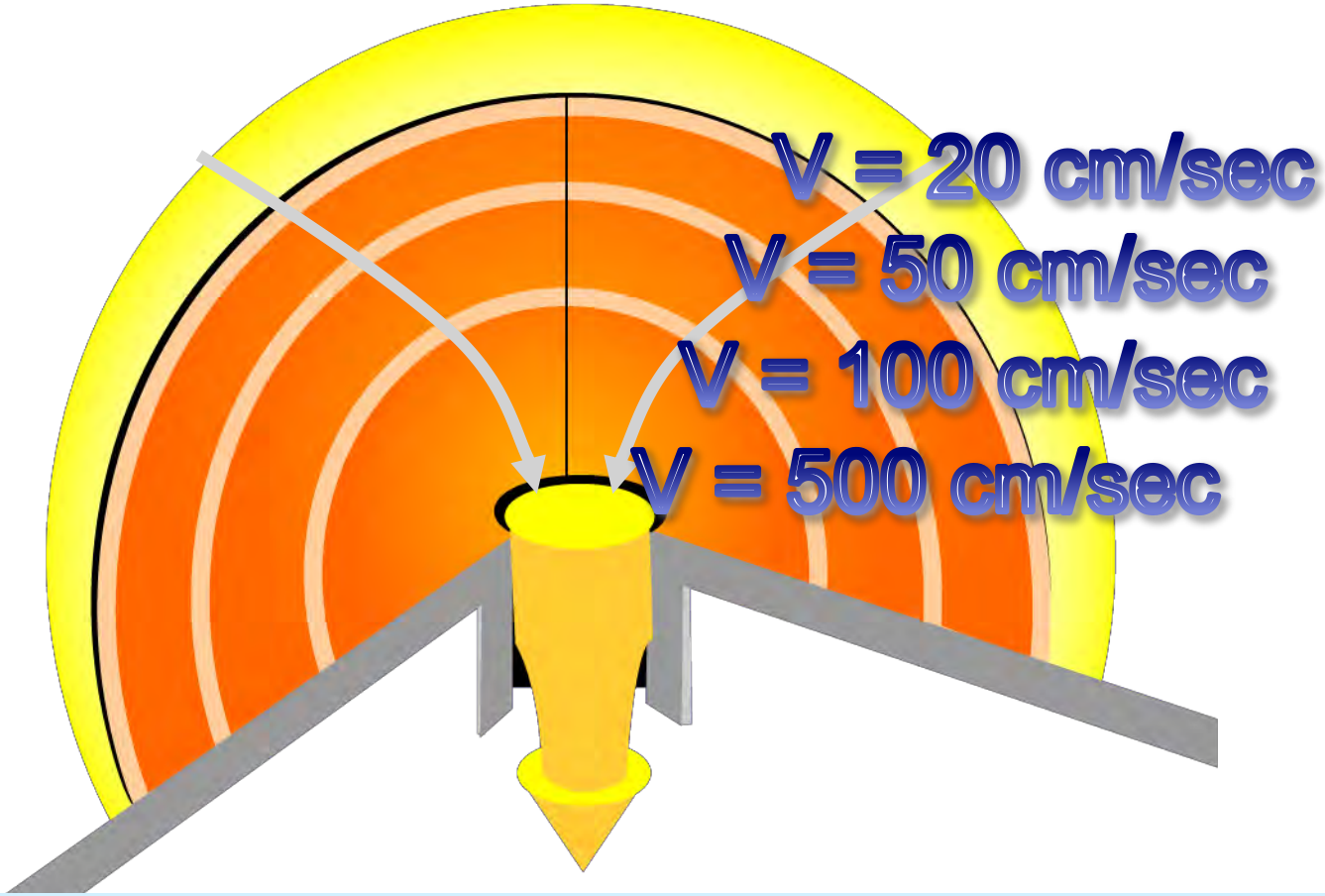
MR Vol = Mitral Inflow Volume – LVOT SV Volume

Volume = (Diameter)^2 x 0.785 x VTI



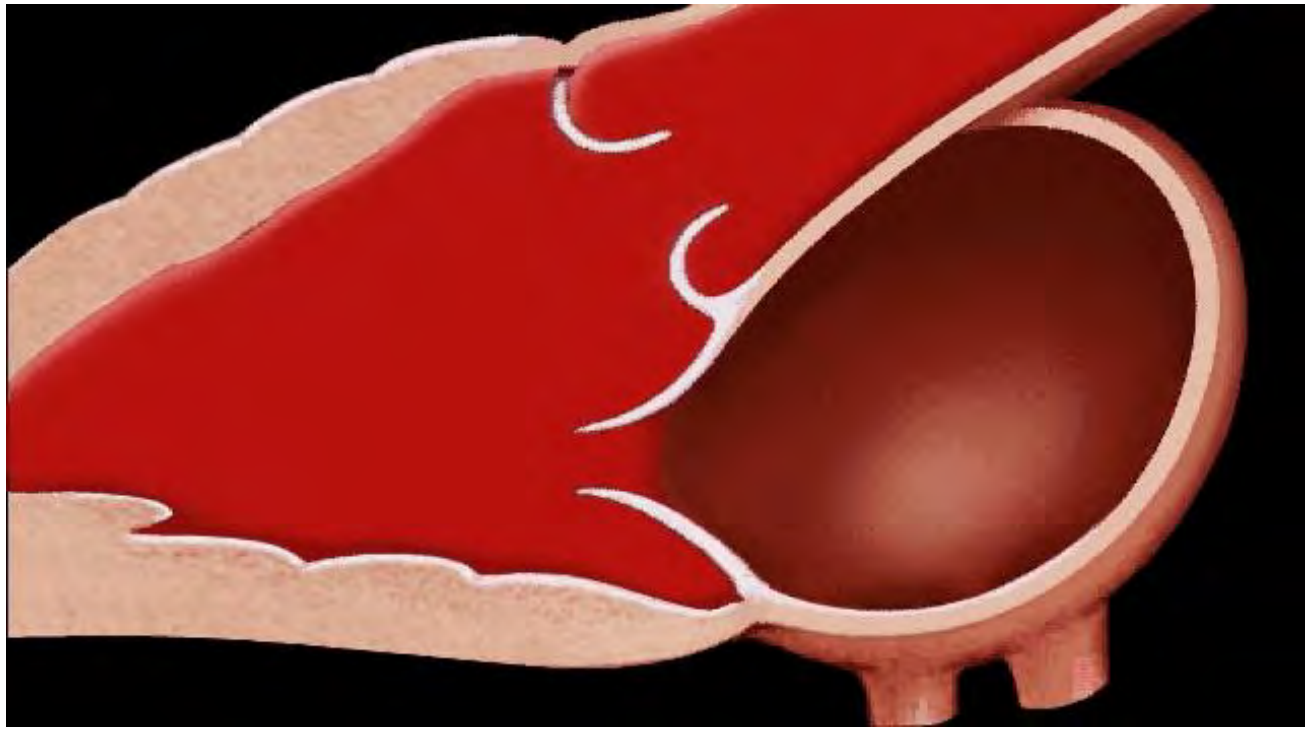
PISA (Proximal Isovelocity Surface Area)

Fluid Acceleration



Flow rate = 6.28 x (PISA radius)^2 x Aliasing Velocity

Quantification of MR – PISA
Effective Regurgitant Orifice (ERO)



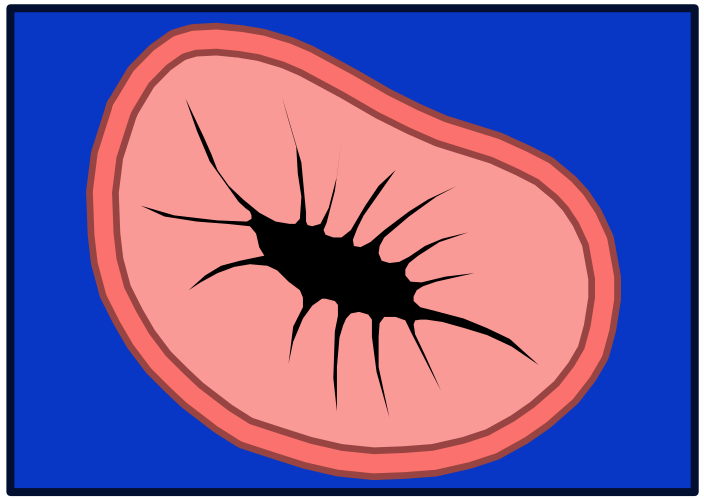
Flow @ PISA = Flow @ ERO

Area x Velocity of PISA

= ***ERO*** x Velocity of MR

Flow Rate = Area x Flow Velocity

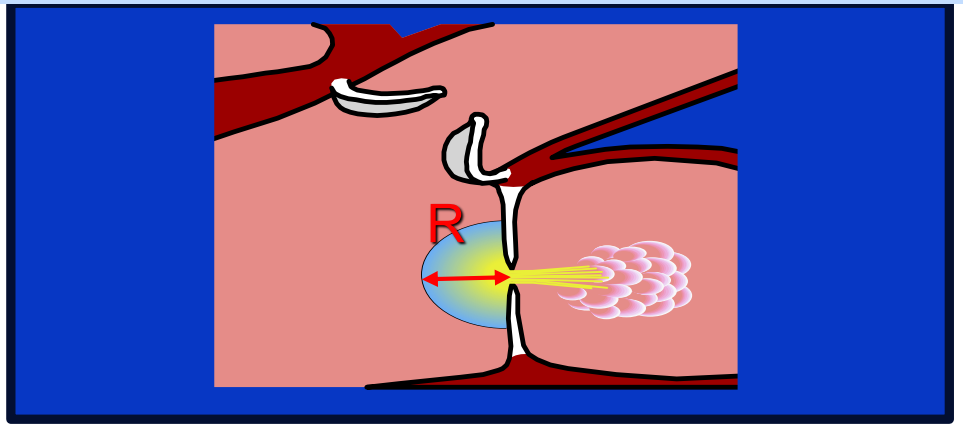
ERO by PISA Method



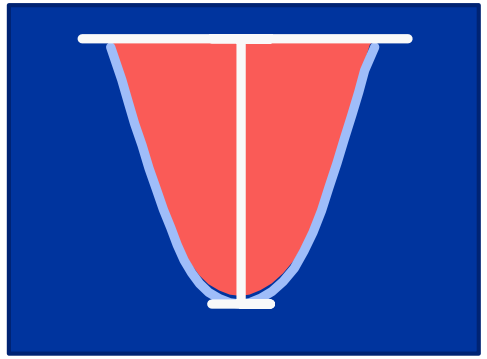
ERO

=

Flow rate at PISA in cm^3 /sec

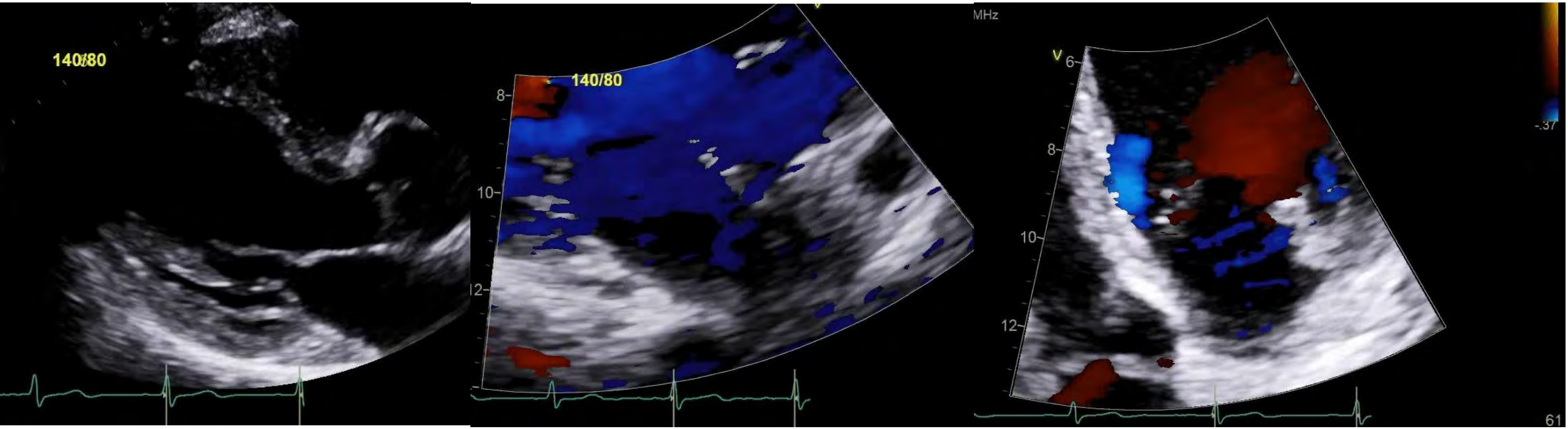


$$\frac{6.28 \times (R)^2 \times \text{PISA vel}}{\text{MR velocity in cm/sec}}$$



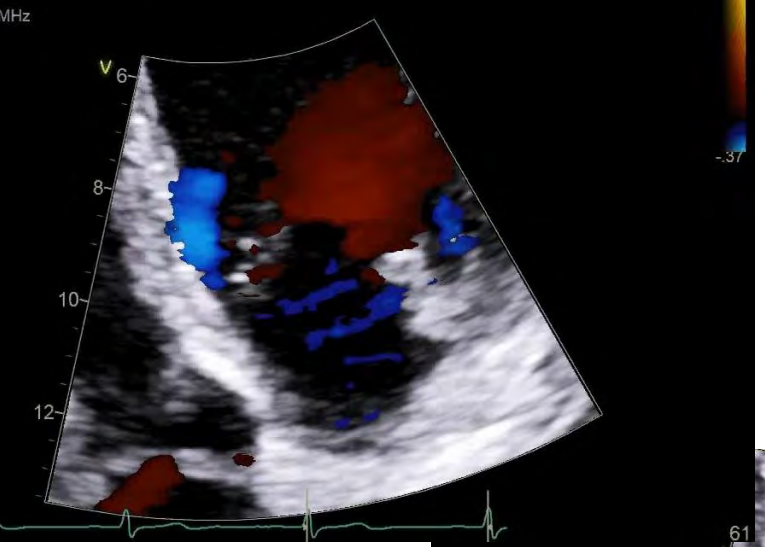
Case #23

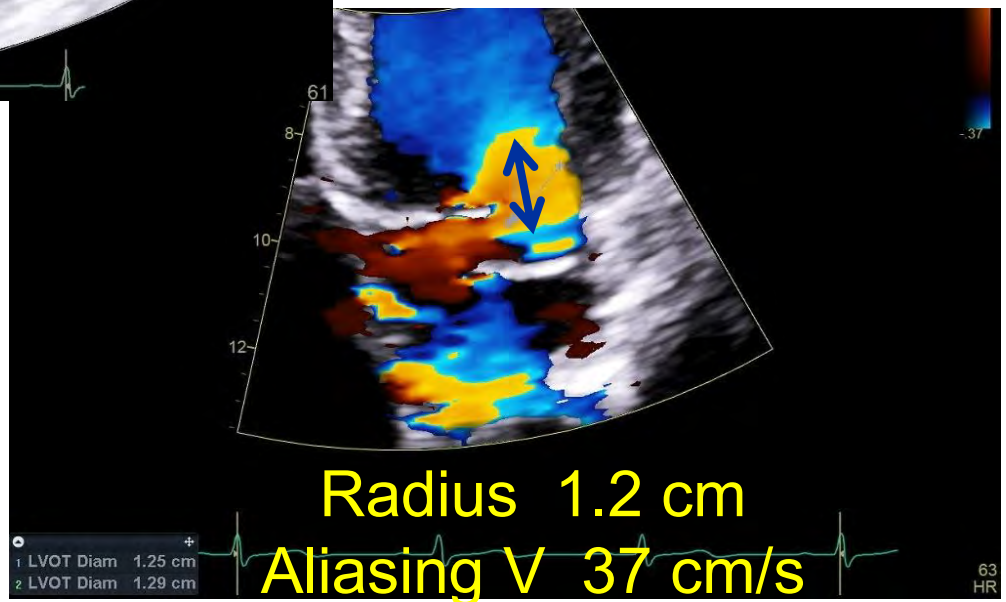
MR Assessment by CFI and PISA
Eccentric MR due to Flail

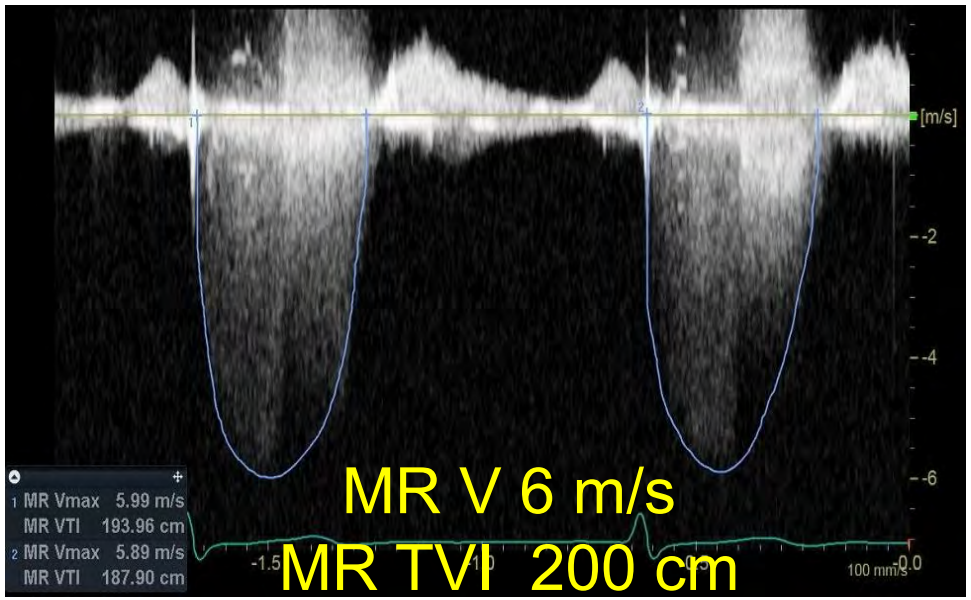


PISA Method for MR Assessment

ERO = 6.28 x $(R)^2$ x PISA vel / MR vel





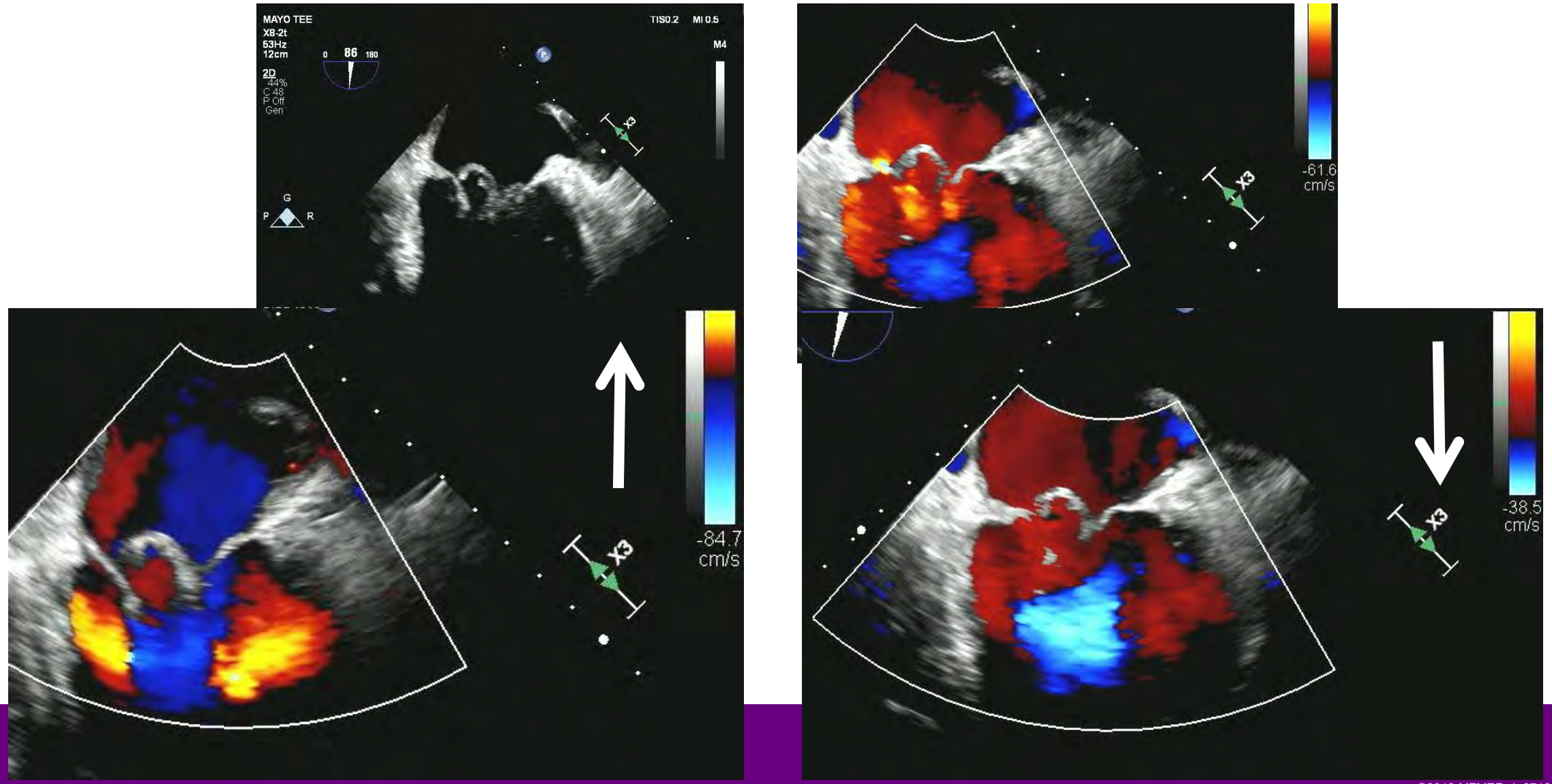


ERO = 6.28 x 1.2^2 x 37 /600 = 0.56 cm^2

Reg volume = 0.56 x 200 = 112 mL

PISA

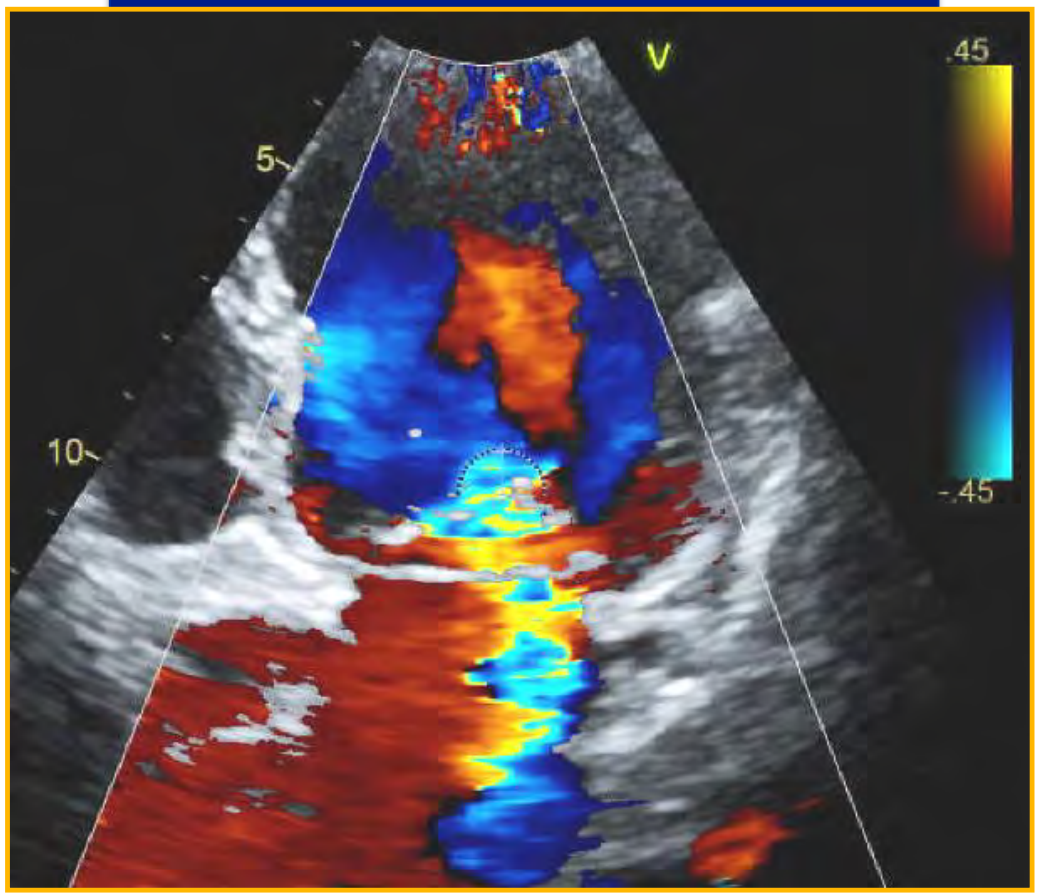
Baseline shift to the same direction of flow



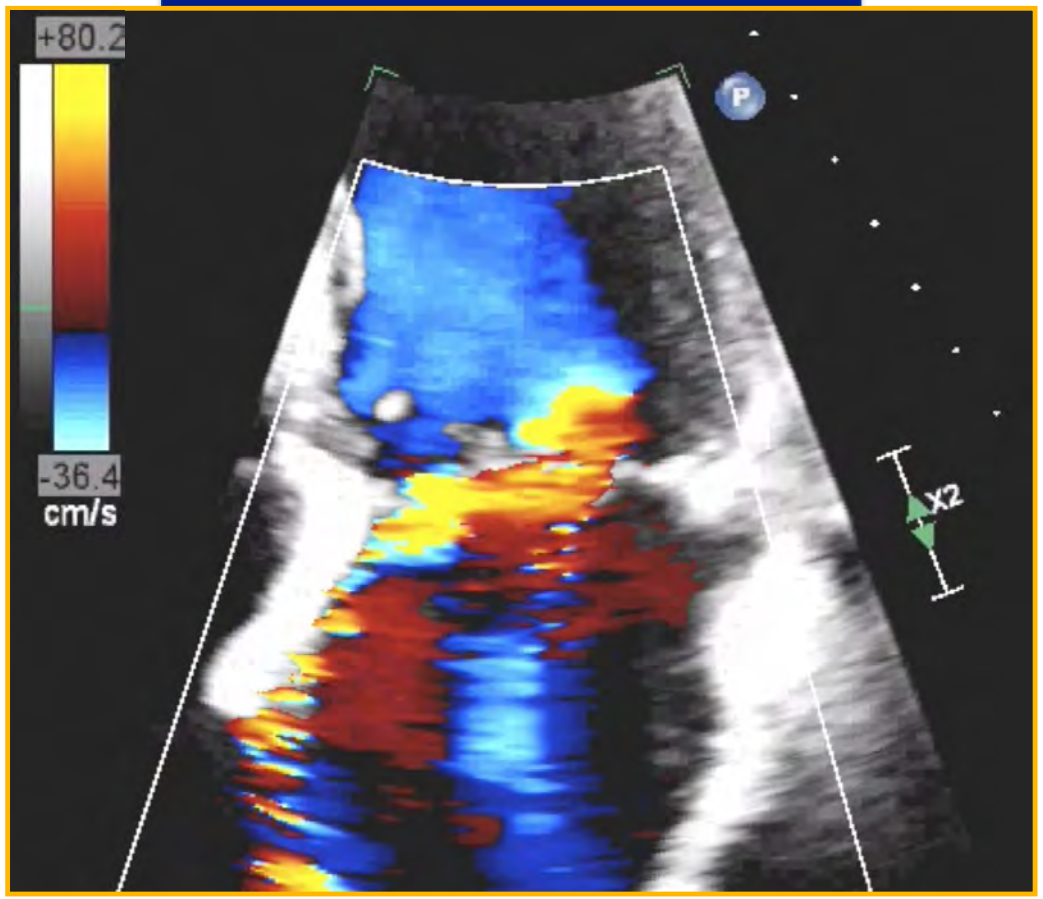
PISA Method

Shift color scale in the direction of flow

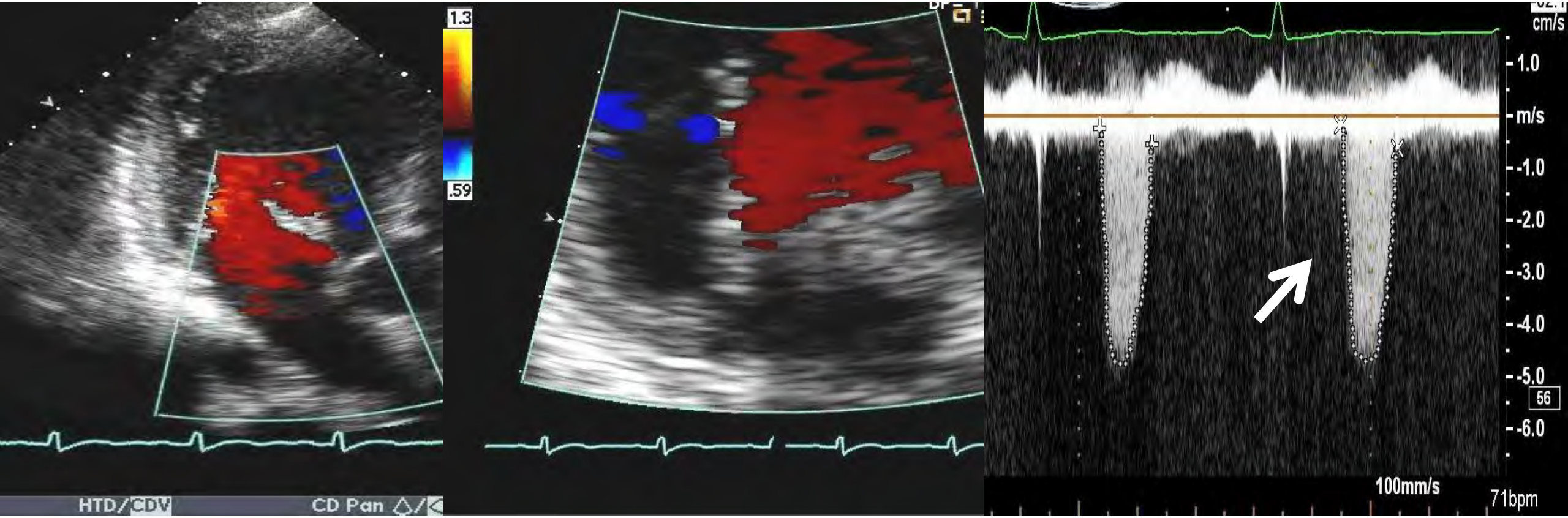
Color Scale *Decreased*



Color Scale *Shifted*

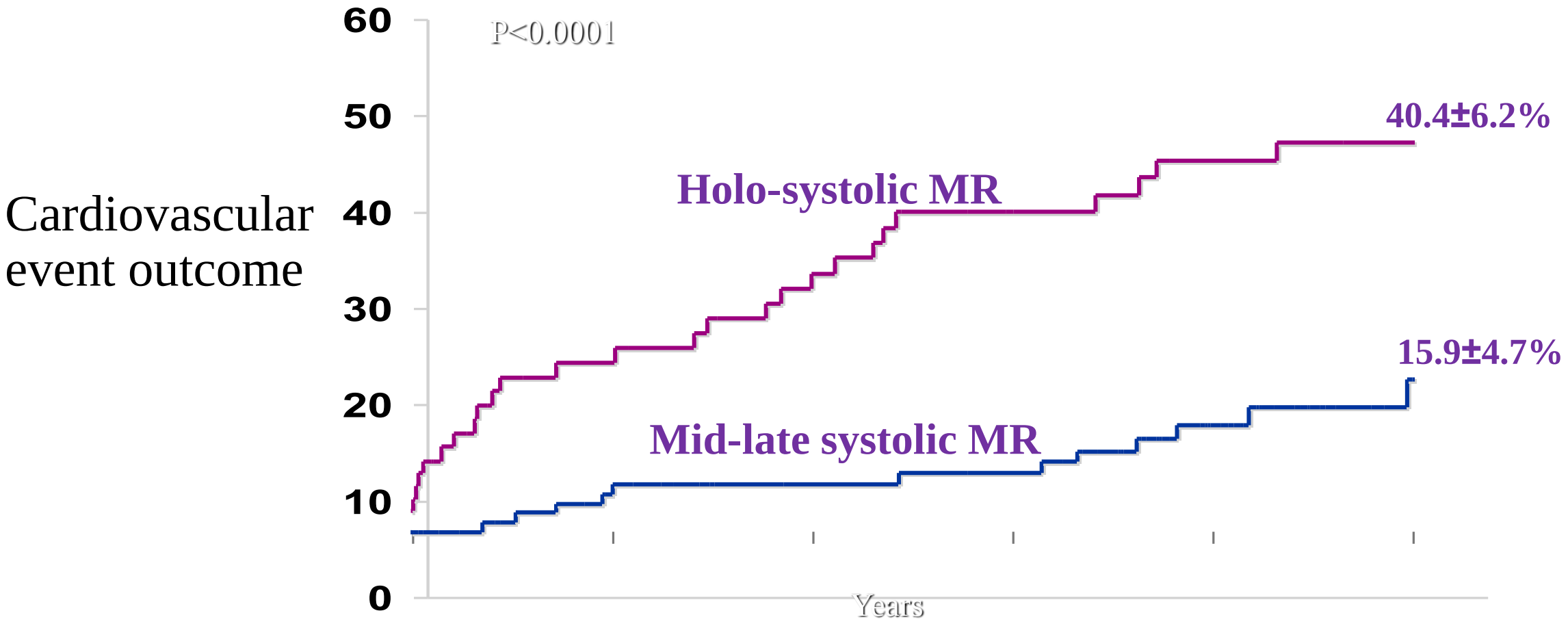


Mid-to-Late Systolic MR in MV prolapse
ERO overestimates MR severity



Clinical Outcome

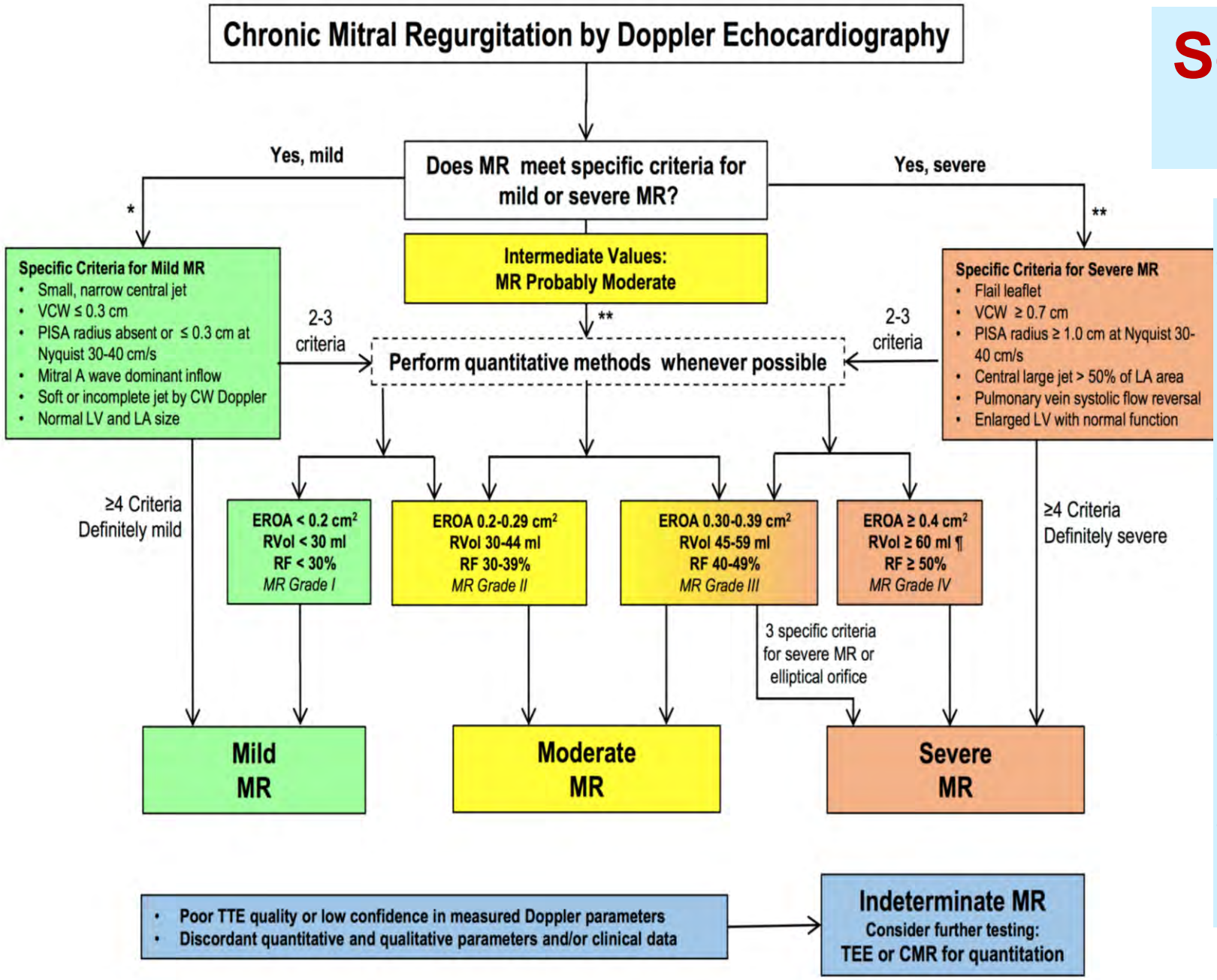
Mid-Late vs. Holosystolic MR



MAYO CLINIC

Topilski and Sarano et al Circulation 2012

Severe MR Definition USA vs ESC



- Primary MR
  - ERO ≥ 0. 4 cm^2
  - Rvol ≥ 60 mL
- Secondary MR
  - ERO ≥ 0. 2 cm^2
  - Rvol ≥ 30 mL
- Semi-Quantitative
- PV, VC, MV E, Jet area

Zoghbi et al. JASE 2017

The NEW ENGLAND JOURNAL of MEDICINE

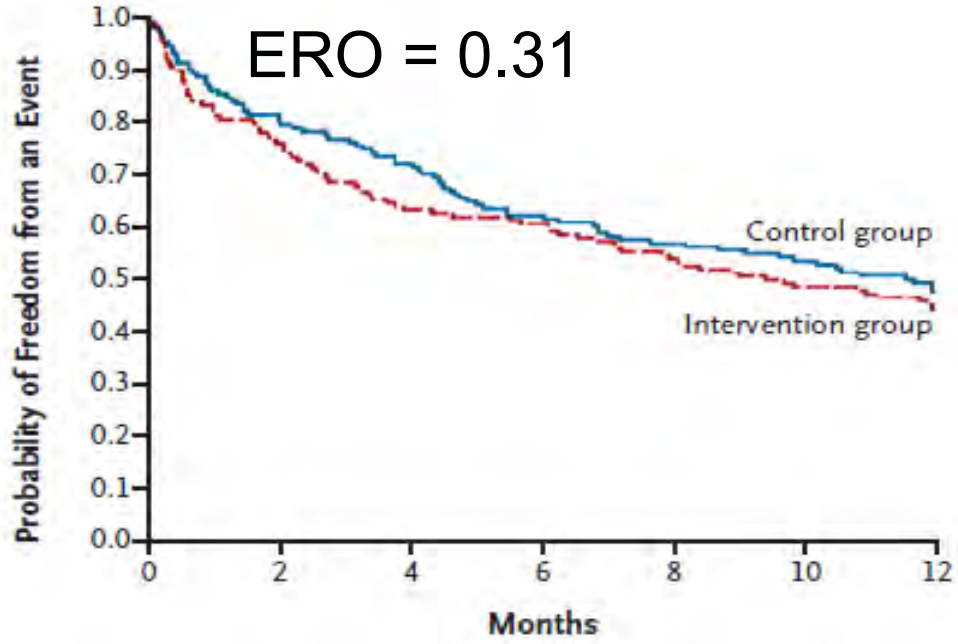
ESTABLISHED IN 1812 DECEMBER 13, 2018 VOL. 379 NO. 24

MITRA-FR

Percutaneous Repair or Medical Treatment for Secondary Mitral Regurgitation

J.-F. Obadia, D. Messika-Zeitoun, G. Leurent, B. Iung, G. Bonnet, N. Piriou, T. Lefèvre, C. Piot, F. Rouleau, D. Carrié, M. Nejjari, P. Ohlmann, F. Leclercq, C. Saint Etienne, E. Teiger, L. Leroux, N. Karam, N. Michel, M. Gilard, E. Donal, J.-N. Trochu, B. Cormier, X. Armoiry, F. Boutitie, D. Maucort-Boulch, C. Barnel, G. Samson, P. Guerin, A. Vahanian, and N. Mewton, for the MITRA-FR Investigators*

ERO = 0.31

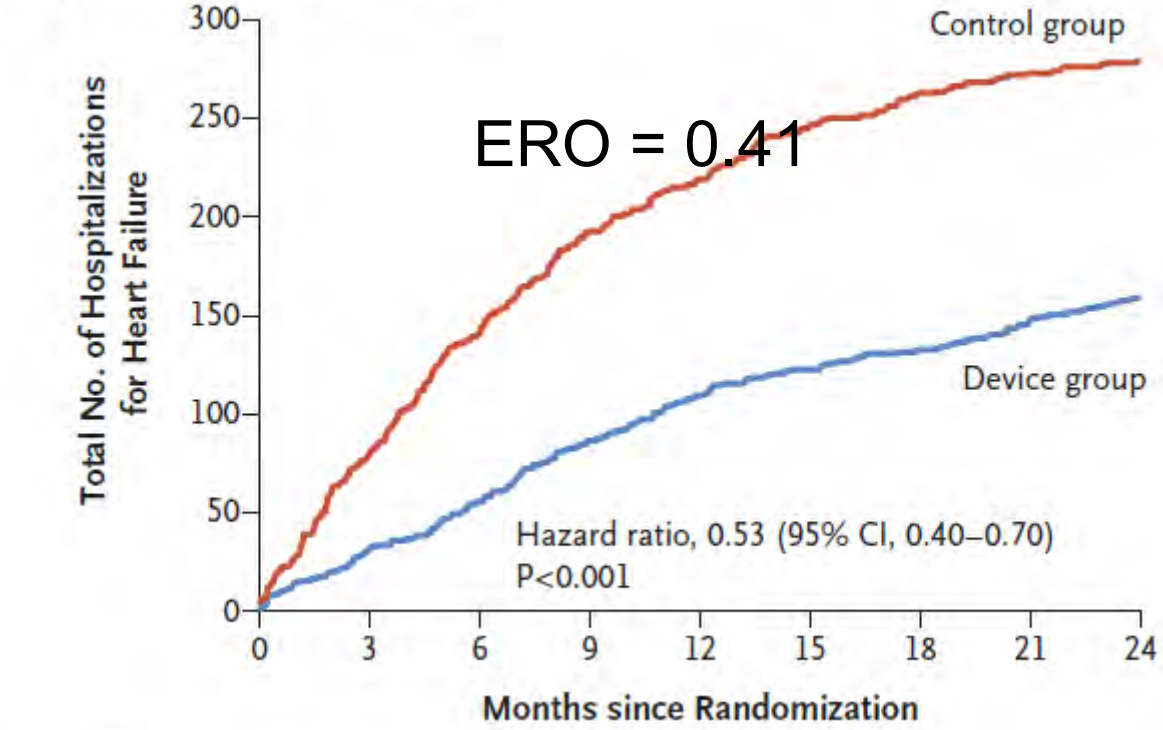


Transcatheter Mitral-Valve Repair in Patients with Heart Failure

COAPT

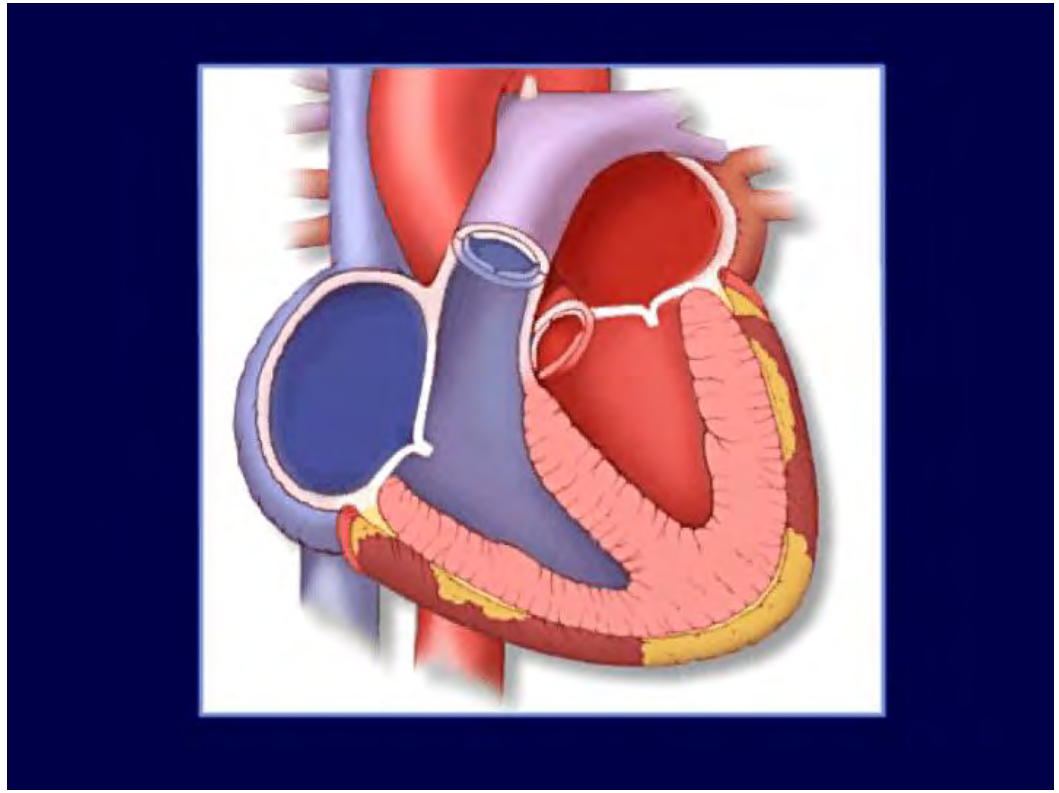
G.W. Stone, J.A. Lindenf im, J.M. Mishell, B. Whisenant, P.A. Grayburn, M. Rinaldi, S.R. Kapadia, V. Rajagopal, I.J. Sarembock, A. Brieke, S.O. Marx, D.J. Cohen, N.J. Weissman, and M.J. Mack, for the COAPT Investigators*

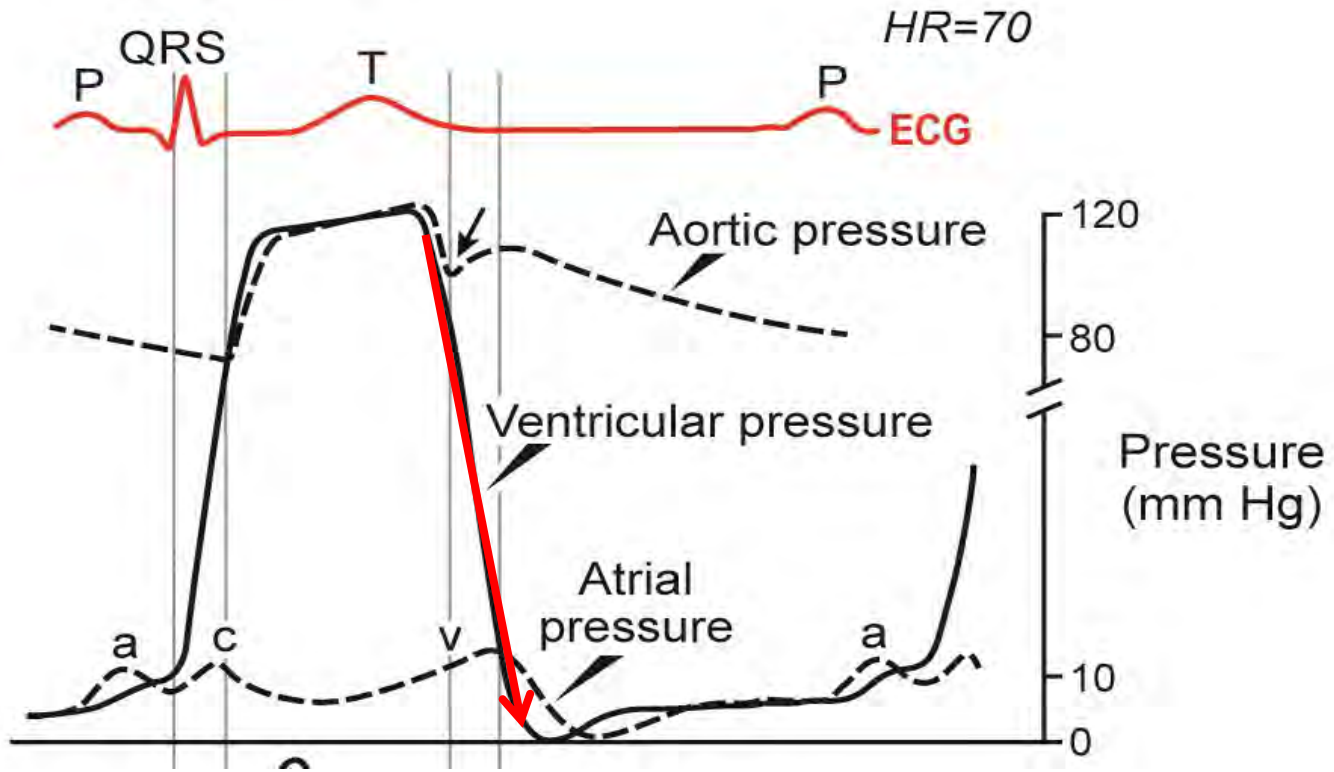
ERO = 0.41



Diastolic Filling with Relaxation

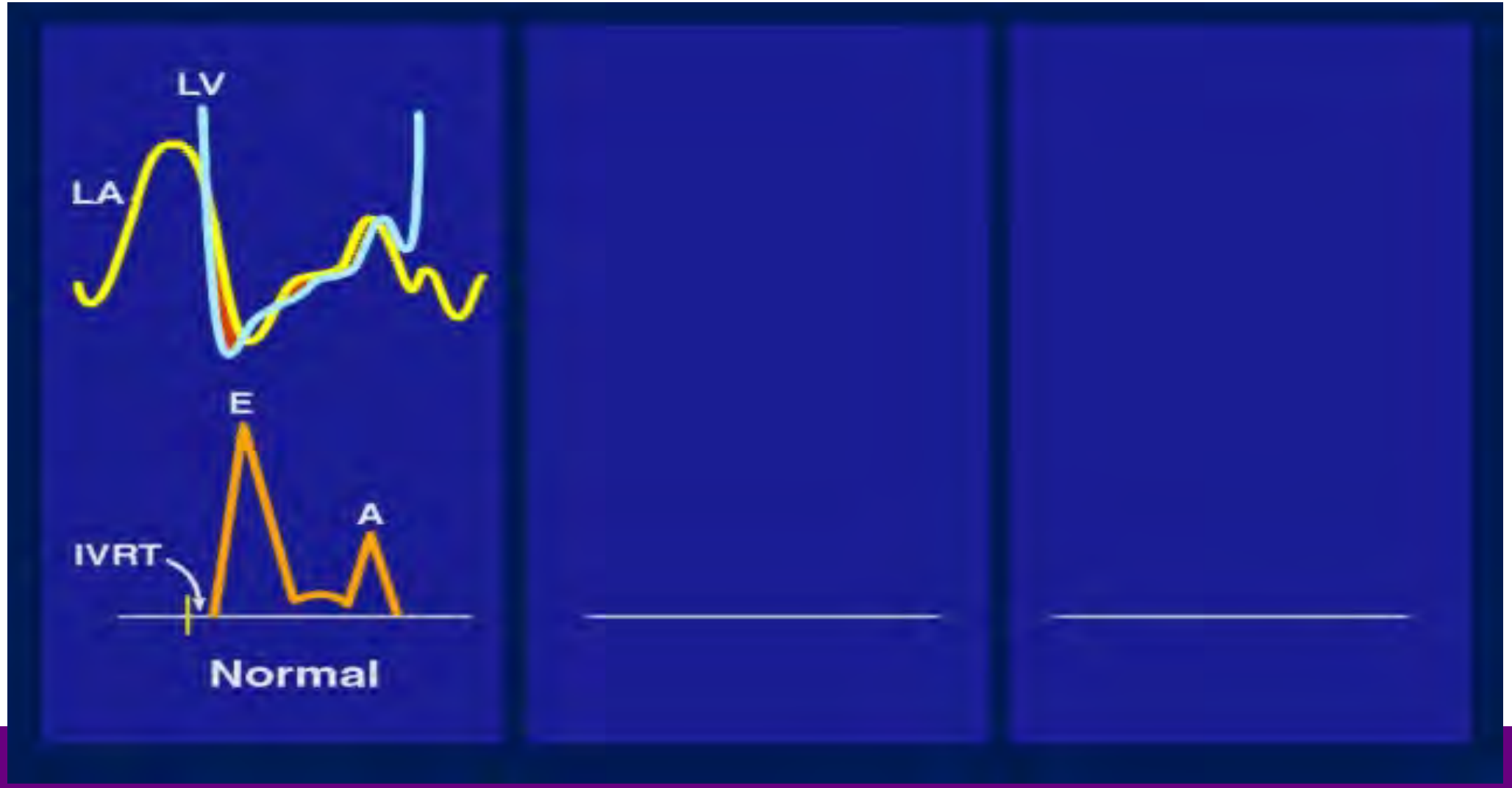
διαστολή: Greek word for dilation





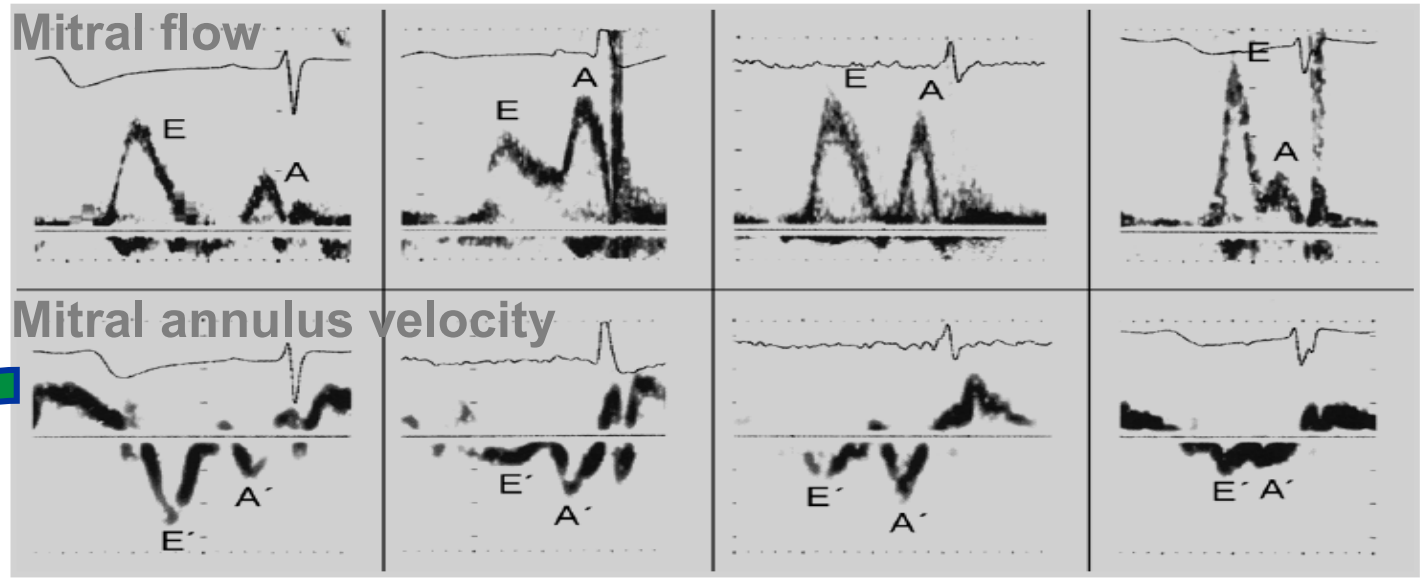
Echo evaluation of diastolic function

Trans-mitral inflow velocity



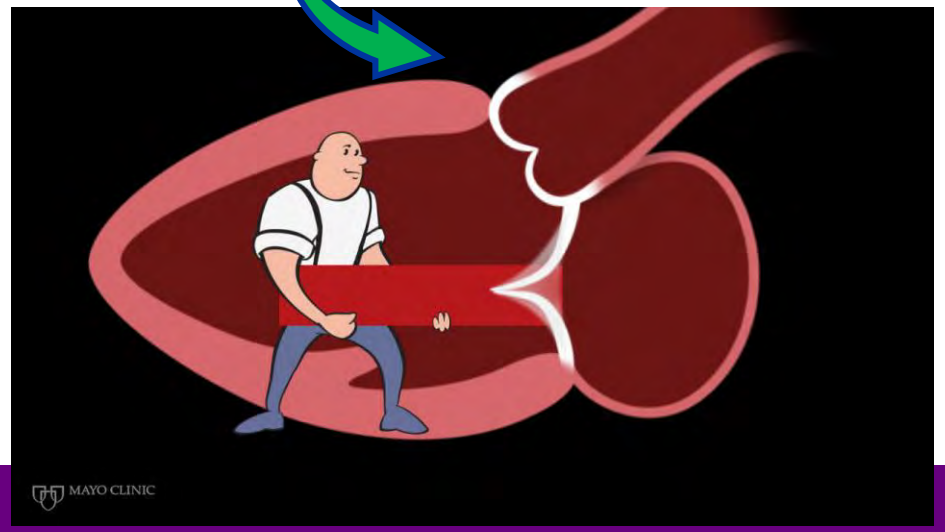
Diastolic Function

Pull or Push

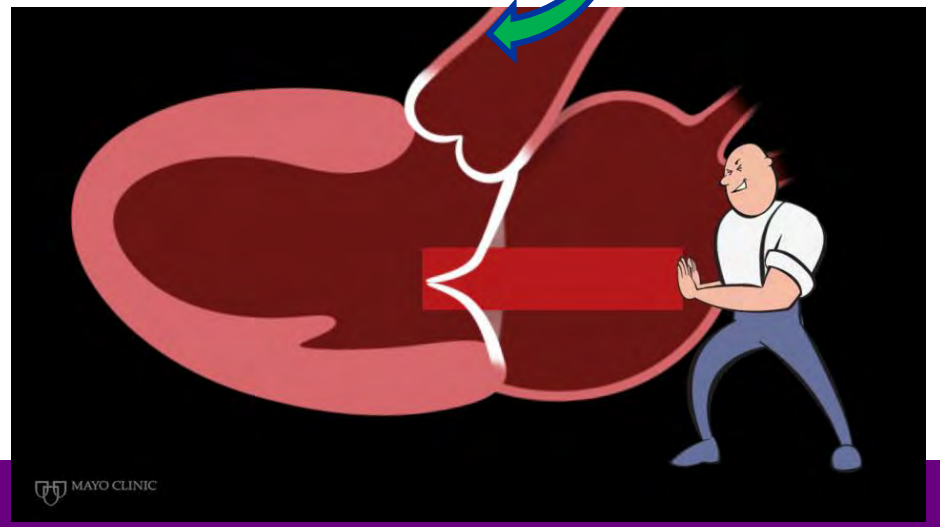


Sohn DW et al: JACC, 1997

Oh JK Circulation 2005

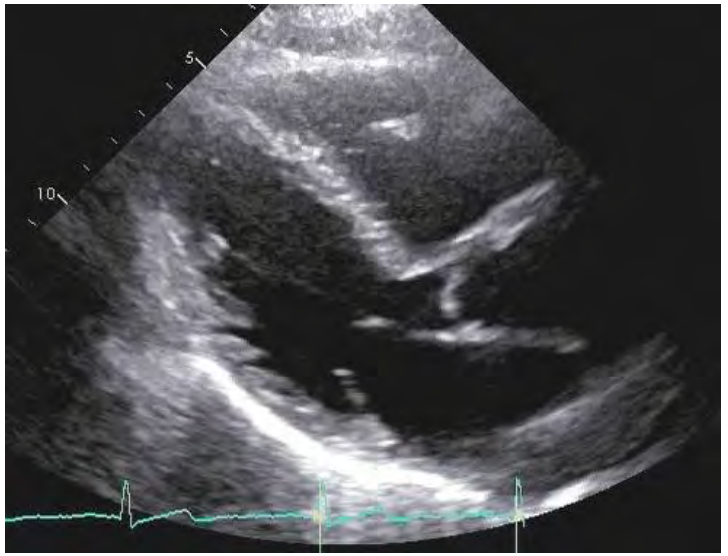


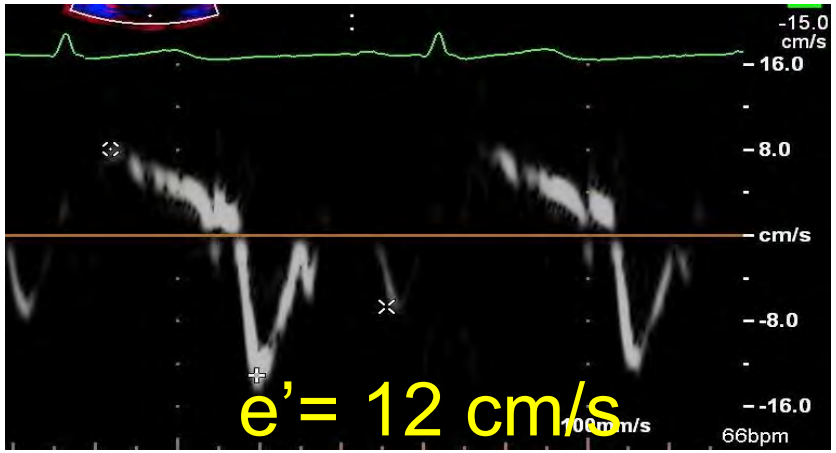
Healthy Pull



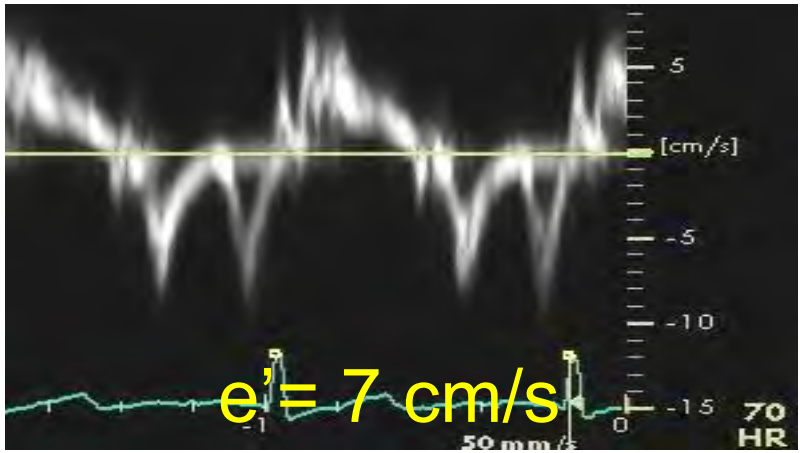
Laborious Push

Myocardial Relaxation (e’)
Normal e’ ≥ 7 cm/s

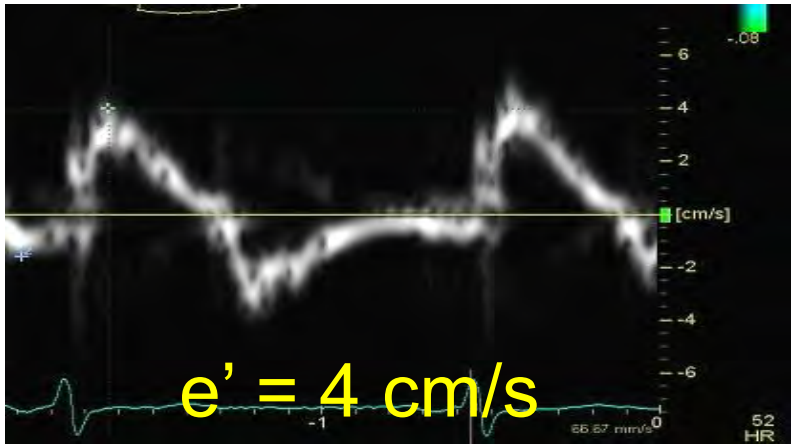




e’= 12 cm/s



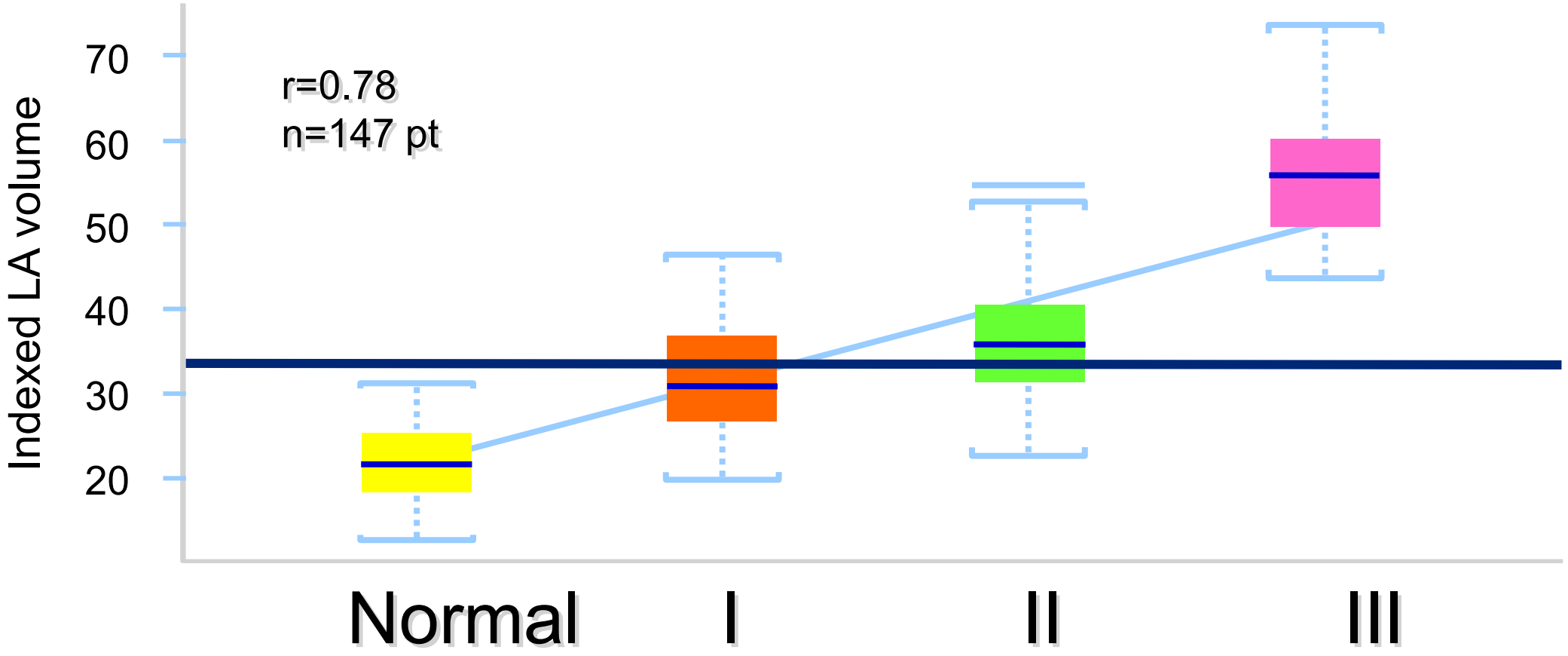
e’= 7 cm/s



e’ = 4 cm/s

MAYO CLINIC

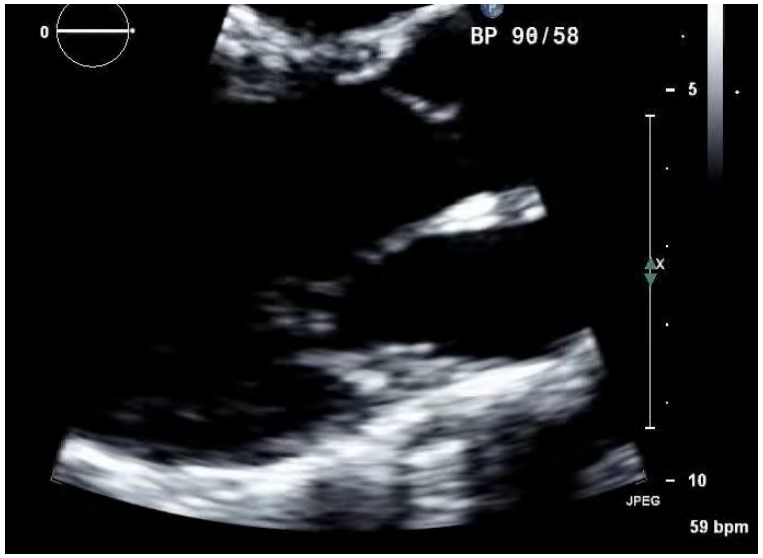
LA Volume Index vs Diastolic Dysfunction

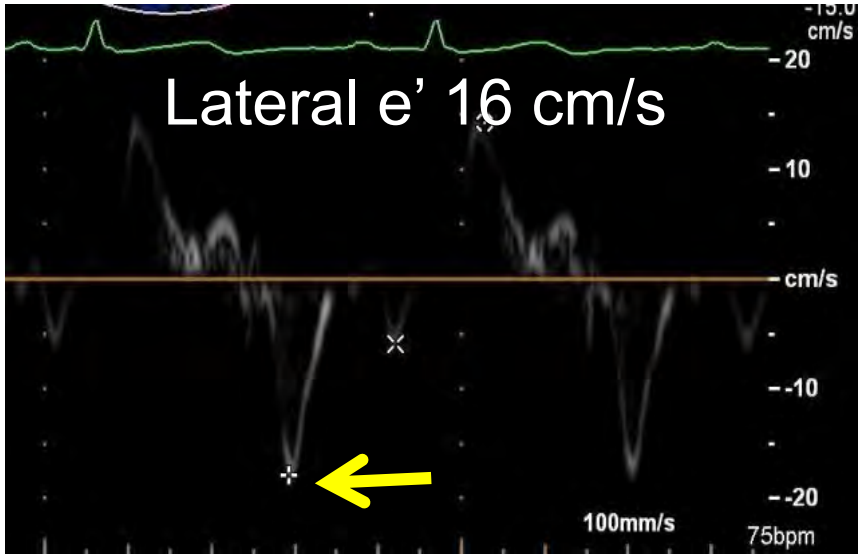


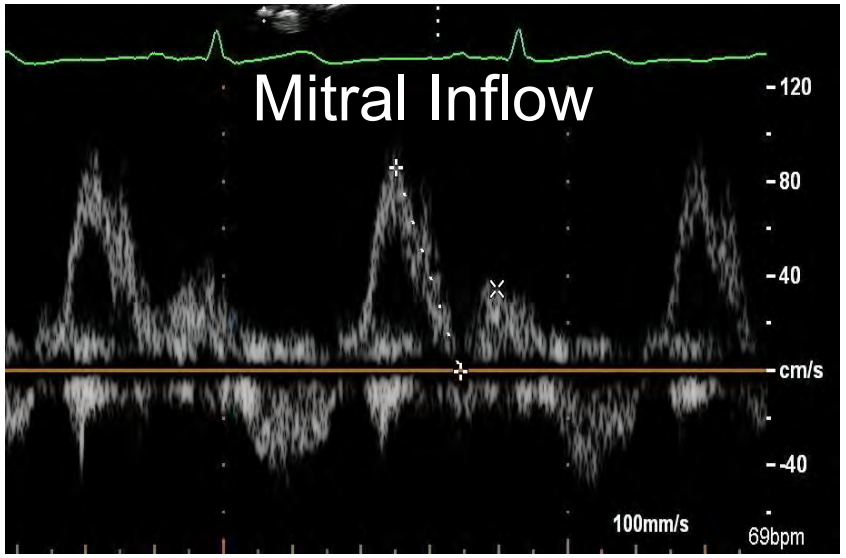
Tsang et al AJC 2002

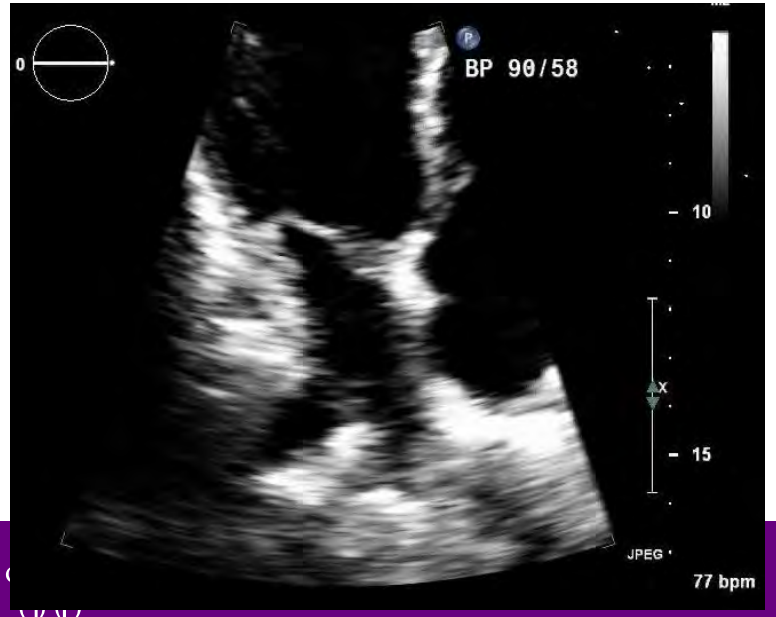
True Normal Diastolic Function

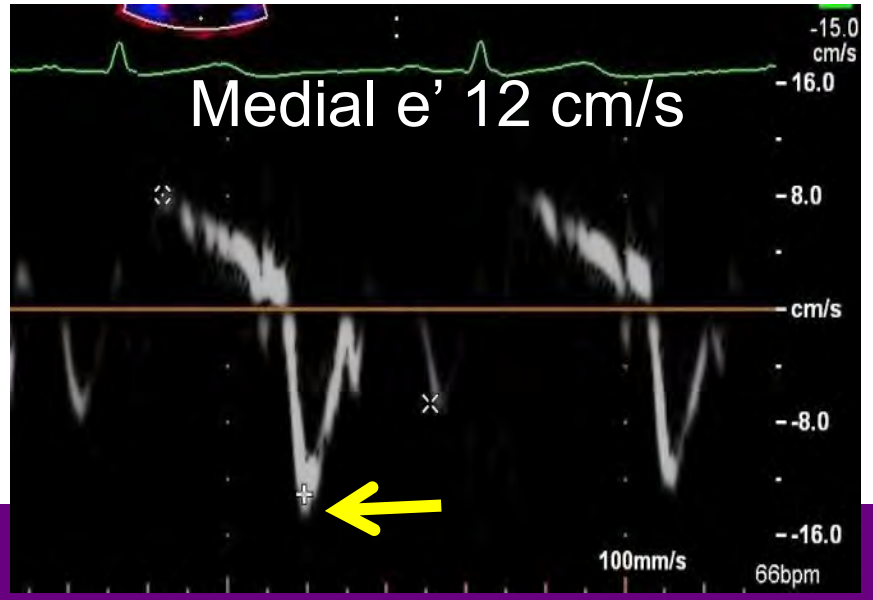
Normal Dilation with Normal Relaxation (e')

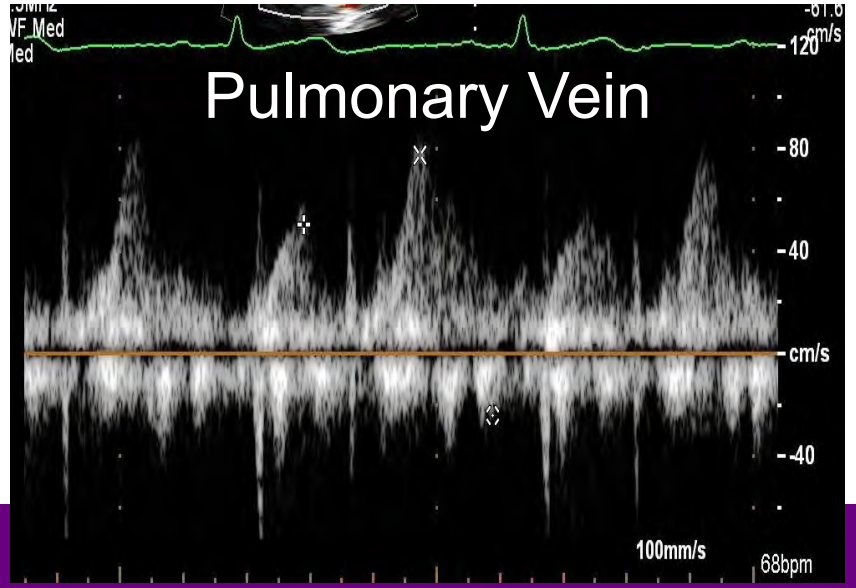






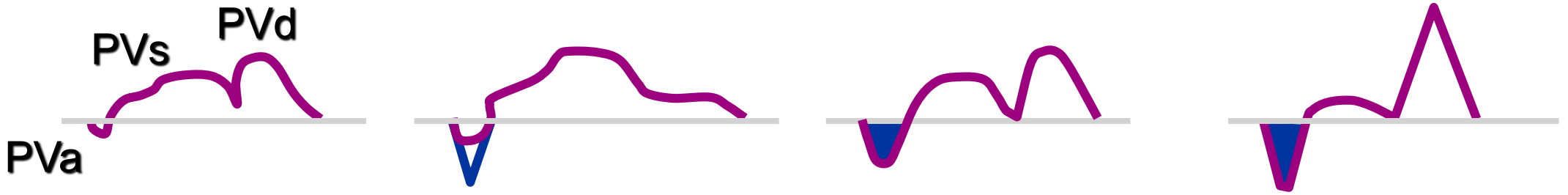






Pulmonary Vein Velocity

PVs decreases as filling pressure increases

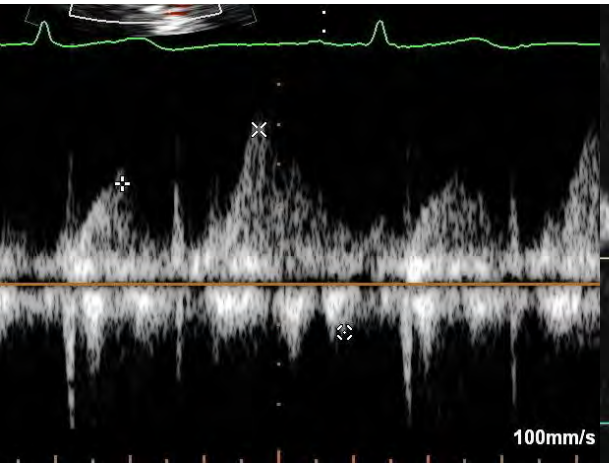


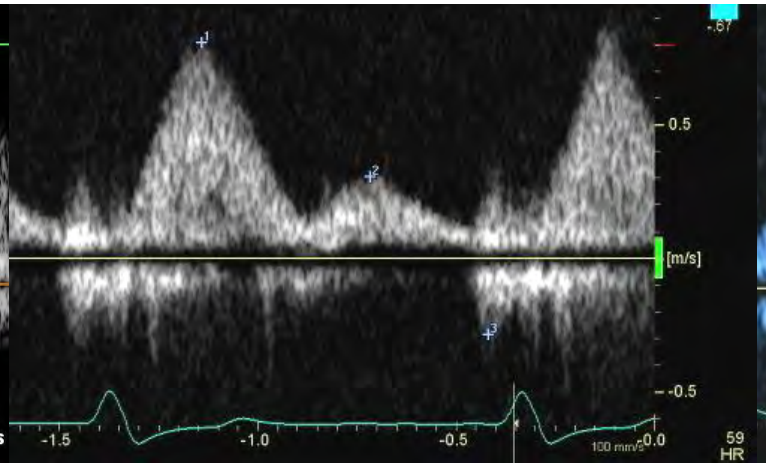
Normal

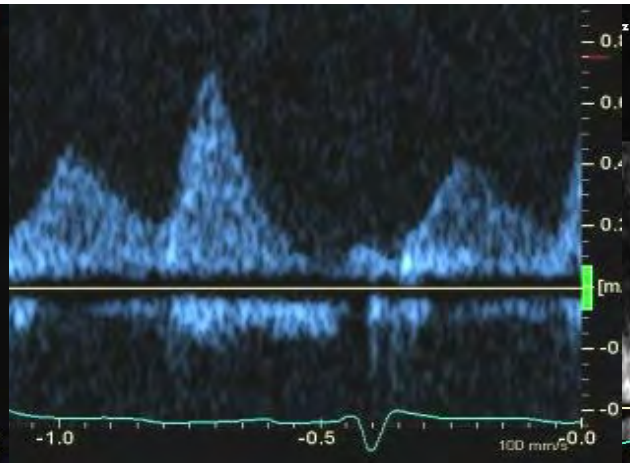
Impaired relaxation

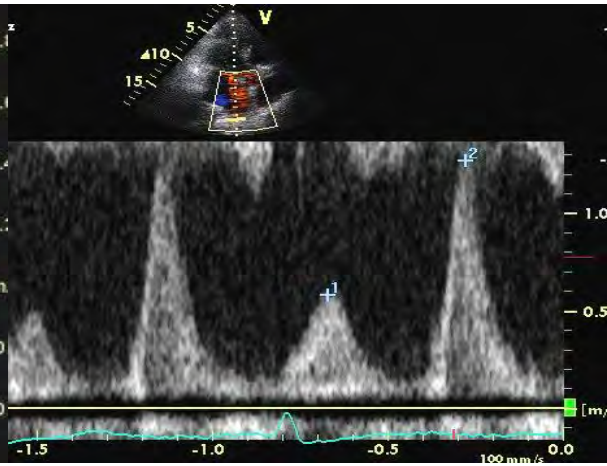
↓ compliance
↑ LAP

↓ compliance
↑↑ LAP





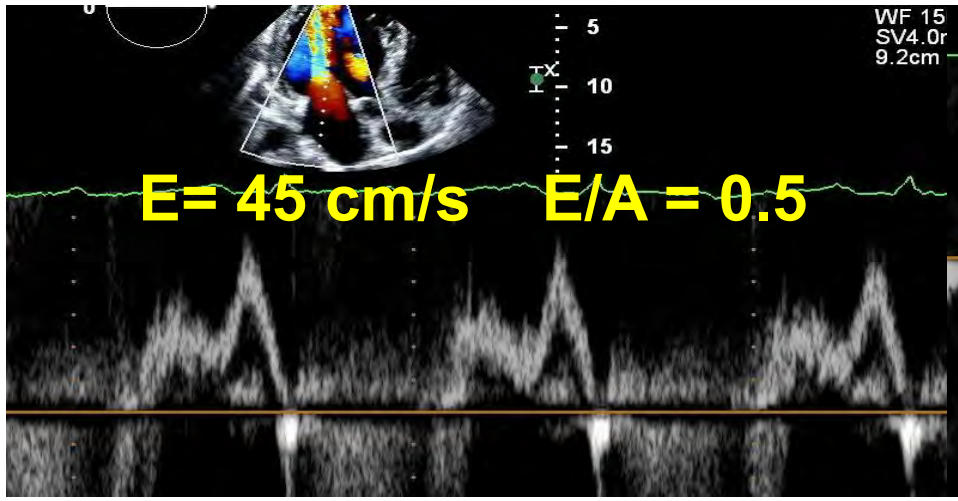


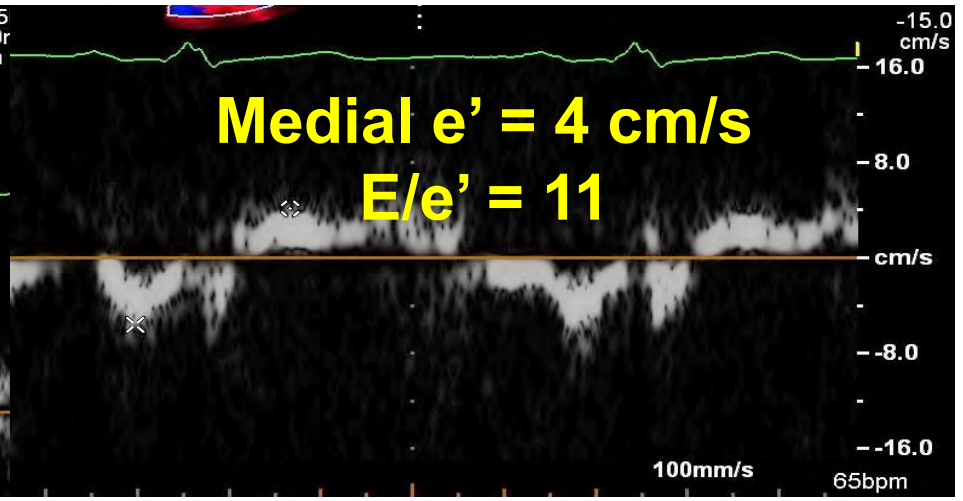


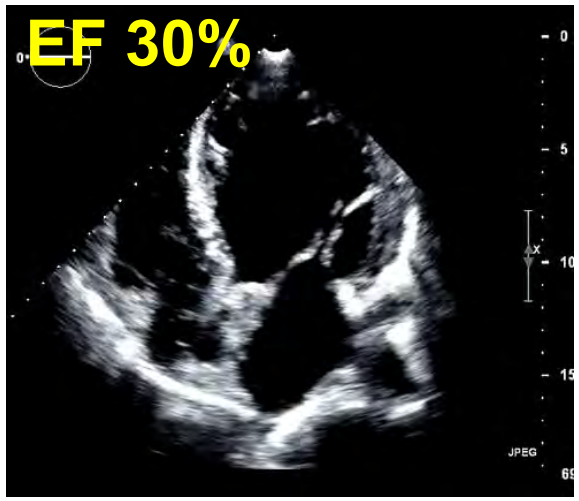
Point to Emphasize

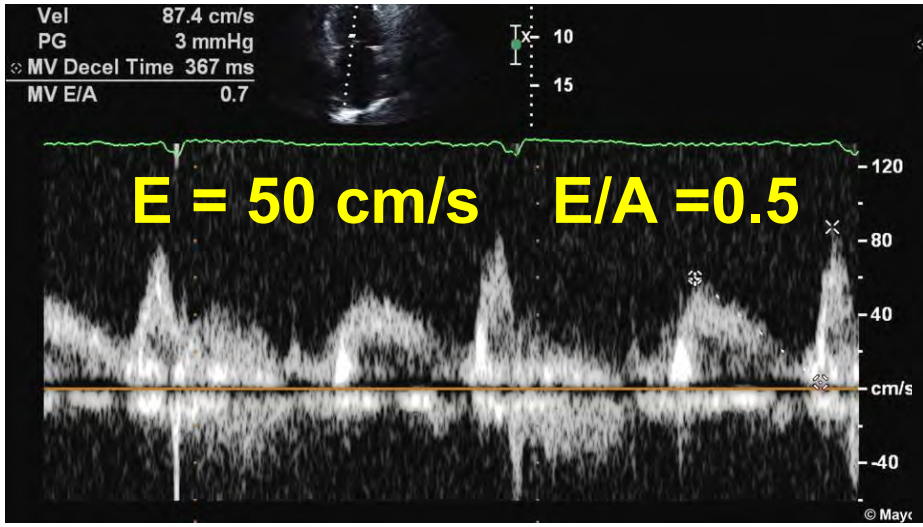
- If myocardial relaxation is normal, diastolic function is normal
- If myocardial relaxation is reduced, diastolic function is abnormal.
  - Medial e’ < 7 cm/sec
  - Lateral e’ <10 cm/sec

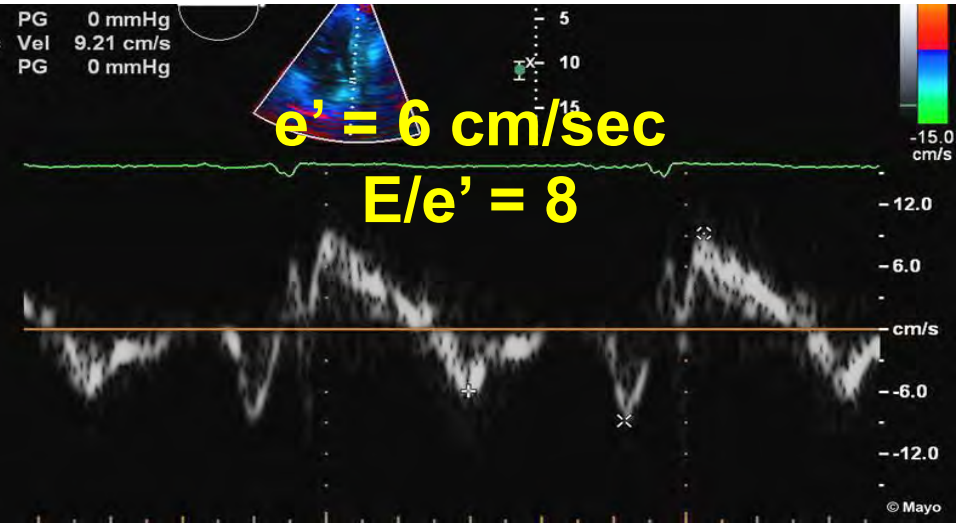
Grade 1 Diastolic Dysfunction (E/A < 0.8 & E/e' <15)

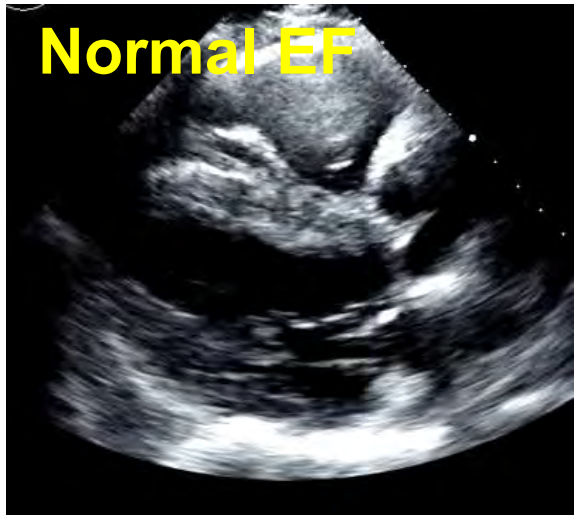








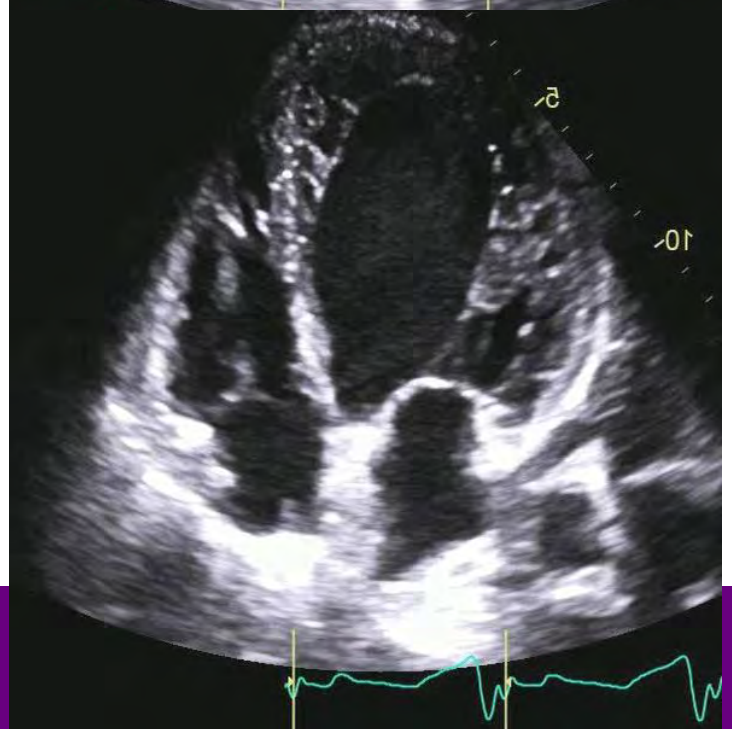


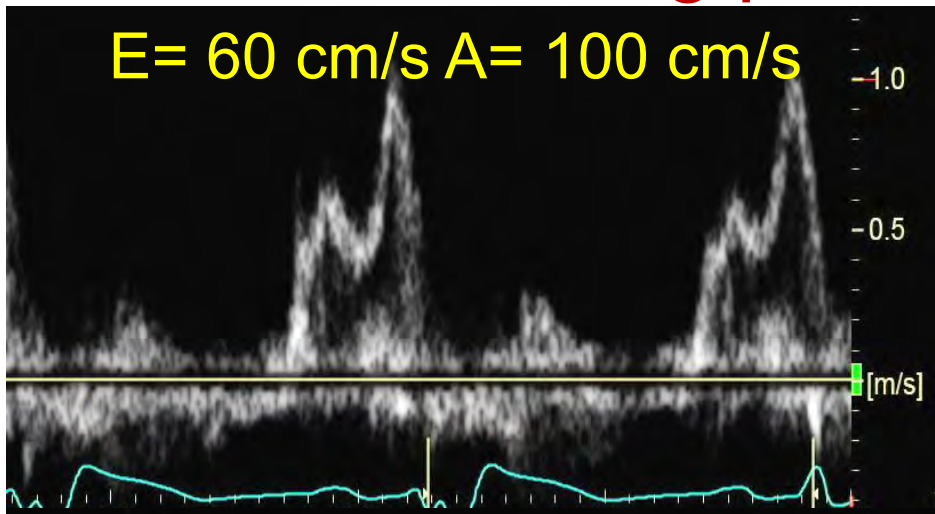


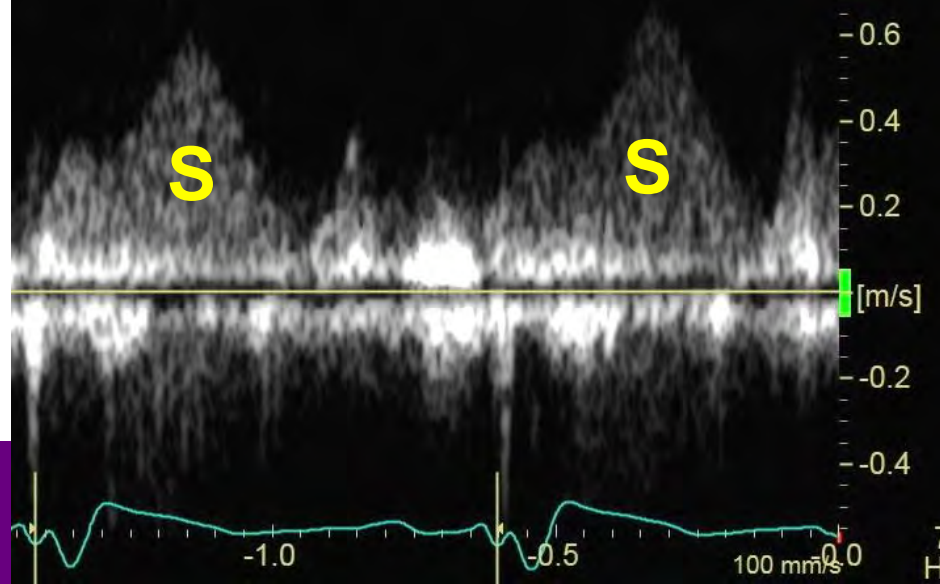
Grade 1 Diastolic Dysfunction

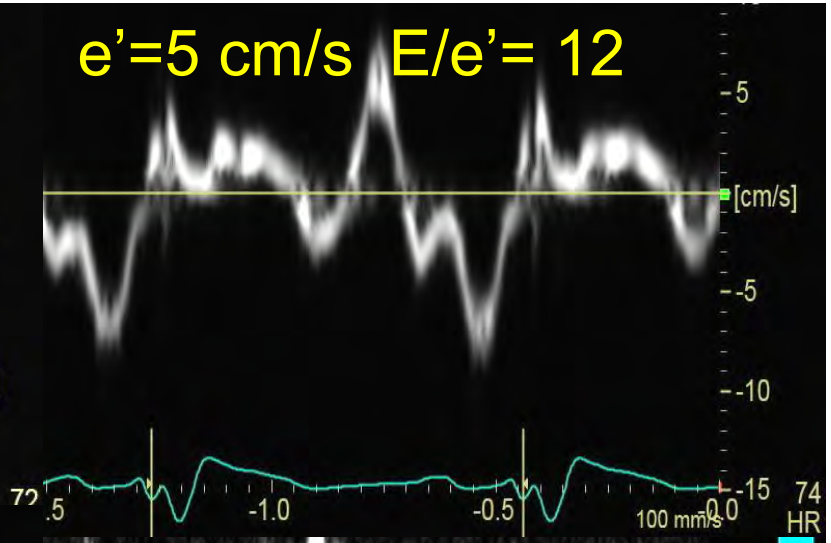
- Main abnormality is reduced relaxation
- Filling pressure is still normal as long as diastolic filling can be completed
- Filling pressure can go up with tachycardia or atrial fibrillation
- Common with aging
- Best diastolic filling in patients with known failure

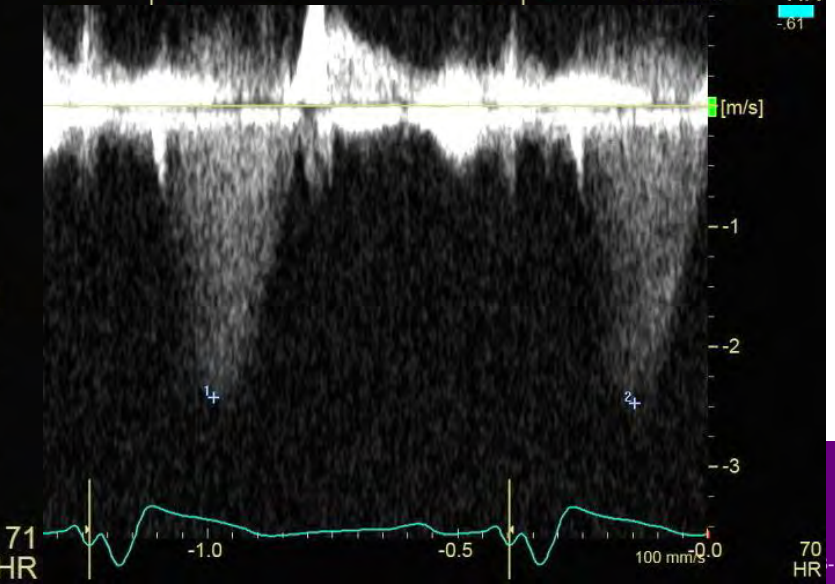
Grade 1 Diastolic Dysfunction in EF 20%
LV filling pressure is normal



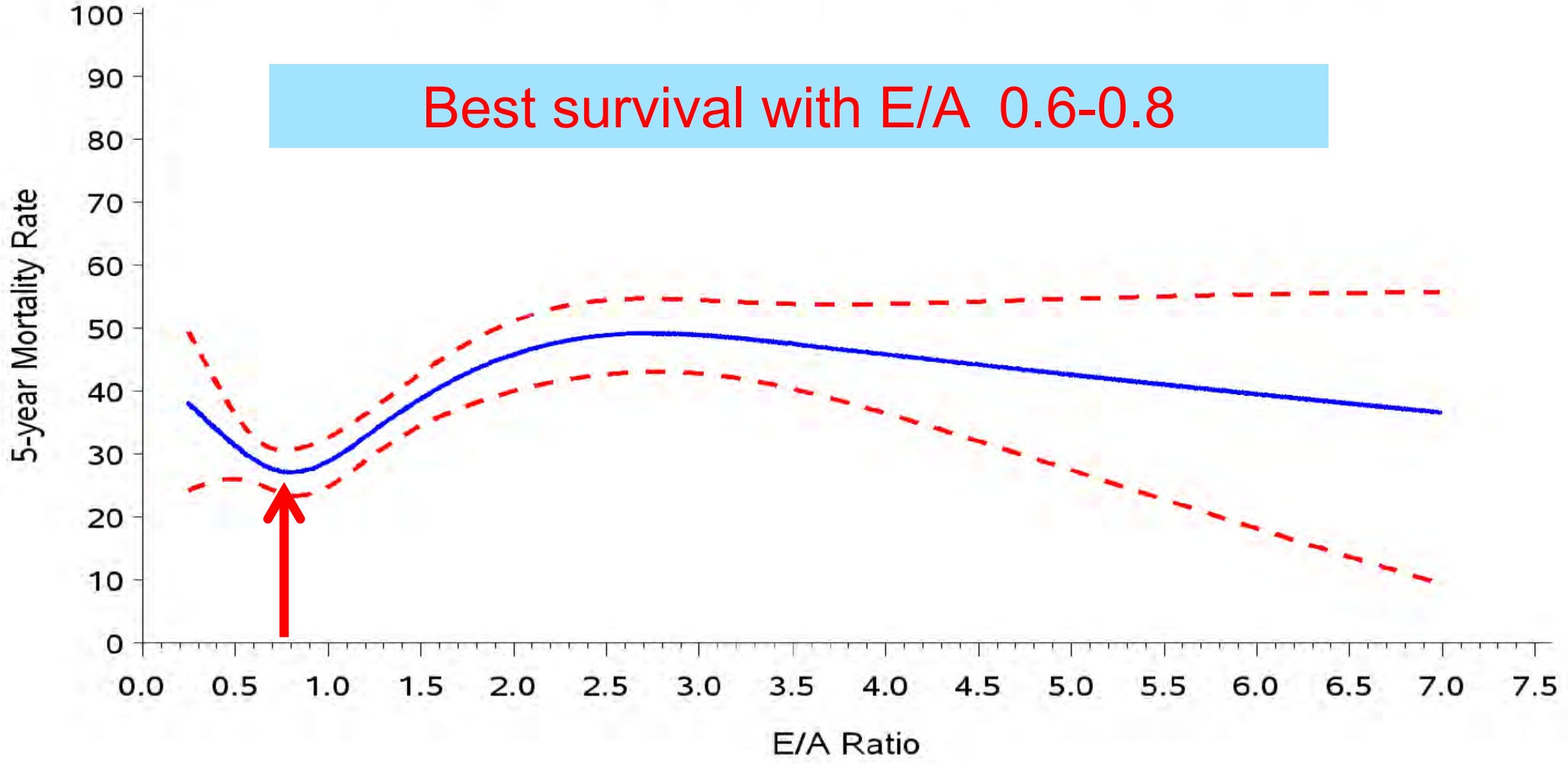








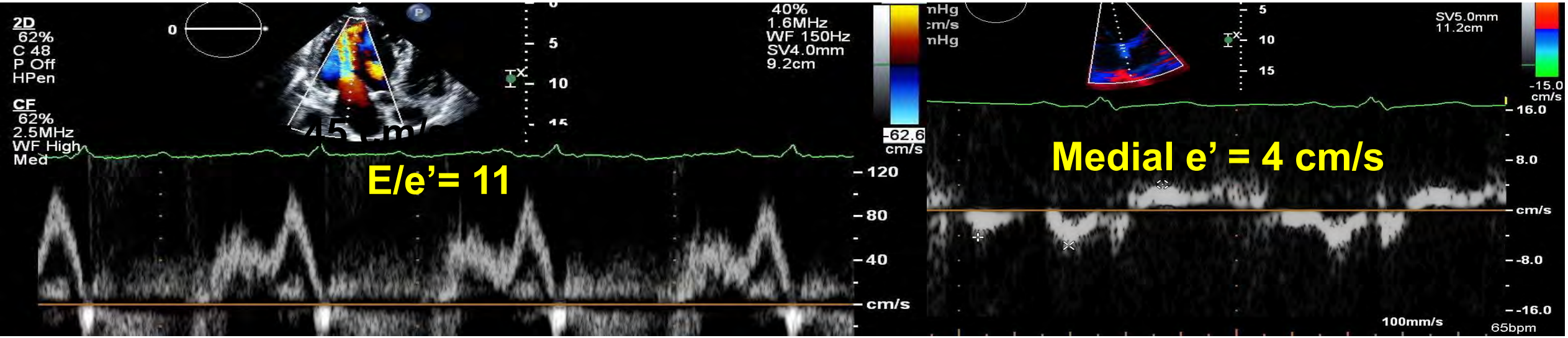
Ischemic Cardiomyopathy Echo Predictor STICH Trial (N=1511)



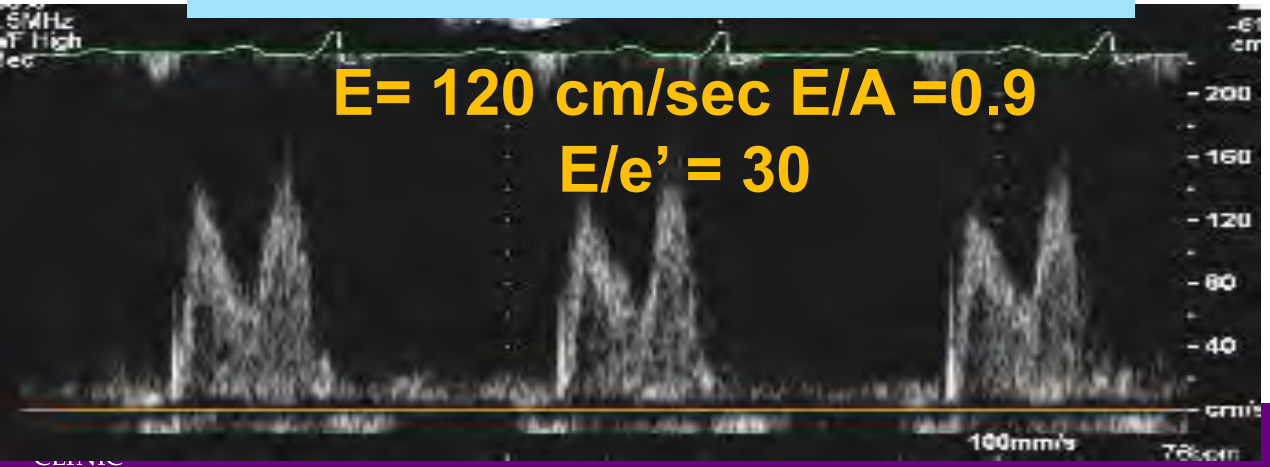
Lin et al. Submitted

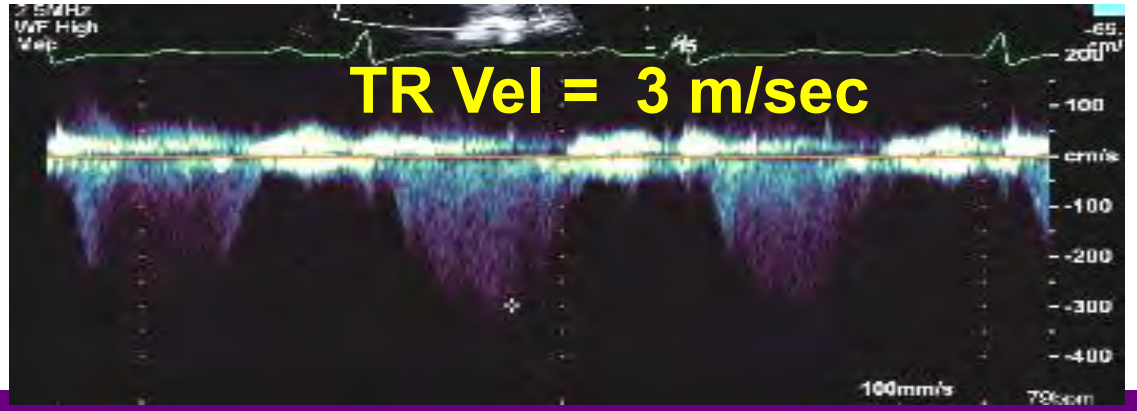
MAYO CLINIC

67 year old man with ischemic CM and HF

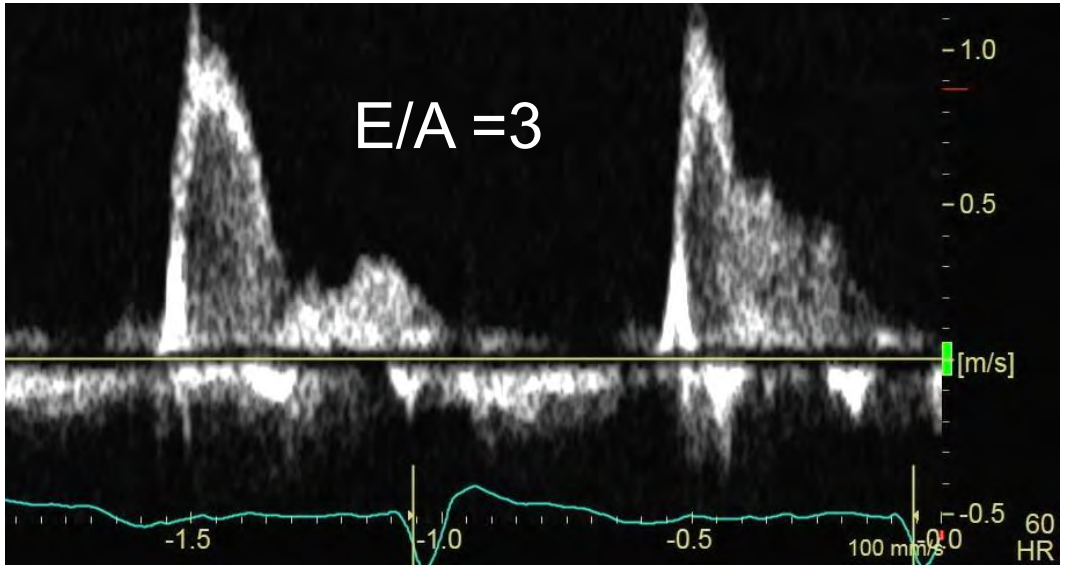


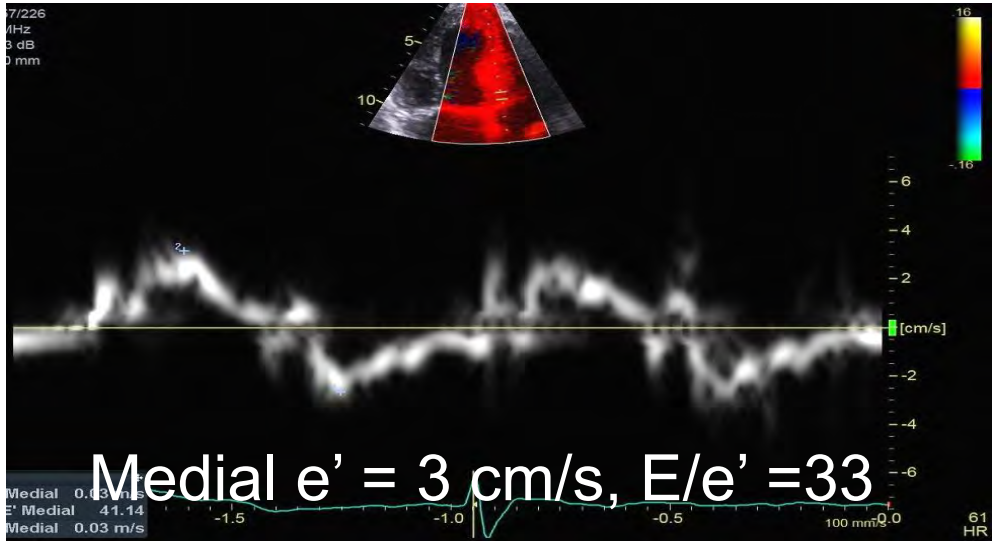
2 months before

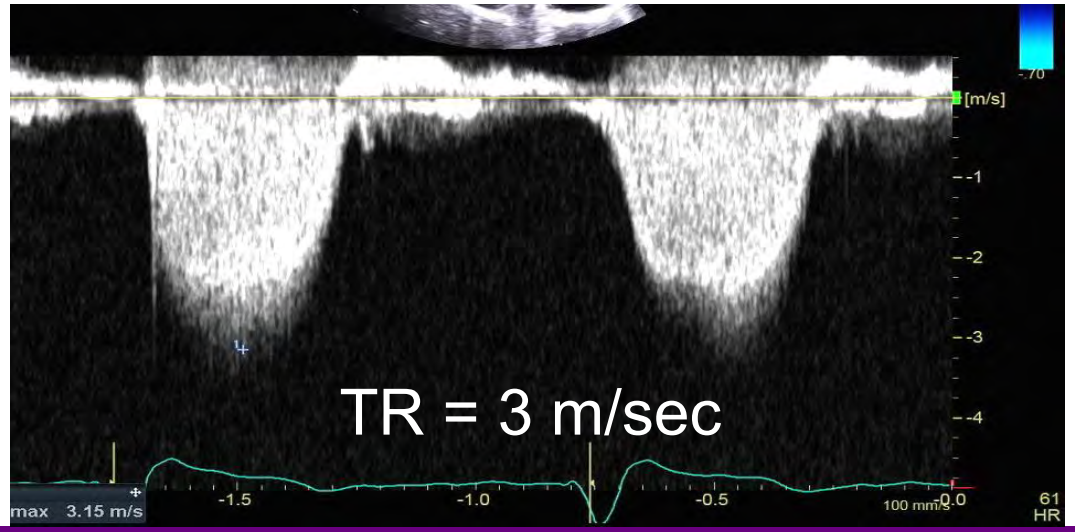


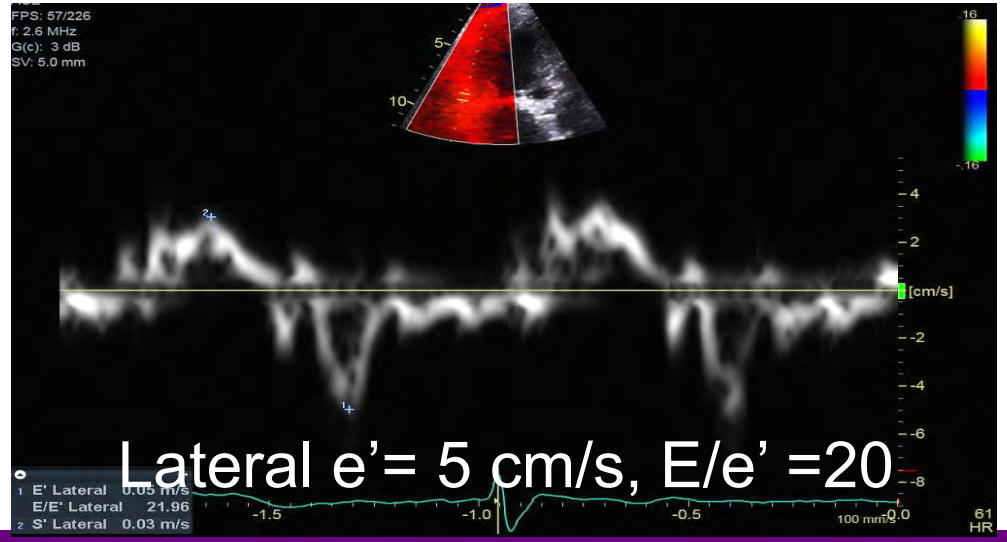


Grade 3 Diastolic Dysfunction (Restrictive Filling)





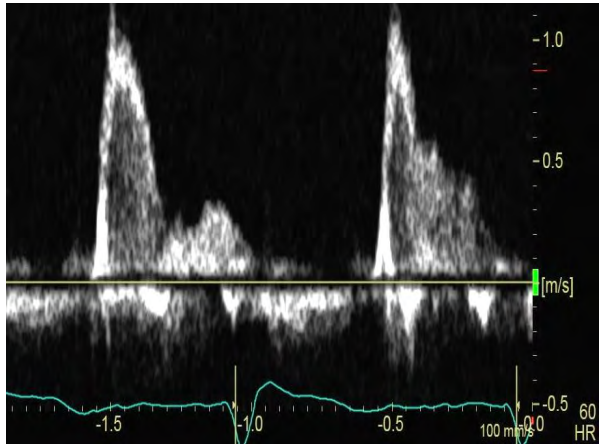


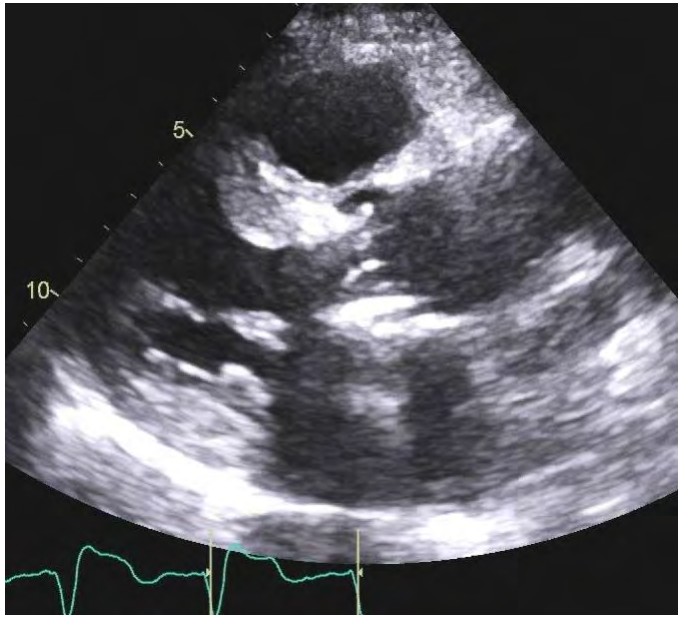


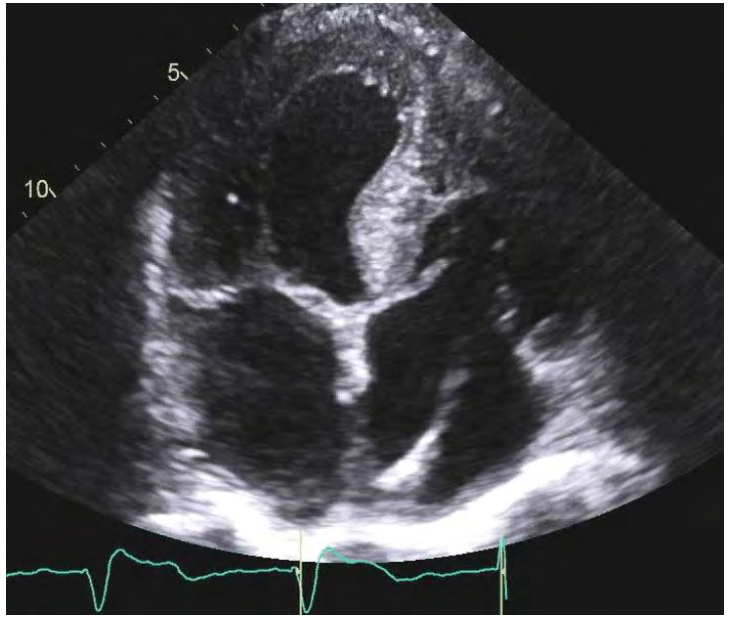
Grade 3 Restrictive Filling Pattern

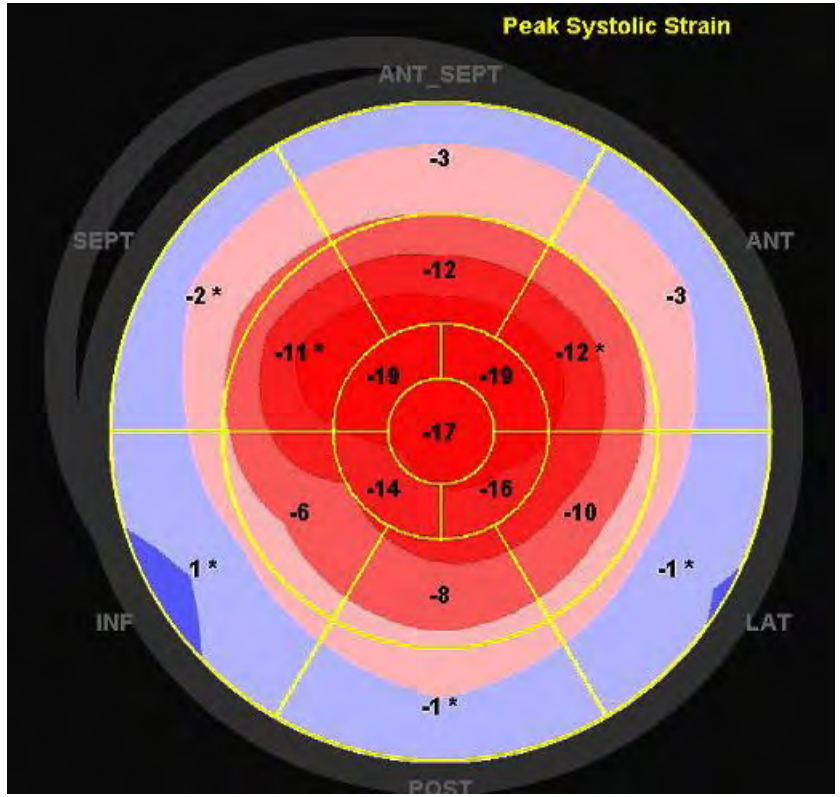
- Relaxation is reduced and filling pressure is markedly elevated (E/e' > 15 and PCWP > 15-20 mmHg)
- Portends a poor prognosis in various CV diseases
- Stroke volume (or diastolic filling volume) is limited, hence bradycardia causes low cardiac output
- Consider amyloidosis or restrictive CM if EF is preserved
- Strain Imaging is MUST

Grade 3 Diastolic Dysfunction





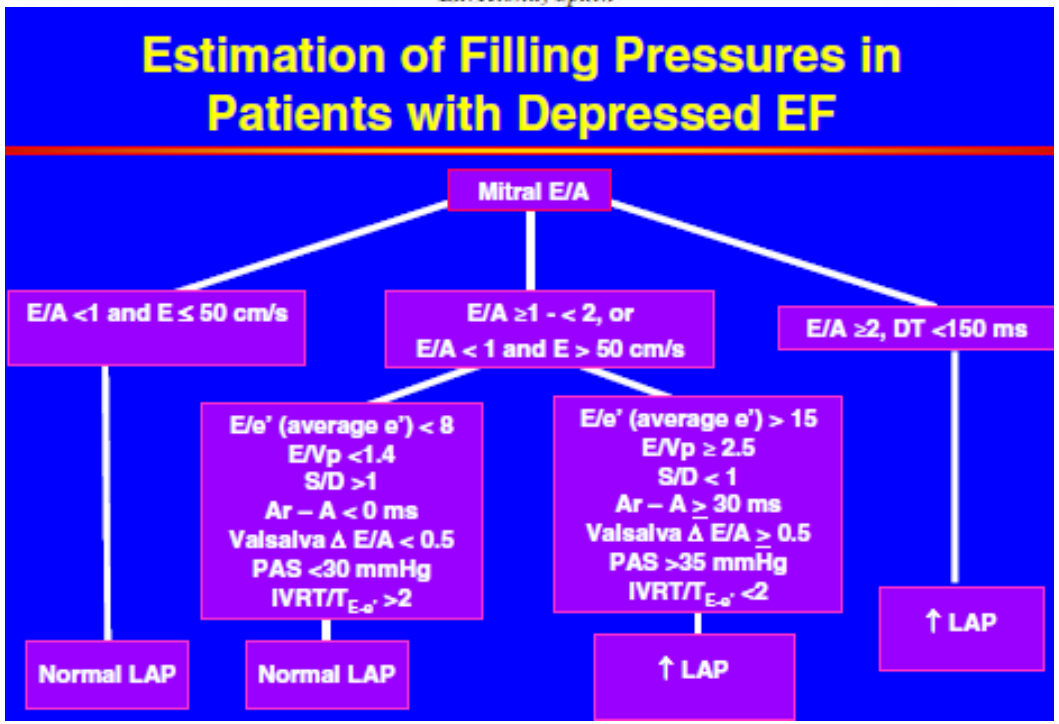




2009 GUIDELINES AND STANDARDS

Recommendations for the Evaluation of Left Ventricular Diastolic Function by Echocardiography

Sherif F. Nagueh, MD, Chair,† Christopher P. Appleton, MD,† Thierry C. Gillebert, MD,*
Paolo N. Marino, MD,* Jae K. Oh, MD,† Otto A. Smiseth, MD, PhD,*
Alan D. Waggoner, MHS,† Frank A. Flachskampf, MD, Co-Chair,*
Patricia A. Pellikka, MD,† and Arturo Evangelista, MD,* *Houston, Texas; Phoenix, Arizona; Ghent, Belgium; Novara, Italy; Rochester, Minnesota; Oslo, Norway; St. Louis, Missouri; Erlangen, Germany; Barcelona, Spain*



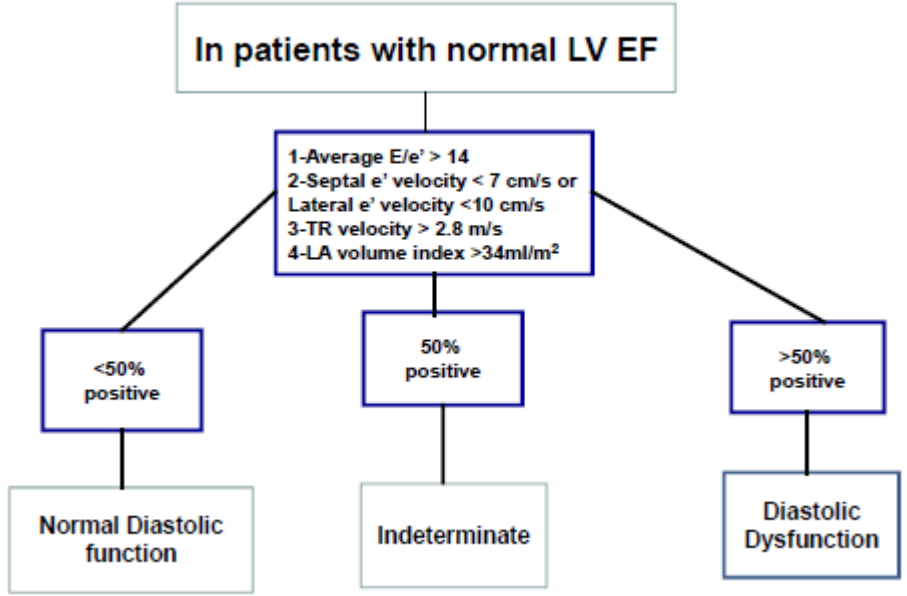
9 Variables using 3 algorithms

ASE/EACVI GUIDELINES AND STANDARDS

2016

Recommendations for the Evaluation of Left Ventricular Diastolic Function by Echocardiography: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging

Sherif F. Nagueh, Chair, MD, FASE,[1] Otto A. Smiseth, Co-Chair, MD, PhD,[2] Christopher P. Appleton, MD,[1]
Benjamin F. Byrd, III, MD, FASE,[1] Hisham Dokainish, MD, FASE,[1] Thor Edvardsen, MD, PhD,[2]
Frank A. Flachskampf, MD, PhD, FESC,[2] Thierry C. Gillebert, MD, PhD, FESC,[2] Allan L. Klein, MD, FASE,[1]
Patrizio Lancellotti, MD, PhD, FESC,[2] Paolo Marino, MD, FESC,[2] Jae K. Oh, MD,[1]
Bogdan Alexandru Popescu, MD, PhD, FESC, FASE,[2] and Alan D. Waggoner, MHS, RDCS[1], *Houston, Texas; Oslo, No … len; Ghent and Liège, Be… Louis, Missouri*

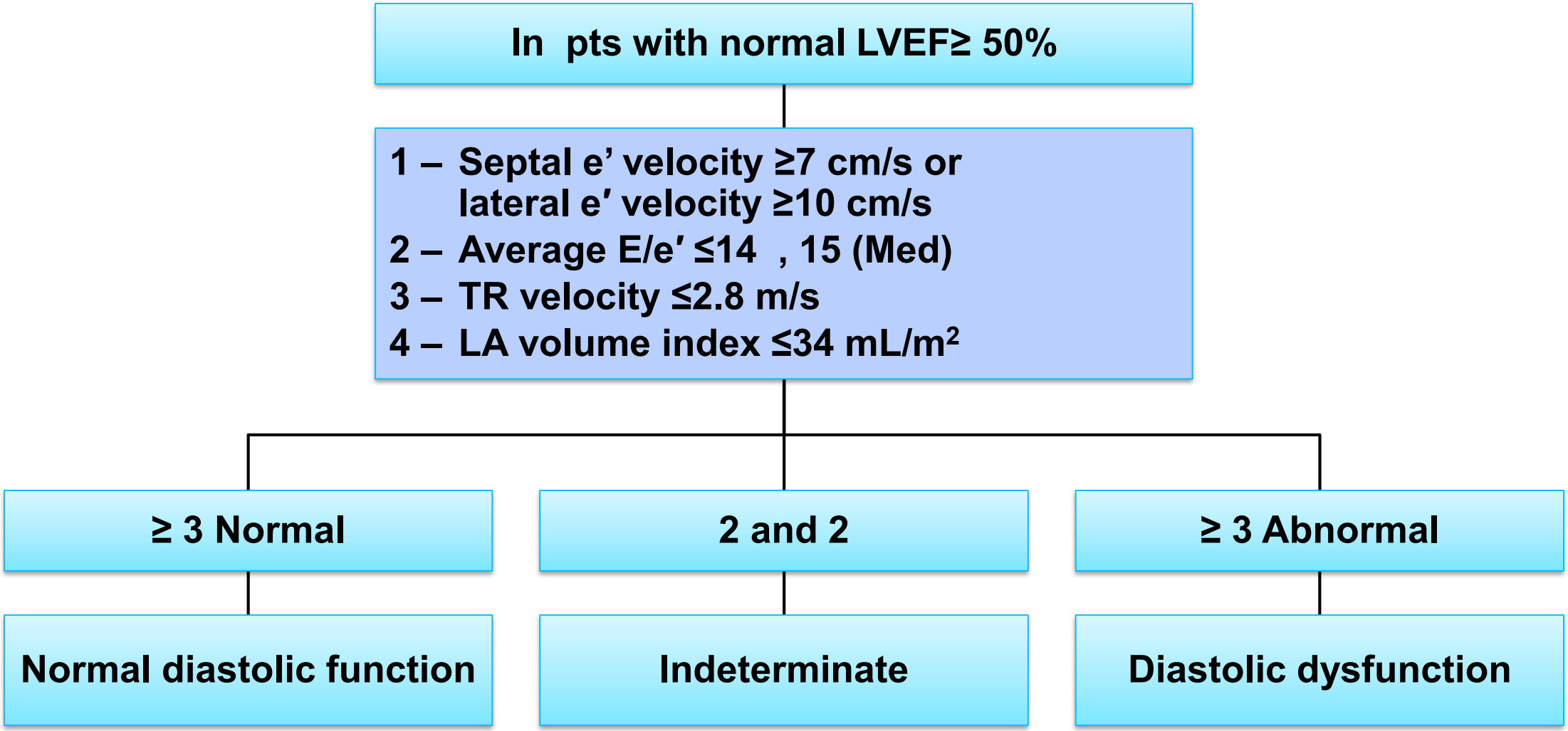


4 Variables using 2 algorithms

Disclosure : I was a member of the 2009 and the 2016 Guideline Committee.

MAYO CLINIC

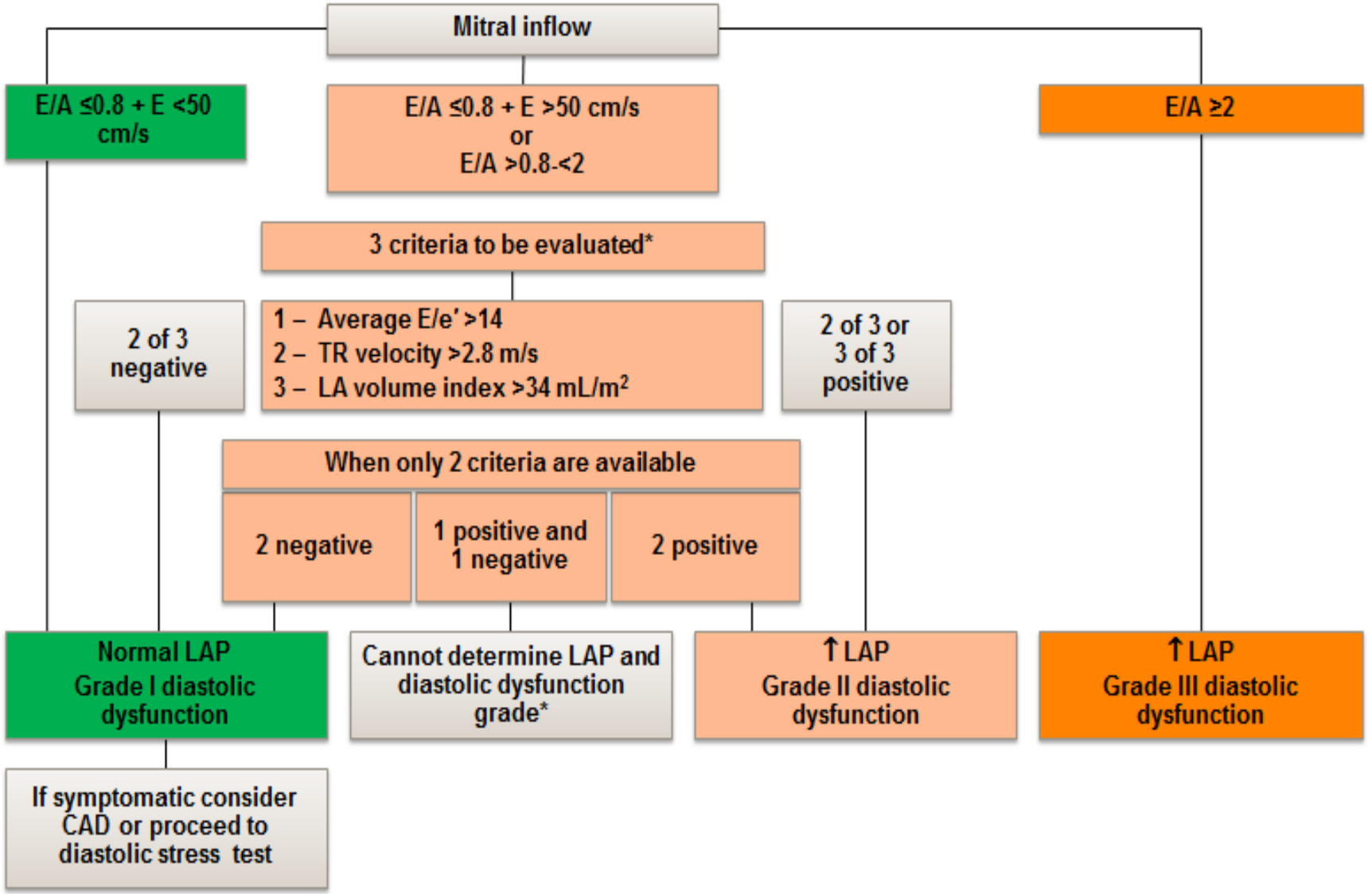
2016 ASE/EACVI #1 Algorithm for Diastolic Function Assessment



Criteria for diagnosis of LV diastolic dysfunction in patients with normal LVEF in JASE 2016

The 2016 Algorithm for Reduced EF (<50%) or Known (or Suspected) Diastolic Dysfunction/EF≥50%

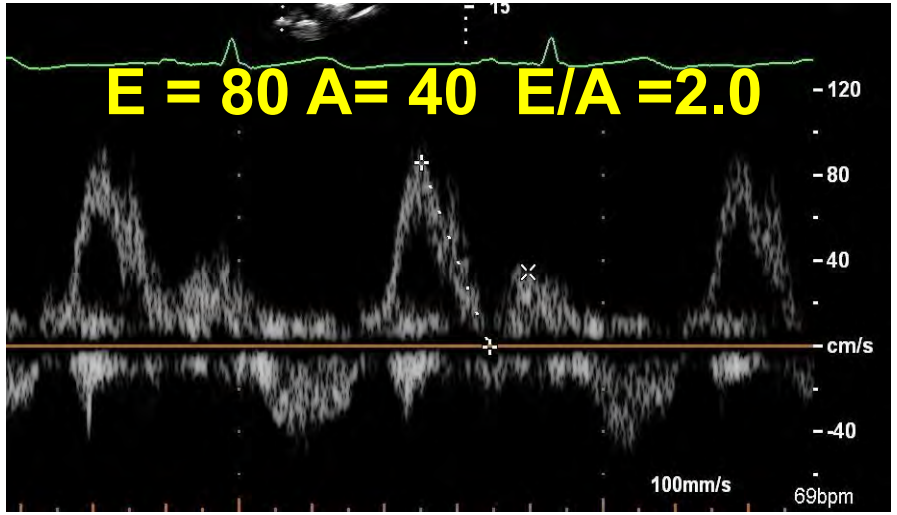
(Hypertension, CAD, Diabetes, MI, History of HF, LVH, LAE)

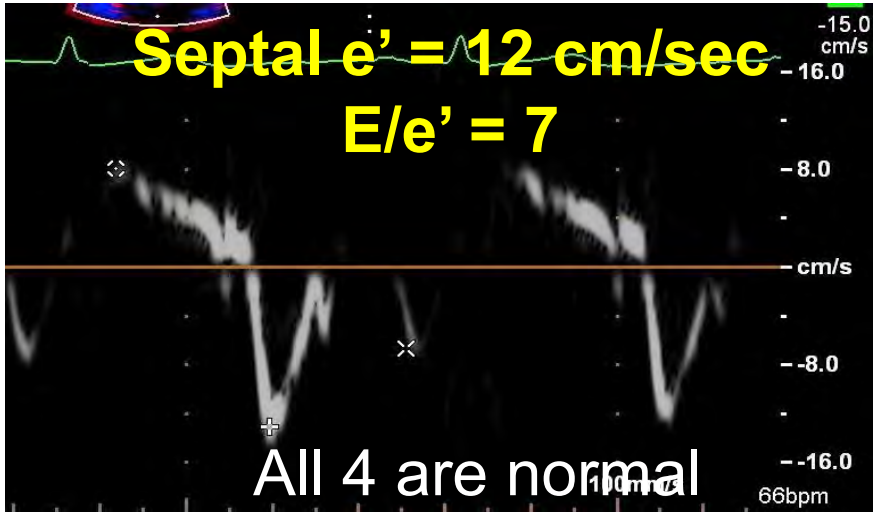


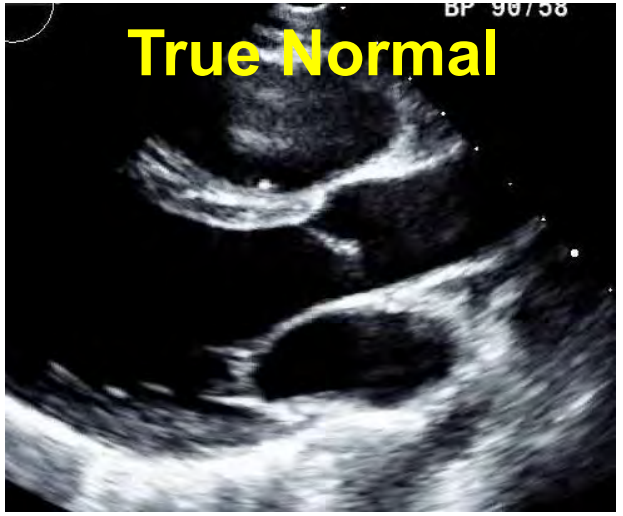
MAYO CLINIC

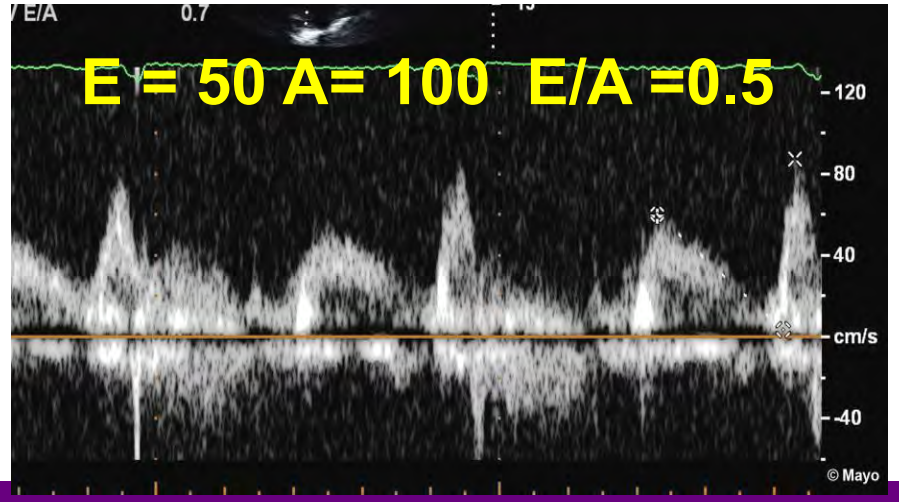
#24 Normal Diastolic Function According to 2016 Guideline

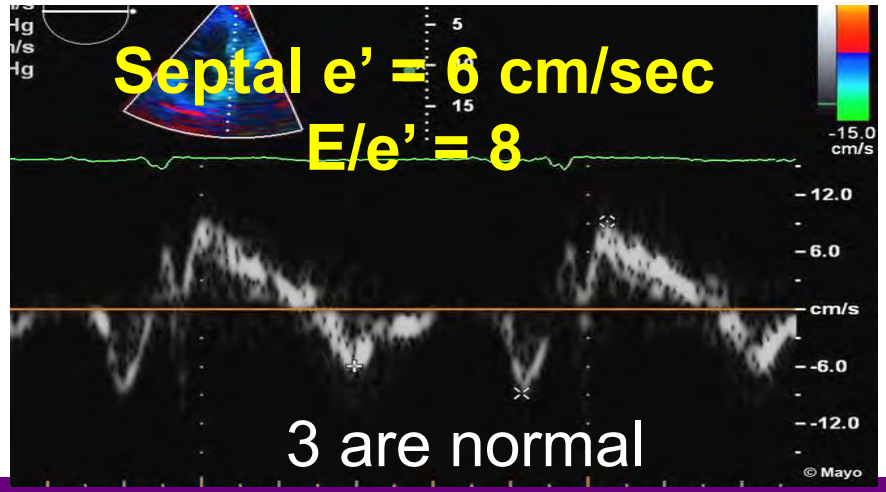
Both have LAVI < 34 mL/m^2 and TR < 2.8 m/sec

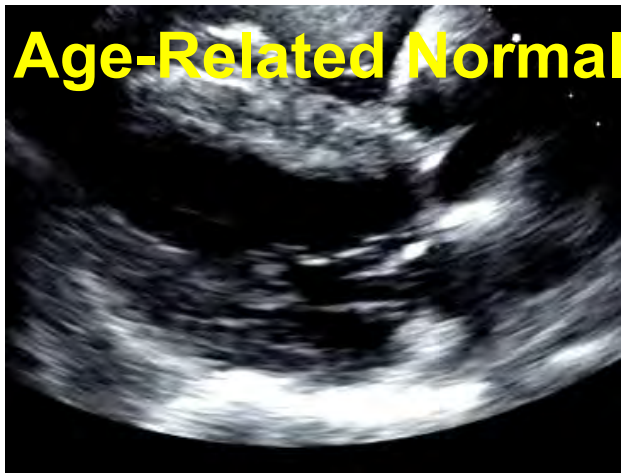








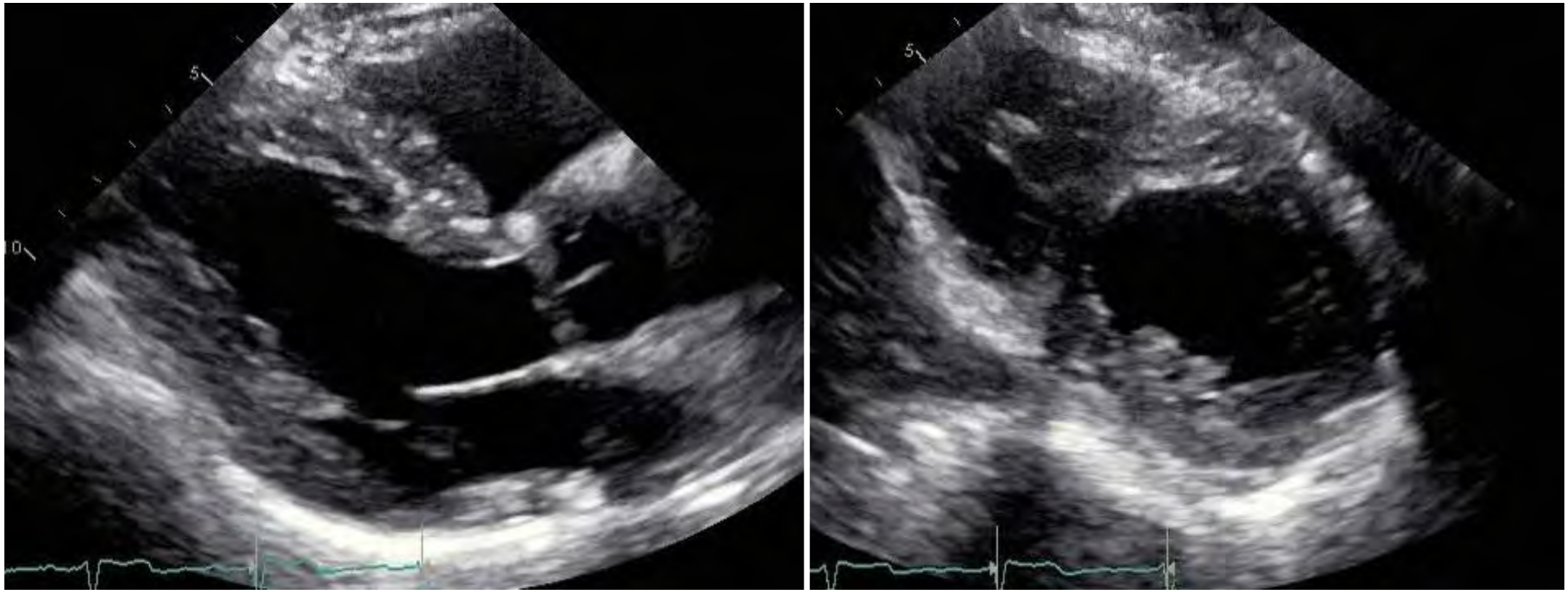




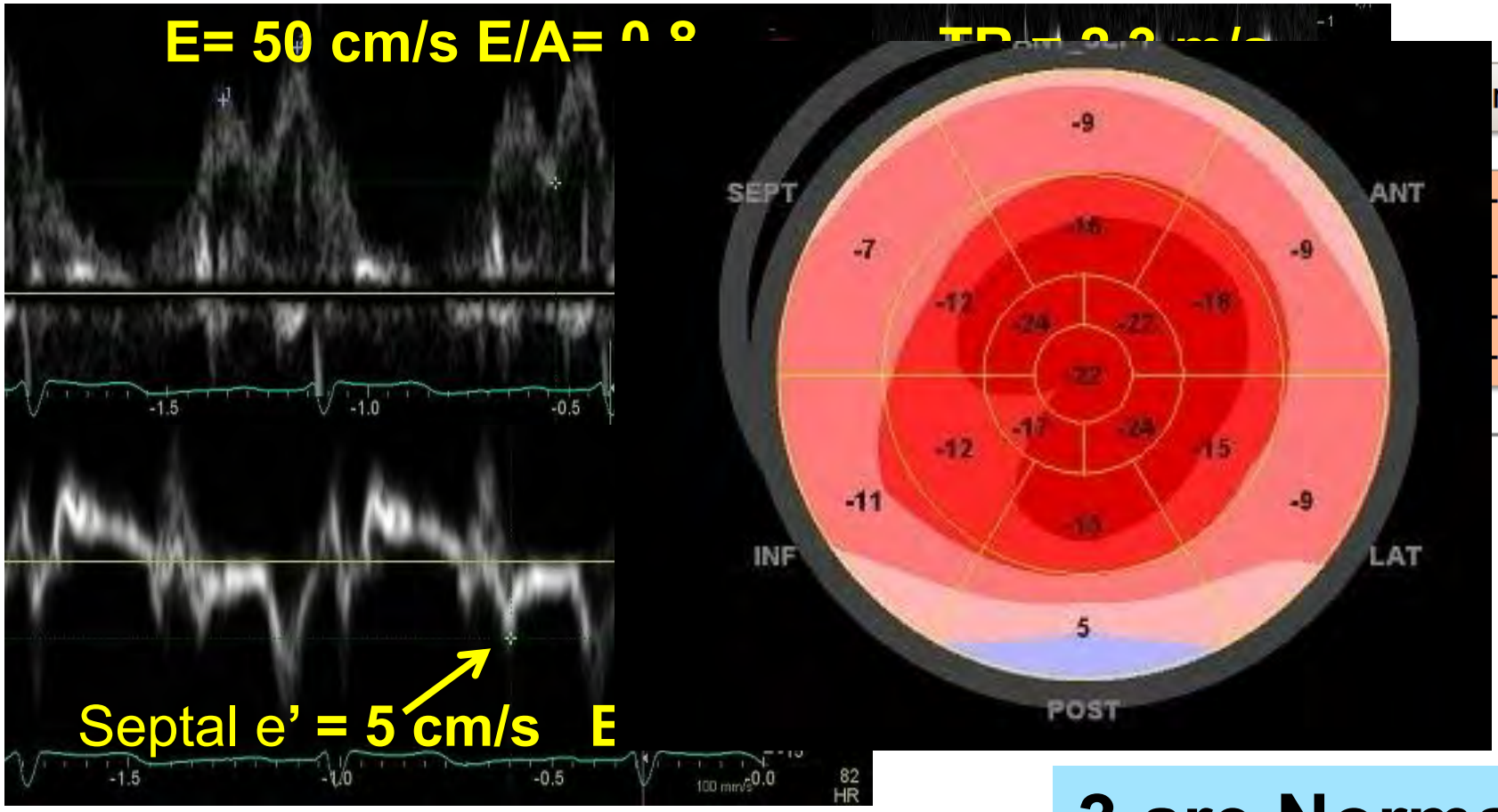
#25

59 year old male with multiple myeloma
No cardiac symptoms

LAVI = 28 mL/m^2



59 year old male with multiple myeloma
No cardiac symptoms



n pts with normal LVEF≥ 50%

- Septal e' velocity ≥7 cm/s or lateral e' velocity ≥10 cm/s
- Average E/e' ≤14 , 15 (Med)
- TR velocity ≤2.8 m/s
- LA volume index ≤34 mL/m^2

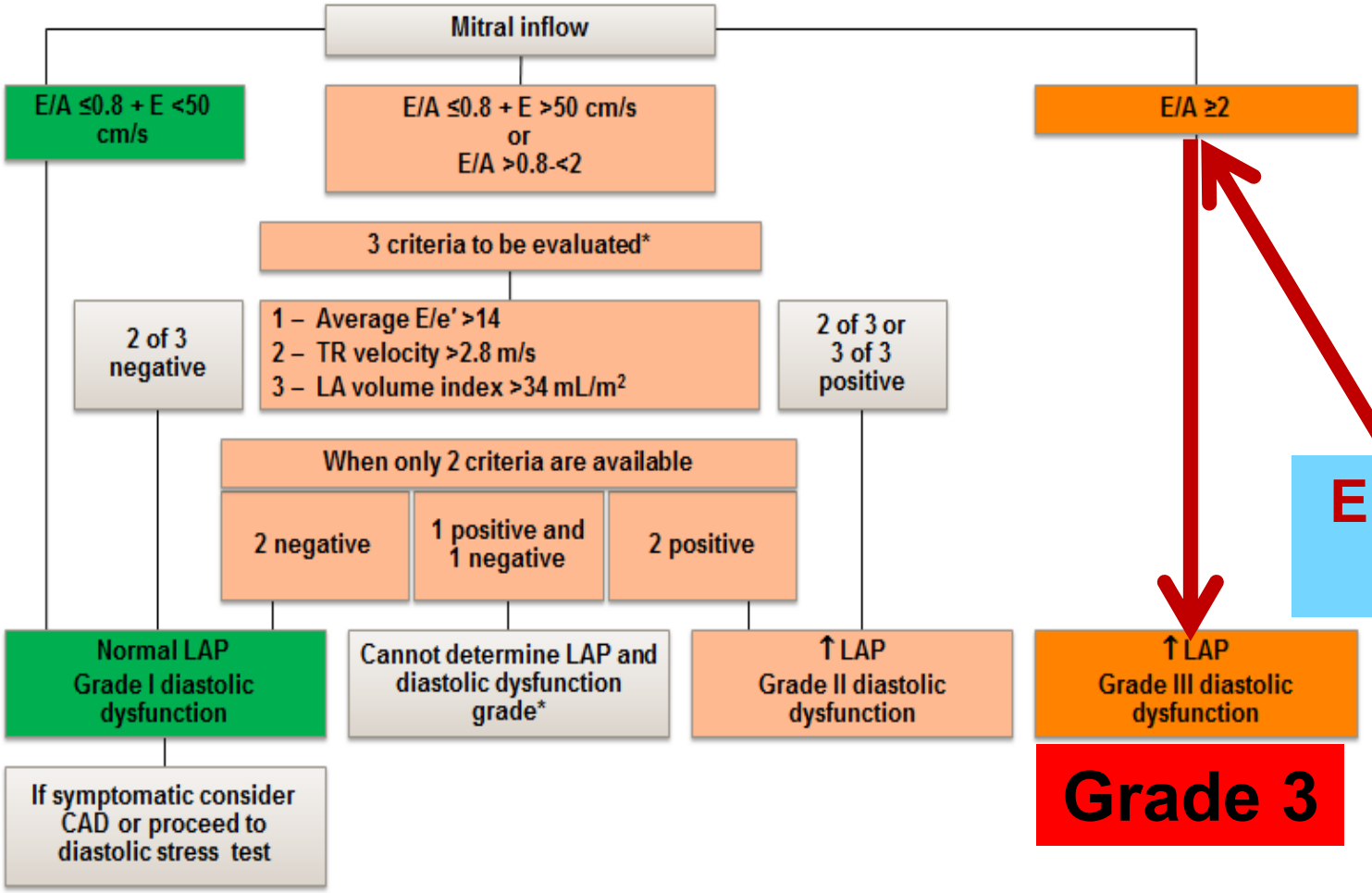
2 and 2	≥ 3 Abnormal
Indeterminate	Diastolic dysfunction

3 are Normal → **Normal DF**

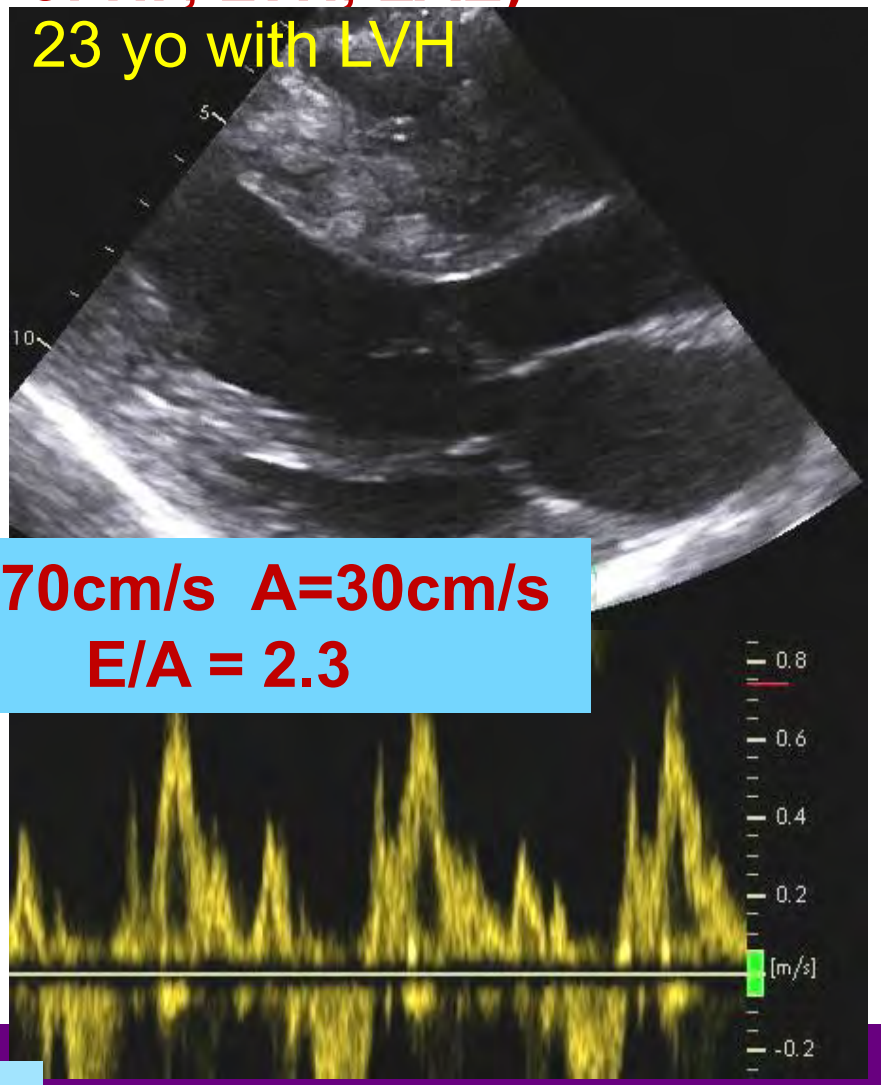
#26

The 2016 Algorithm for Reduced EF (<50%) or Known (or Suspected) Diastolic Dysfunction/EF≥50%

(Hypertension, CAD, Diabetes, MI, History of HF, LVH, LAE)



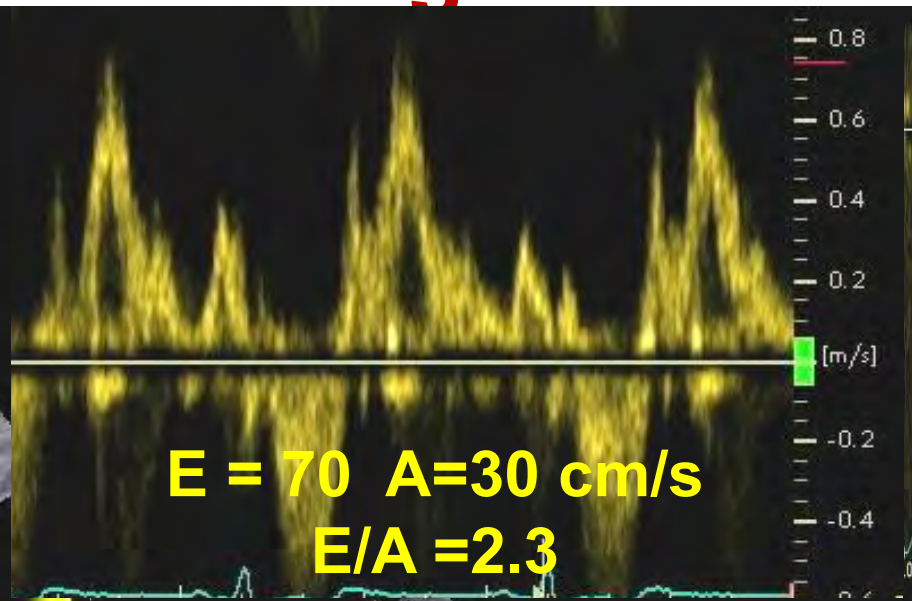
Grade 3

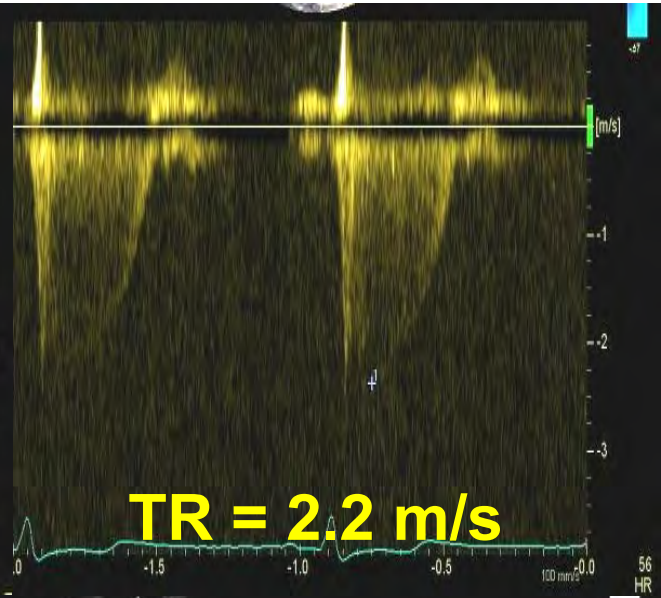


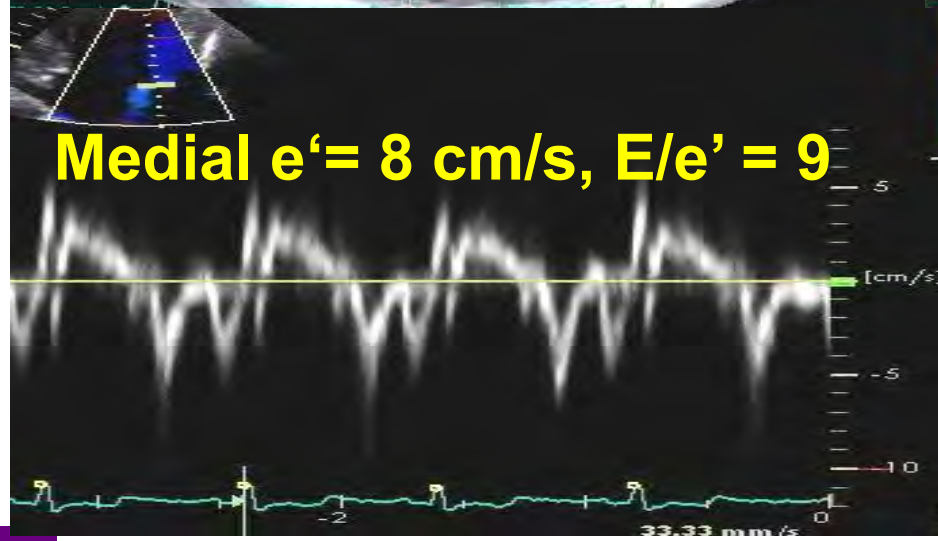
1= Grade 1 2= Grade 2 3= Grade 3 4= Normal

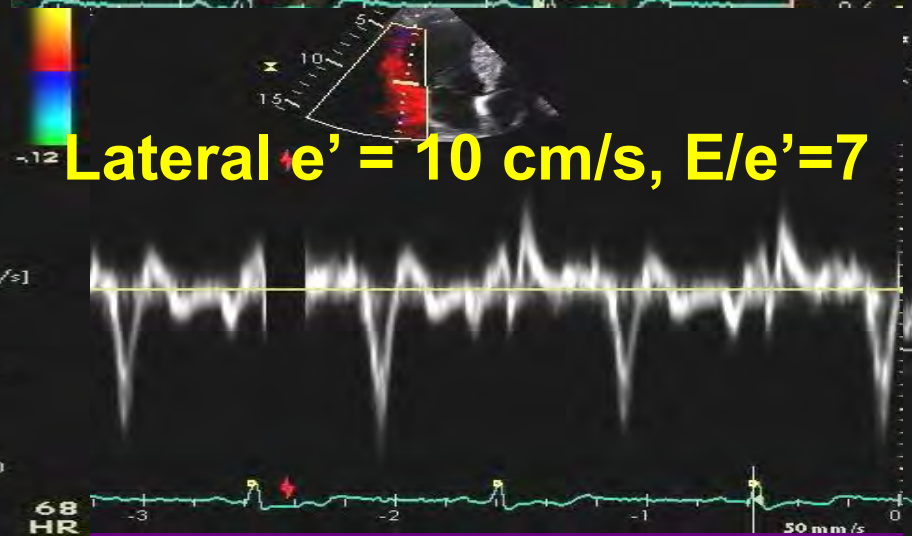
23 year old male with LVH in ECG

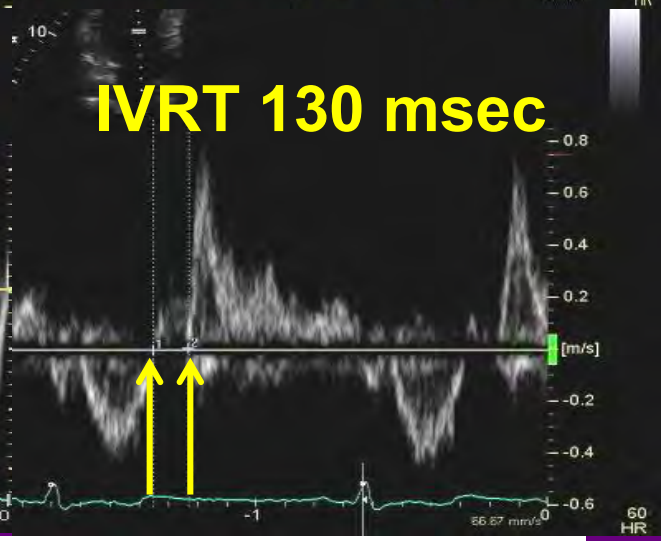
Normal Filling Pressure







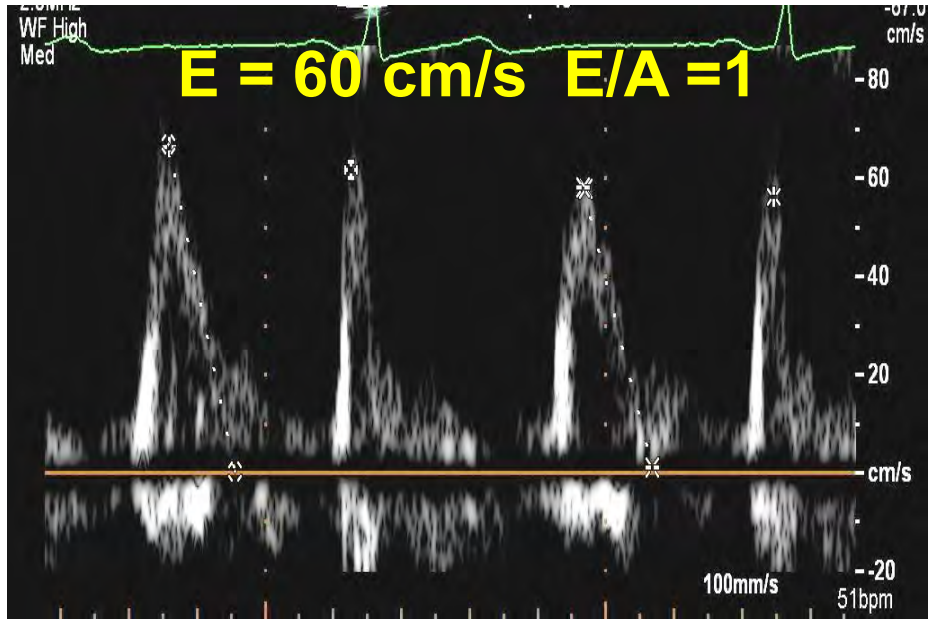


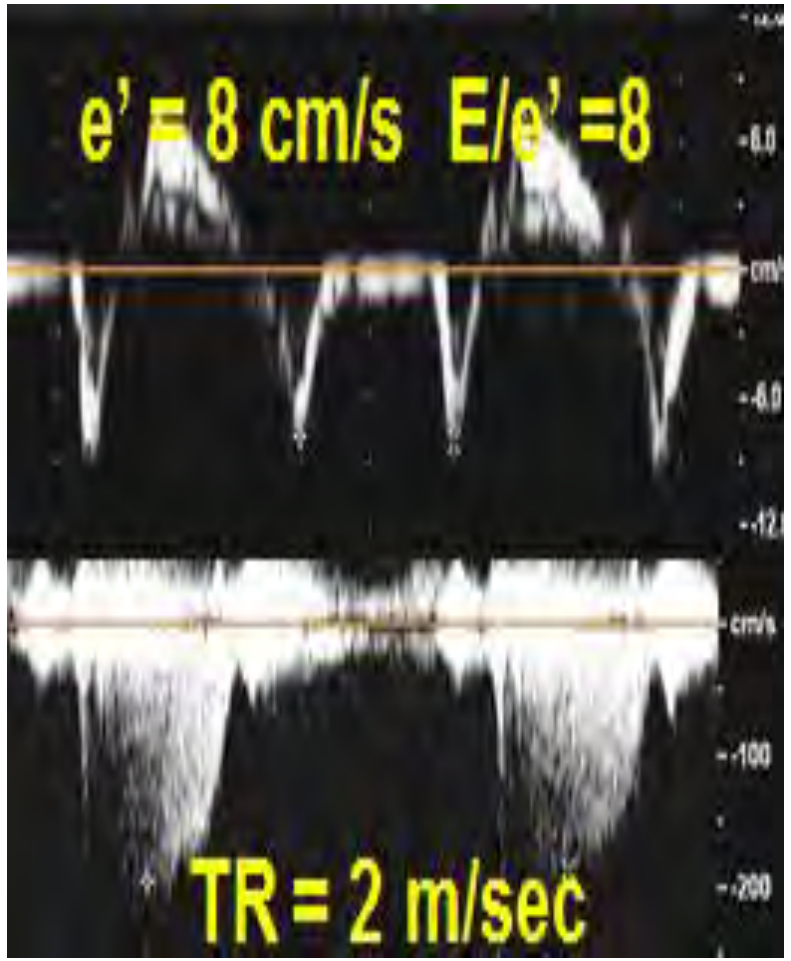


Normal Filling Pressure although Diastolic Function is Reduced for Patient's Age

#27

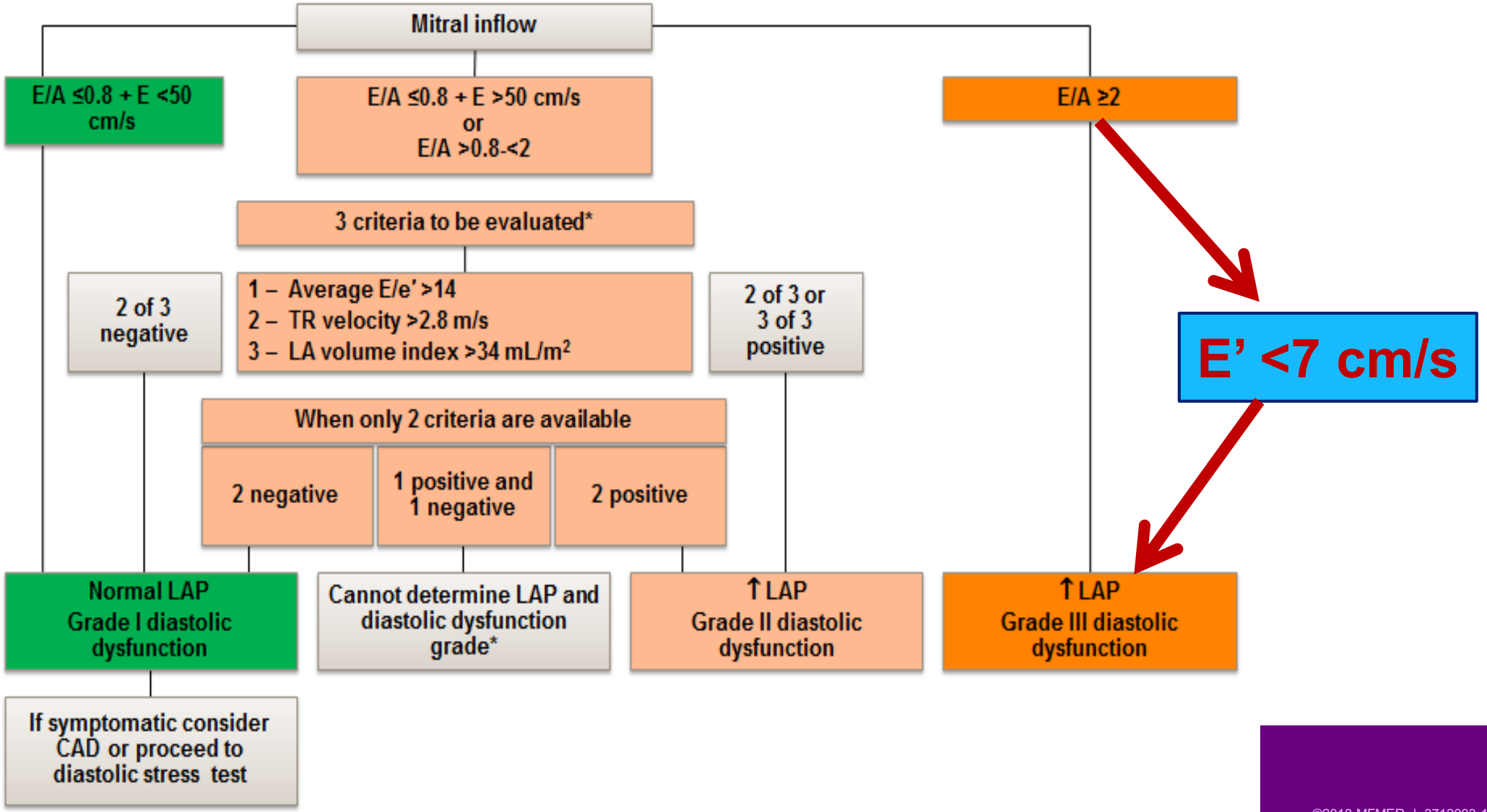
40 yo man with anterior STEMI
LVEF 45%





The 2016 Algorithm for Reduced EF (<50%) or Known (or Suspected) Diastolic Dysfunction/EF≥50%

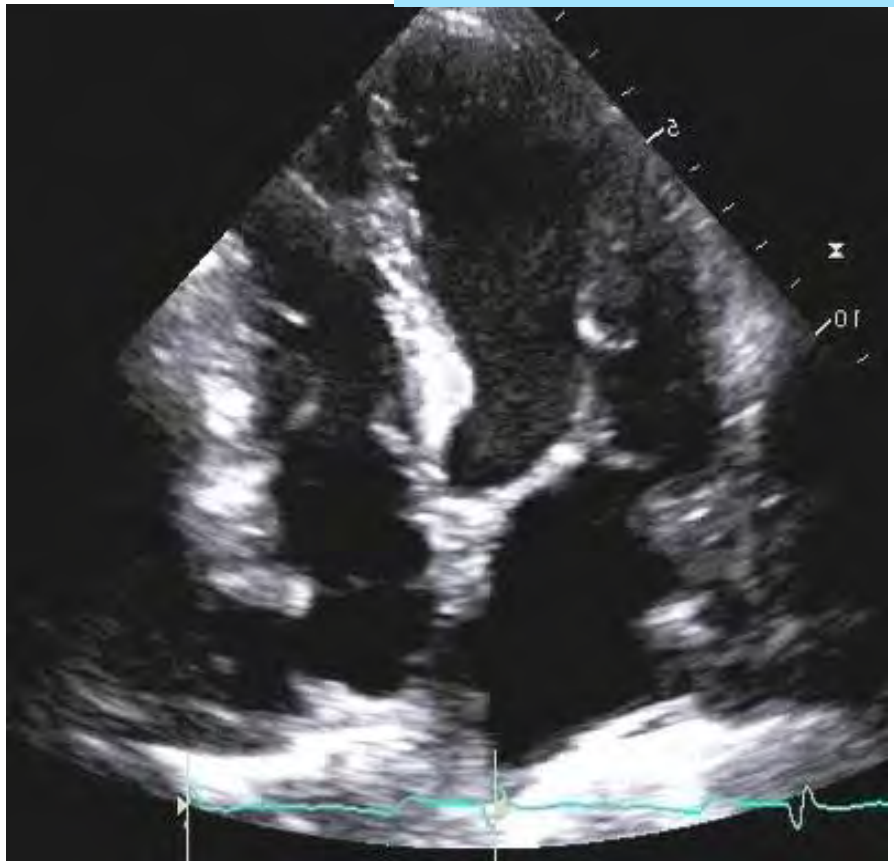
(Hypertension, CAD, Diabetes, MI, History of HF, LVH, LAE)



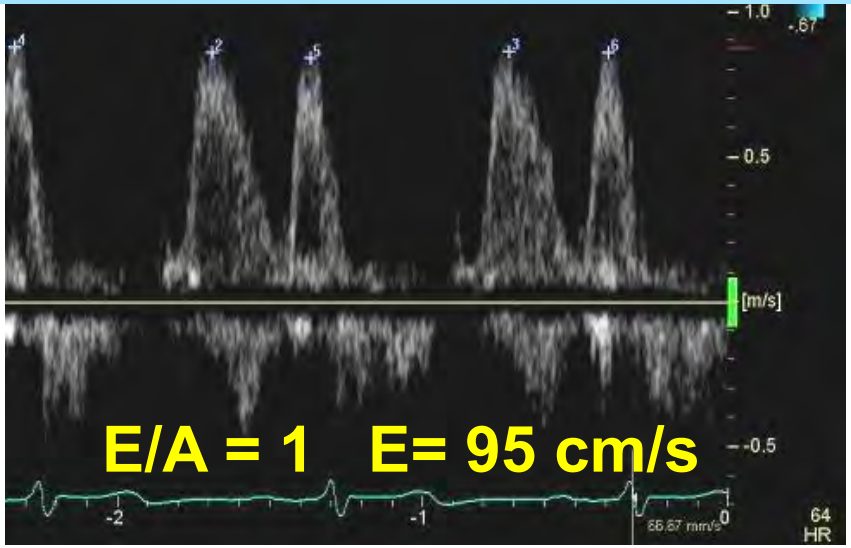
Case #28

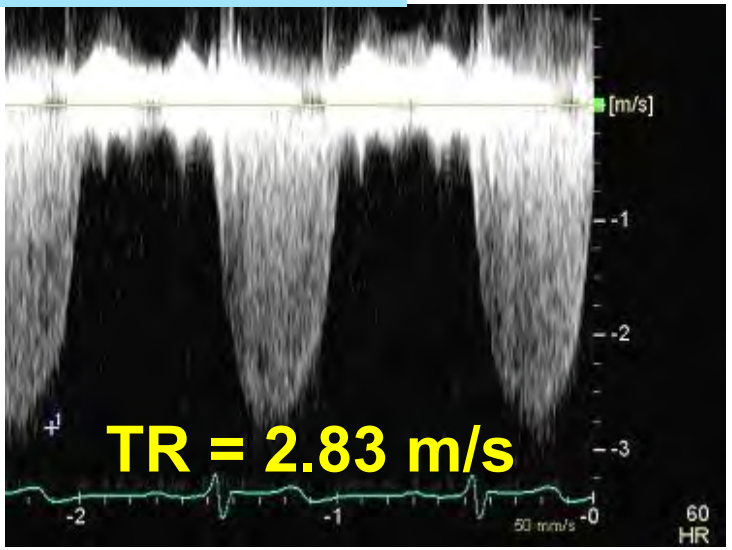
82 year old male with dyspnea
All 4 parameters are abnormal

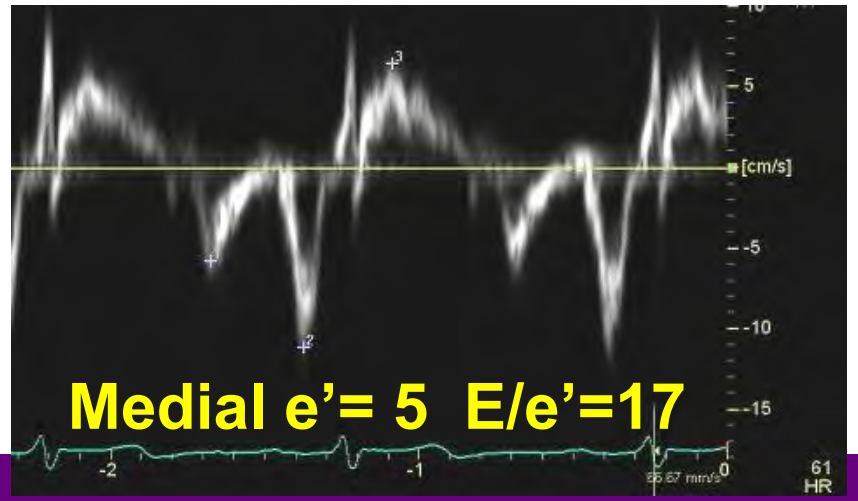
Diastolic Dysfunction and Increased Filling Pressure

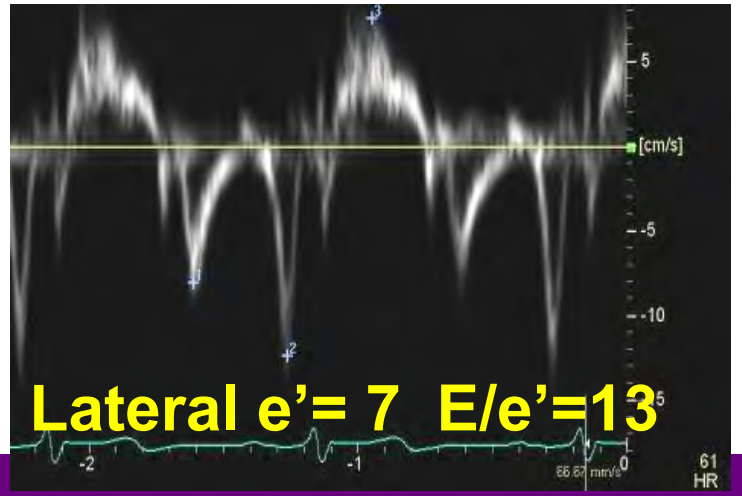


LAVI = 38 mL/m²





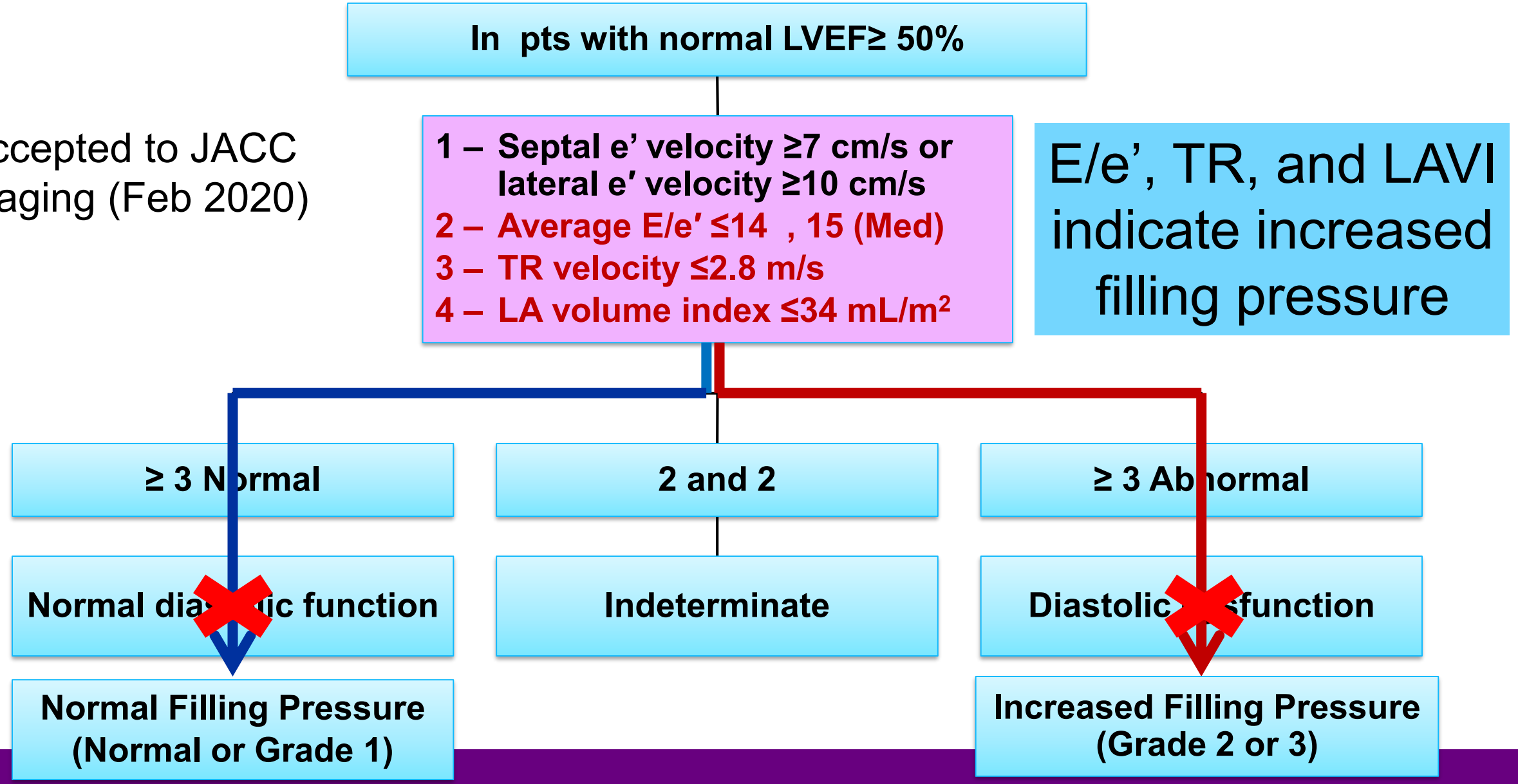




MAYO CLINIC

Revised Algorithm #1 for Diastolic Function Assessment

Accepted to JACC Imaging (Feb 2020)



Individuals with HPT, CAD, LVH, DM, or MI Can Have Normal Diastolic Function

Especially in Young Individuals

Proposal for making the 2016 Guideline better

- Combine 2 algorithms to 1 algorithm
- Use one e' velocity
- Change (normal and abnormal) diastolic function to filling pressure, then determine grading
- Use additional parameters or methods when indeterminate or complex (MAC, LBBB, HCM, Atrial Fibrillation)

SPECIAL ISSUE: NONINVASIVE ASSESSMENT OF LEFT VENTRICULAR DIASTOLIC FUNCTION

DEBATES IN IMAGING

The 2016 Diastolic Function Guideline

Is it Already Time to Revisit or Revise Them?

Jae K. Oh, MD,[a] William R. Miranda, MD,[a] Jared G. Bird, MD,[a] Garvan C. Kane, MD, PhD,[a] Sherif F. Nagueh, MD[b]

A Proposal For Modifications To The Current Diastolic Function Guideline

Jae K. Oh, MD, William R. Miranda, MD, Jared G. Bird, MD, Garvan C. Kane, MD, PhD

Determination of diastolic function is an integral part of an echocardiography examination, especially in patients with symptoms of heart failure. To standardize the evaluation of diastolic function, the American Society of Echocardiography (ASE)/European Association of Cardiovascular Imaging (EACVI) diastolic function working group published recommendation guidelines in 2009 and 2016 (1). In the (DD), designed for estimating left ventricular (LV) filling pressure and grading diastolic function. The 2016 guideline emphasized the specificity for detecting DD. In selected patients who were referred to cardiac catheterization, assessment of filling pressure according to the 2016 guideline was shown to be reliable and interobserver variability was excellent (2). However, its sensitivity for detecting DD (especially grade 1) markedly decreased. Almeida et al. (3) showed that the incidence of DD in 1,000 individuals (mean age of 62 years) was 1.4% based on the 2016 guideline compared to 38.1% based on the 2009 guideline.

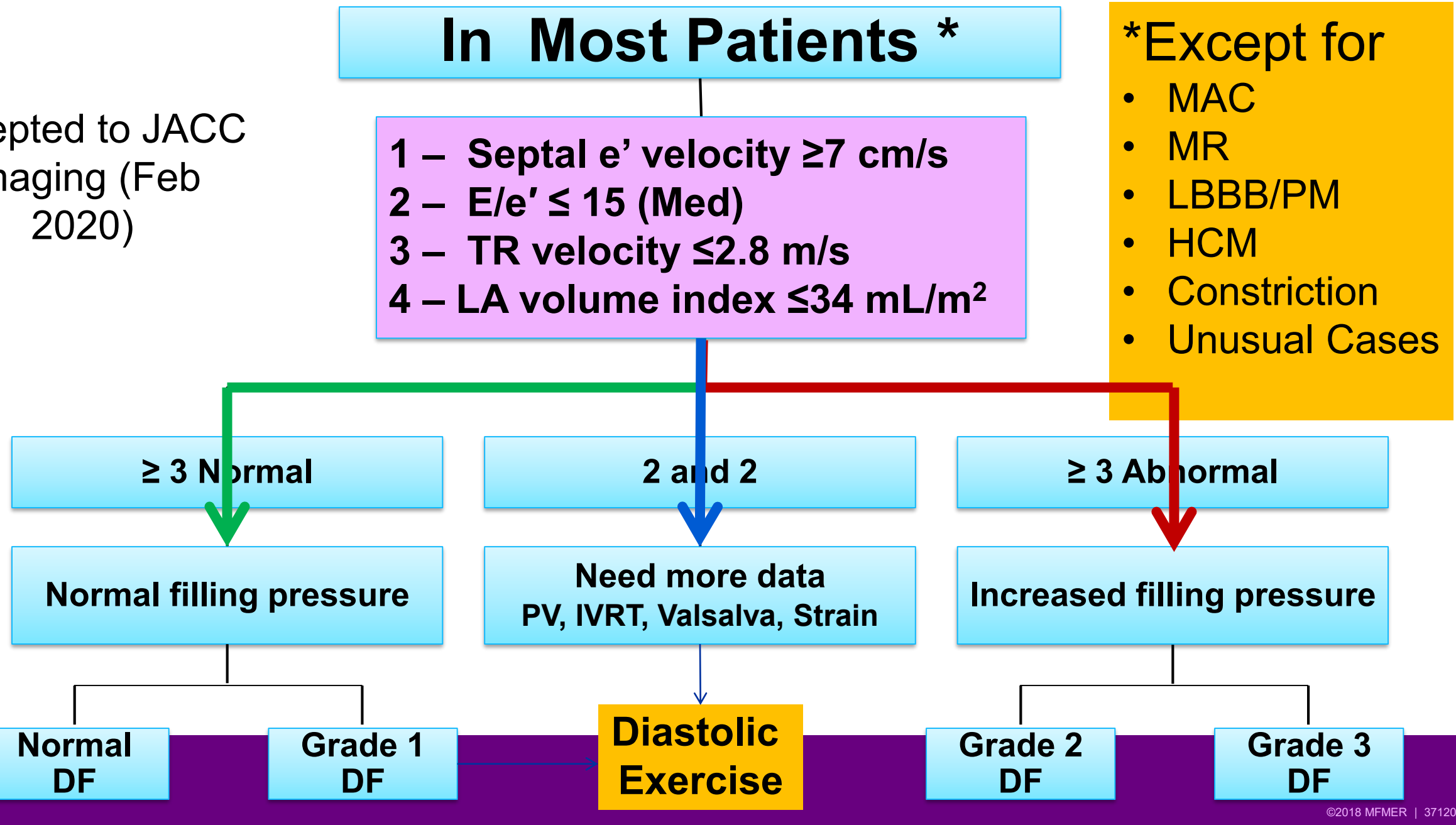
In addition, the 2016 guideline recommended adjudication of DD based on clinical history or imaging data in the algorithm B. However, individuals with

MAYO CLINIC

JK Oh et al JACC Imaging Jan. 2020

Revised Algorithm for Diastolic Function Assessment

Accepted to JACC Imaging (Feb 2020)



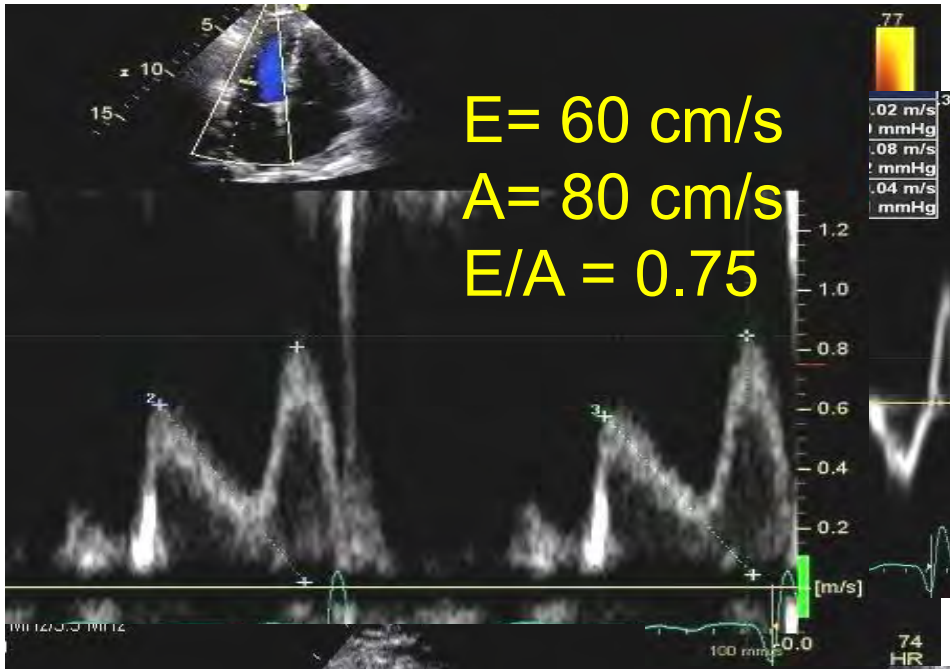
Difficult Situations

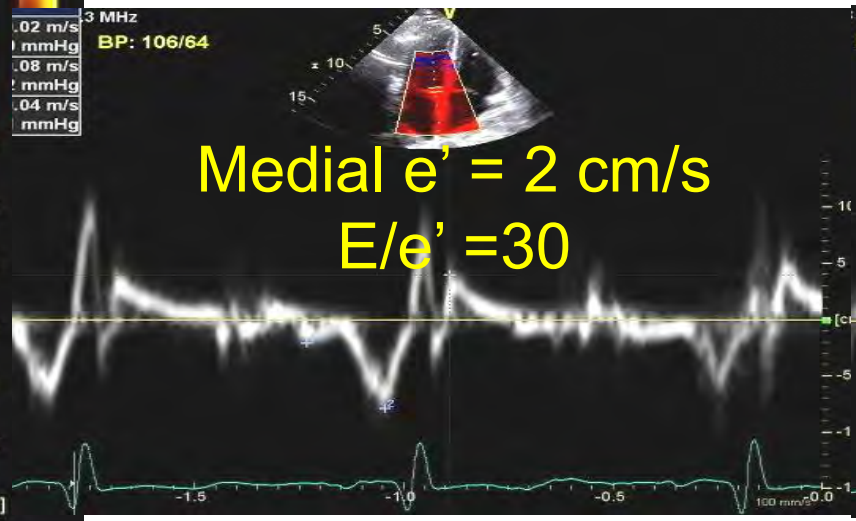
- Assessment of diastolic function or filling pressure in
  - 2 normal and 2 abnormal
  - HCM
  - LBBB
  - MAC
  - Atrial Fibrillation
- Additional supportive parameters
  - Pulmonary vein
  - L wave
  - Valsalva
  - IVRT and timing intervals
  - Left atrial strain (reservoir)

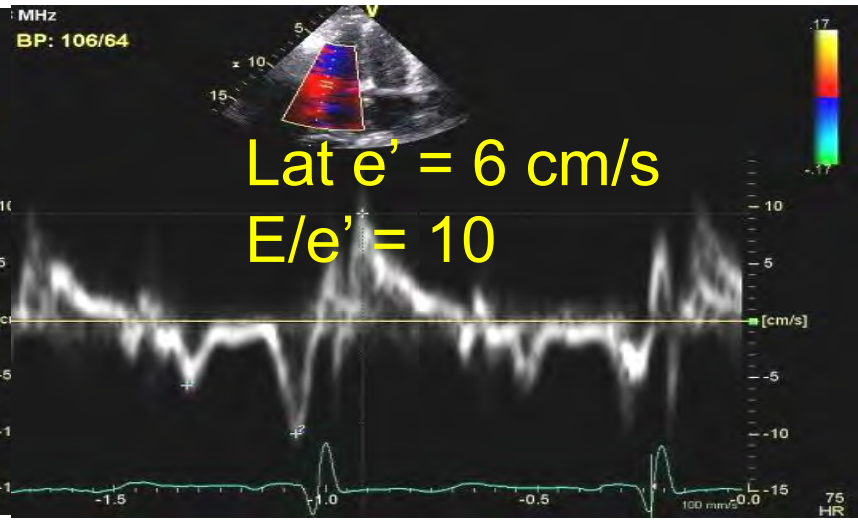
Case #29

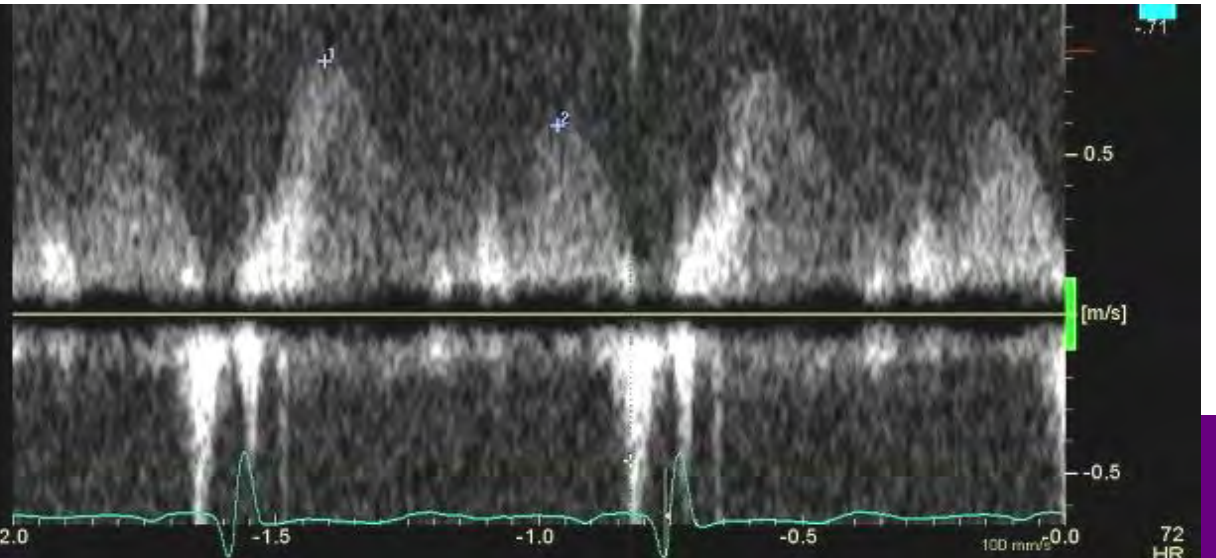
Grade diastolic function in 80 YO man with dyspnea

TR = 3.5 m/sec







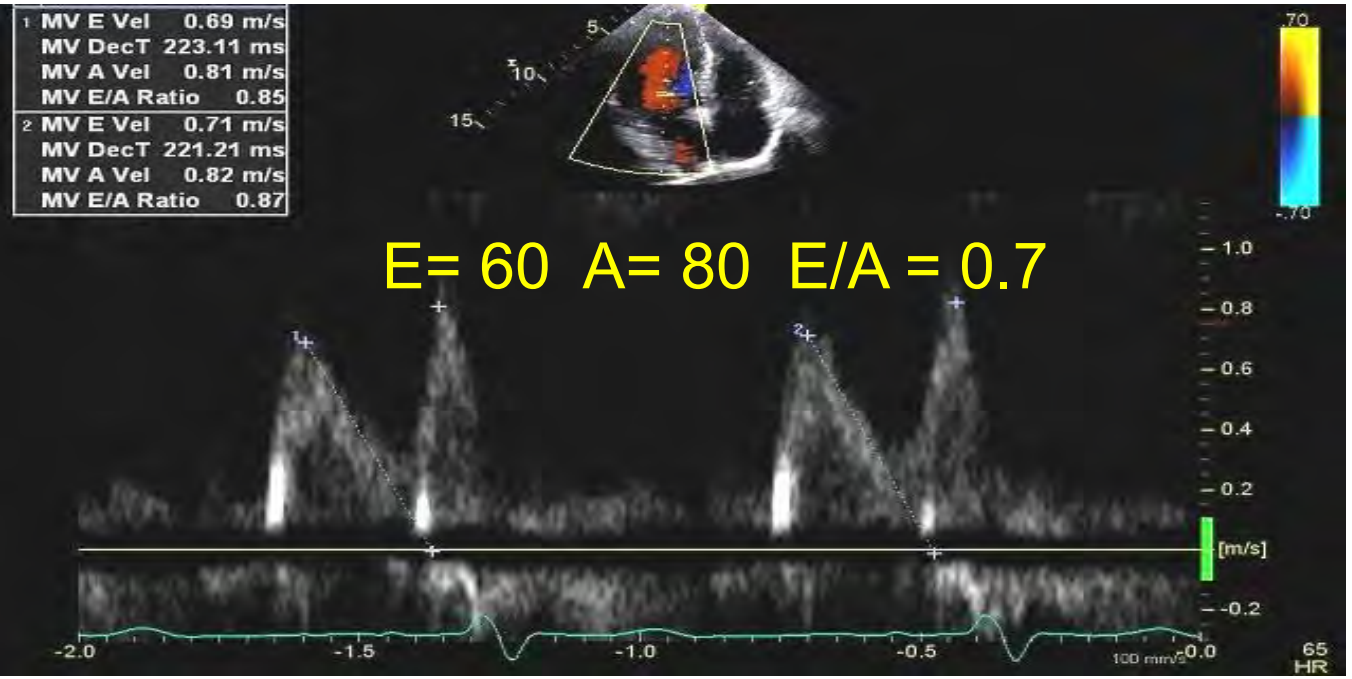


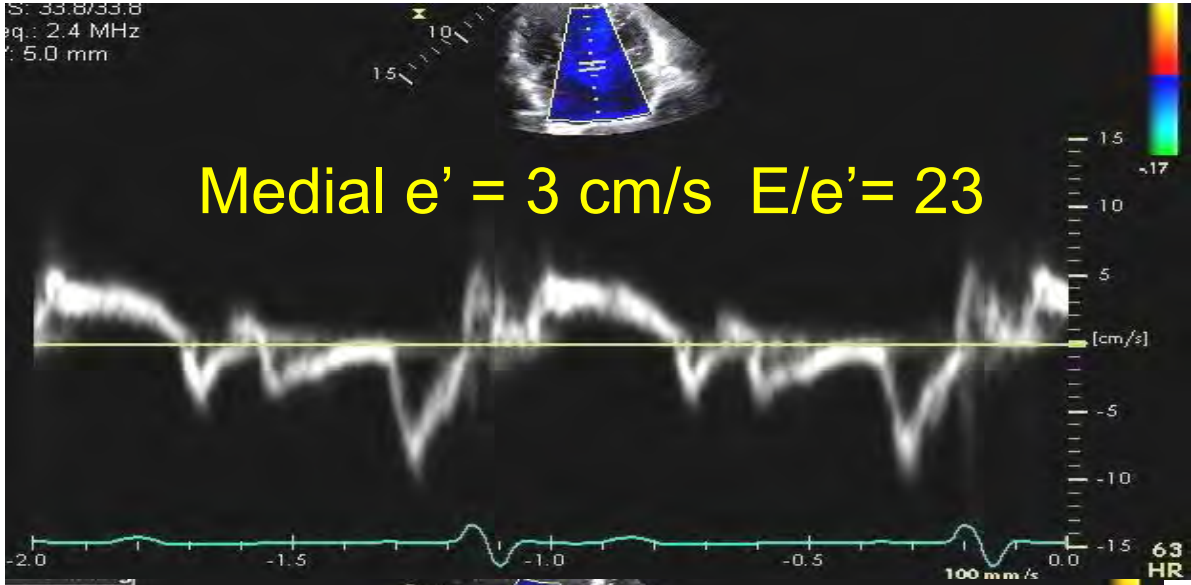
80 year old man with dyspnea and PHT
Cardiac Cath Data

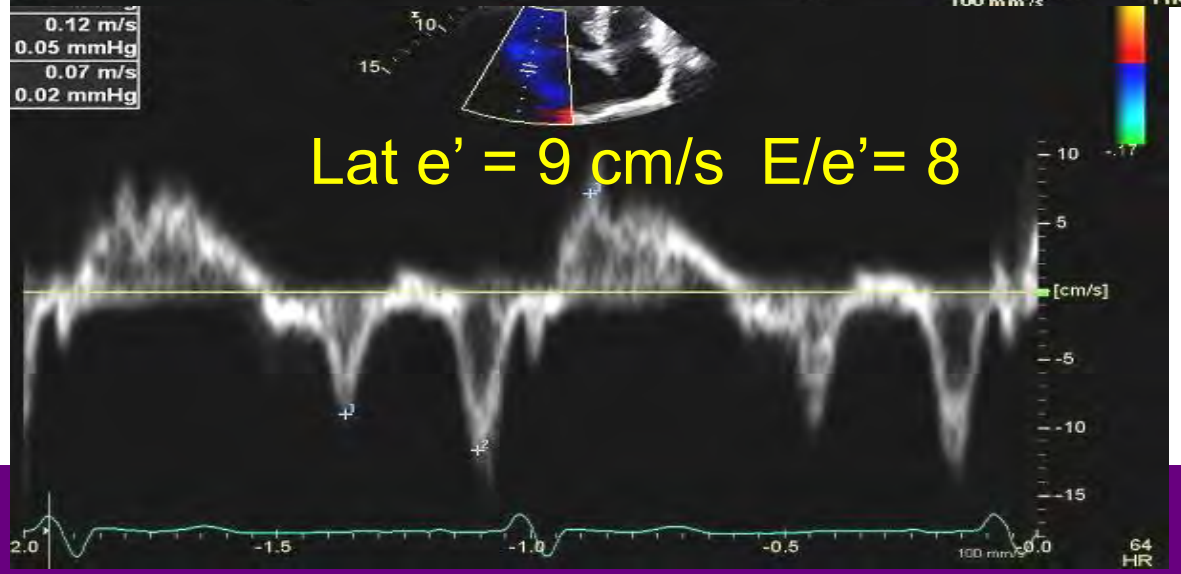
- RA pressure 2 mmHg
- RVSP 50 mmHg
- Mean PASP 28 mmHg
- PCWP 4 mmHg
- LVEDP 13 mmHg
- Cardiac Index 1.5 L/min/m^2

Case #30

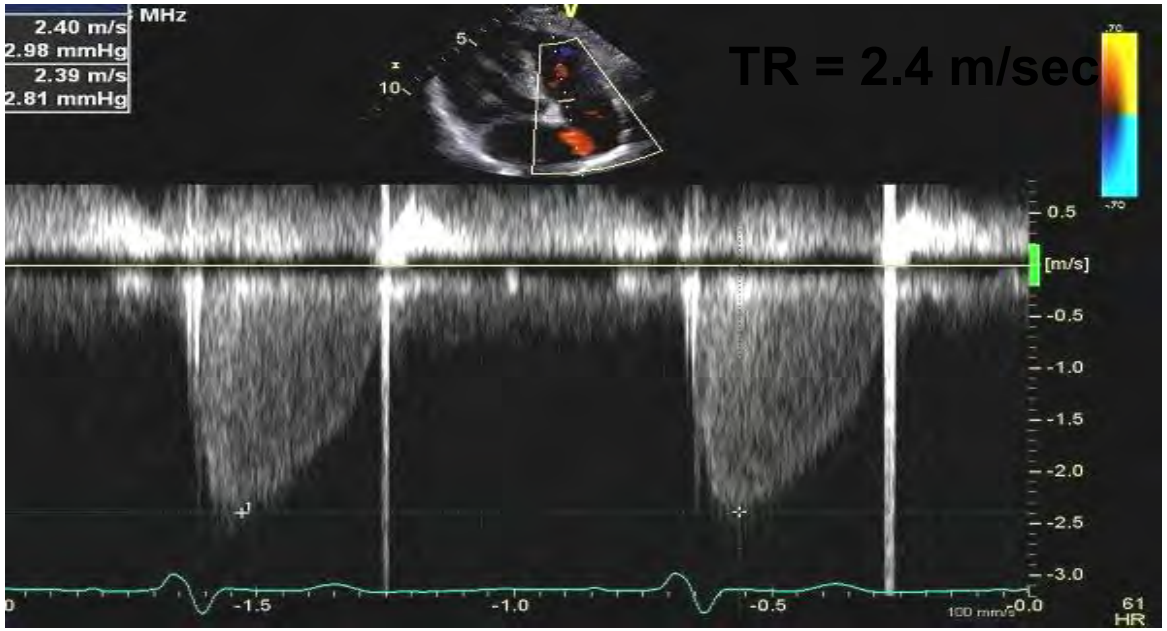
67 yo woman with LBBB

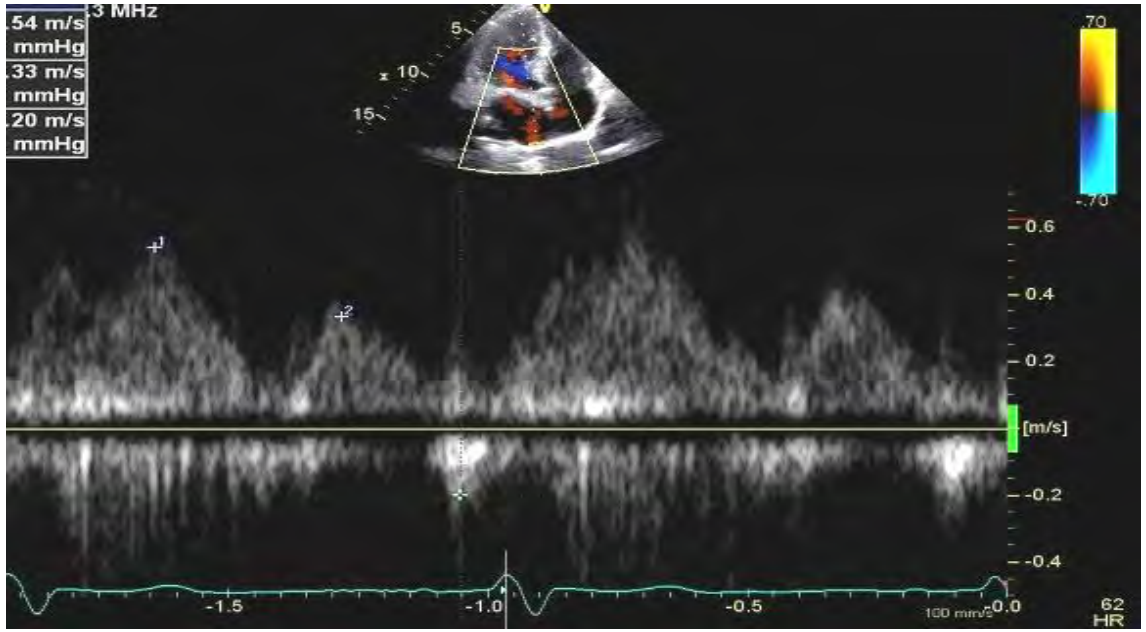


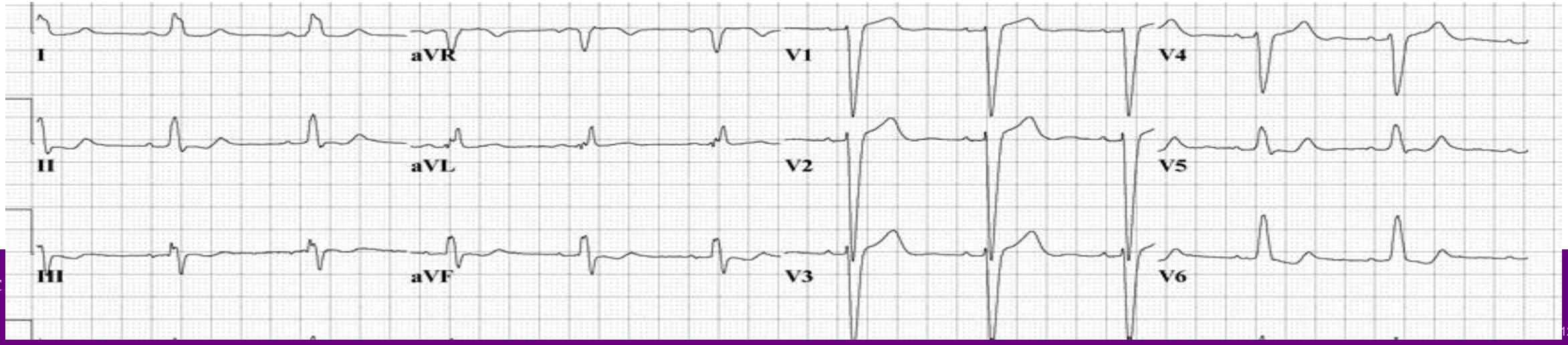




67 yo with LBBB



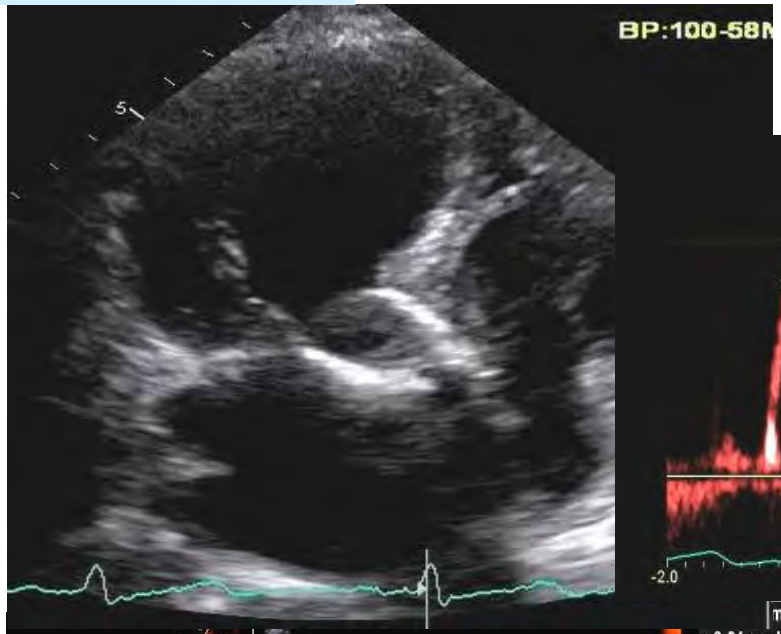


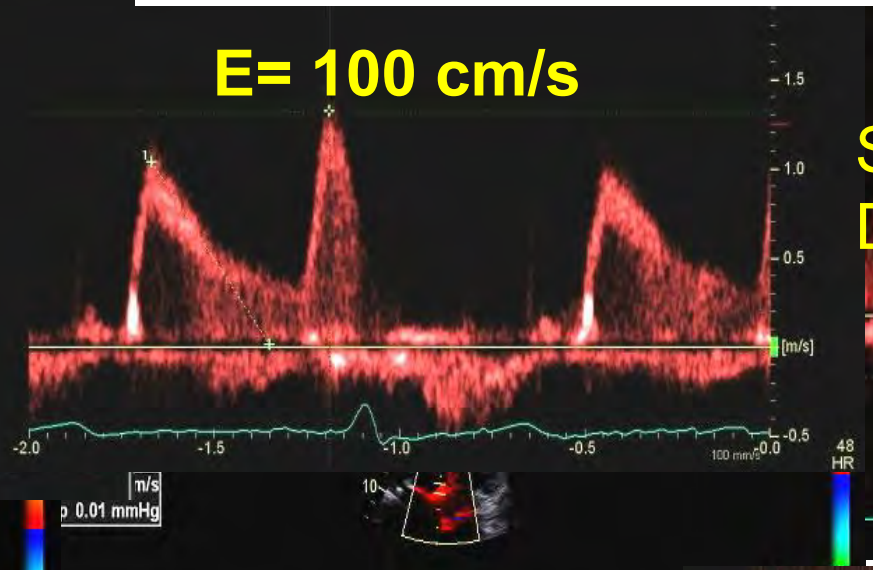


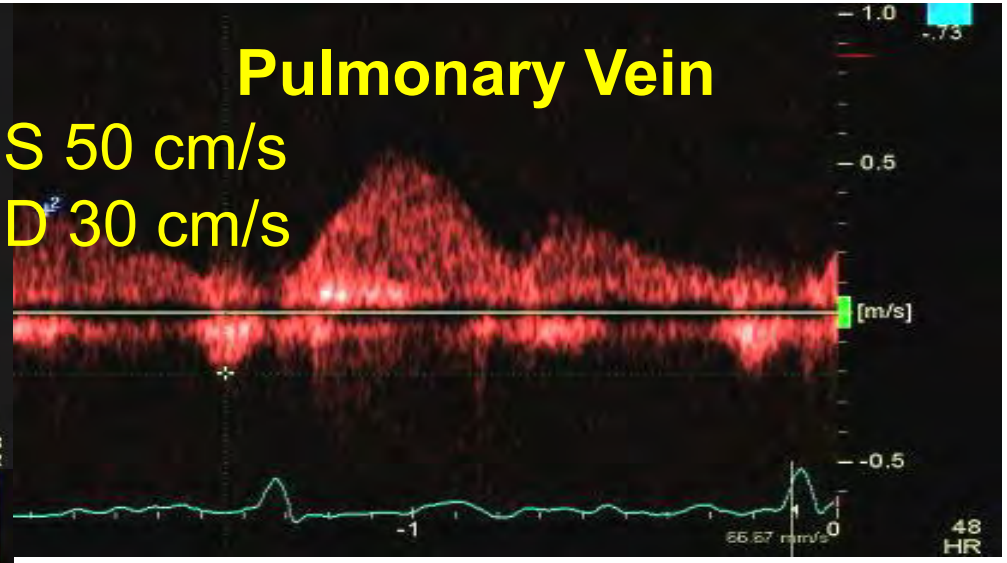
How is filling pressure in a 80 yo woman with Mitral annulus calcification and TAVR?

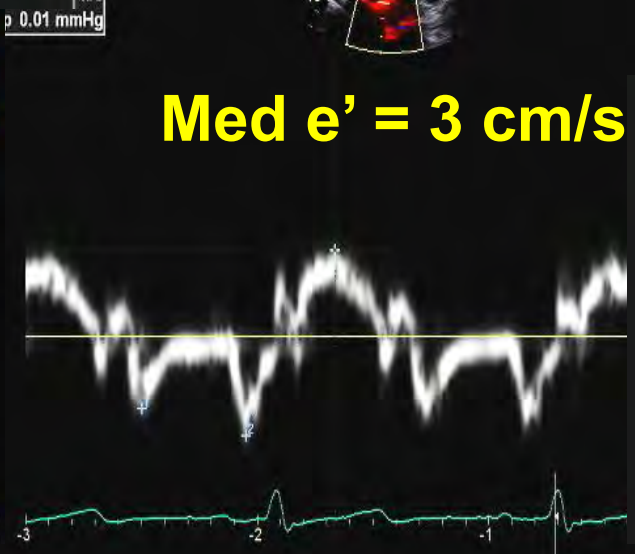
Case #31

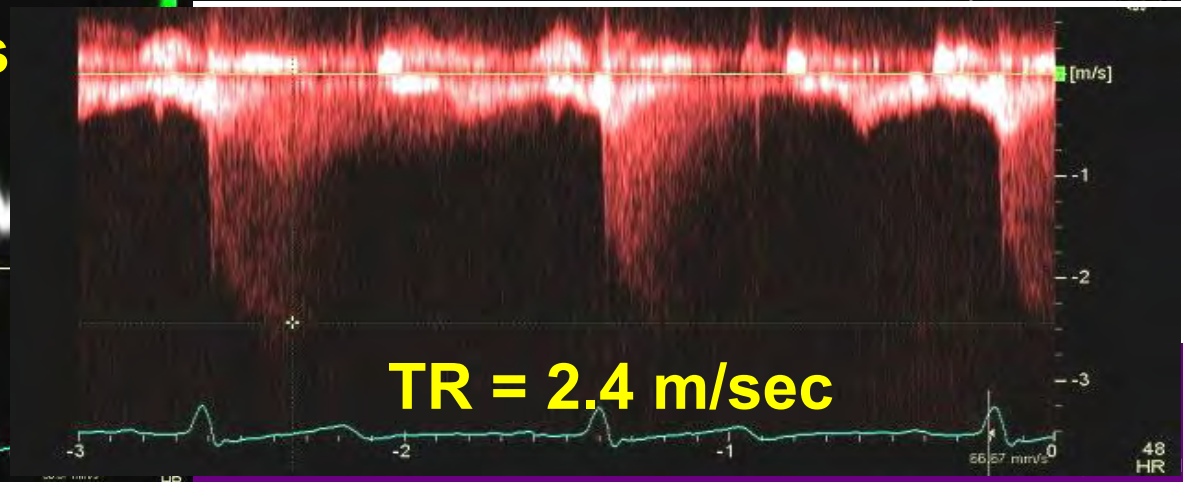
1=Normal 2= Increased 3= Indeterminate







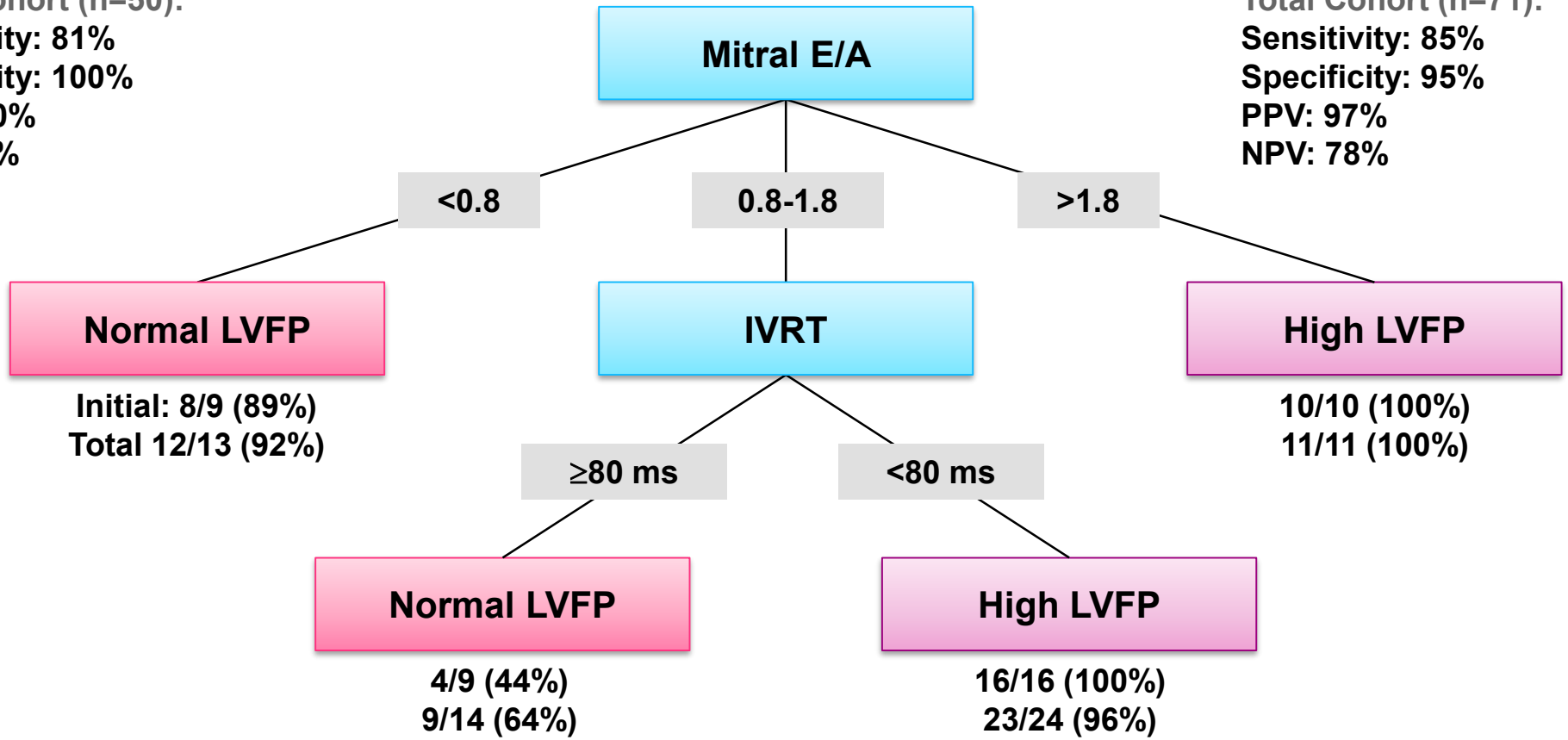




Proposed Clinical Algorithm for Estimation of Left Ventricular Filling Pressure in Subjects With Mitral Annular Calcification

Initial Cohort (n=50):
Sensitivity: 81%
Specificity: 100%
PPV: 100%
NPV: 67%

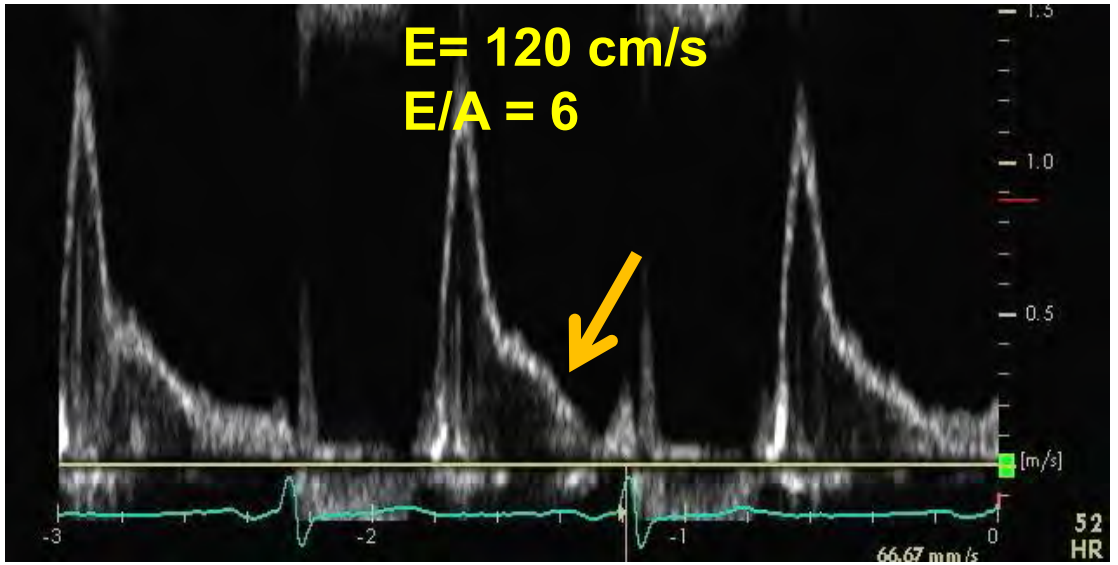
Total Cohort (n=71):
Sensitivity: 85%
Specificity: 95%
PPV: 97%
NPV: 78%

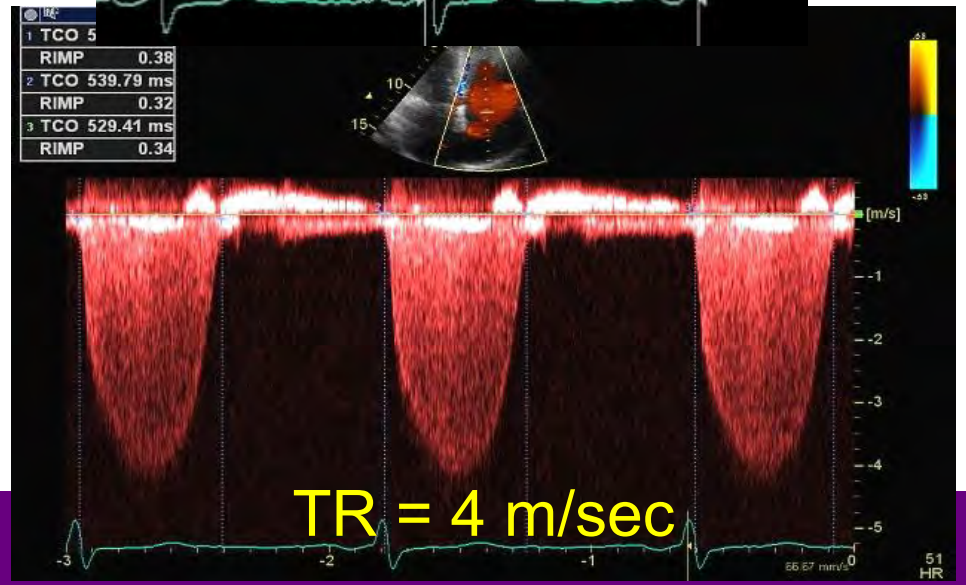


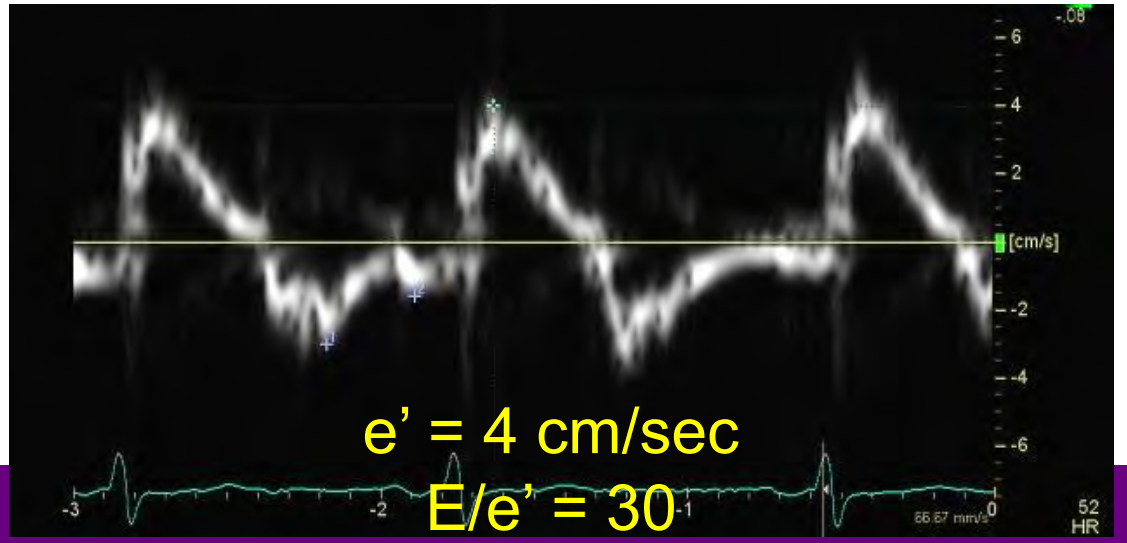
Abudiab et al: J Am Coll Cardiol Img, 2017

Case #32

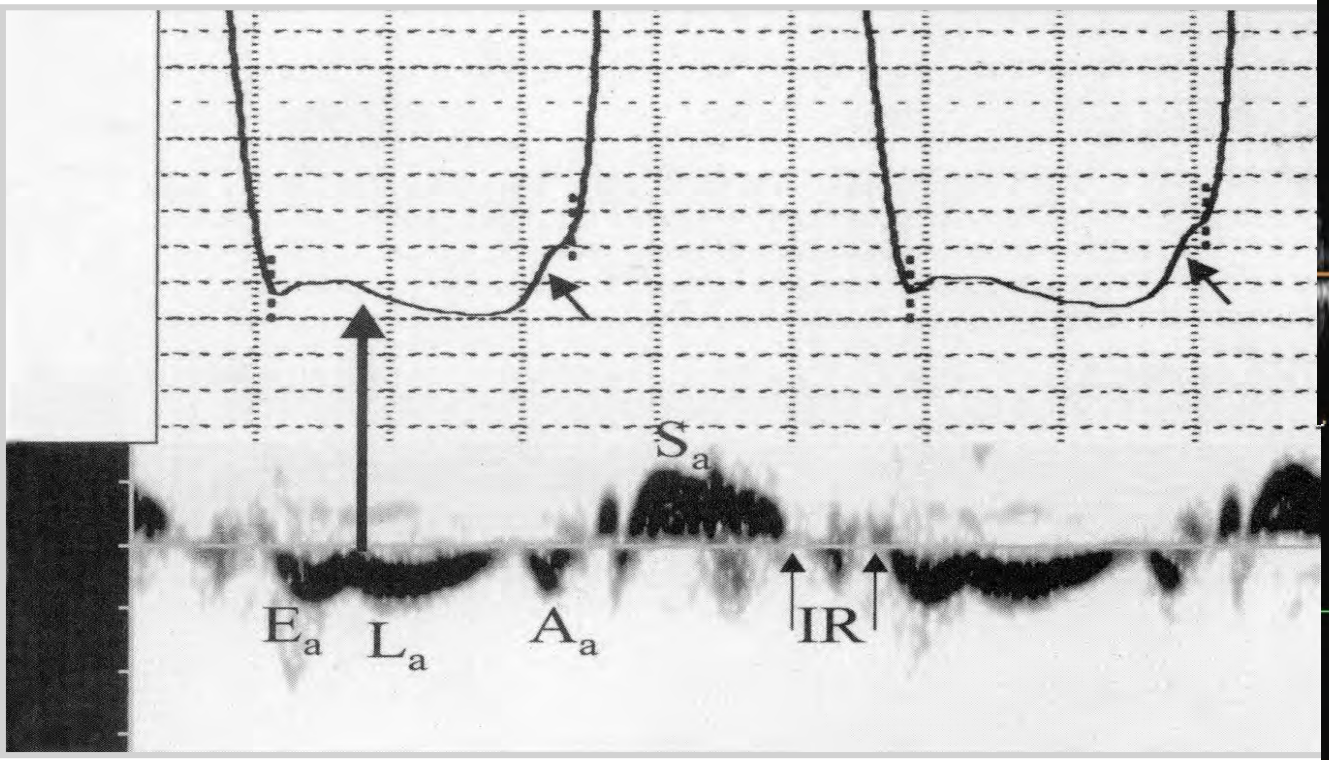
"L" wave ≥ Grade 2
Mid-diastolic flow from delayed relaxation

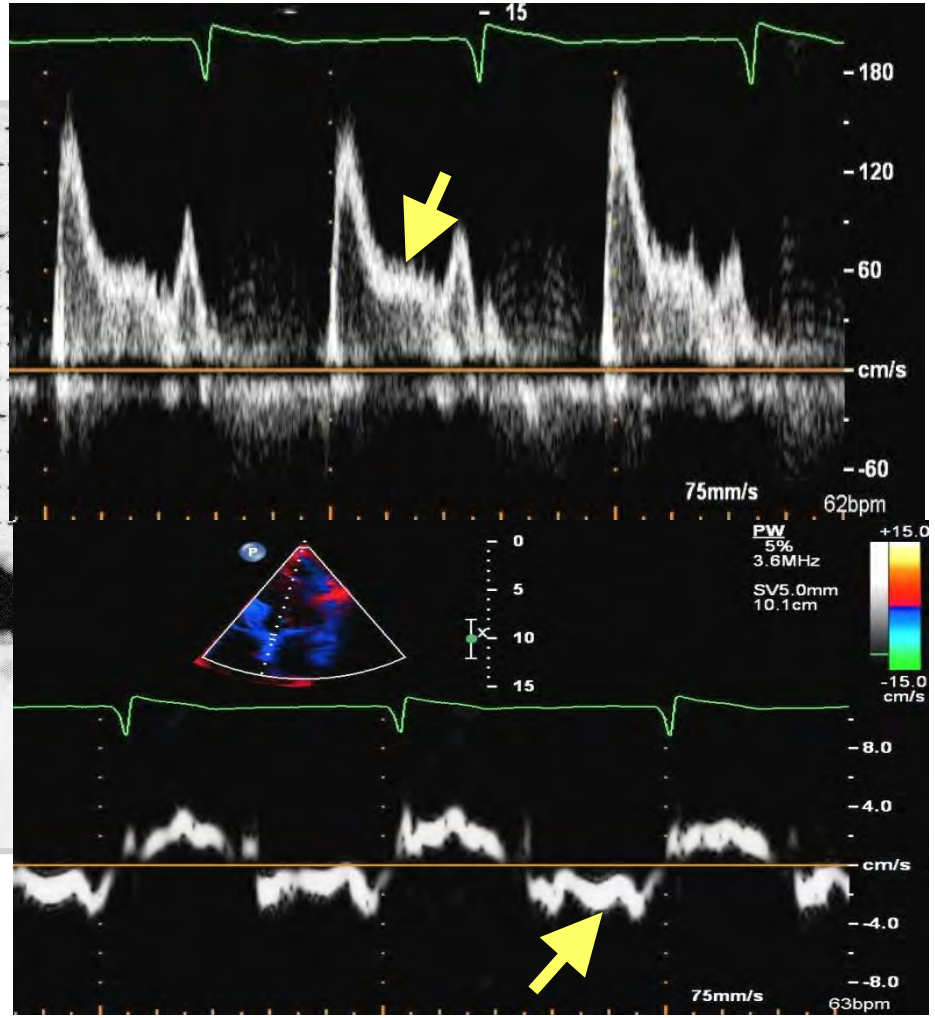






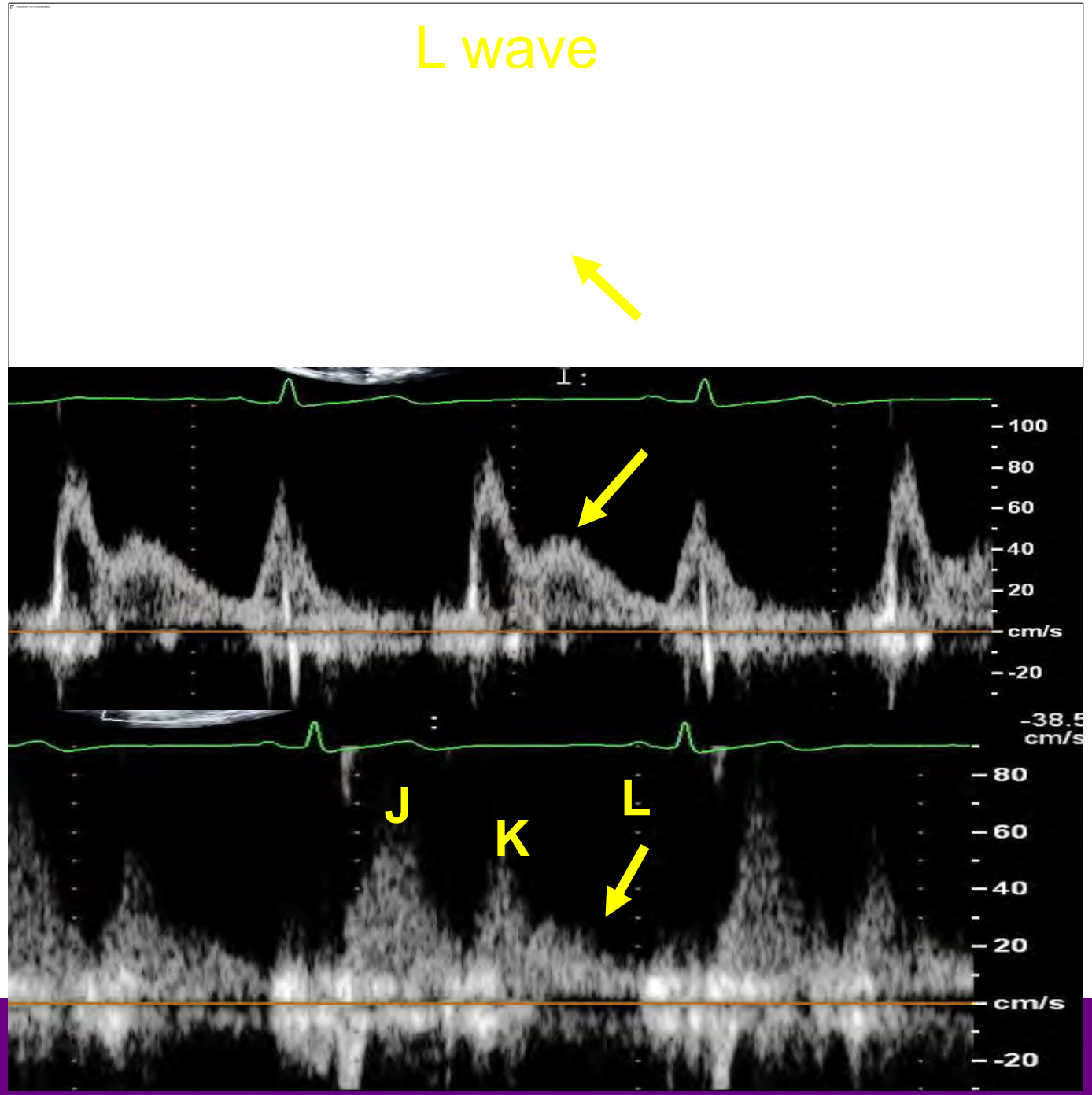
Mid-diastolic mitral flow (L)
Delayed relaxation





Frommelt et al: J Am Soc Echocardiogr 16:176, 2003

L wave



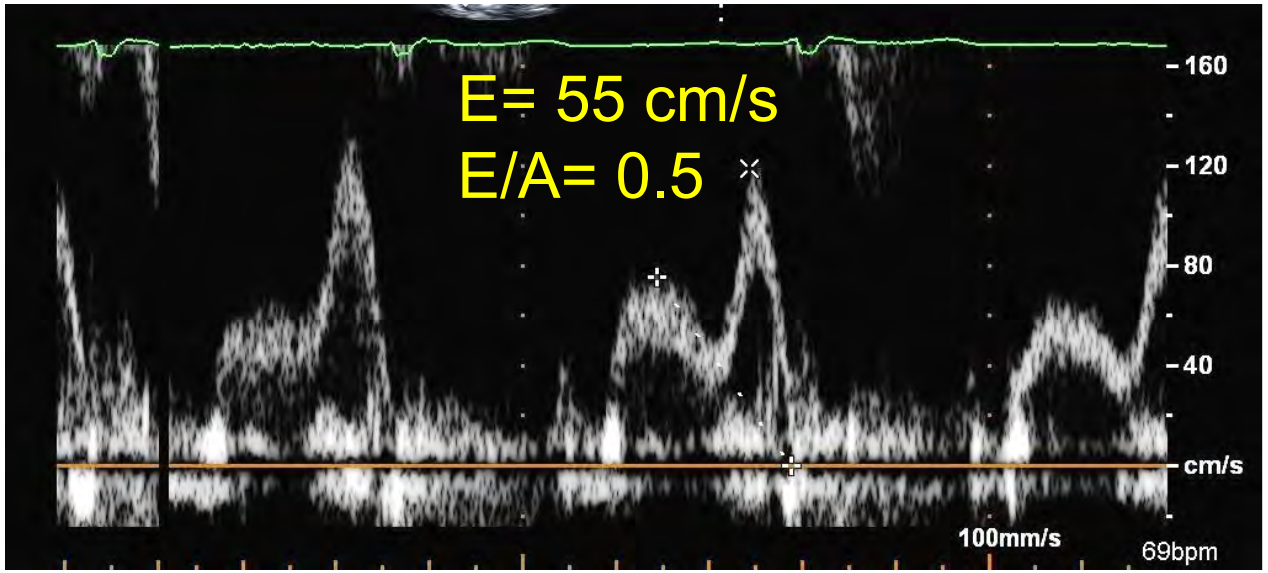
Diastolic Function in A. Fib

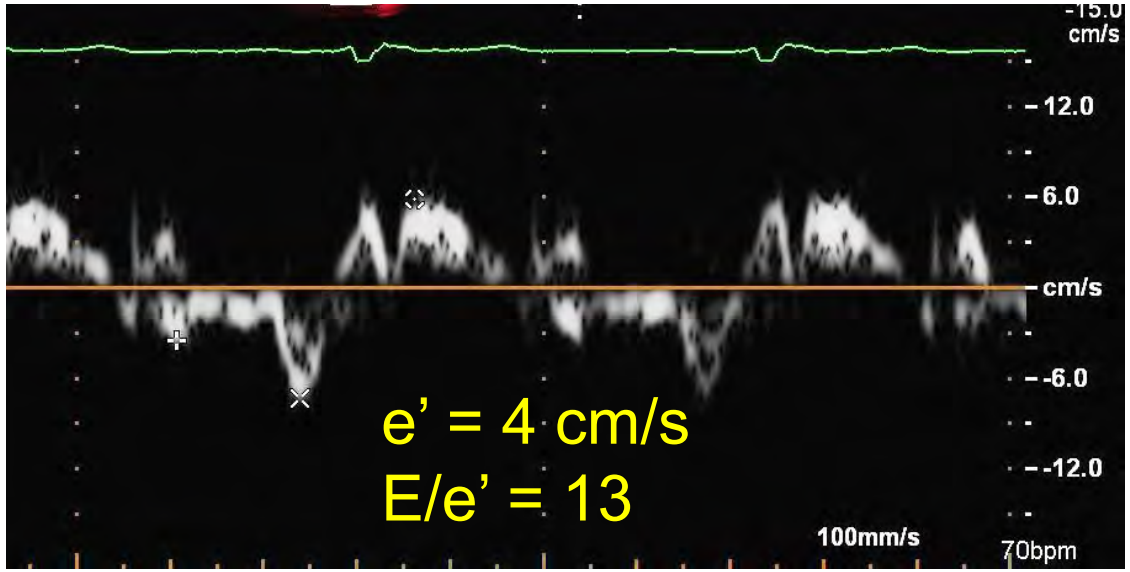
- DT < 160 msec
- Other measurements
  - IVRT ≤ 65 msec
  - E/e' ≥ 11
  - TR velocity > 2.8 m/sec

MAYO CLINIC

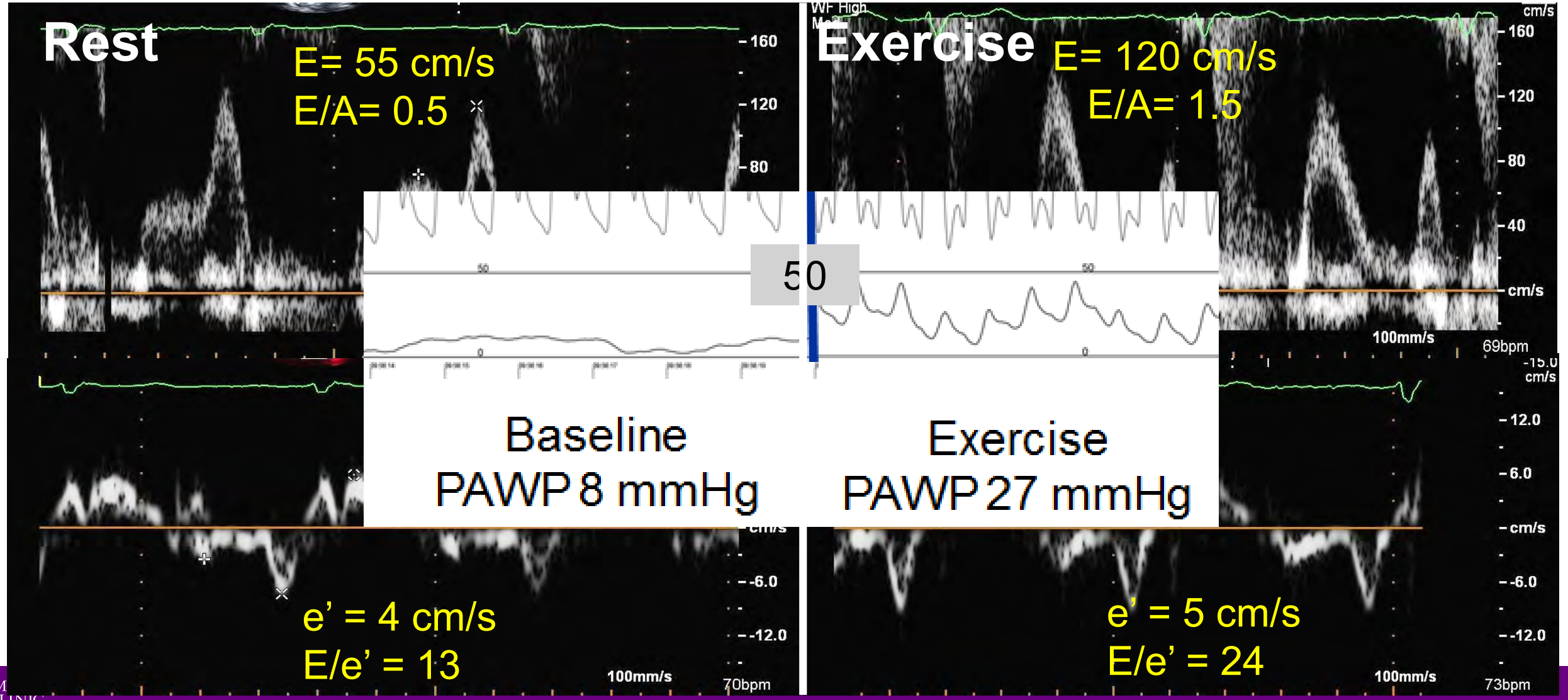
78 year old male with exertional dyspnea
Resting Study with EF 60%

Case #33





78 year old male with exertional dyspnea
Diastolic Exercise Test

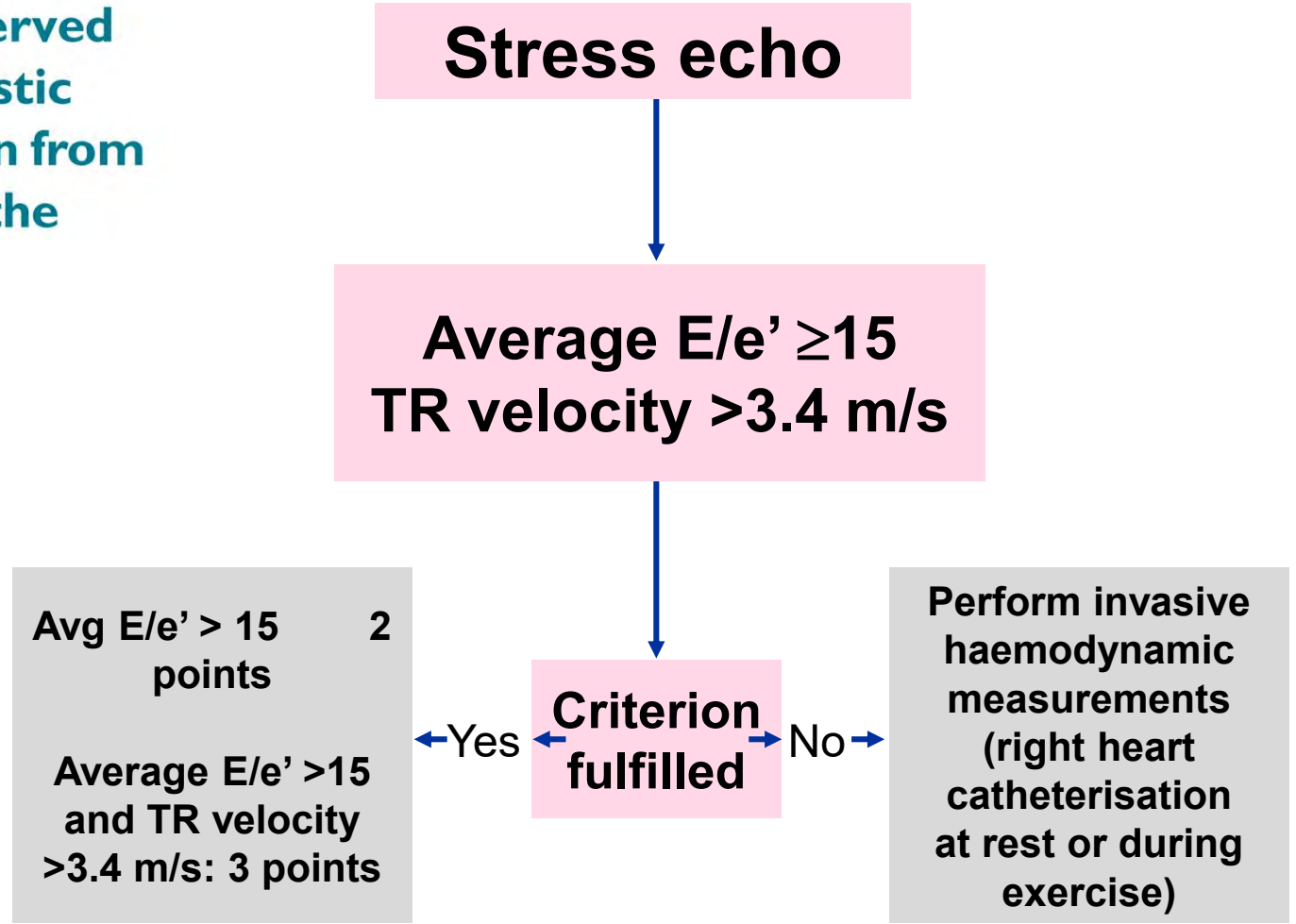


MAYO CLINIC

ESC European Society of Cardiology
European Heart Journal (2019) 40, 3297–3317
doi:10.1093/eurheartj/ehz641
FASTTRACK CLINICAL RESEARCH
Heart failure/cardiomyopathy

How to diagnose heart failure with preserved ejection fraction: the HFA–PEFF diagnostic algorithm: a consensus recommendation from the Heart Failure Association (HFA) of the European Society of Cardiology (ESC)

Advanced HFpEF Workup
Echo Stress Test

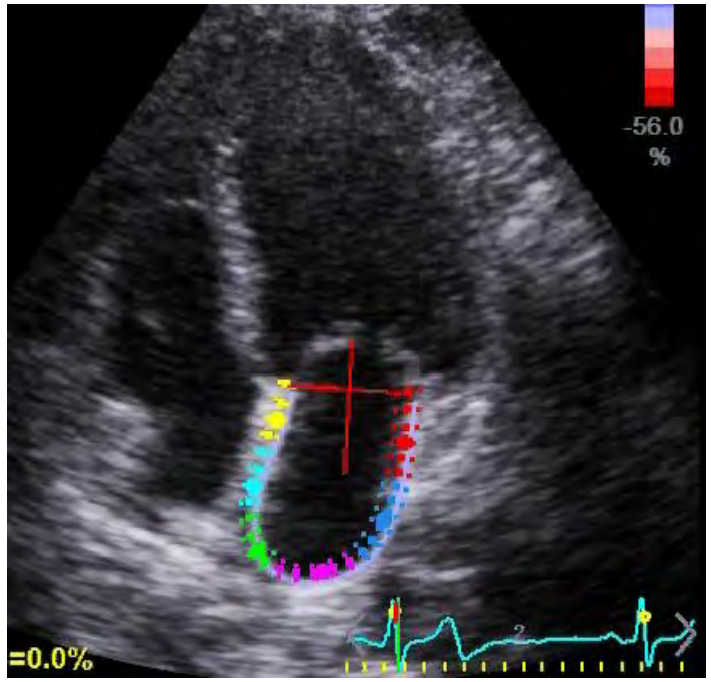


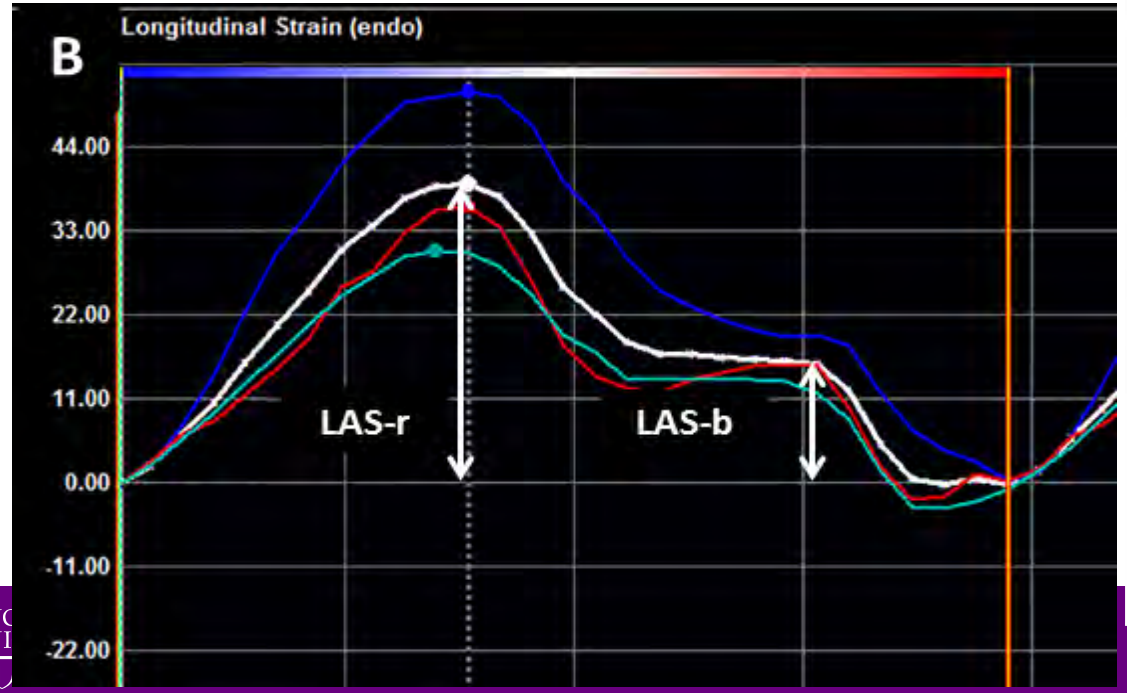
Diastolic Stress Test

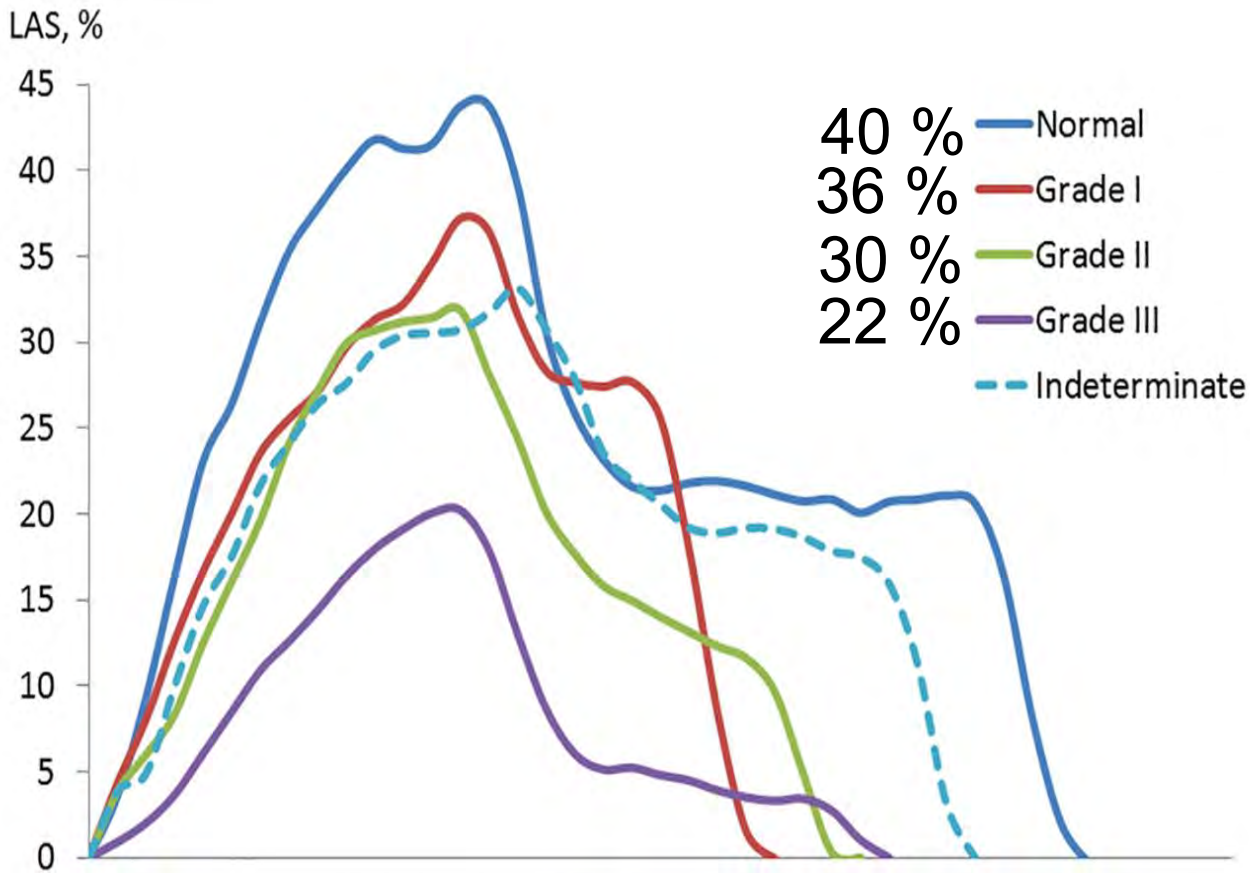
Baseline and Peak (or Post) Exercise

- Supine bike or Treadmill
- 25 watts (3 min) increments
- Assess LVEF, size, and wall motion
- Mitral inflow (E, A, and DT)
- Mitral annulus velocity
- E/e’ ratio
- TR velocity

LA Systolic (Reservoir) Strain
Mayo Clinic



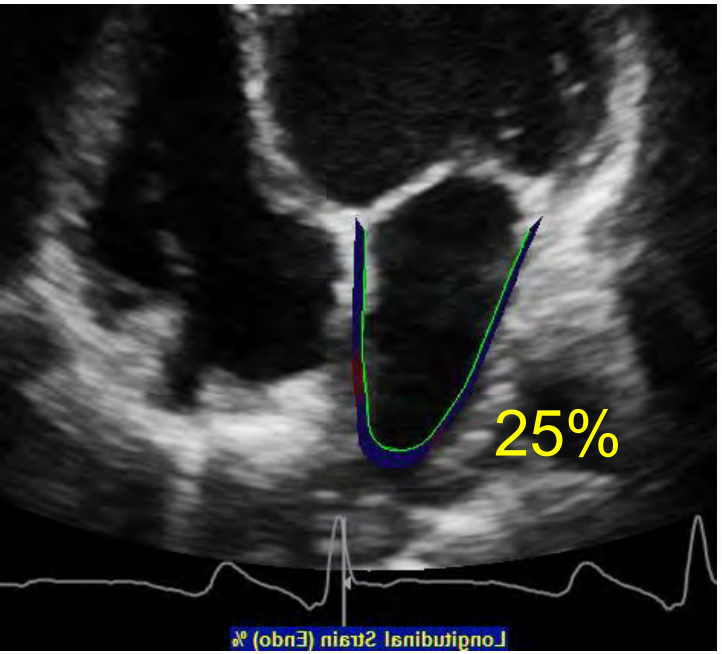


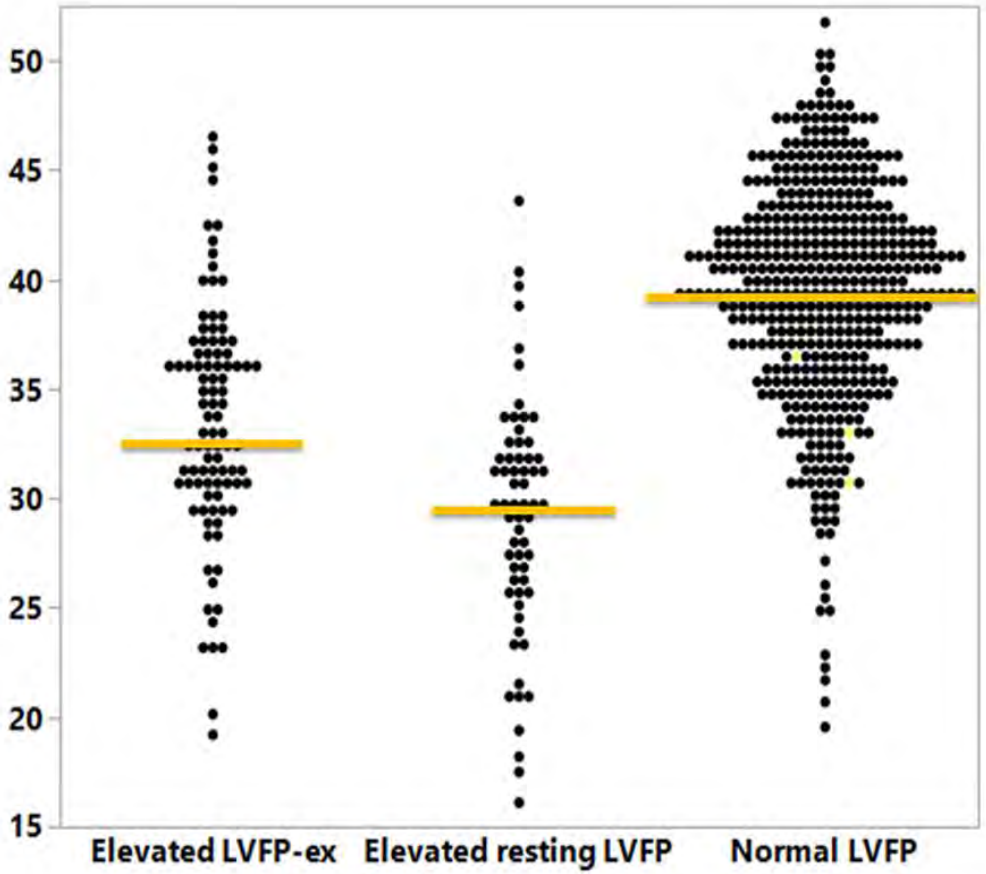


	Normal	Grade I	Grade II	Grade III	Indeterminate
	N=358	N=156	N=56	N=7	N=50
LAS-R	40.0 ± 5.0	36.0 ± 5.2	29.8 ± 4.9	22.4 ± 4.9	33.2 ± 5.7
LAS-B	15.7 ± 4.1	17.3 ± 4.3	14.2 ± 4.8	5.1 ± 2.8	15.6 ± 5.4

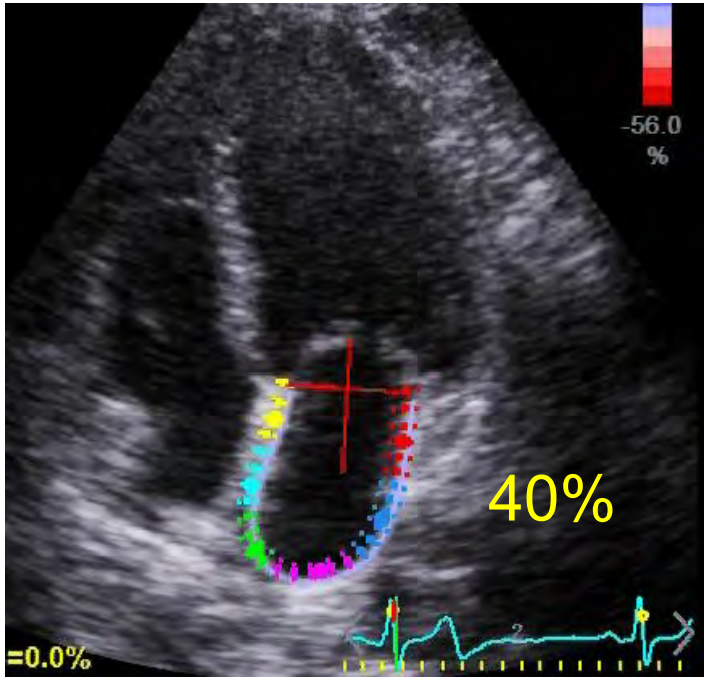
Z. Ye et al (Submitted)

LA strain for detecting elevated LV Filling Pressure 563 consecutive patients with exercise echo



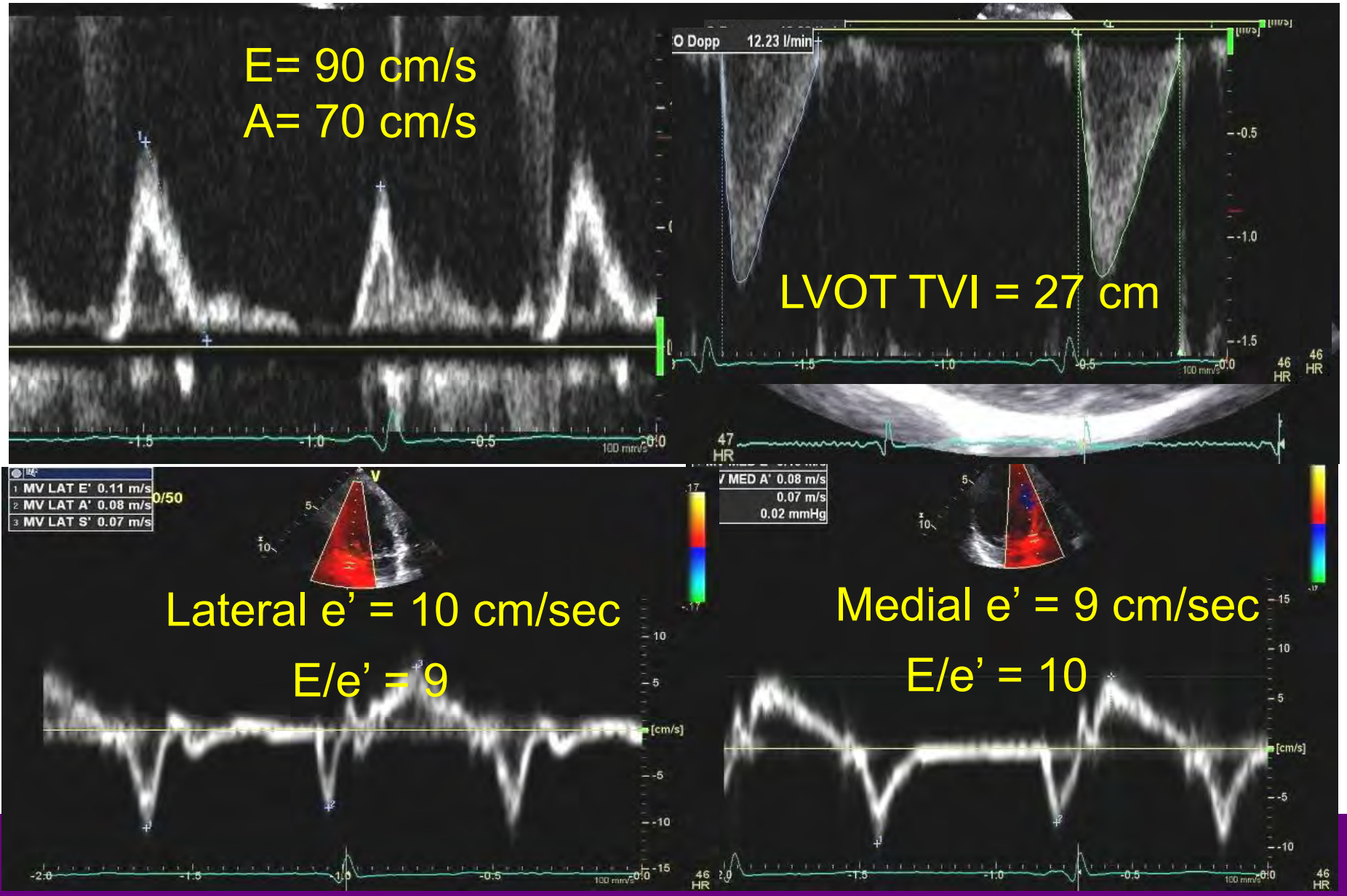


Comparisons of LAS-r between groups,
Student t-test $P<0.001$ for all the comparisons



Z. Ye et al (Submitted)

71 year old woman with TR = 2.6 & LAVI = 39 mL/m^2



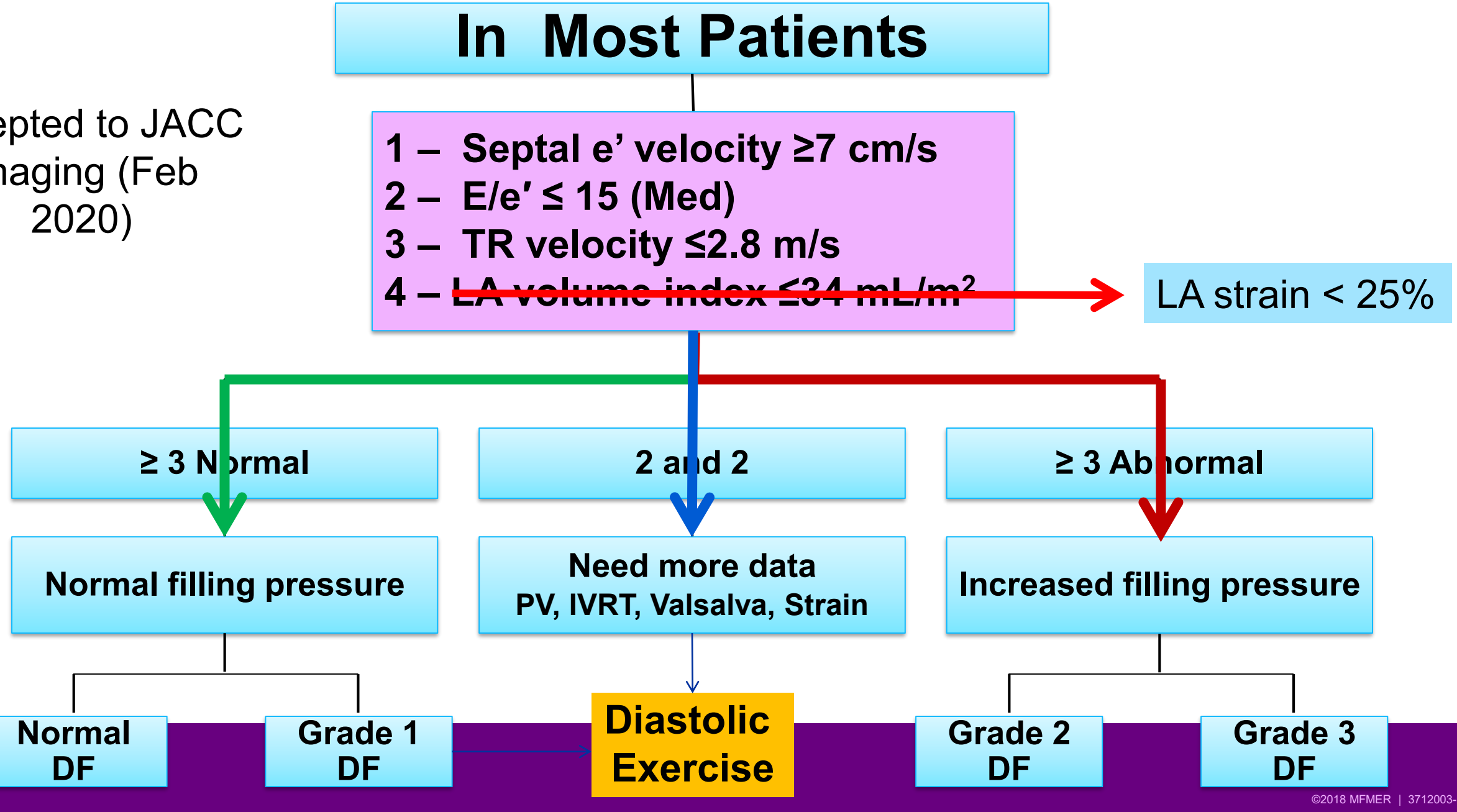
European Heart Journal – Cardiovascular Imaging (2015) 16, 1031–1041
doi:10.1093/ehjci/jev083

Echocardiographic reference ranges for normal cardiac Doppler data: results from the NORRE Study

- LA volume index is > 34 mL/m^2 in 10.5% of normal control
  - 8.5 % in 20-40 years of age
  - 14.2 % in 40-60
  - 6.0 % in >60
- Reasons for LA enlargement
  - Increased filling pressure
  - Increased volume
  - Athlete's heart
  - Measurement error

Revised Algorithm for Diastolic Function Assessment

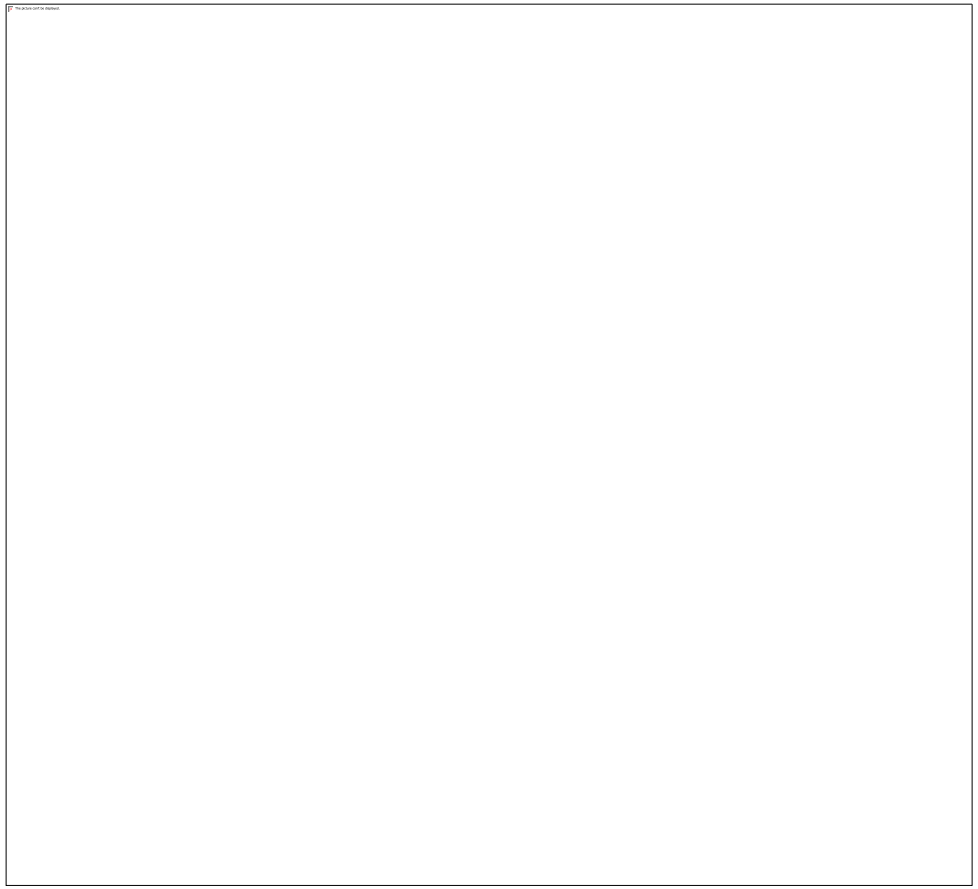
Accepted to JACC Imaging (Feb 2020)

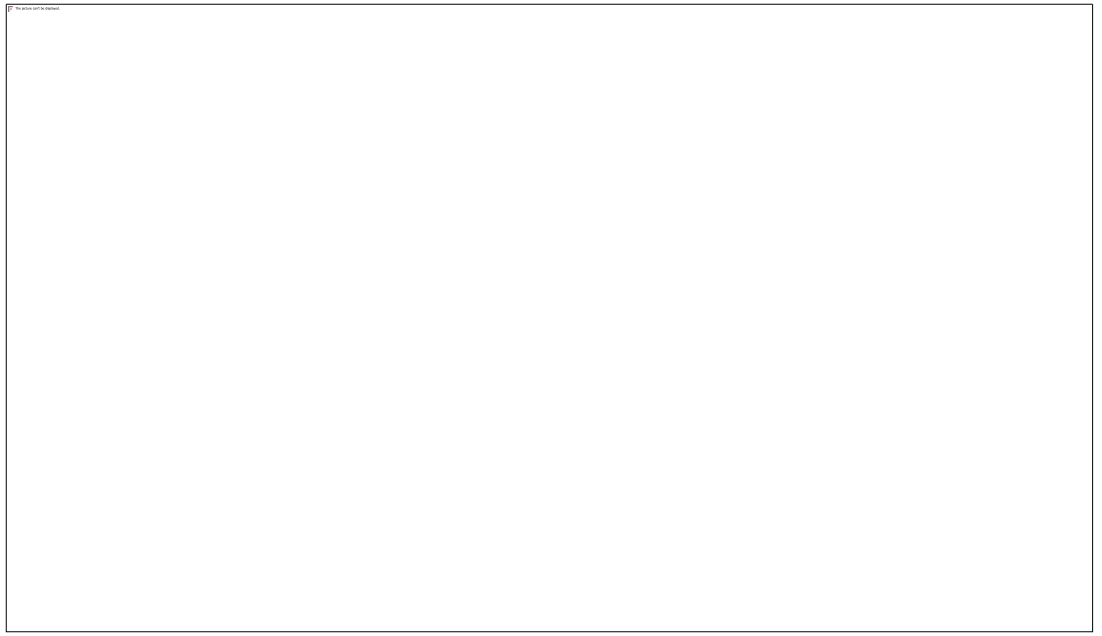


Cases #34-

In clinical practice, we do not have to use all echo parameters for diastolic function assessment. Diastolic function parameters do have hierarchial strength. More data are not always better.

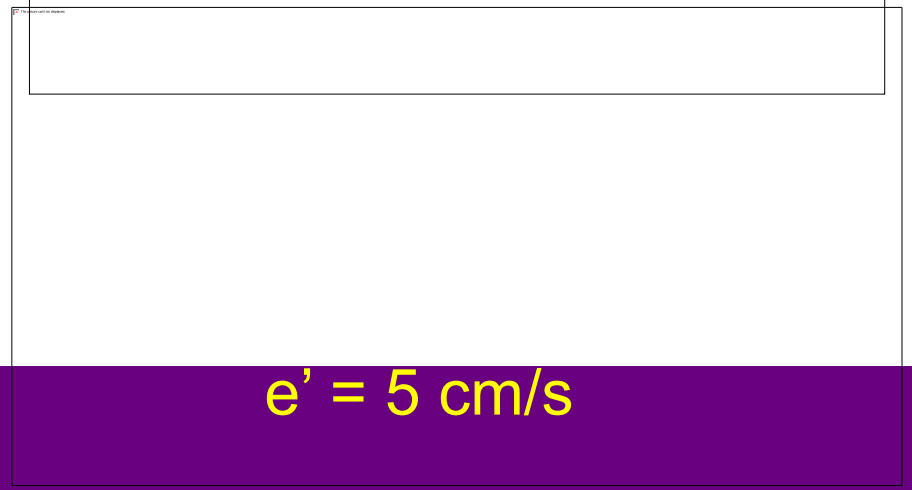
Normal Diastolic Function



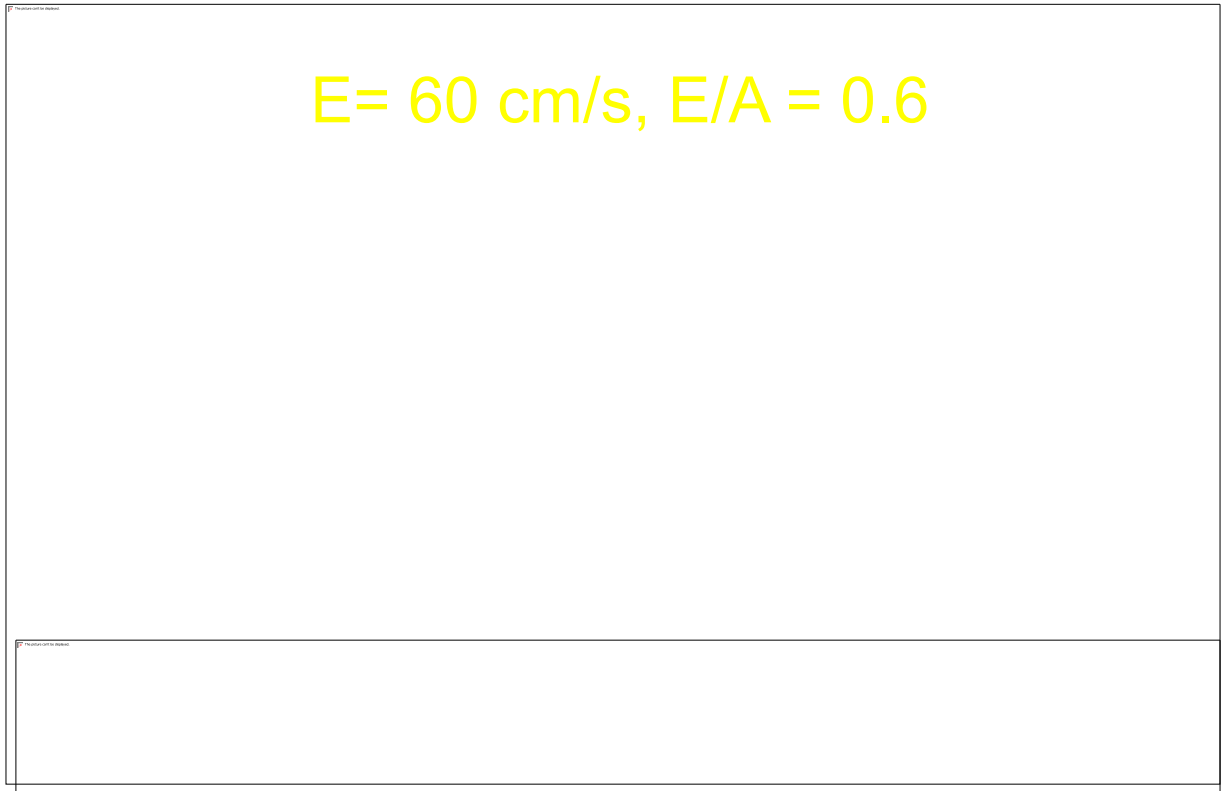


Medial e’ 15 cm/sec

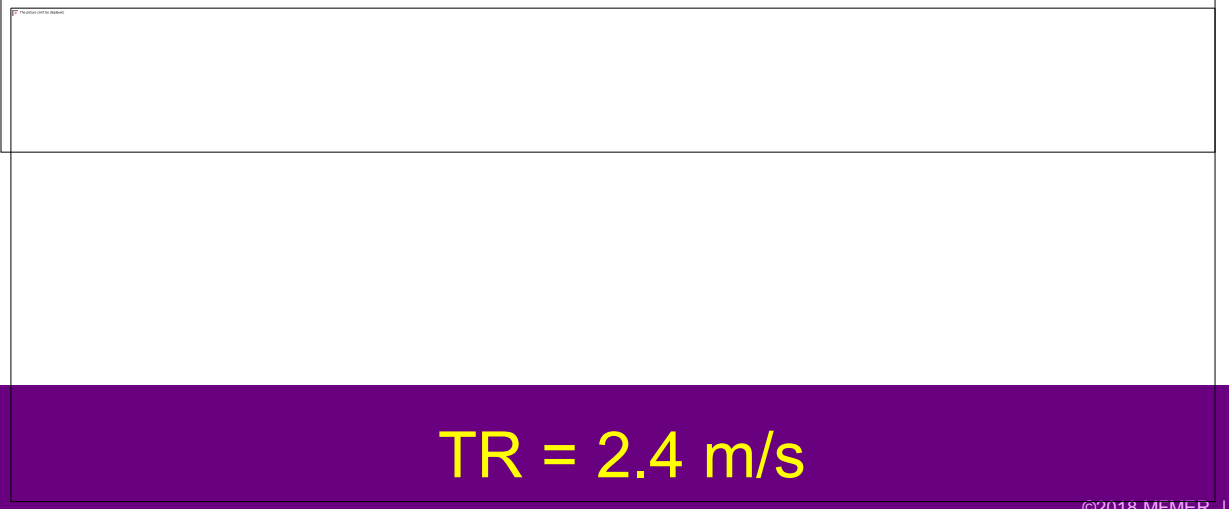
Mitral Annulus Calcification Grade 1



e’ = 5 cm/s

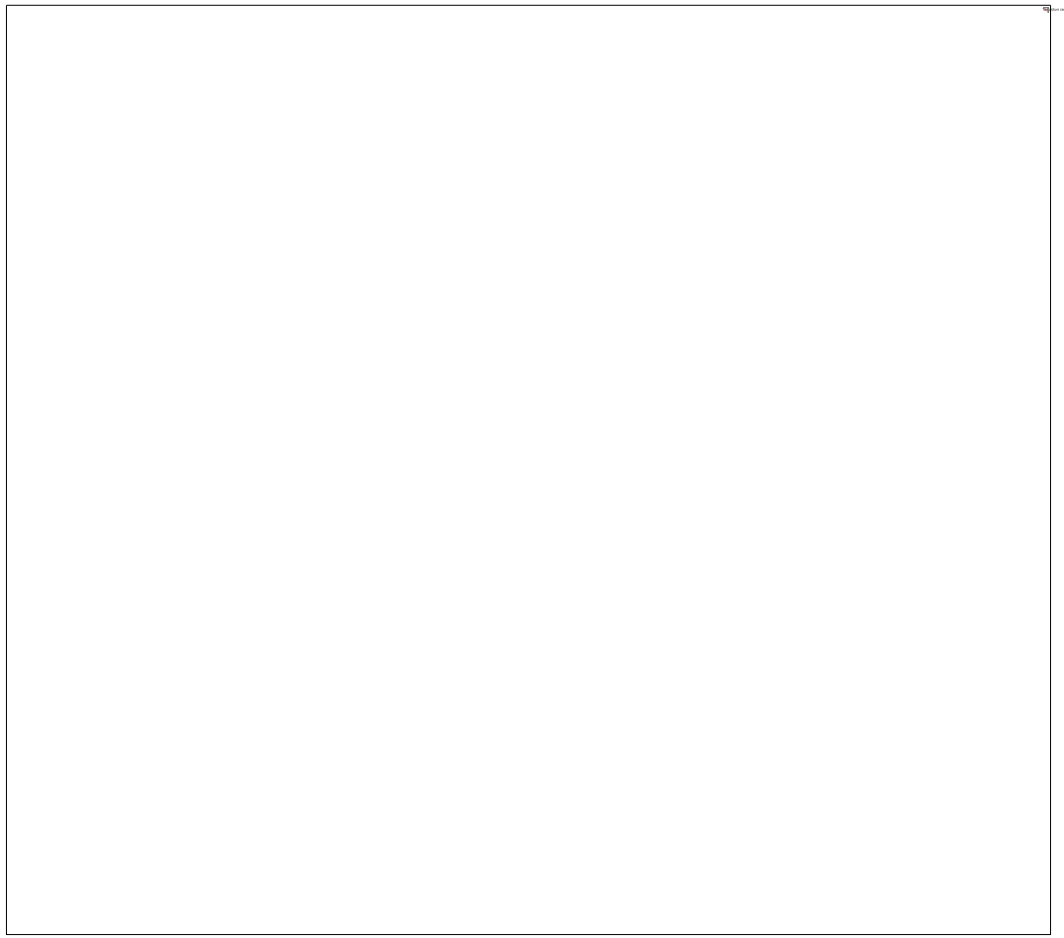


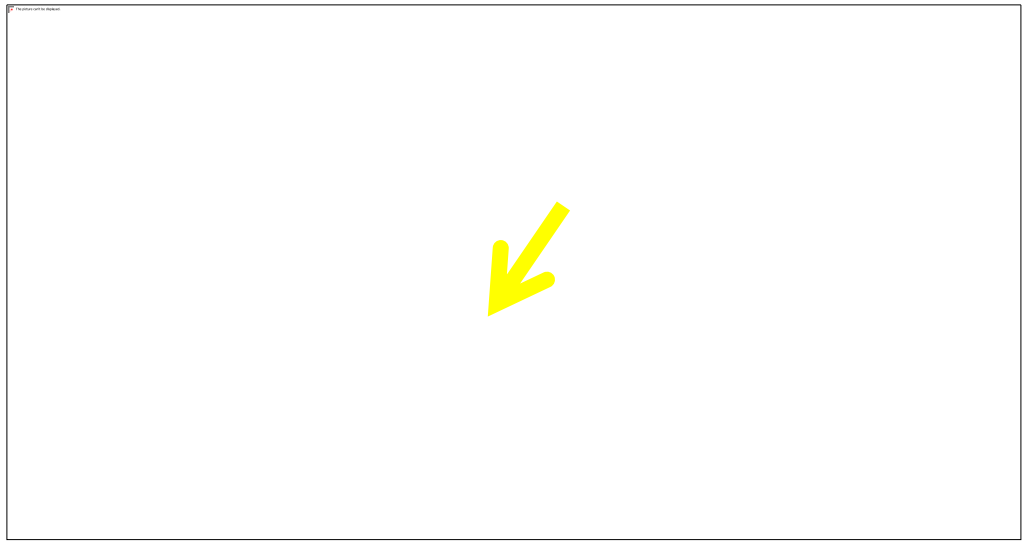
E= 60 cm/s, E/A = 0.6

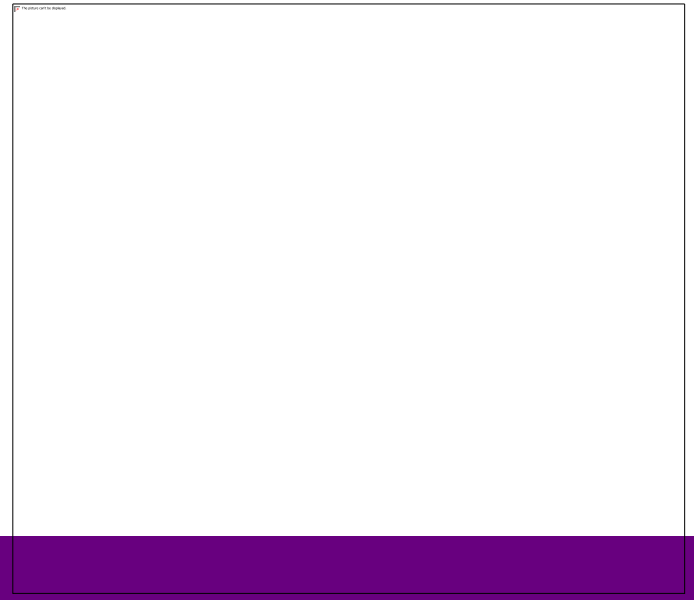


TR = 2.4 m/s

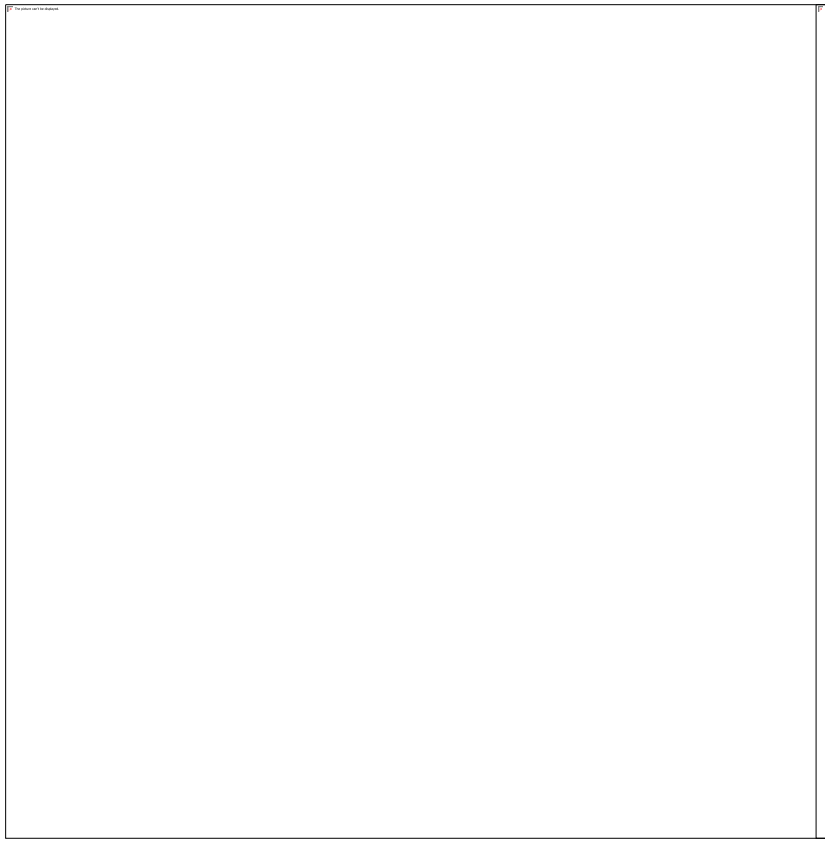
Mitral Annulus Calcification

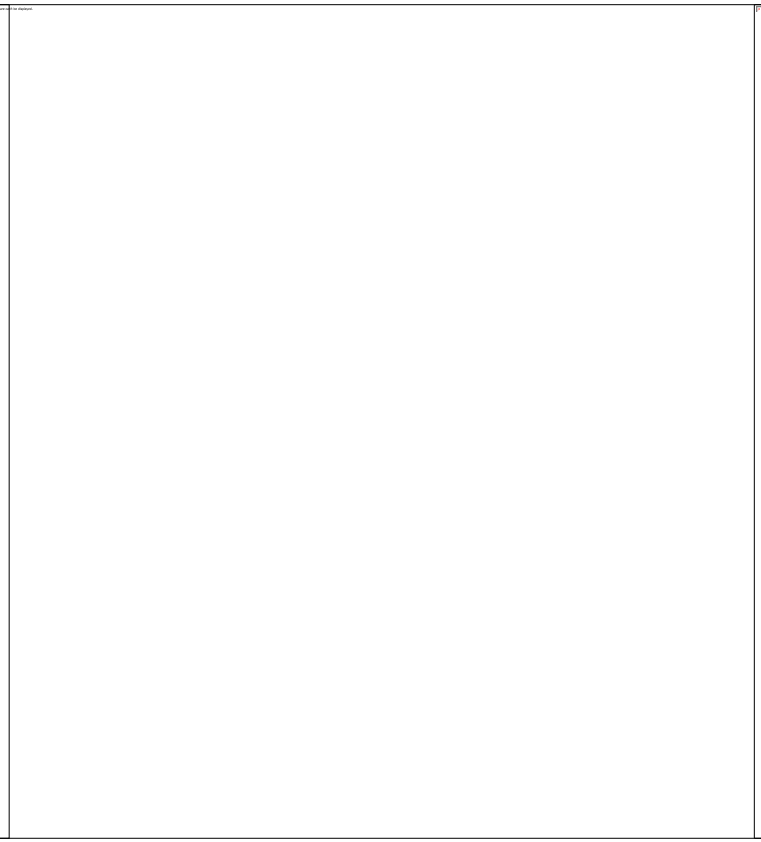
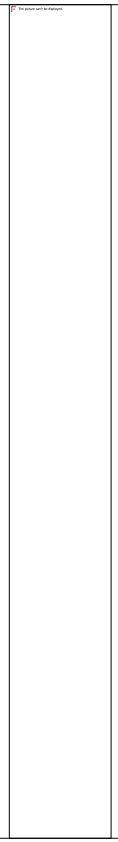
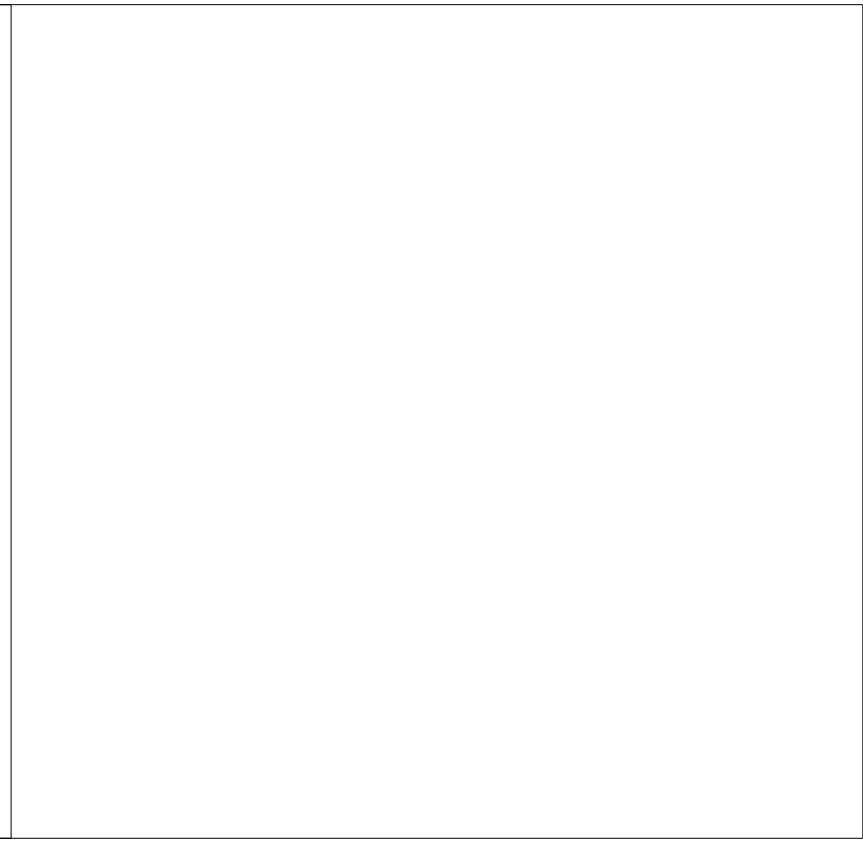






Diastolic Function ?

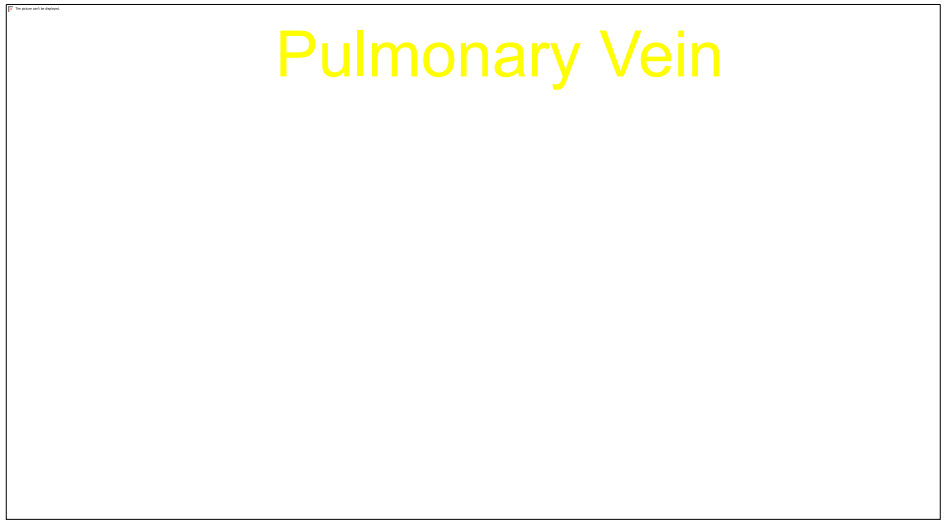


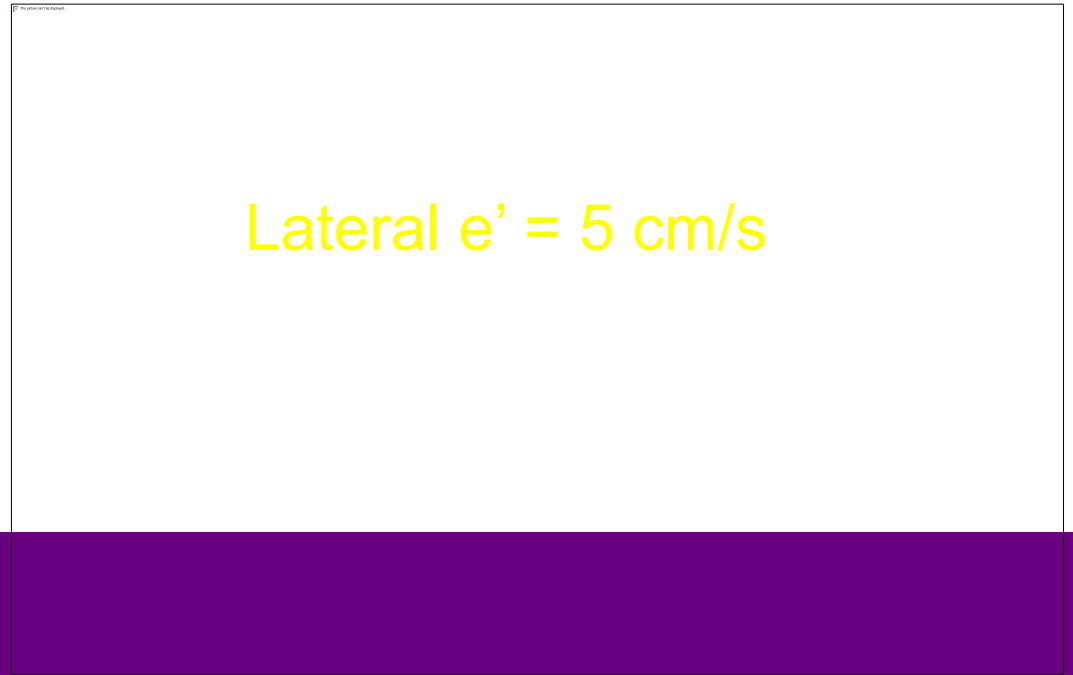
Grade 3 Dysfunction

E= 100 cm/s

Pulmonary Vein

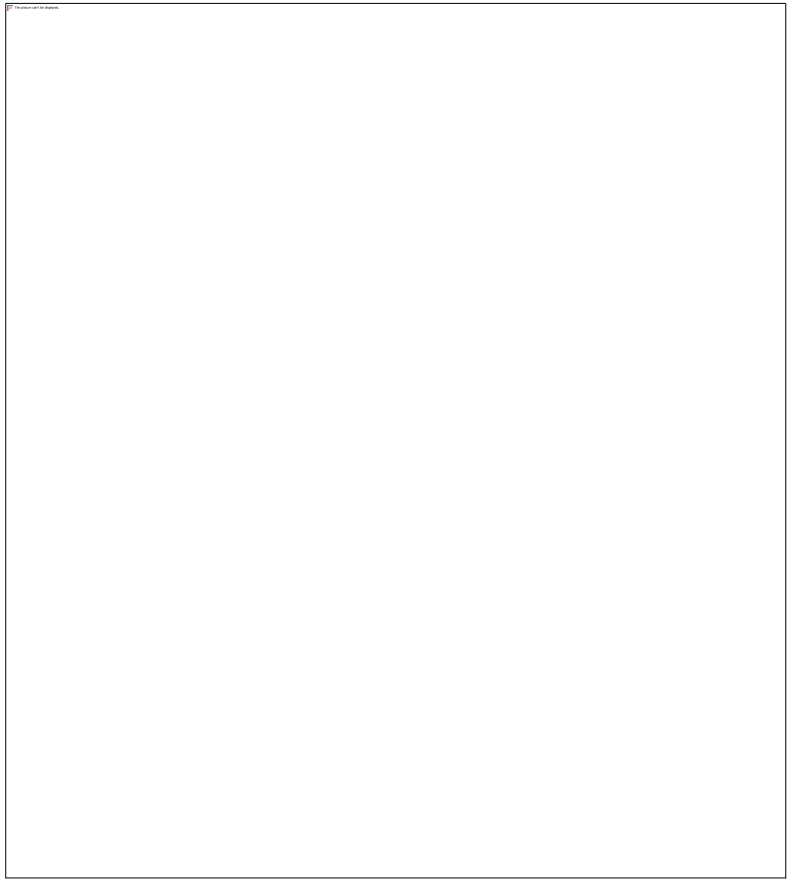


Lateral e’ = 5 cm/s



Medial e’ = 3 cm/s

Atrial Fibrillation with rate of 90s

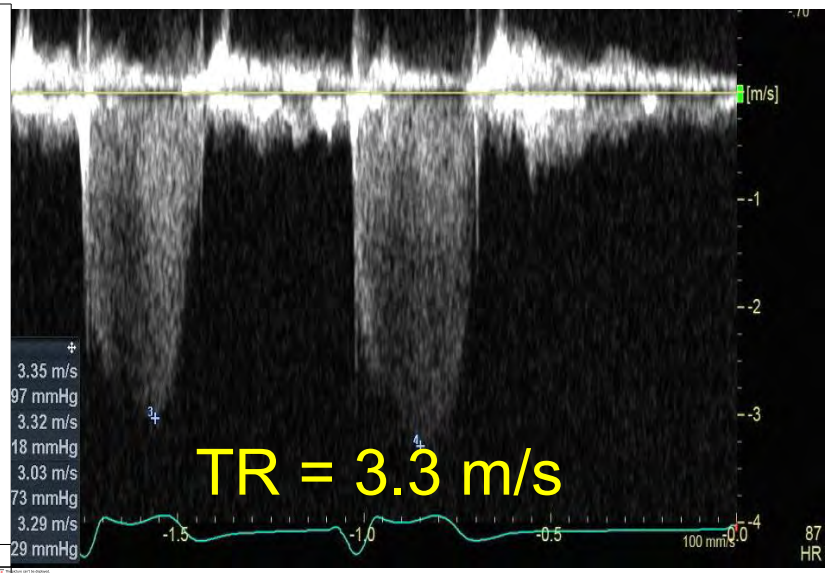


- E= 120 cm/s
- No variability
- DT < 150 ms

Atrial Fibrillation with E/e' medial = 15

E= 110 cm/s

Lateral e' = 10 cm/s



Medial e' = 7 cm/s

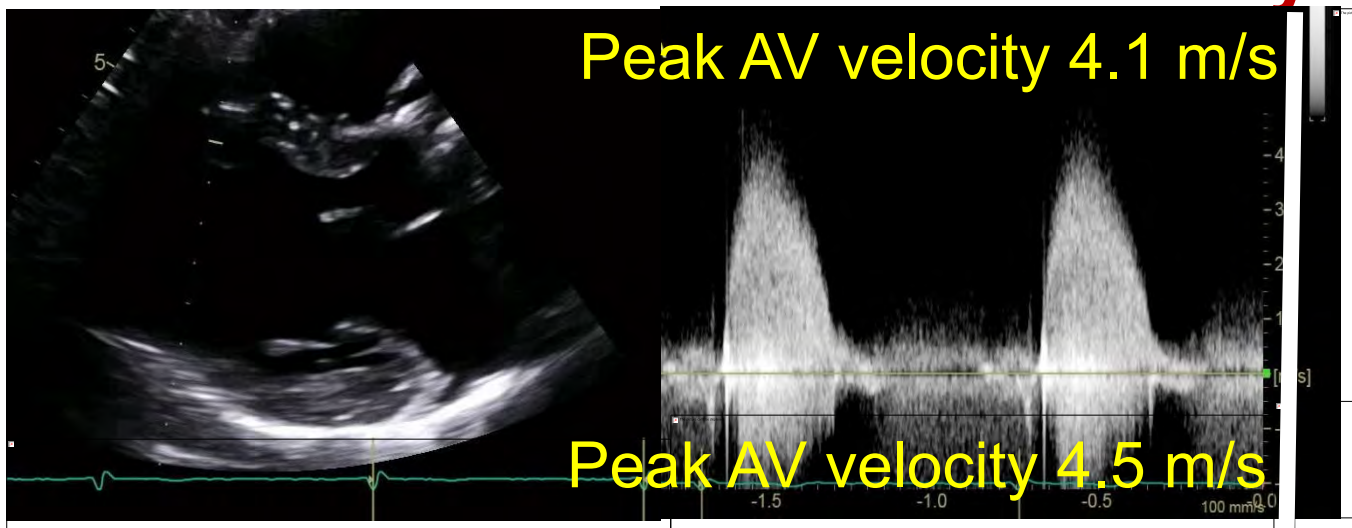
RVOT W

Clinical Applications of Diastolic Function Assessment

- Determine diastolic dysfunction and estimate filling pressures
- Evaluation of dyspnea and HFpEF (Diastolic HF)
- Evaluation of constriction vs myocardial disease
- Prognostic in all cardiac conditions
  - Coronary artery disease
  - Valvular heart diseases
  - Myocardial diseases
  - Constriction

3 patients with severe aortic stenosis

Who is most symptomatic?



E= 60 cm/s

Medial e' = 7 cm/s

E/e' =9

Normal

E= 40 cm/s

e'= 5 cm/s

E/e' =7

Peak AV velocity 4.2 m/s

Grade 1

E = 90 cm/s

e' = 5 cm/s

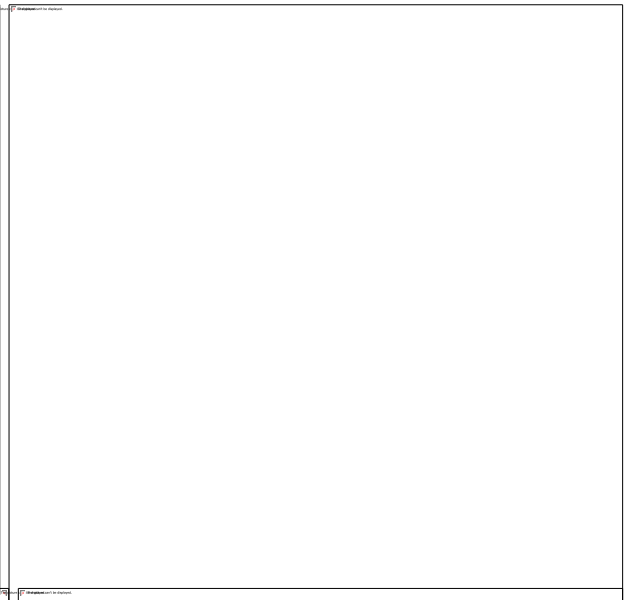
E/e' = 18

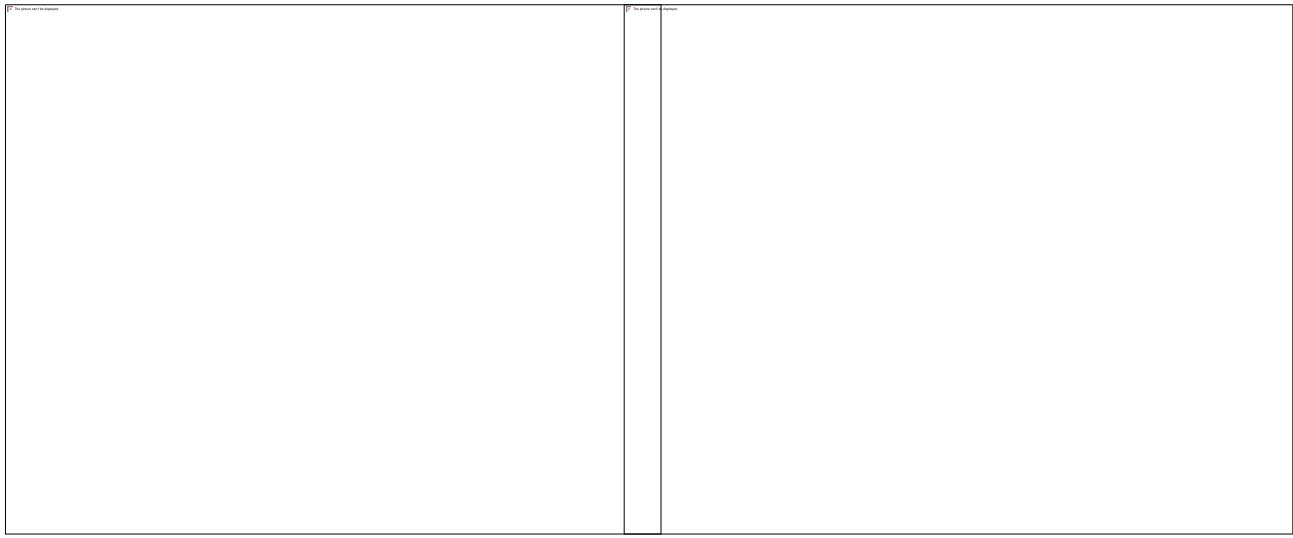
Grade 3

MAYO CLINIC

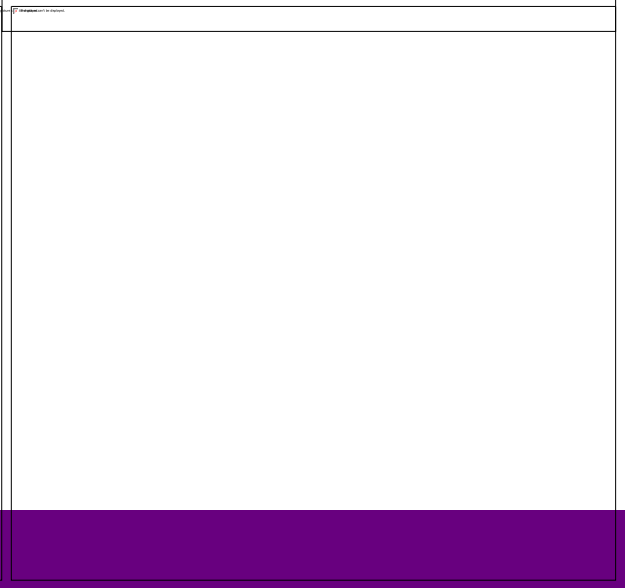
63 yo woman with Amyloidosis treated with Melphalan and Dexamethasone

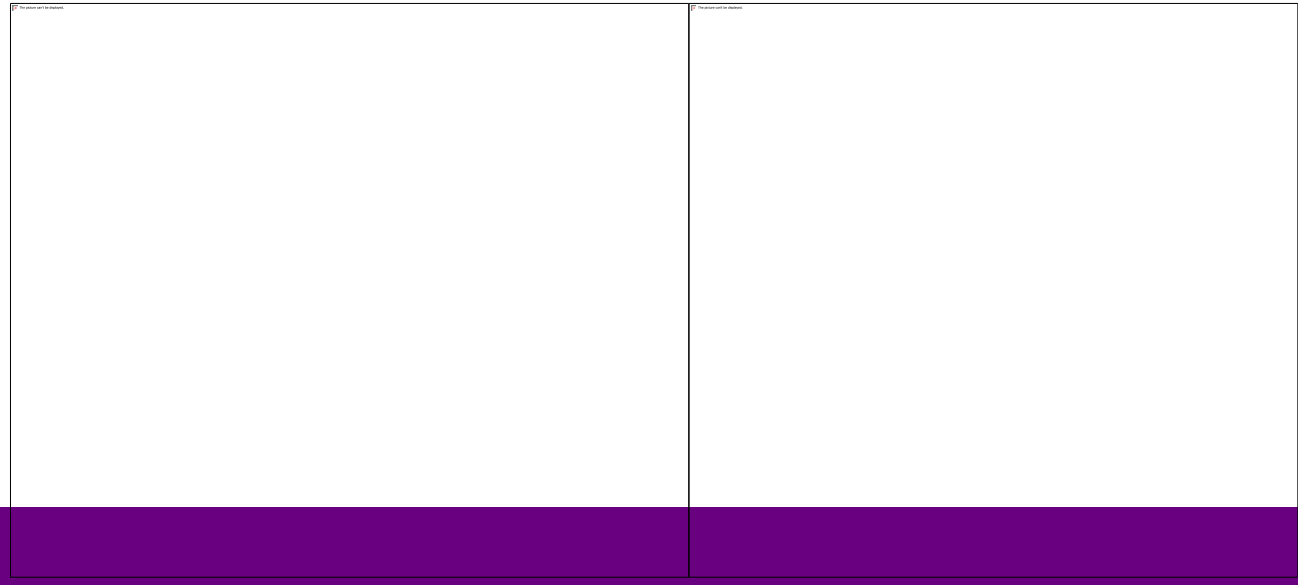
May





December



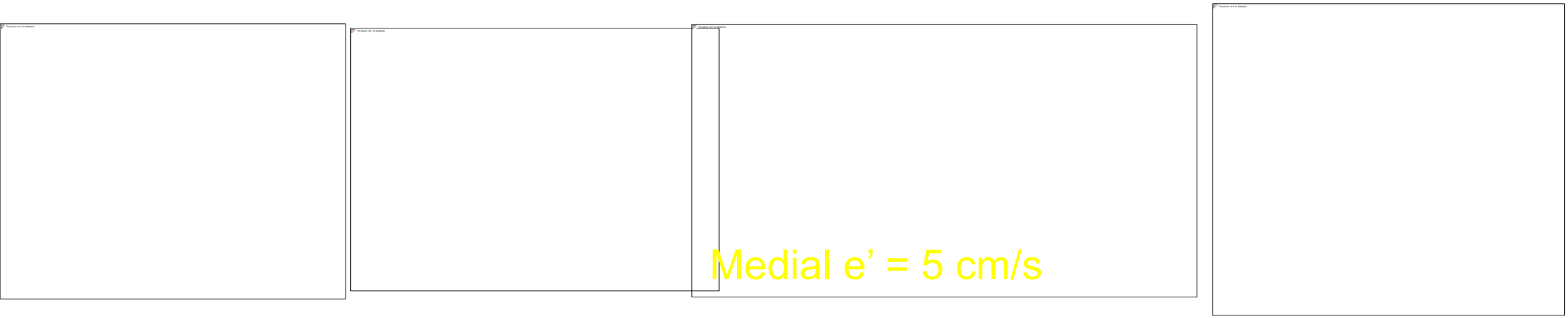


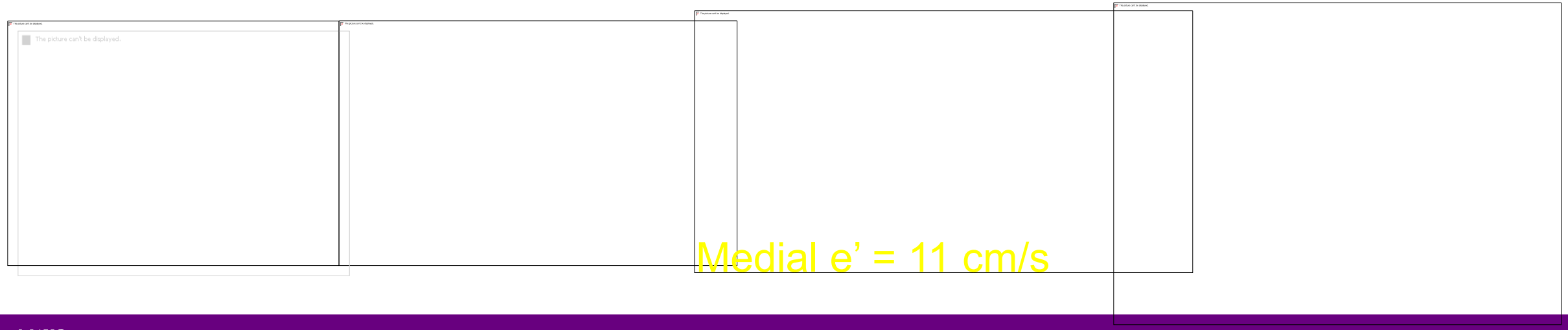
MAYO CLINIC

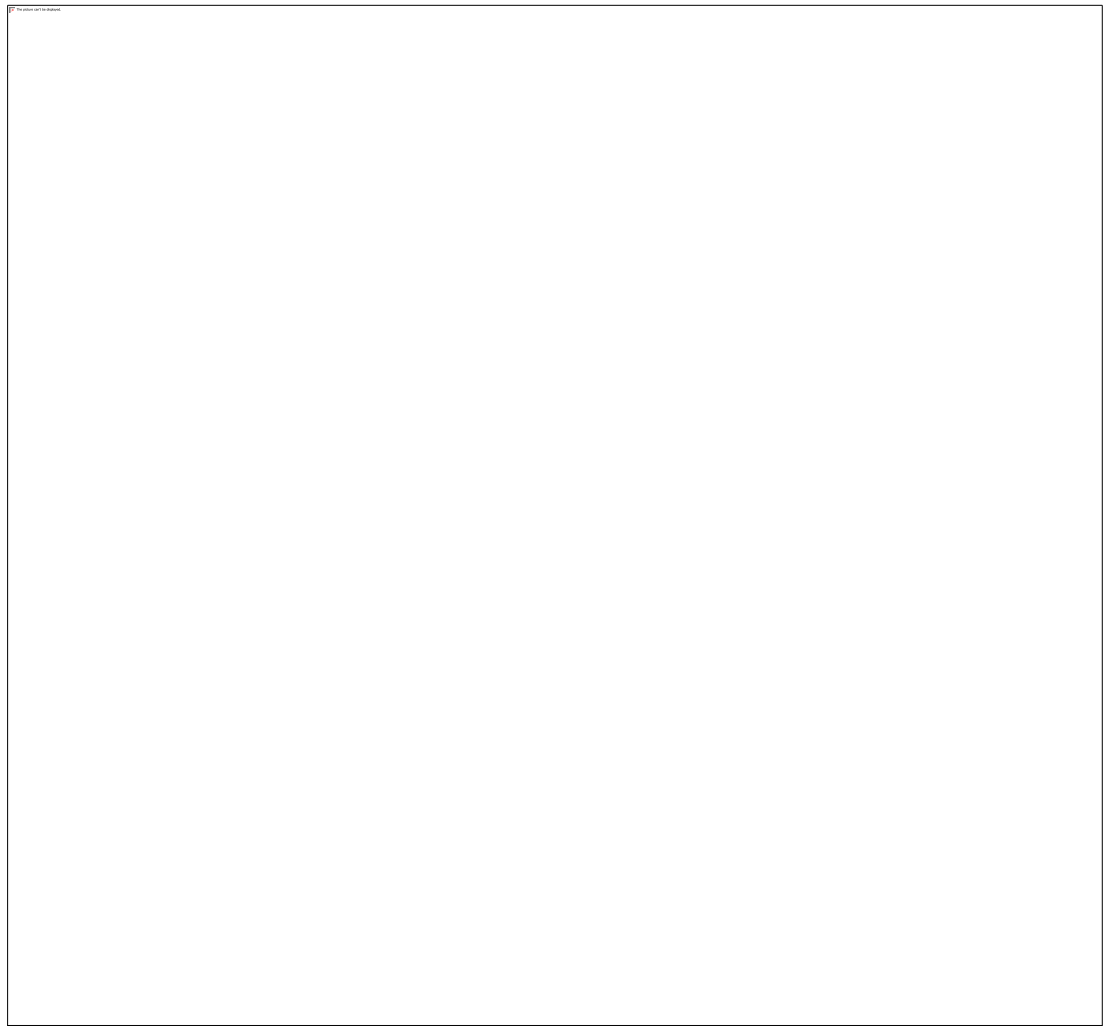
Case #40

Restriction or Constriction?

Diagnosis based on 2-D , e' and strain imaging







MAYO CLINIC

Thank You !

oh.jae@mayo.edu