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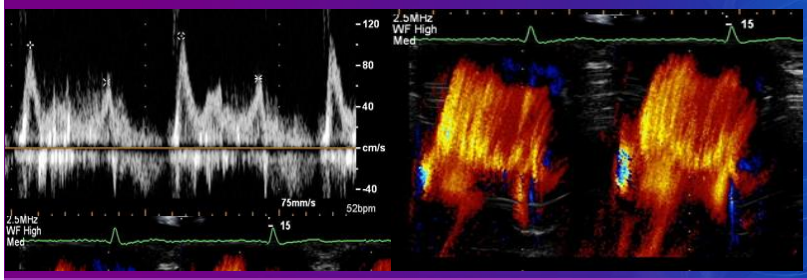
Assessment of Diastolic Function

Challenging, but Can be Simple

ASE Echo Board Review 2019



Jae K. Oh, MD
Samsung Professor of CV Diseases

Learning Objectives for Diastology
After this talk, you will be able to

- Understand physiology and hemodynamics of diastole
- Know correlation between Echo diastolic parameters and underlying hemodynamics
- Appreciate how 2016 Guideline was created
- Understand pitfalls of Echo diastolic function assessment
- Classify and grade diastolic function
- Estimate filling pressure reliably in most patients at rest and with exercise

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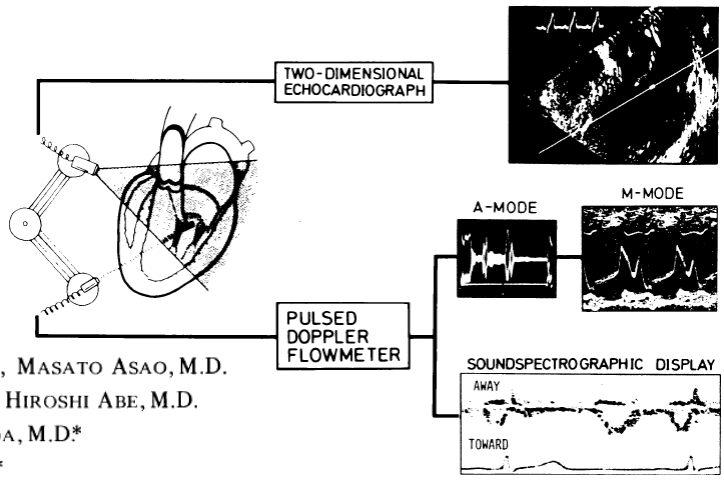
Do you believe Diastolic Function Assessment is Essential in Echocardiography and Patient management ?

1. YES
2. NO
3. I Am Not Sure
4. Only Important for Board Examination

Transmitral Blood Flow Reflecting Diastolic Behavior of the Left Ventricle in Health and Disease
–A Study by Pulsed Doppler Technique–



AKIRA KITABATAKE, M.D., MICHITOSHI INOUE, M.D., MASATO ASAO, M.D.
JUN TANOUCHI, M.D., TOHRU MASUYAMA, M.D., HIROSHI ABE, M.D.
HISAKI MORITA, M.D.*, SCHOICHI SENDA, M.D.*
AND HIROHIDE MATSUO, M.D.*

Kitabatake et al Japanese Circ J 1982

Transmitral Blood Flow Reflecting Diastolic Behavior of the Left Ventricle in Health and Disease
–A Study by Pulsed Doppler Technique–

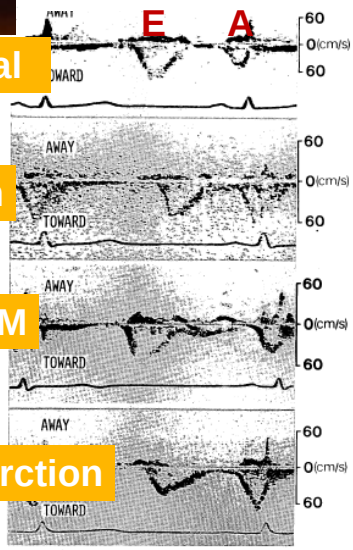
Kitabatake Circ J. 1982

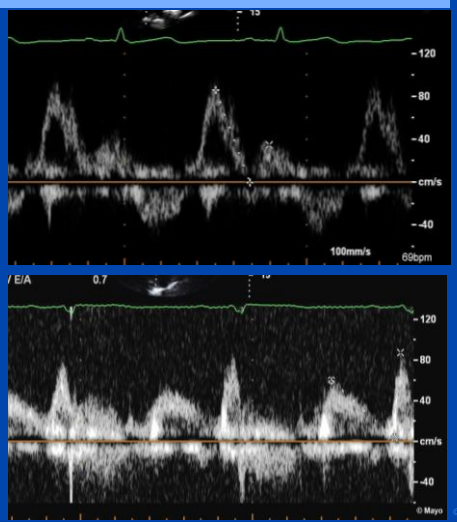
Healthy Normal

Hypertension

Hypertrophic CM

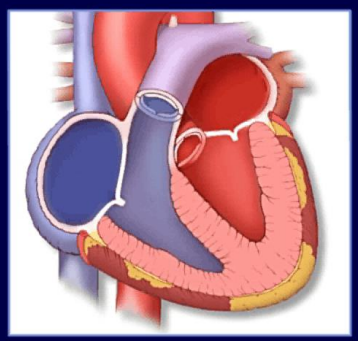
Myocardial Infarction

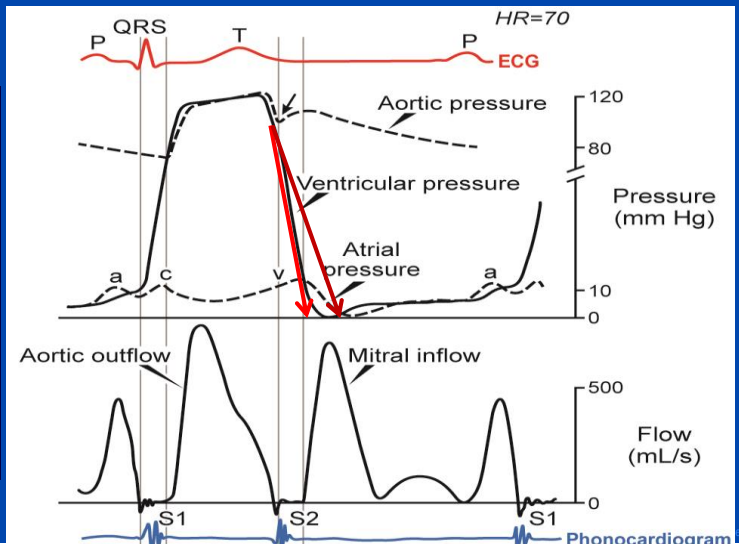




Diastolic Filling with Relaxation

διαστολή: Greek word for dilation





A Clinical Study of Left Ventricular Relaxation

YUZO HIROTA, M.D.

Circulation 1980

SUMMARY Left ventricular (LV) relaxation was studied in patients with hypertrophic cardiomyopathy (HCM, n = 18), congestive cardiomyopathy (CCM, n = 11), hypertensive heart disease (HHD, n = 8), coronary artery disease (CAD) without left ventricular (LV) asynergy (n = 9) and with LV asynergy (n = 17), mitral stenosis (MS, n = 16), and mitral regurgitation (MR, n = 8). The time constant T and peak negative dP/dt were used as indexes of LV relaxation, and 18 normal subjects served as controls.

The time constant T was higher in elderly patients among normal controls ($r = 0.652$, $p < 0.01$), which suggests that prolongation of relaxation is a phenomenon of aging. The normal value of the time constant T was 33 ± 8 msec (mean ± SD), and that of peak negative dp/dt was 1864 ± 390 mm Hg/sec. The time con-

Myocardial relaxation is one of the earliest manifestations of mechanical dysfunction of the human LV. The time constant tau (T) is higher in the elderly and patients with HCM, CAD, and cardiomyopathies.

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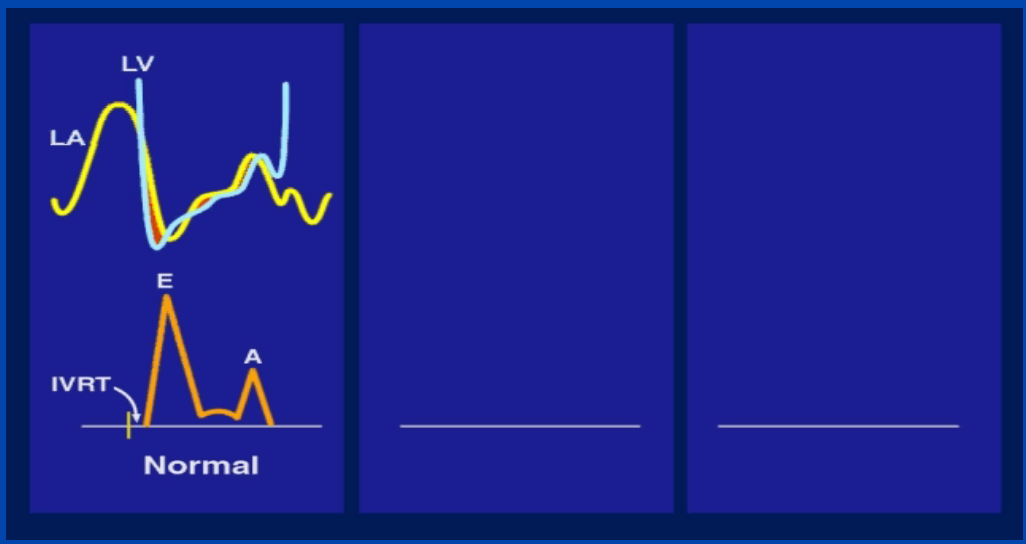
Echo evaluation of diastolic function

Trans-mitral inflow velocity



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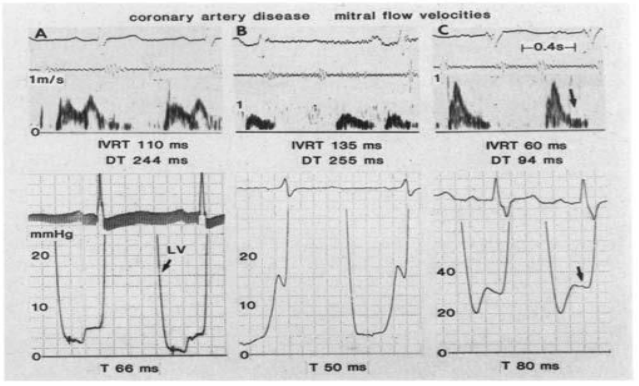
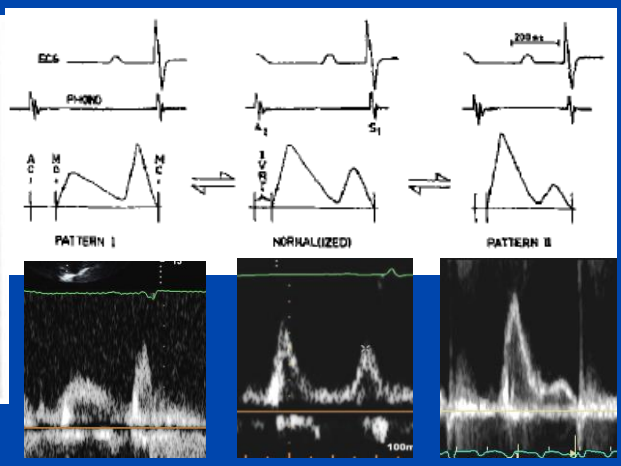
Relation of Transmitral Flow Velocity Patterns to Left Ventricular Diastolic Function: New Insights From a Combined Hemodynamic and Doppler Echocardiographic Study

CHRISTOPHER P. APPLETON, MD, LIV K. HATLE, MD, RICHARD L. POPP, FACC
Stanford, California and Tucson, Arizona





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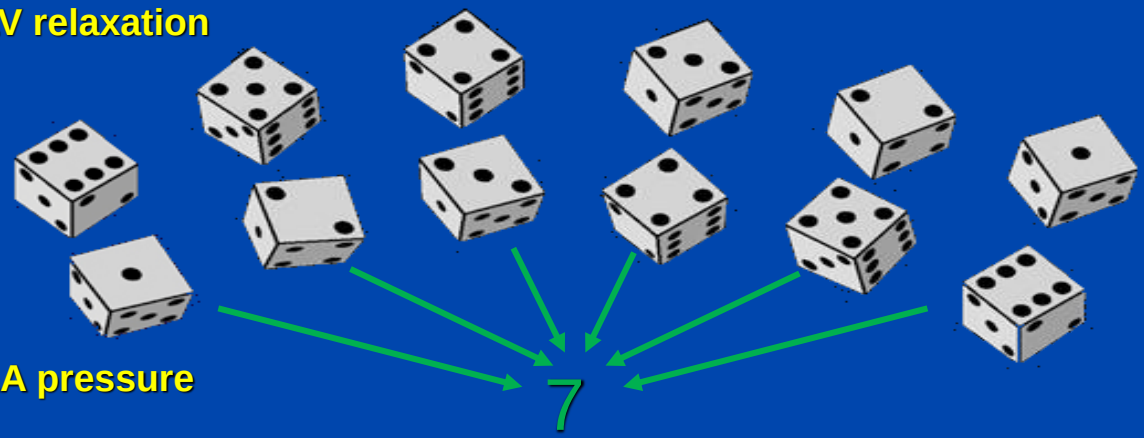
Pseudo-normalization

LV relaxation



LA pressure

7

All combinations = 7
(ie, same mitral inflow velocity pattern)

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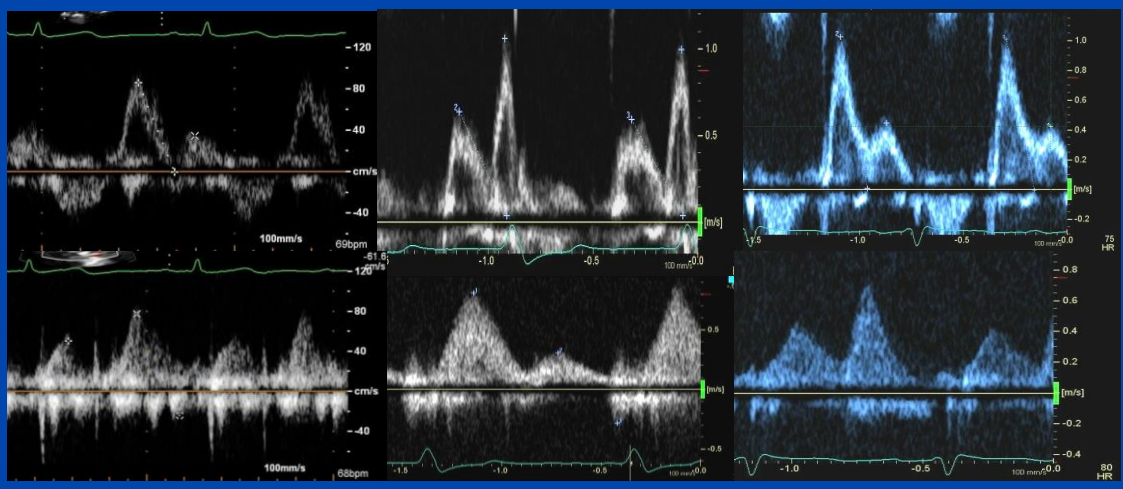
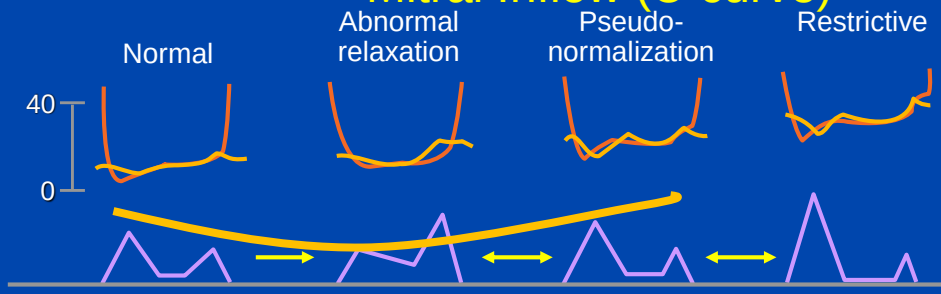
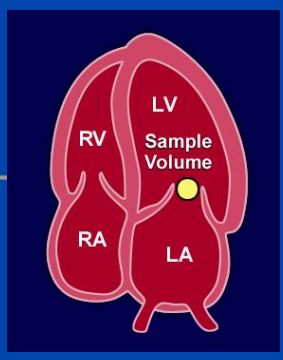
Mitral Inflow and Pulmonary Vein Flow
Diastolic Function Assessment



Normal Grade 1 Grade 3

Diastolic Function Grading
Mitral Inflow (U curve)

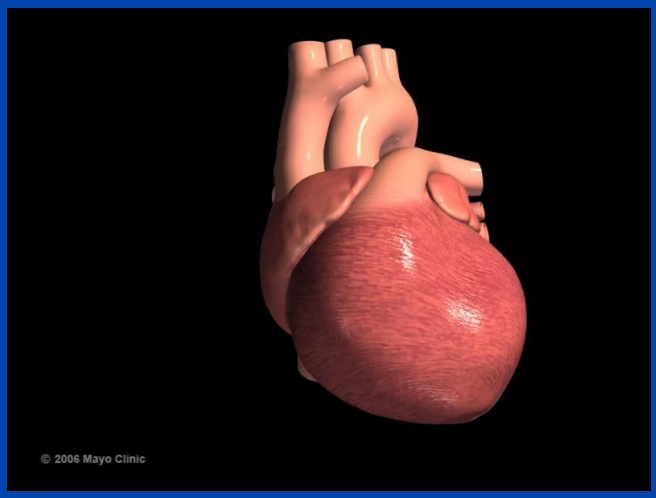




LAP	**NL (< 15)**	**Normal**	**↑ ↑**	**↑ ↑ ↑**
TAU	**NL (< 45)**	**↑**	**↑**	**↑ ↑**
Grade		**1**	**2**	**3**

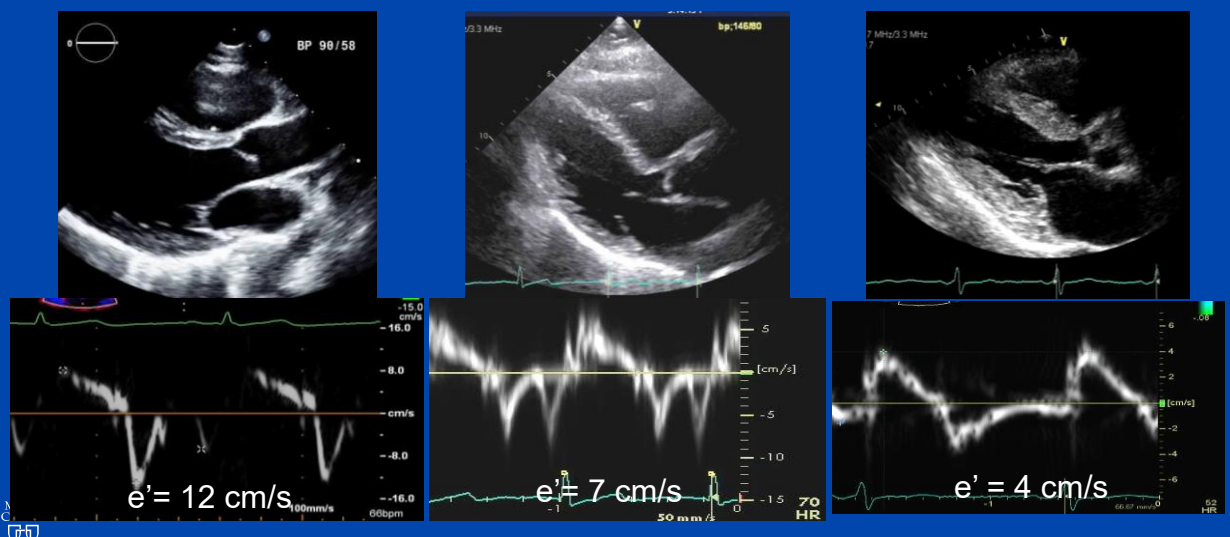
Concept from Appleton and Hatle, 1985

Assessment of LV Relaxation by Echo
e' velocity reflects LV relaxation



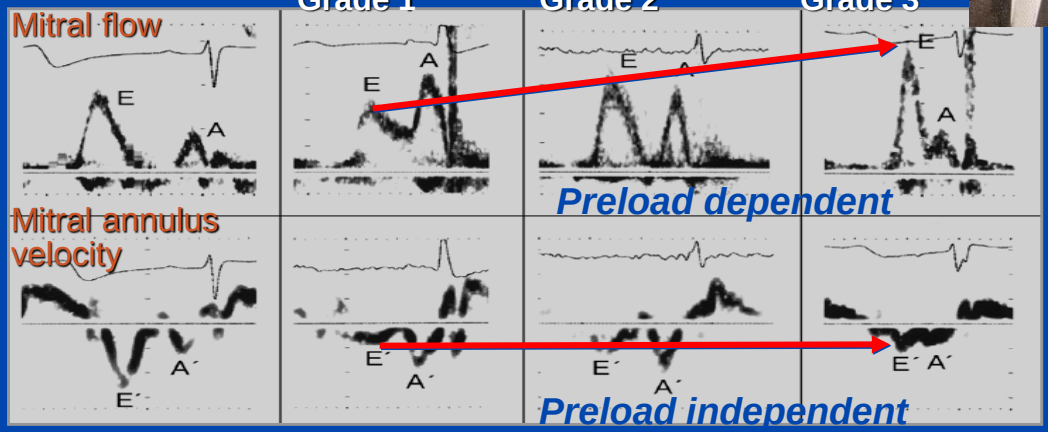
Myocardial Relaxation is the Key for Diastole

Myocardial Relaxation (e')



Evaluation of Diastolic Function

*Mitral Inflow and Annulus **Velocity***



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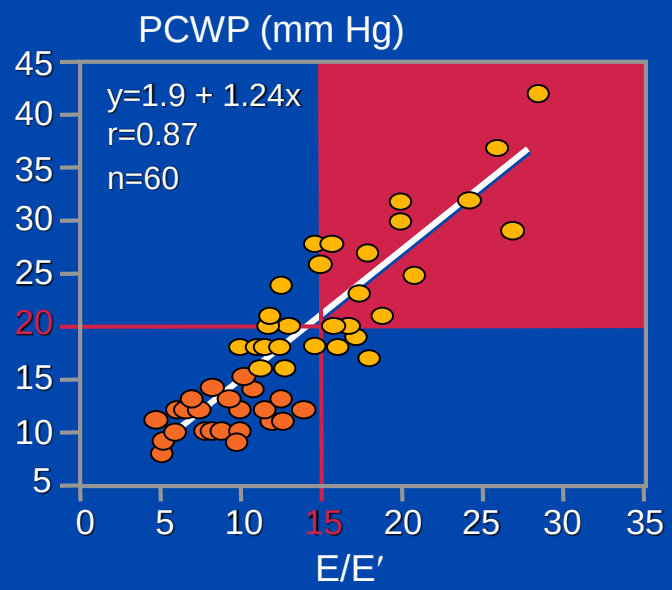
DW Sohn et al: JACC, 1997

As LV filling pressure ↑

- Mitral E ↑
- Annulus E′ ↓
- E/E′ ↑



Nagueh et al: JACC, 1997
Ommen et al: Circ, 2000

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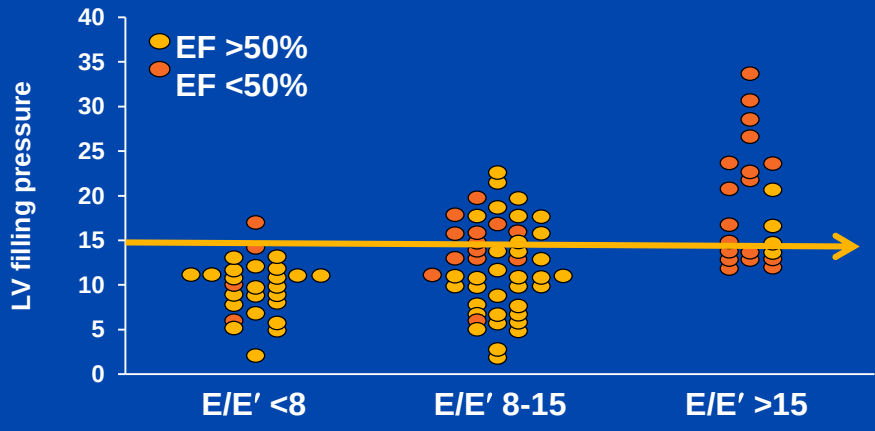
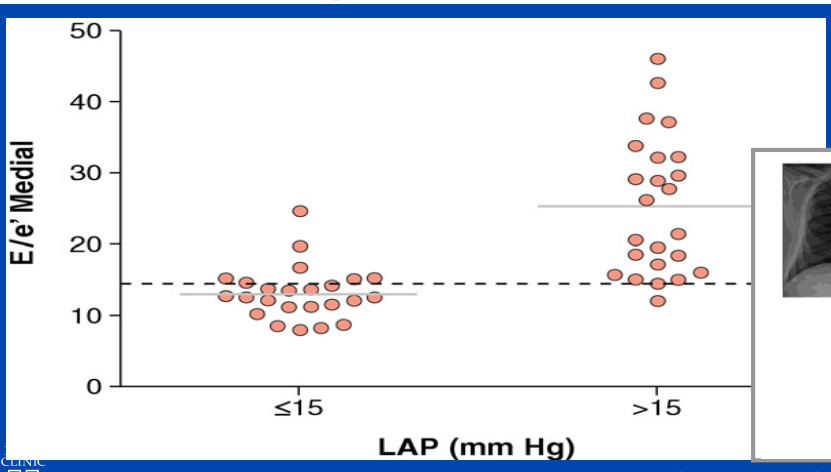
Estimation of LV Filling Pressures
E/e' (Medial MV annulus)

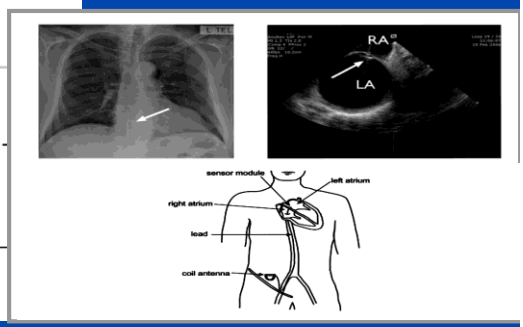


Ommen SR et al: Circulation 102:1788, 2000

ORIGINAL RESEARCH

Serial Doppler Echocardiography and Tissue Doppler Imaging in the Detection of Elevated Directly Measured Left Atrial Pressure in Ambulant Subjects With Chronic Heart Failure

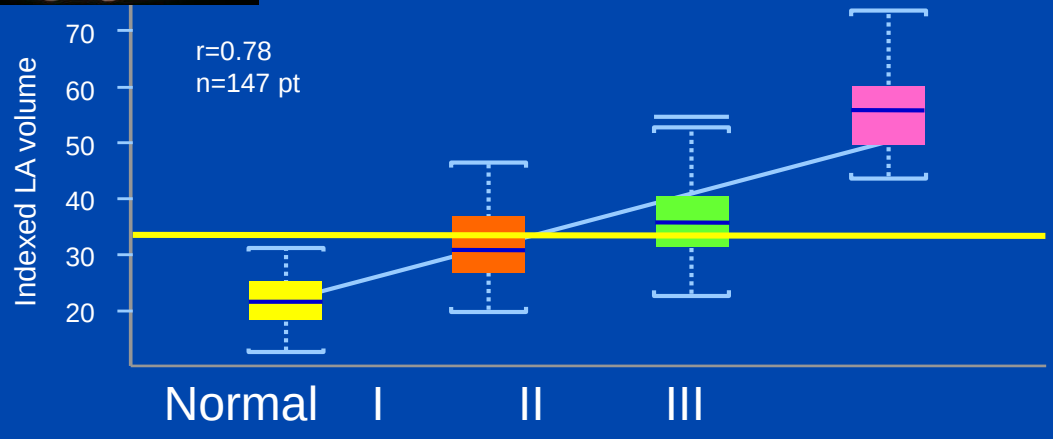




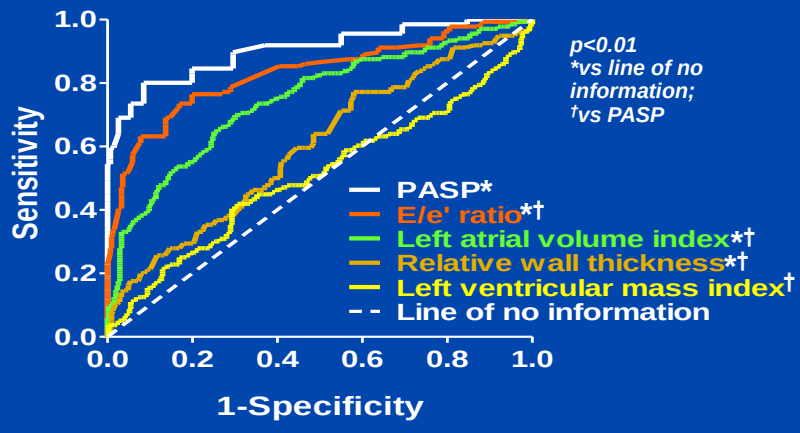
Ritzema et al JACC Imaging 2011

What are normal values for e' and E/e' ? Who has normal diastolic function?

LA Volume Index vs Diastolic Dysfunction



Hypertensive Heart Disease vs HFpEF
Importance of PASP and E/e'



Lam C et al, JACC, 2009

ASE/EACVI GUIDELINES AND STANDARDS

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;*

Four Major Diagnostic Parameters
Normal Values

1. **E' velocity ≥ 7(med), 10 (lat) cm/s**
2. **E/e' ≤ 14 (Av), 15(Med)**
3. **TR velocity ≤ 2.8 m/sec**
4. **LAVI ≤ 34 mL/m²**

JASE and EJ CV Imaging April 2016

New Criteria for Diastolic Function Assessment

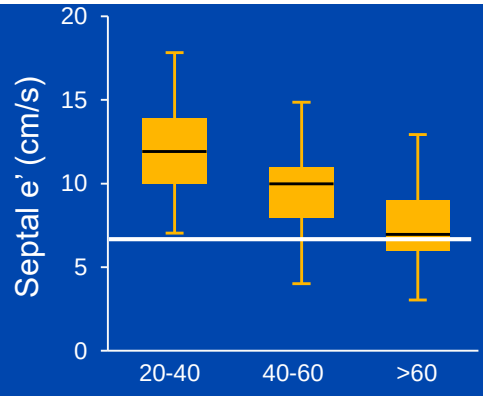
In pts with normal LVEF≥ 50%

1 – Septal e' velocity ≥7 cm/s or lateral e' velocity ≥10 cm/s
2 – Average E/e' ≤14 , 15 (Med)
3 – TR velocity ≤2.8 m/s
4 – LA volume index ≤34 mL/m²

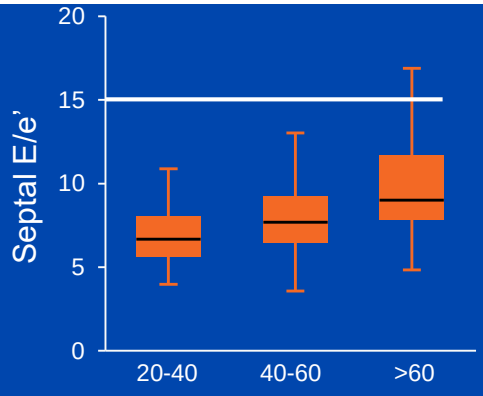
≥ 3 Normal	2 and 2	≥ 3 Abnormal
Normal diastolic function	Indeterminate	Diastolic dysfunction

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

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



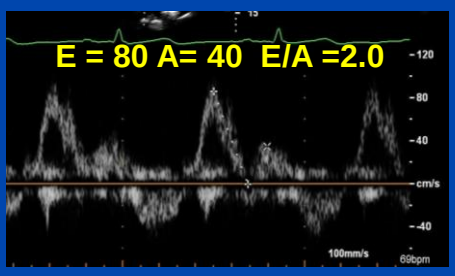
Septal e' based on Age Groups

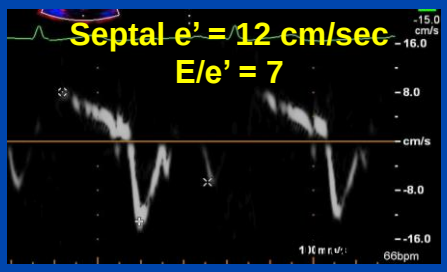


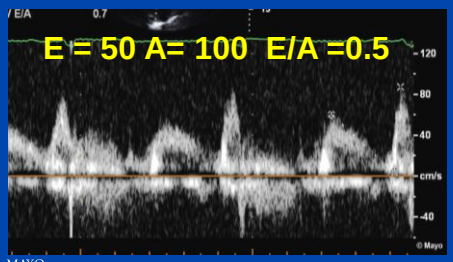
Septal E/e' based on Age Groups

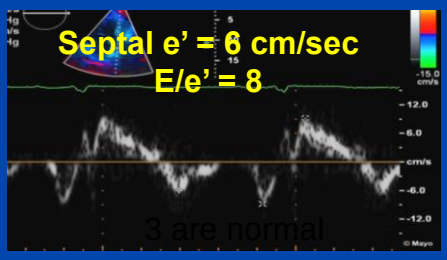
Luis Caballero et al: EHJ, 2015

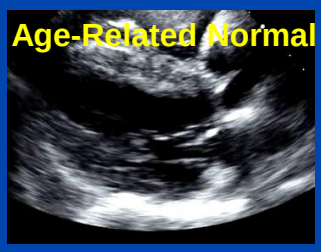
Normal Diastolic Function According to 2016 Guideline
Both have LAVI < 34 mL/m^2 and TR < 2.8 m/sec











3 are normal

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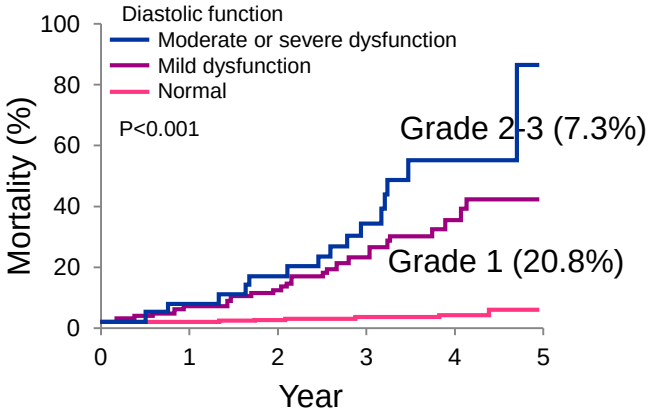
Burden of Systolic and Diastolic Ventricular Dysfunction in the Community

Asymptomatic patients with Grade 1 have > 40% Mortality at 4 year



- Majority was asymptomatic
- Mean age 62.8 year old
- 4.5% Diabetes
- 12.2% CAD
- 25% Hypertension

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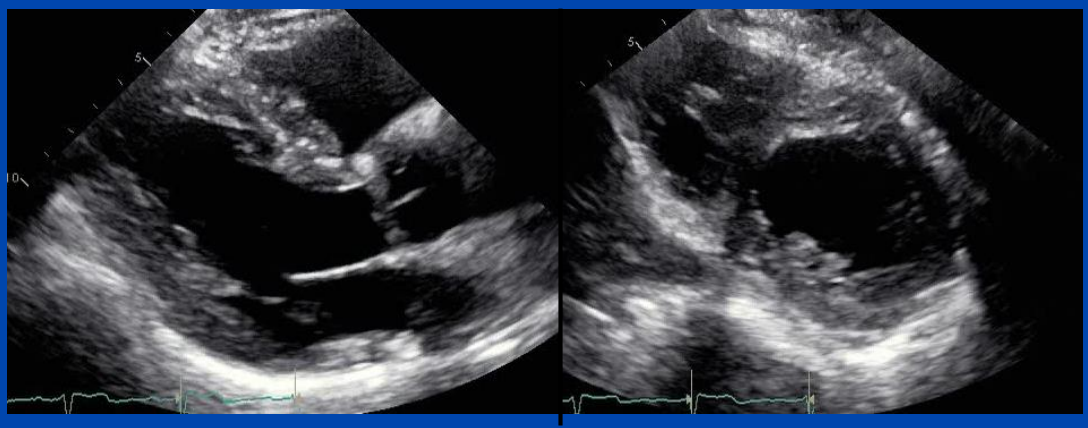
Redfield et al. JAMA 2003

#2

59 year old male with multiple myeloma
No cardiac symptoms

LAVI = 28 mL/m^2



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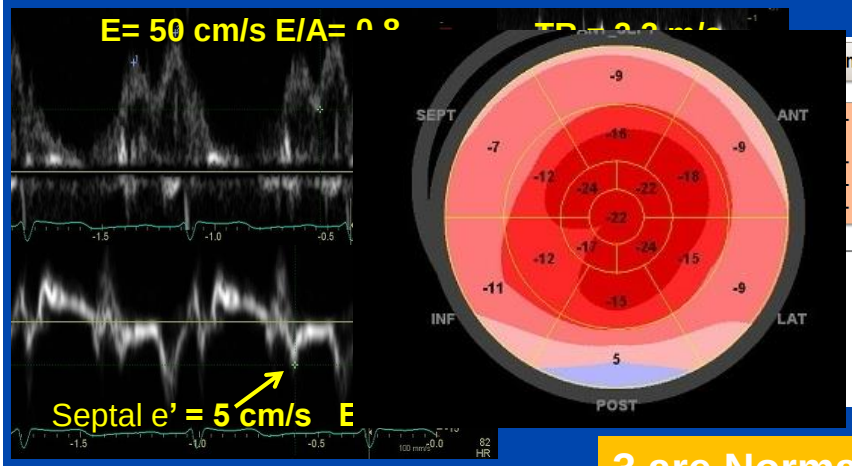
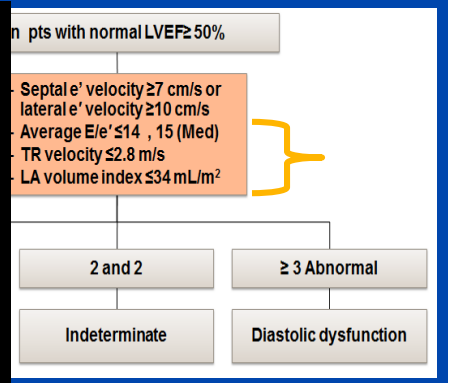
59 year old male with multiple myeloma
No cardiac symptoms





3 are Normal → **Normal DF**

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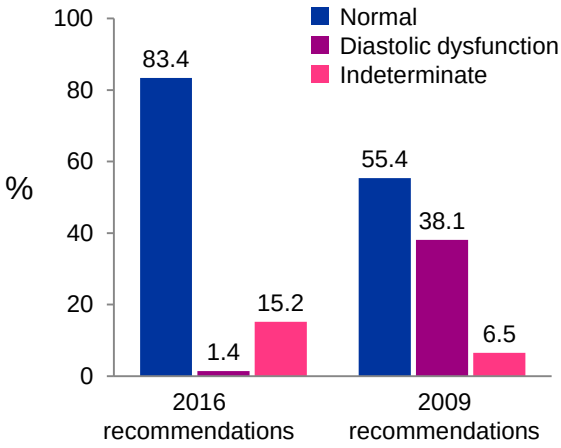
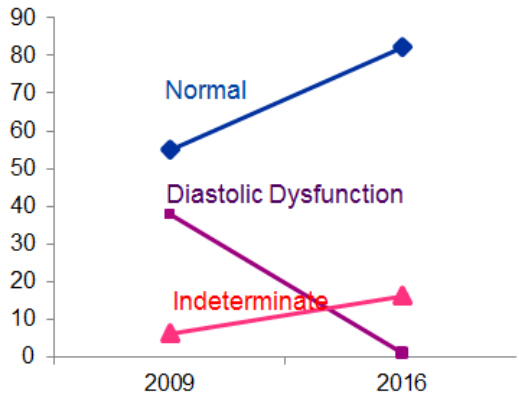
ESC European Society of Cardiology
European Heart Journal - Cardiovascular Imaging (2018) 19, 380–386
doi:10.1093/ehjci/jex252

Impact of the 2016 ASE/EACVI recommendations on the prevalence of diastolic dysfunction in the general population





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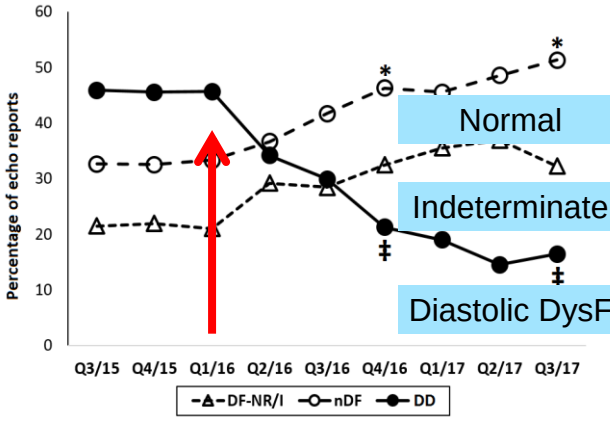
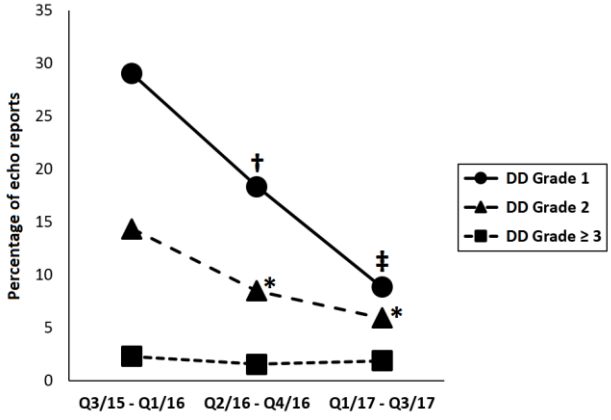
Almeida et al EJCVI 2018

Impact of the 2016 ASE/EACVI Guidelines for Evaluation of Diastolic Function – A Real World Experience.





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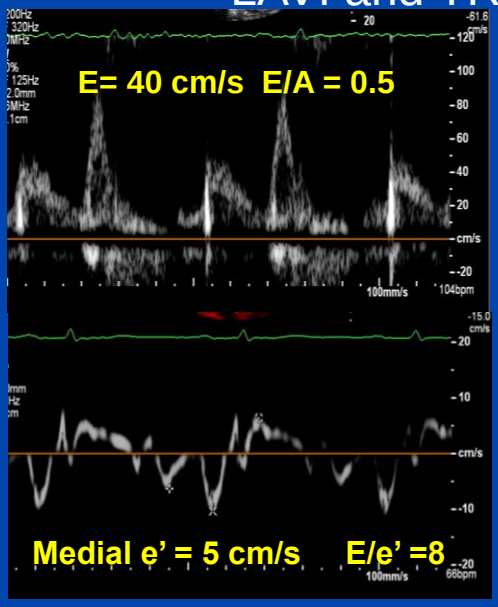
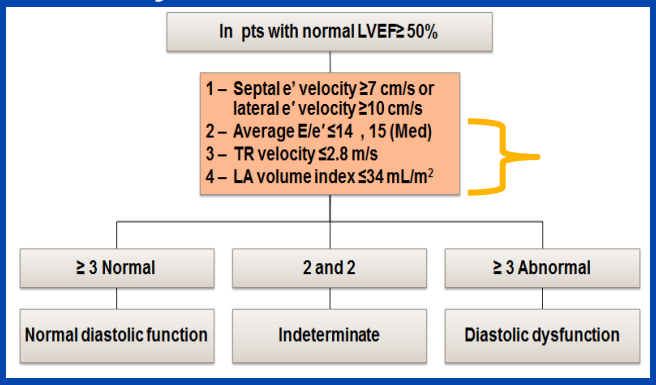
Prabhakaran Gopalakrishnan MD et al AHA 2018

72 year old male with dyspnea
LAVI and TR Velocity are Normal





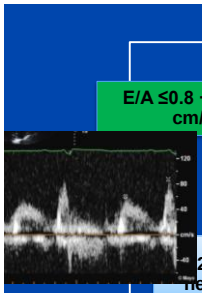
3 are Normal → **Normal DF**

What if he has hypertension, ?

Abnormal Diastolic Dysfunction by History and 2-D
2016 Diastolic Function Guideline (Algorithm #2)

- Reduced LVEF (< 50%)
- Hypertension
- Coronary artery diseases
- Diabetes Mellitus
- LVH
- LA enlargement

We are assuming abnormal relaxation, hence reduced e' velocity. The best diastolic function in this population is grade 1 based on mitral inflow velocity



Mitral inflow

E/A ≤0.8 + E <50 cm/s

E/A ≤0.8 + E >50 cm/s or E/A >0.8-<2

E/A ≥2

2 of 3 negative

3 criteria to be evaluated*

1 – Average E/e' >14
2 – TR velocity >2.8 m/s
3 – LA volume index >34 mL/m²

2 of 3 or 3 of 3 positive

When only 2 criteria are available

2 negative

1 positive and 1 negative

2 positive

Normal LAP
Grade I diastolic dysfunction

Cannot determine LAP and diastolic dysfunction grade*

↑ LAP
Grade II diastolic dysfunction

↑ LAP
Grade III diastolic dysfunction

If symptomatic consider CAD or proceed to diastolic stress test

In patients with depressed LVEF or normal EF with diastolic dysfunction

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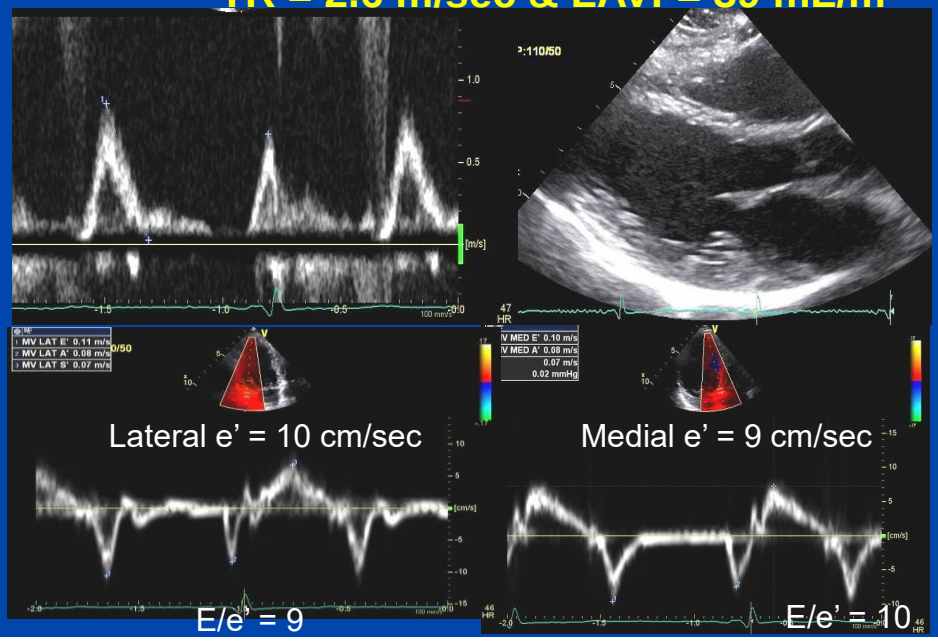
71 year old woman with TR = 2.6 m/sec & LAVI = 39 mL/m²



Lateral e' = 10 cm/sec

Medial e' = 9 cm/sec

E/e' = 9

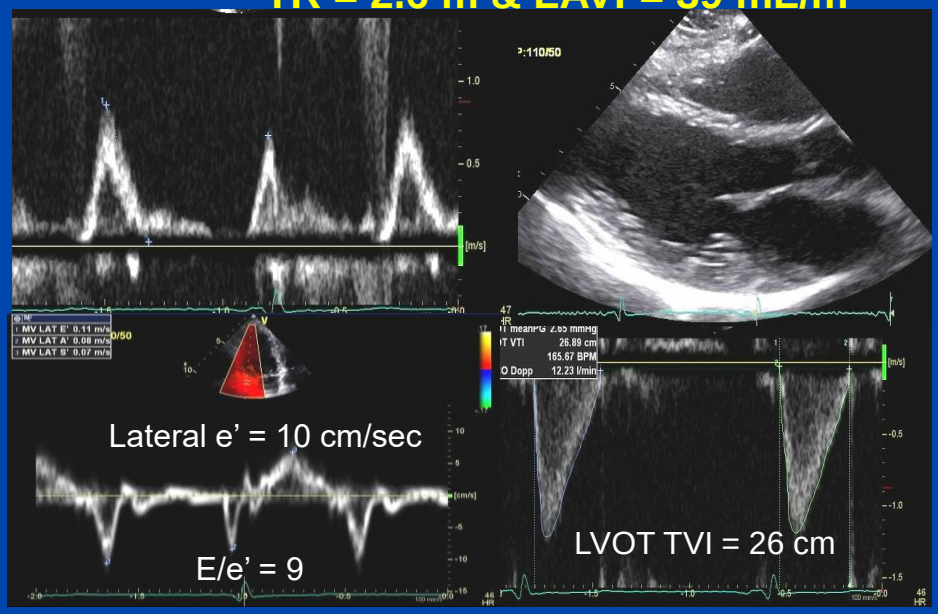
E/e' = 10

E/e' NL < 14
e' NL > 7
LAVI Enlarged
TR NL < 2.8

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

MAYO CLINIC

71 year old woman with TR = 2.6 m & LAVI = 39 mL/m²



E/e' NL < 14
e' NL > 7
LAVI Enlarged
TR NL < 2.8

Reasons for LA enlargement

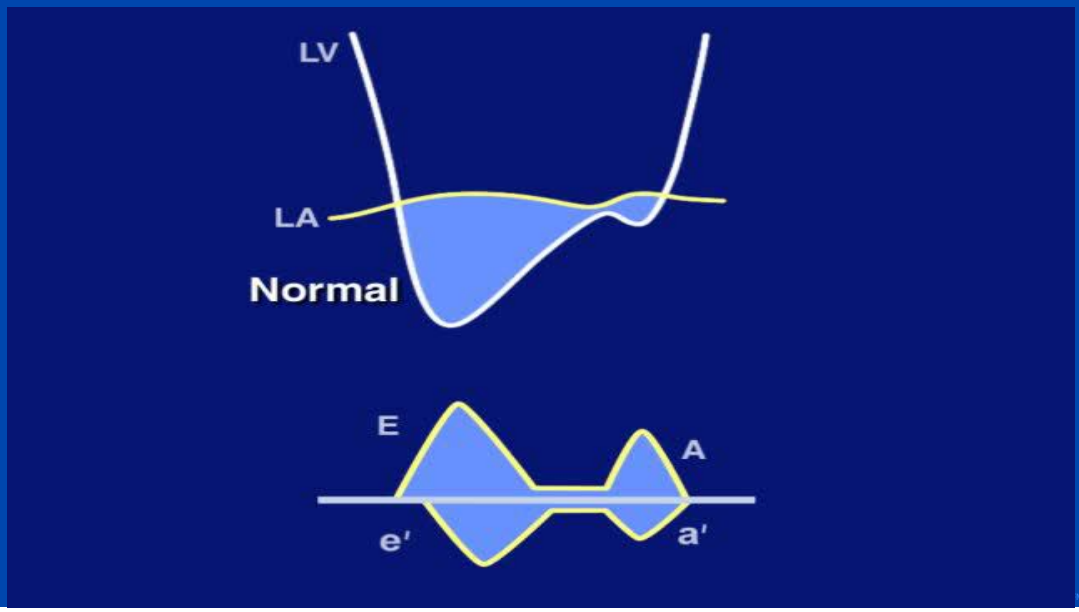
- Diastolic dysfunction
- Increased filling pressure
- Increased volume
- Athlete's heart
- Measurement error

Definition of Diastolic Function and Dysfunction

- **Normal Diastolic Function**
  - Normal Myocardial Relaxation
  - Normal Mitral Annulus e' velocity
- **Abnormal Diastolic Function**
  - Abnormal Myocardial Relaxation
  - Reduced Mitral annulus e' velocity
- **Increased Filling Pressure**
  - Abnormal Relaxation , E/e', TR and (LA Volume)

MAYO CLINIC

Diastolic Function Assessment by E and e'



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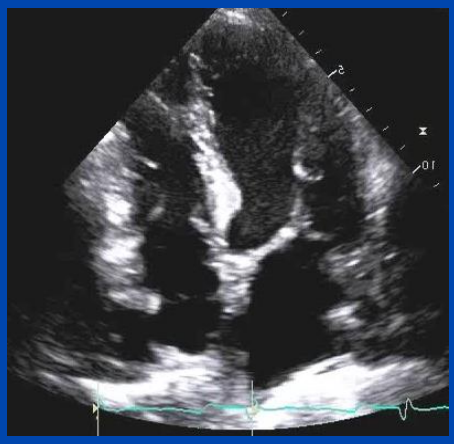
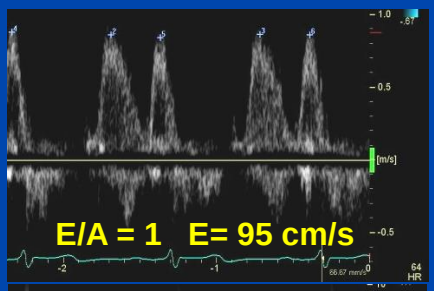
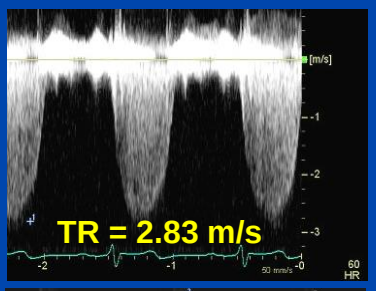
ARS

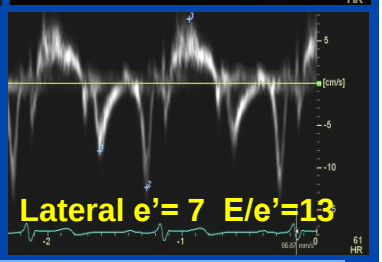
82 year old male with dyspnea



LAVI = 38 mL/m²







1= Gr 1 2=Gr 2 3= Gr 3 4=Abnormal Diastolic Function

The 2016 Algorithm #1

In pts with normal LVEF≥ 50%

1 – Septal e' velocity ≥7 cm/s or lateral e' velocity ≥10 cm/s
2 – Average E/e' ≤14 , 15 (Med)
3 – TR velocity ≤2.8 m/s
4 – LA volume index ≤34 mL/m²

≥ 3 Normal	2 and 2	≥ 3 Abnormal
Normal diastolic function	Indeterminate	Diastolic dysfunction

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

Suggested Algorithm #1 for Diastolic Function Assessment

In pts with normal LVEF≥ 50%

1 – Septal e' velocity ≥7 cm/s or lateral e' velocity ≥10 cm/s
2 – Average E/e' ≤14 , 15 (Med)
3 – TR velocity ≤2.8 m/s
4 – LA volume index ≤34 mL/m²

E/e', TR, and LAVI indicate increased filling pressure

≥ 3 Normal	2 and 2	≥ 3 Abnormal
Normal diastolic function	Indeterminate	Diastolic dysfunction
Normal Filling Pressure		Increased Filling Pressure

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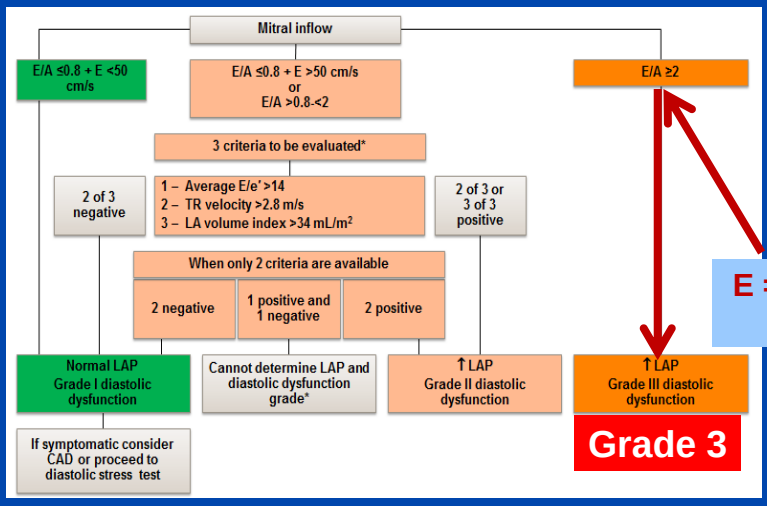
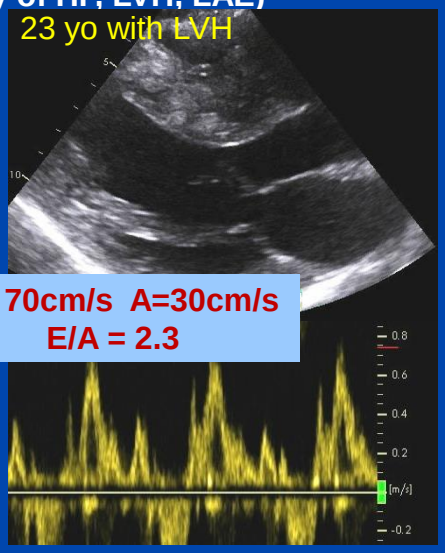
The 2016 Algorithm for Reduced EF (<50%) or Known (or Suspected) Diastolic Dysfunction/EF≥50%

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





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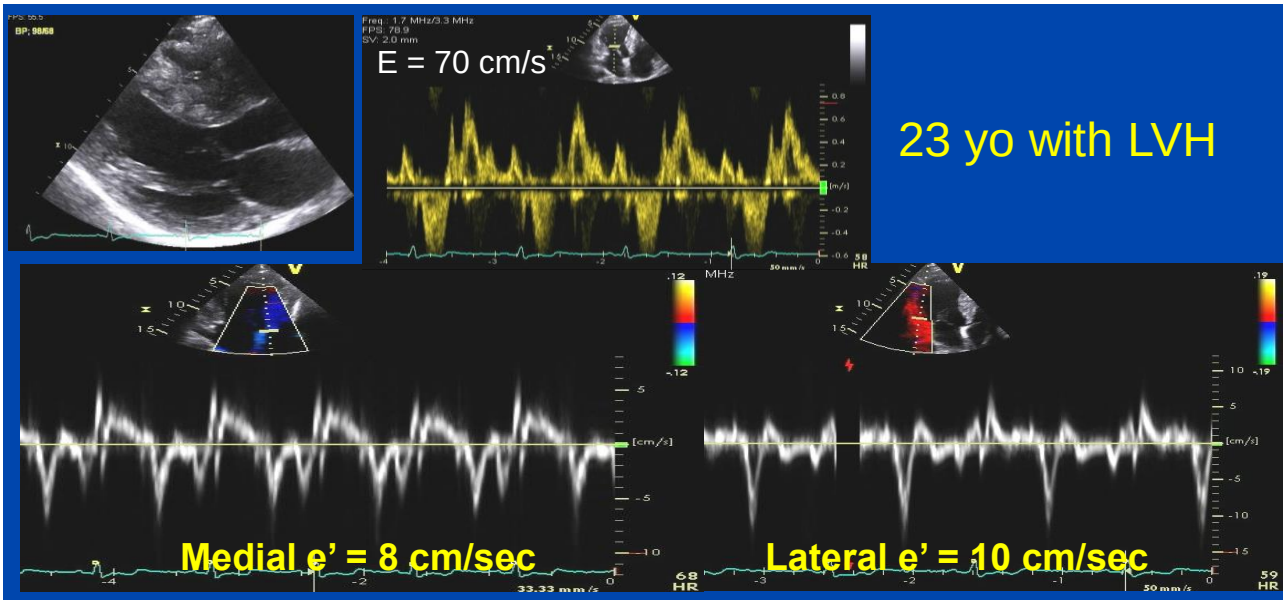


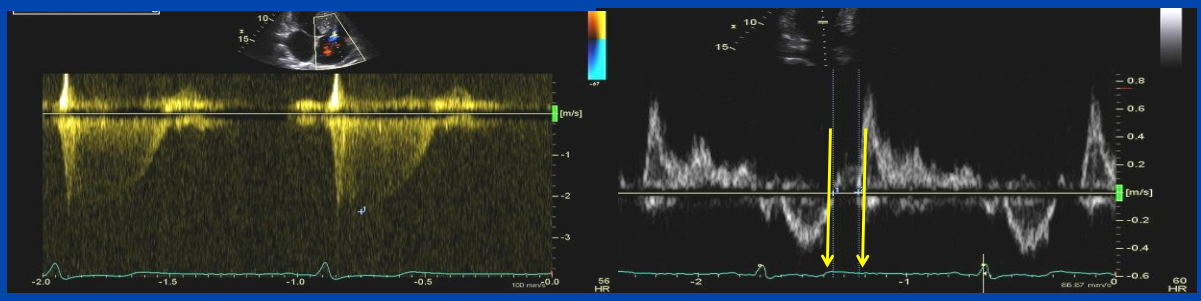
E/e' = 9

E/e' = 7

Can he have a normal diastolic function ?

23 yo man with HCM

LAVI 29 mL/m^2

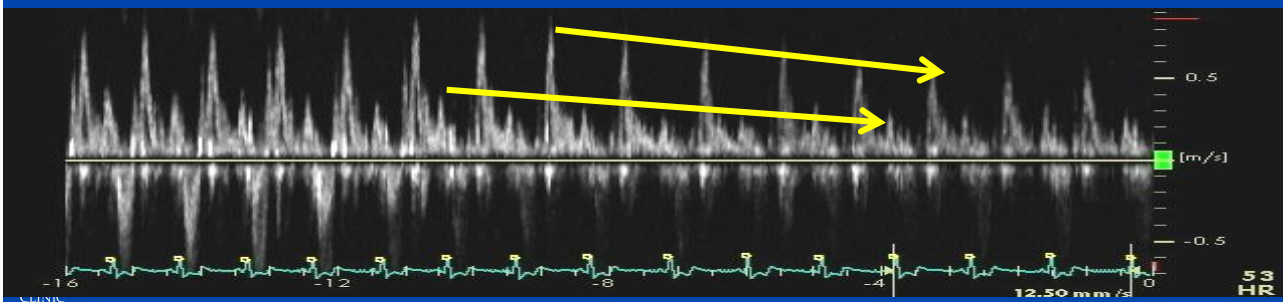


TR = 2 m/sec

IVRT = 120 msec

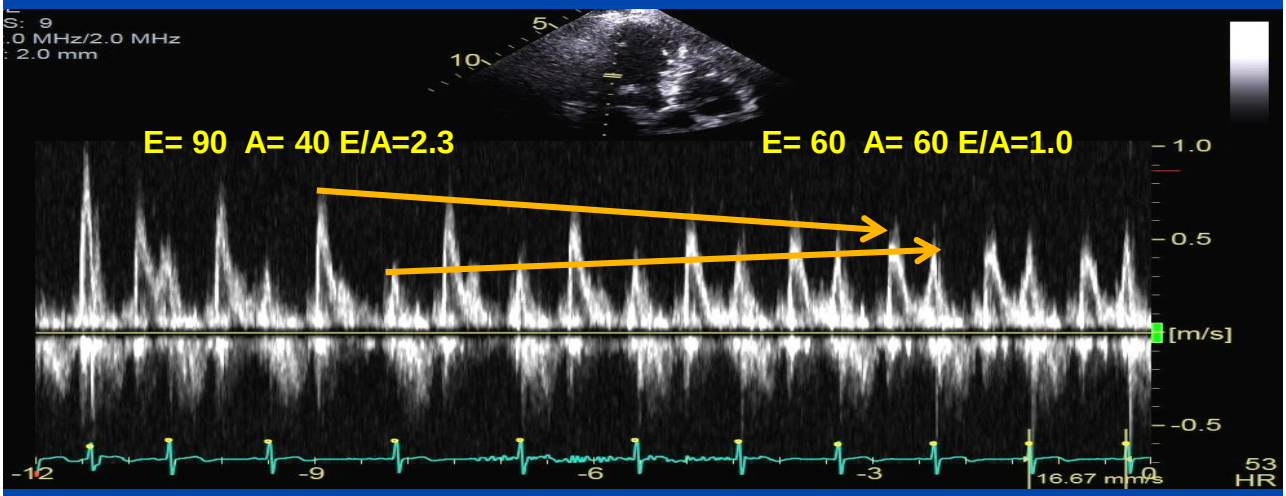
Valsalva in 23 yo HCM
Normal filling pressure

Normal Valsalva : Both E and A decrease with E/A change < 0.5



E/A= 2.3 E/A = 2.0

Valsalva Maneuver : E/A reduced > 0.5
Grade 2 Dysfunction

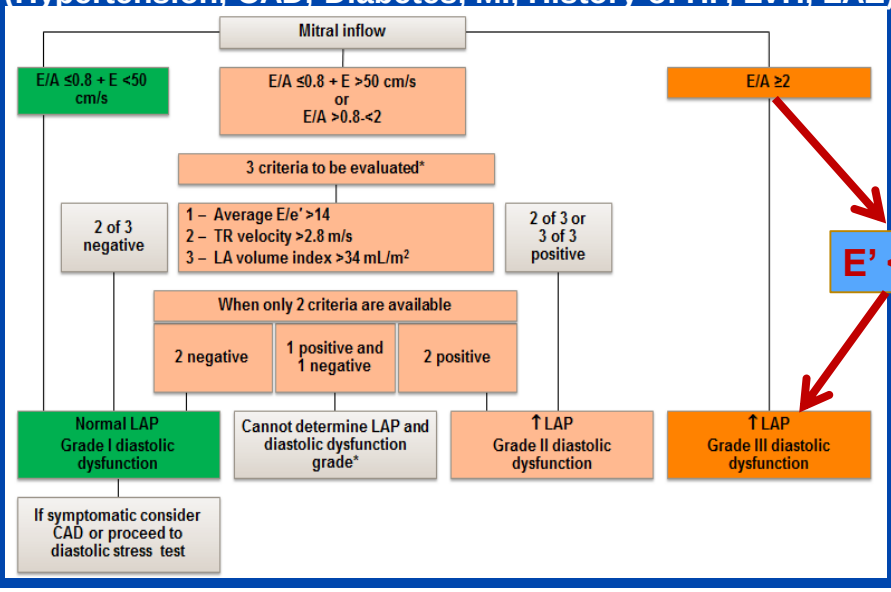


Individuals with HPT, CAD, LVH, DM, or MI Can Have Normal Diastolic Function

Especially in Young Individuals

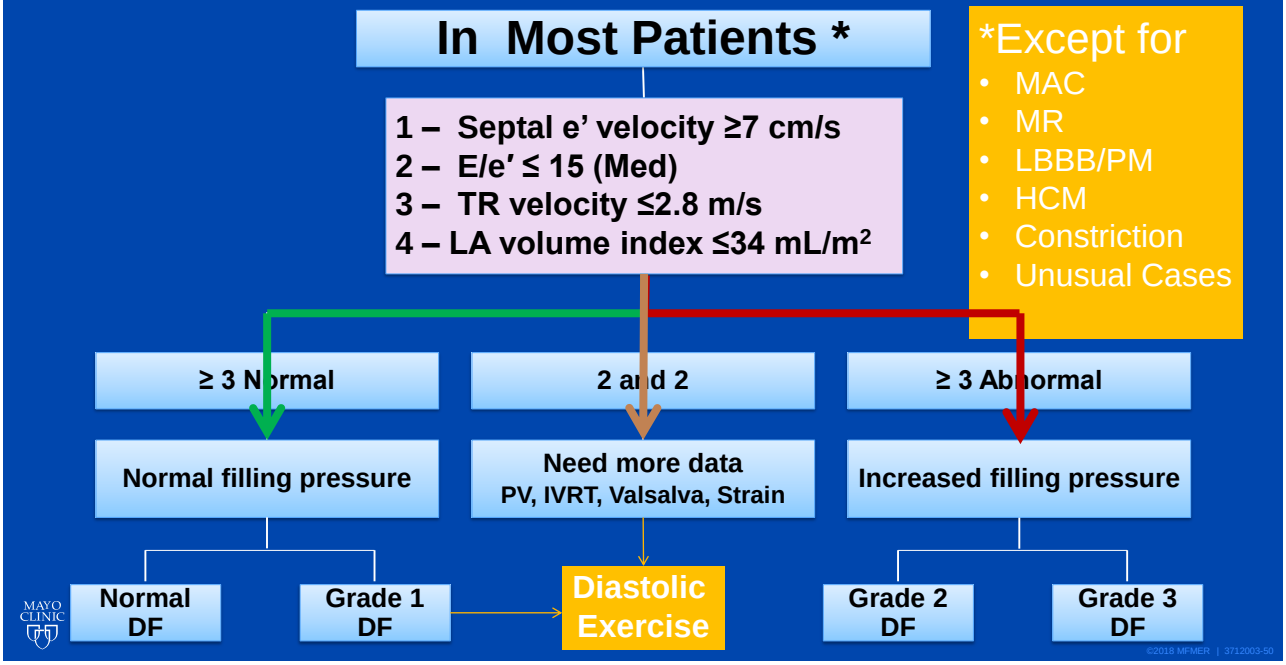
The 2016 Algorithm for Reduced EF (<50%) or Known (or Suspected) Diastolic Dysfunction/EF≥50%

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



What about combining 2 algorithms together?

Revised Algorithm for Diastolic Function Assessment



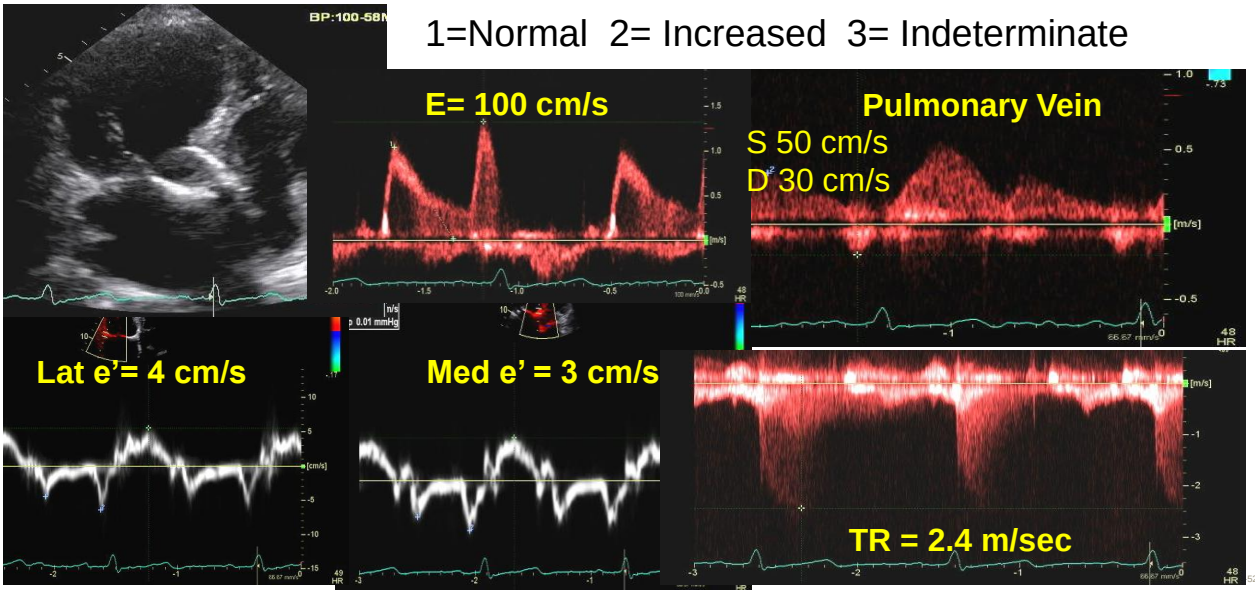
Difficult Situations

- Assessment of diastolic function or filling pressure in
  - 2 normal and 2 abnormal
  - HCM
  - LBBB
  - MAC
  - Atrial Fibrillation
- Additional supportive parameters
  - Pulmonary vein
  - Valsalva
  - IVRT and timing intervals

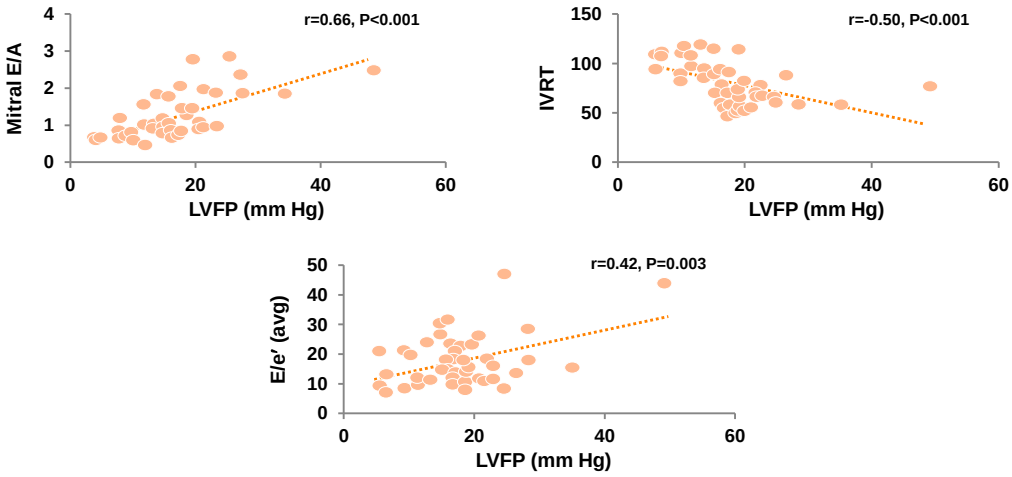
MAYO CLINIC

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

1=Normal 2= Increased 3= Indeterminate

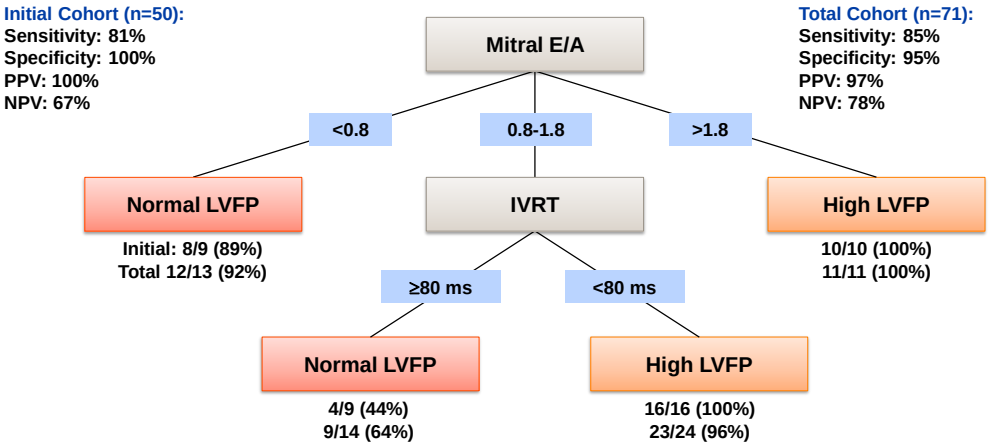


Correlation of Selected Doppler Variables With Left Ventricular Filling Pressure



Abudiab et al: J Am Coll Cardiol Img, 2017

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



Abudiab et al: J Am Coll Cardiol Img, 2017

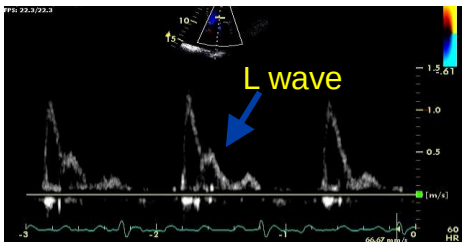
Diastolic Function in A. Fib

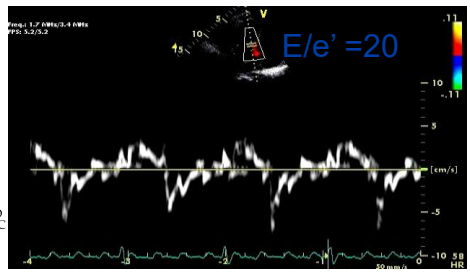
- DT < 160 msec (with reduced EF)
- DT < 130 msec poor survival
- Other measurements
  - IVRT ≤ 65 msec
  - E/e' ≥ 11
  - TR velocity

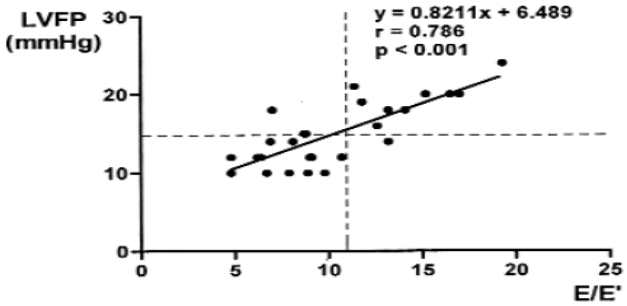
MAYO CLINIC

Mitral Annulus Velocity in the Evaluation of Left Ventricular Diastolic Function in Atrial Fibrillation

Dae-Won Sohn, MD, Jong-Min Song, MD, Joo-Hee Zo, MD, In-Ho Chai, MD, Hyo-Soo Kim, MD, Hong-Gu Chun, MA, and Hee-Chan Kim, PhD, *Seoul, Korea*







JASE 1999

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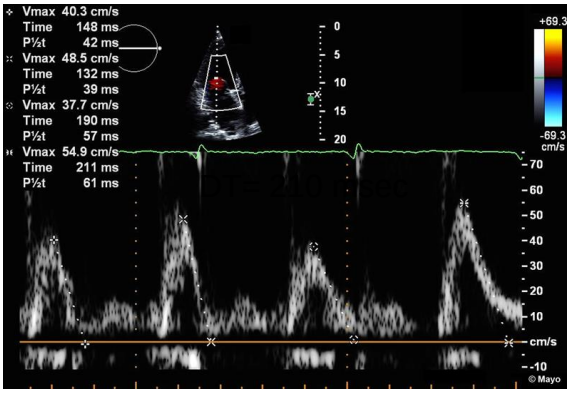
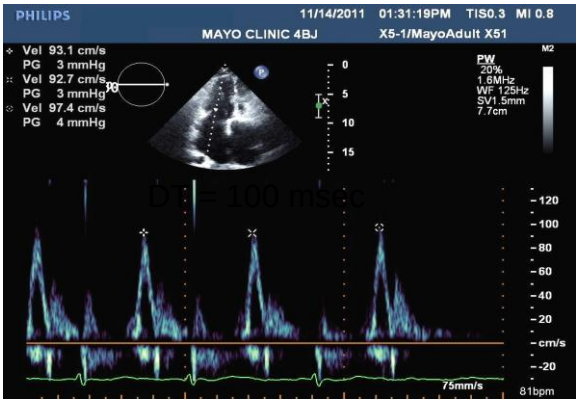
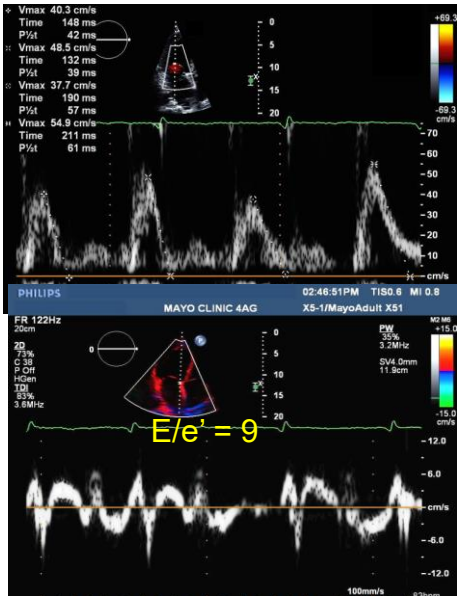
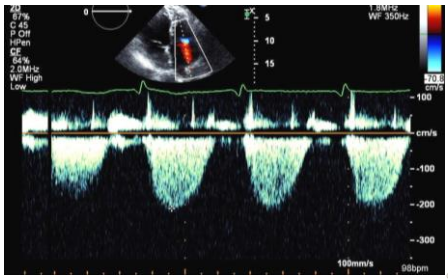
Atrial Fibrillation
Variation in E velocities : NL Pressure



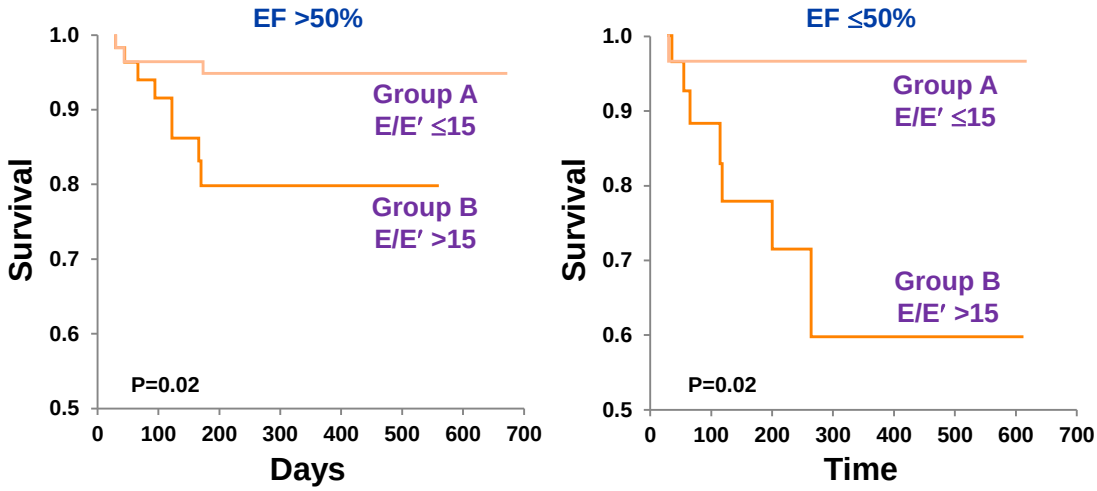


Atrial Fibrillation
Variation in E velocities and E/e' <11



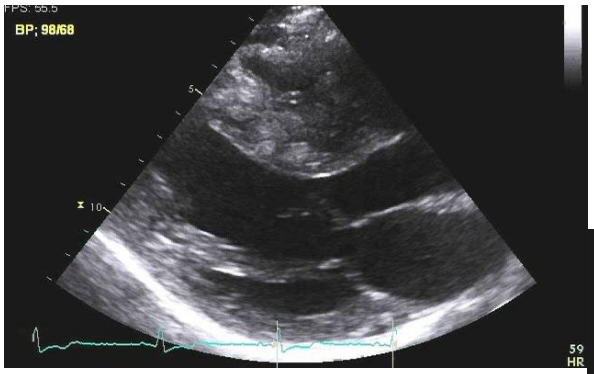


E/e′ Predicts Survival in Nonvalvular Atrial Fibrillation

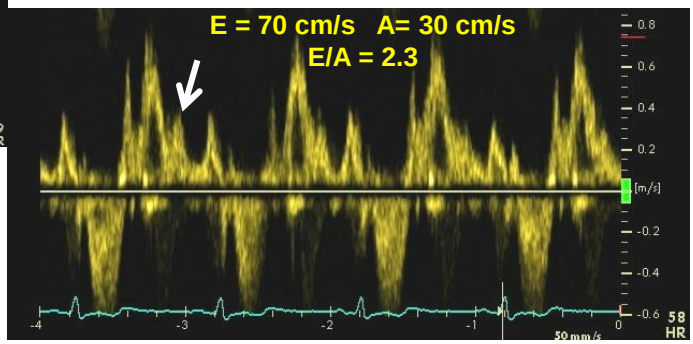


Okura et al: Heart 92:1248, 2006

23 YO with LVH on ECG
What does the white arrow indicate?

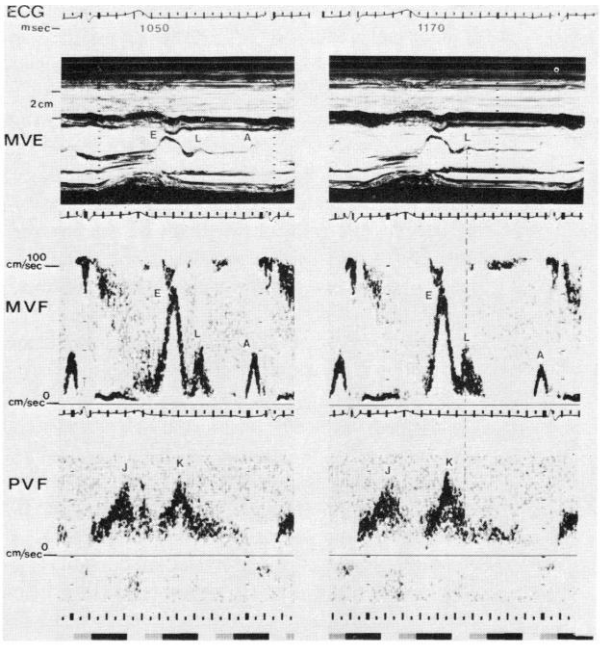


1. J wave
2. K wave
3. O wave
4. L wave



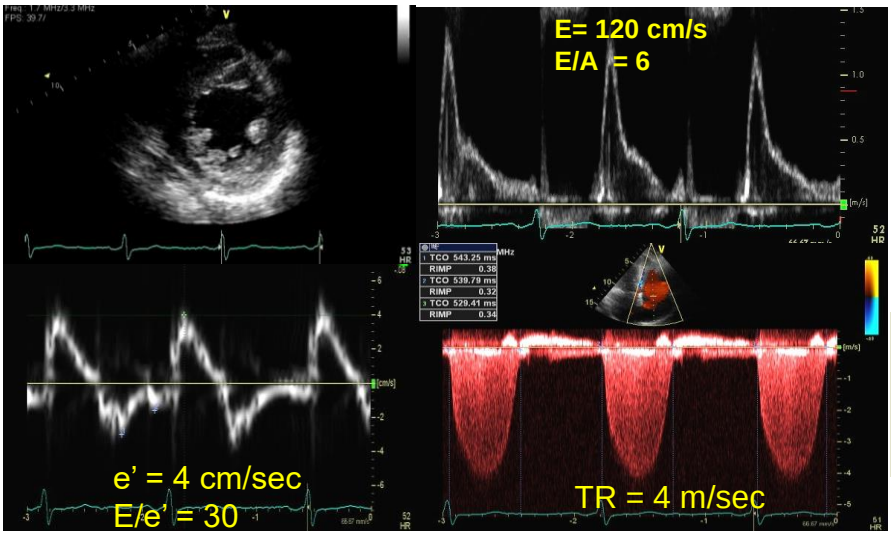
L wave

- Usually > 40 cm/sec
- Related to delayed myocardial relaxation
- Indicates increased filling pressure
  - Grade 2 or 3 dysfunction
- Can be present in normal heart with bradycardia
  - Usually < 40 cm/sec



Keren et al. Circulation 1986

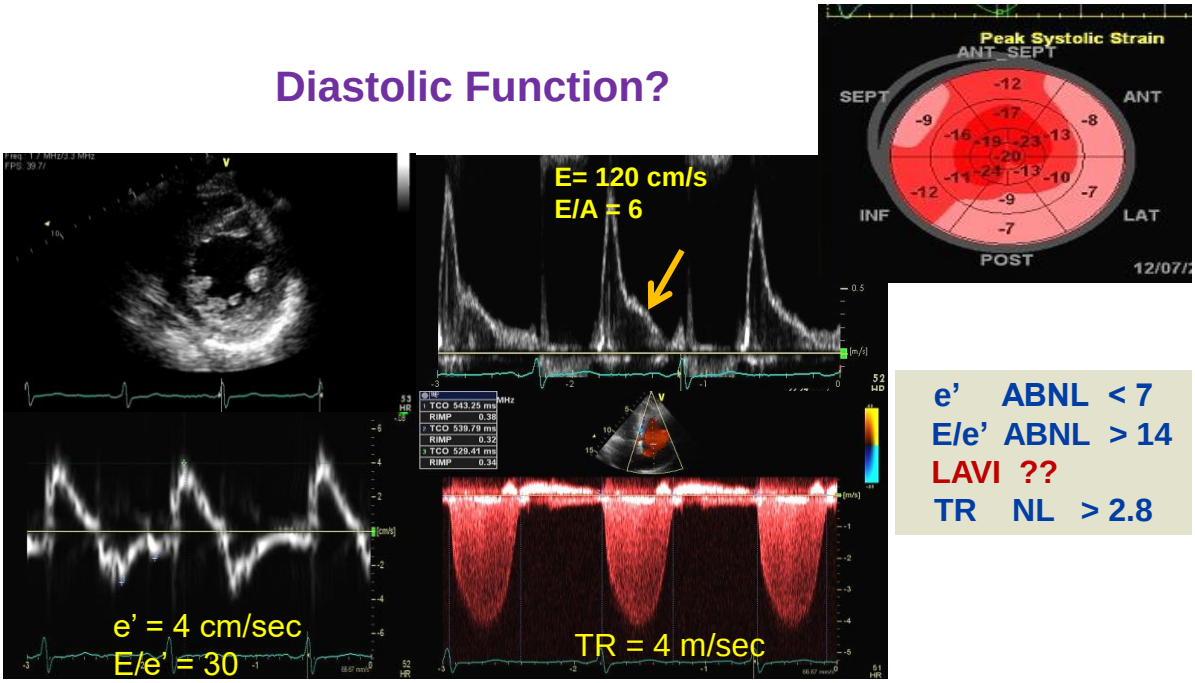
Diastolic Function?



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

e' ABNL < 7
E/e' ABNL > 14
LAVI ??
TR ABNL > 2.8

Diastolic Function?



e' ABNL < 7
E/e' ABNL > 14
LAVI ??
TR NL > 2.8

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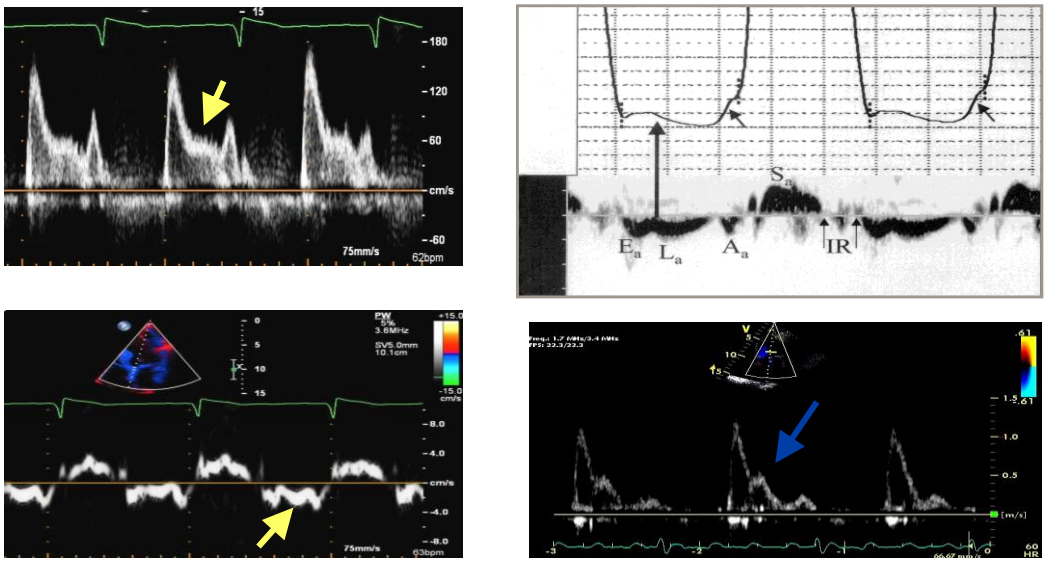
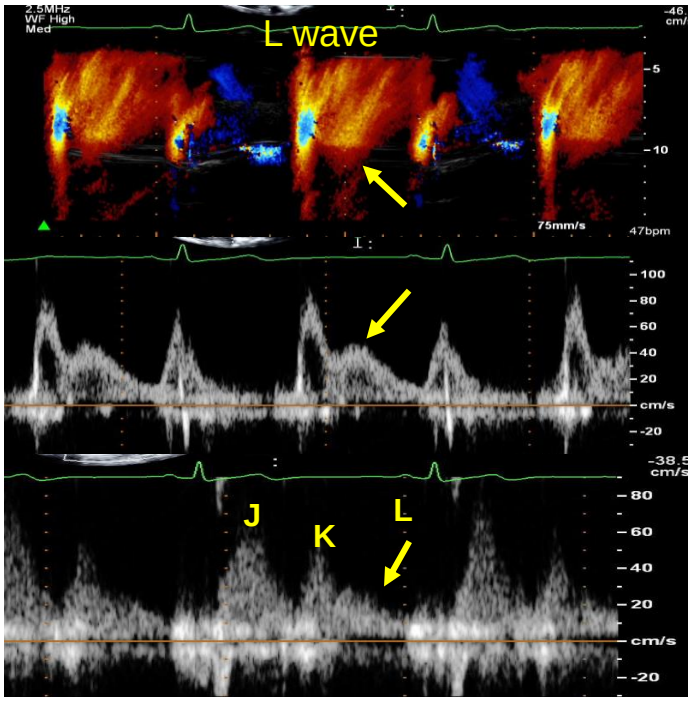
Mid-diastolic mitral flow (L)
Delayed relaxation



MAYO CLINIC

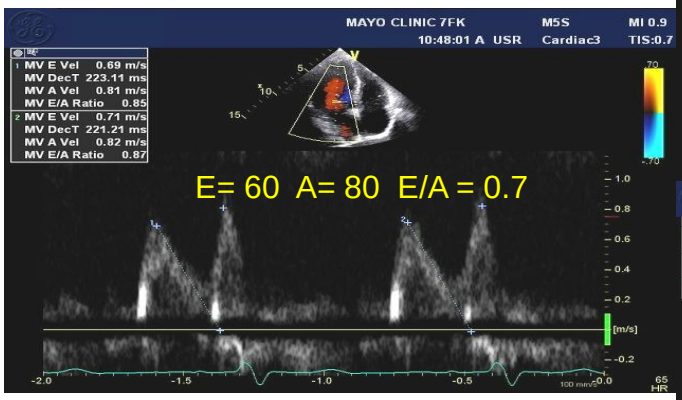
Frommelt et al: J Am Soc Echocardiogr 16:176, 2003

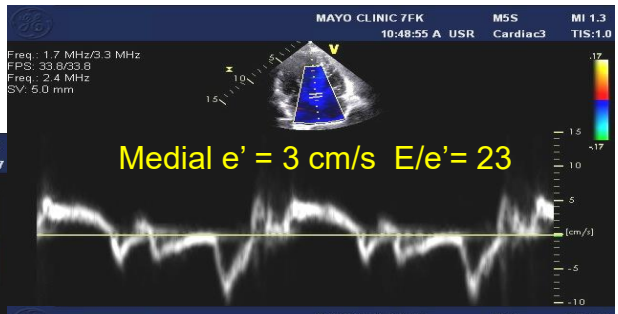


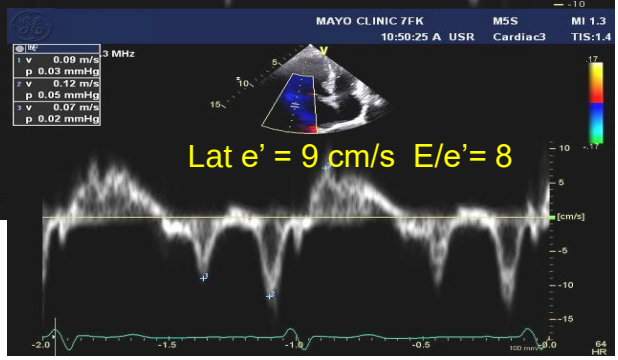
Mitral annulus e' velocity

- ASE/EACVI recommends average value
- E' from one location is acceptable
- We need a caution in using e'
  - Primary pulmonary hypertension
  - Pacemaker
  - LBBB
  - Wall motion abnormality
  - Mitral annulus calcification
  - Hypertrophic CM

67 yo woman with LBBB







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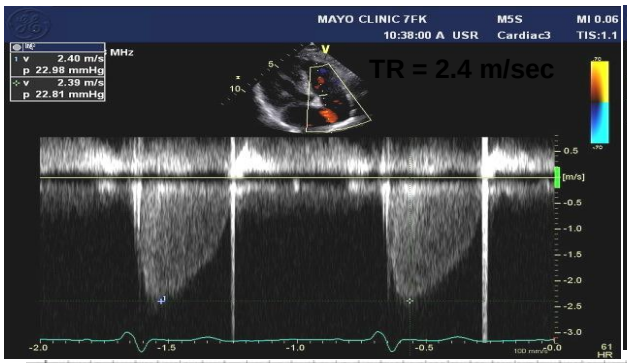
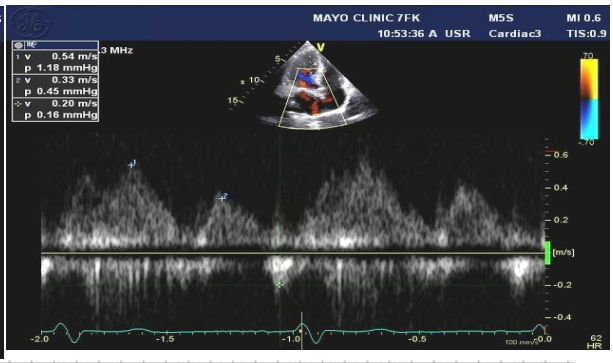
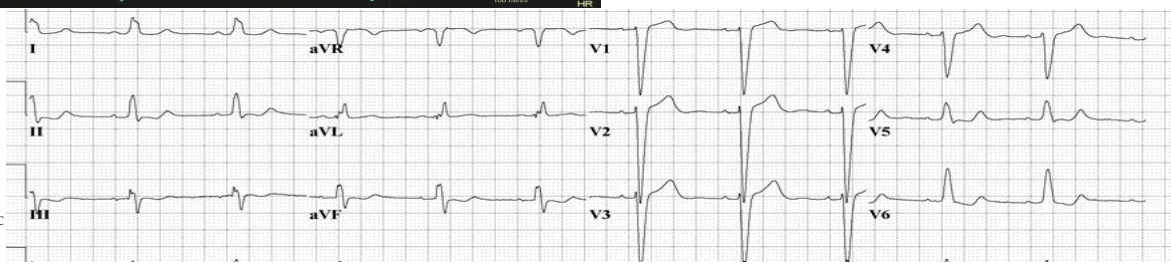
67 yo with LBBB







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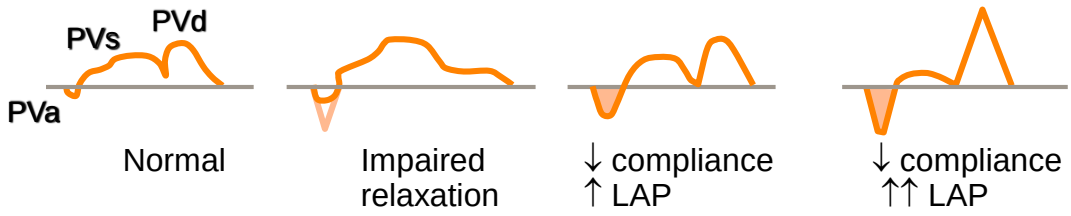
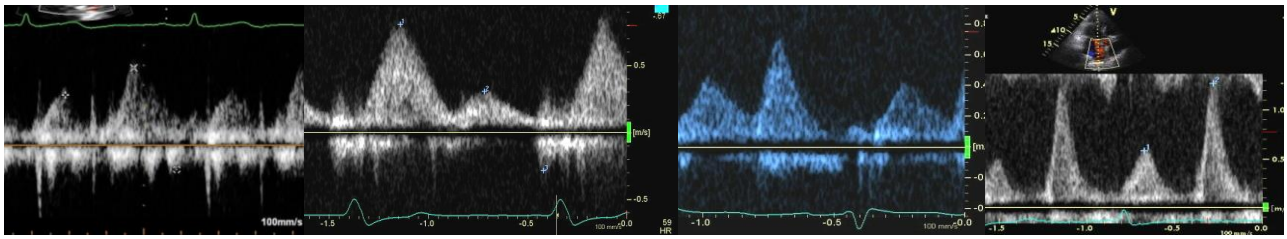
Pulmonary Vein Velocity

PVs decreases as filling pressure increases





MAYO CLINIC

Imaging

Tissue Doppler Imaging in the Estimation of Intracardiac Filling Pressure in Decompensated Patients With Advanced Systolic Heart Failure

Wilfried Mullens, MD; Allen G. Borowski, RDCS; Ronan J. Curtin, MD; James D. Thomas, MD; W.H. Tang, MD

Background—The ratio of early transmitral velocity to tissue Doppler mitral annular early diastolic velocity (E/Ea) has been correlated with pulmonary capillary wedge pressure (PCWP) in a wide variety of cardiac conditions. The objective of this study was to determine the reliability of mitral E/Ea for predicting PCWP in patients admitted for advanced decompensated heart failure.

Methods and Results—Prospective consecutive patients with advanced decompensated heart failure (ejection fraction ≤30%, New York Heart Association class III to IV symptoms) underwent simultaneous echocardiographic and hemodynamic evaluation on admission and after 48 hours of intensive medical therapy. A total of 106 patients were included (mean age, 57±12 years; ejection fraction, 24±8%; PCWP, 21±7 mm Hg; mitral E/Ea ratio, 20±12). No correlation was found between mitral E/Ea ratio and PCWP, particularly in those with larger left ventricular volumes, more impaired cardiac indexes, and the presence of cardiac resynchronization therapy. Overall, the mitral E/Ea ratio was

Conclusion: In decompensated patients with advanced systolic heart failure, tissue Doppler-derived mitral E/e' ratio may not be as reliable in predicting intracardiac filling pressures, particularly in those with larger LV volume, more impaired cardiac indices, and the presence of cardiac resynchronization therapy.

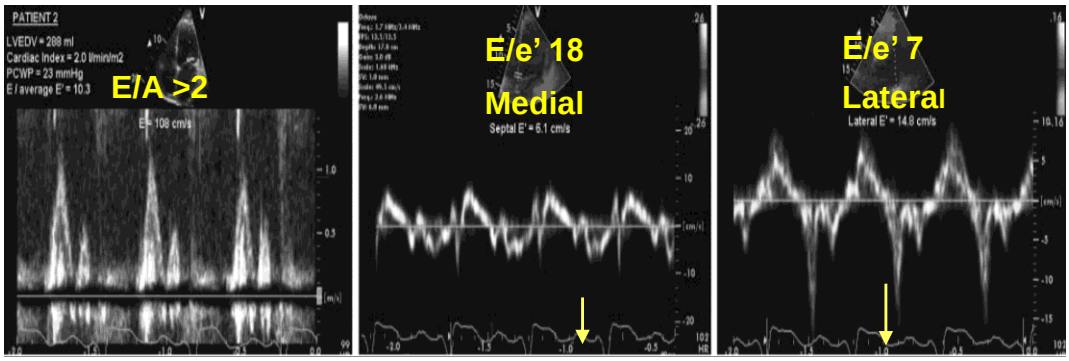
use, hemodynamic assessment via pulmonary artery catheters has decreased substantially over the last decade.[4–6]

Editorial p 13
Clinical Perspective p 70

E/Ea and hemodynamic measurements in patients with advanced decompensated heart failure (ADHF), a patient cohort in which hemodynamic assessment is often considered. We further aimed to explore the potential clinical utility of serial mitral E/Ea assessment in estimating changes in intracardiac filling pressures in response to intensive medical therapy in the ADHF setting.

MAYO CLINIC

Discordance between PCWP and E/e' Reduced LVEF and LBBB



PCWP 23

Mullens et al: Circ 119:62, 2009

Circulation
Cardiovascular Imaging
JOURNAL OF THE AMERICAN HEART ASSOCIATION

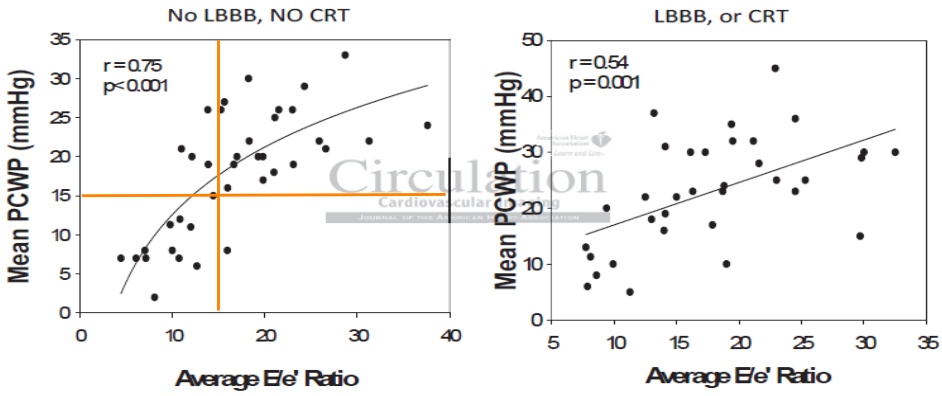
American Heart Association
Learn and Live

June 2011

Echocardiographic Evaluation of Hemodynamics in Patients with Decompensated Systolic Heart Failure

Sherif F. Nagueh, Rajat Bhatt, Rey P. Vivo, Selim R. Krim, Sebastian Imre Sarvari, Kristoffer Russell, Thor Edvardsen, Otto A. Smiseth and Jerry D. Estep

Circ Cardiovasc Imaging published online March 11, 2011;
DOI: 10.1161/CIRCIMAGING.111.963496



Diastolic Function Evaluation in HCM

- E' velocity is reduced in almost all patients
- E/e' predicts clinical outcome
- Use following parameters (ASE 2016 Guideline)
  - E/e' >15
  - LAVI >34 mL/m^2
  - TR velocity > 2.8 m/sec
  - PV Ar-A duration ≥ 30 msec
- The majority rules

MAYO CLINIC

Evaluation of Left Ventricular Filling Pressures by Doppler Echocardiography in Patients With Hypertrophic Cardiomyopathy

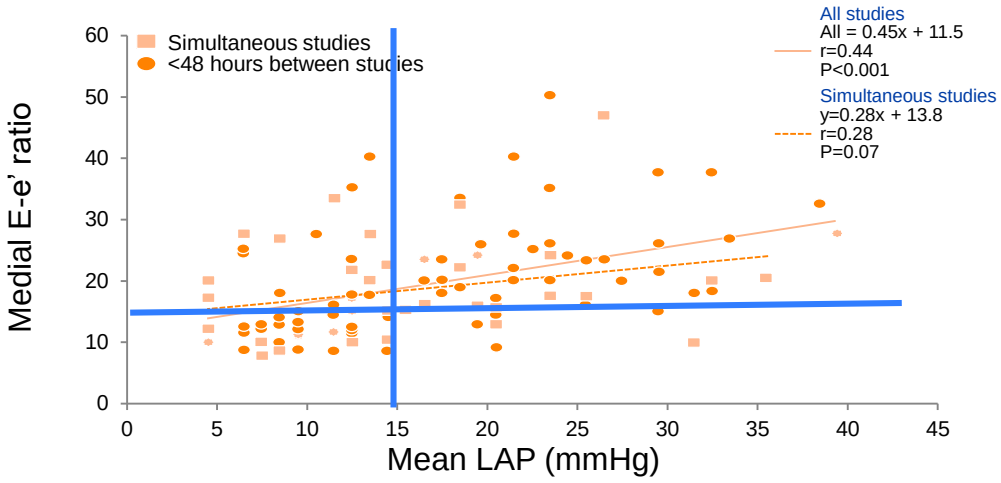
Correlation With Direct Left Atrial Pressure Measurement at Cardiac Catheterization

Jeffrey B. Geske, MD; Paul Sorajja, MD; Rick A. Nishimura, MD; Steve R. Ommen, MD

Conclusions—In 100 symptomatic patients with HCM, Doppler echo estimates of LV filling pressure correlate modestly with direct measurement of LAP. Given the complex nature of diastolic dysfunction in HCM, precise characterization of LV filling pressure in an individual patient cannot be determined with the use of these noninvasive parameters. **(*Circulation*. 2007;116:2702-2708.)**

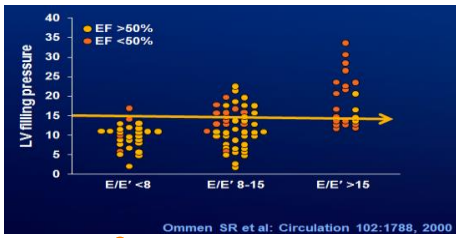
MAYO CLINIC

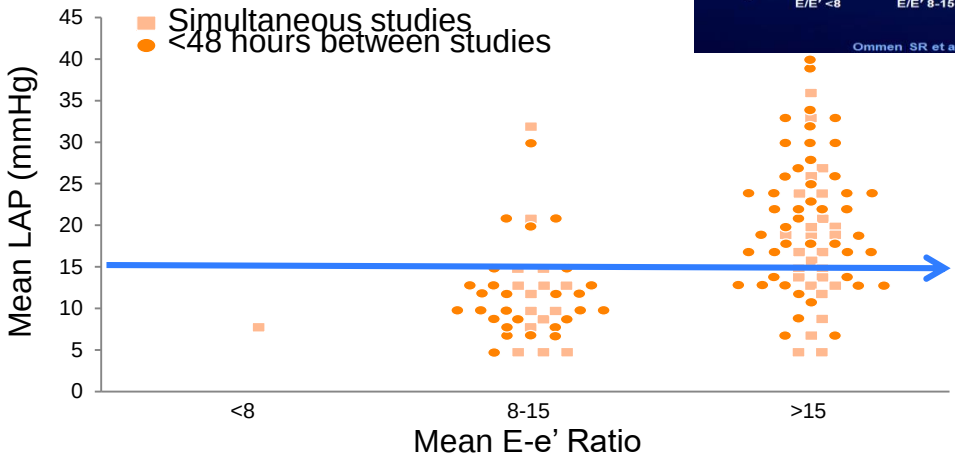
Medial E/e' Ratio Versus Mean LAP in HCM



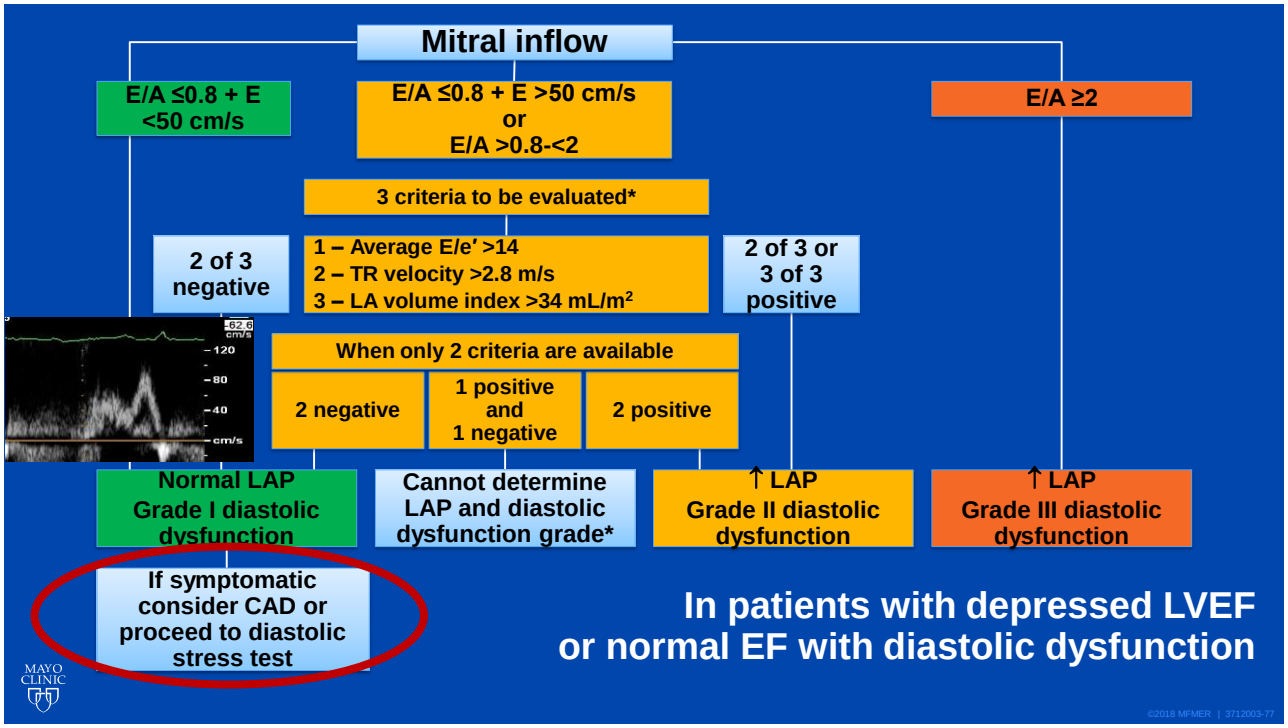
Geske et al: Circulation; 116:2702, 2007

Mean LAP vs Medial E-e' ratio
Hypertrophic CM





Geske et al: Circulation; 116:2702, 2007



Diastolic Stress Echocardiography First Published in Jan 2005

Diastolic Stress Echocardiography: A Novel Noninvasive Diagnostic Test for Diastolic Dysfunction Using Supine Bicycle Exercise Doppler Echocardiography

Jong-Won Ha, MD, PhD, Jae K. Oh, MD, Patricia A. Pellikka, MD, Steve R. Ommen, MD, Vicky L. Stussy, RN, RDCS, Kent R. Bailey, PhD, James B. Seward, MD, and A. Jamil Tajik, MD, *Rochester, Minnesota*

Left ventricular filling pressures can be estimated reliably by combining mitral inflow early diastolic velocity (E) and annulus velocity (E'). An increased E/E' ratio reflects elevated filling pressures and may be useful in assessing an abnormal increase in filling pressures for patients with diastolic dysfunc-

in E/E' during exercise (group 1A) and 9 (
1B). For group 2, E/E' did not increa
exercise. Despite different responses of I
was no significant difference in changes
inflow indices (E, A, E/A, deceleration time
groups. Although the percentage of dys

Editorial Comment

Diastolic Stress Echocardiography: The Time Has Come for Its Integration into Clinical Practice

Jae K. Oh, MD and Garvan C. Kane, MD, PhD, *Rochester, Minnesota*

In this issue of JASE, Studer Bruengger *et al.*[1] report diastolic exercise data in young nonathletic and endurance-trained healthy individuals, along with maximal oxygen consumption (Vo_{2max}). They confirm a previous observation[2] from older healthy individuals in that the E/e' ratio (an echocardiographic estimate of pulmonary capillary wedge pressure) remains within the normal range with exercise in healthy young subjects. Although there was a slight increase in septal E/e' (overall, 6.8 ± 1.3 to 7.2 ± 1.2, $P = .02$) and lateral E/e' (overall, 5.0 ± 0.8 to 6.2 ± 0.9, $P < .0001$) with exercise, the investigators did not document any difference in the response to exercise between the athletic and nonathletic young healthy groups. Moreover, there was a reserve capacity or clinical diagnosis of coronary disease or diastolic dysfunction can be better demonstrated with a stress test designed specifically to assess the reserve.[5]

Patients with diastolic dysfunction may have a similar hemodynamic profile (in terms of cardiac output and filling pressure) at rest as healthy individuals with normal diastolic function. With exercise, normal subjects are able to increase cardiac output without increasing filling pressure significantly, because of increased myocardial relaxation, which results in more efficient early diastolic suction with much lower minimal LV diastolic pressure. Reduced myocardial relaxation is one of the earliest manifestations of mechanical dysfunction

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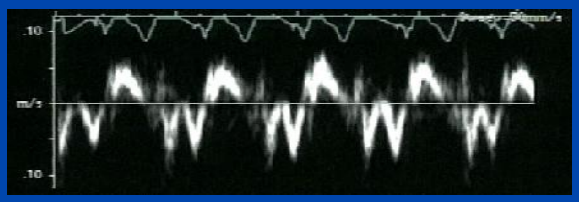
Ha et al JASE 2005 and Oh et al JASE 2014

73 yo woman with Hypertension and Exertional Dyspnea
No ischemia

"This patient has delayed myocardial relaxation, but filling pressure is not increased at rest"

E = 50 cm/s DT = 250 ms



e' = 7 cm/s

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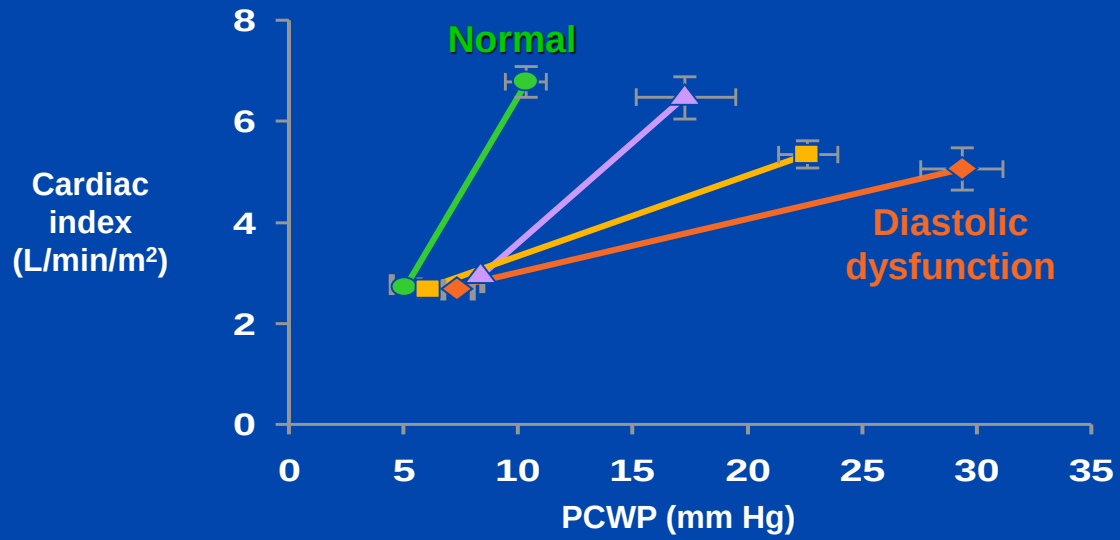
Change in CI and PCWP with Exercise
Normal and Abnormal Diastolic Function



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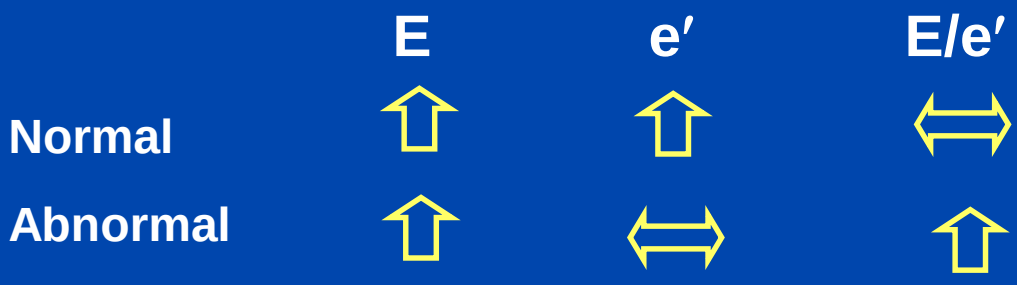
Dynamic Diastology
Filling Pressure (E/e′) with Exercise



LV filling pressure (E/e') does not increase much with exercise in normal heart, but increases in symptomatic patients with diastolic dysfunction.

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

Effects of Treadmill Exercise on Mitral Inflow and Annular Velocities in Healthy Adults

Jong-Won Ha, MD, PhD, Fabijan Lulic, MD, Kent R. Bailey, PhD, Patricia A. Pellikka, MD, James B. Seward, MD, A. Jamil Tajik, MD, and Jae K. Oh, MD

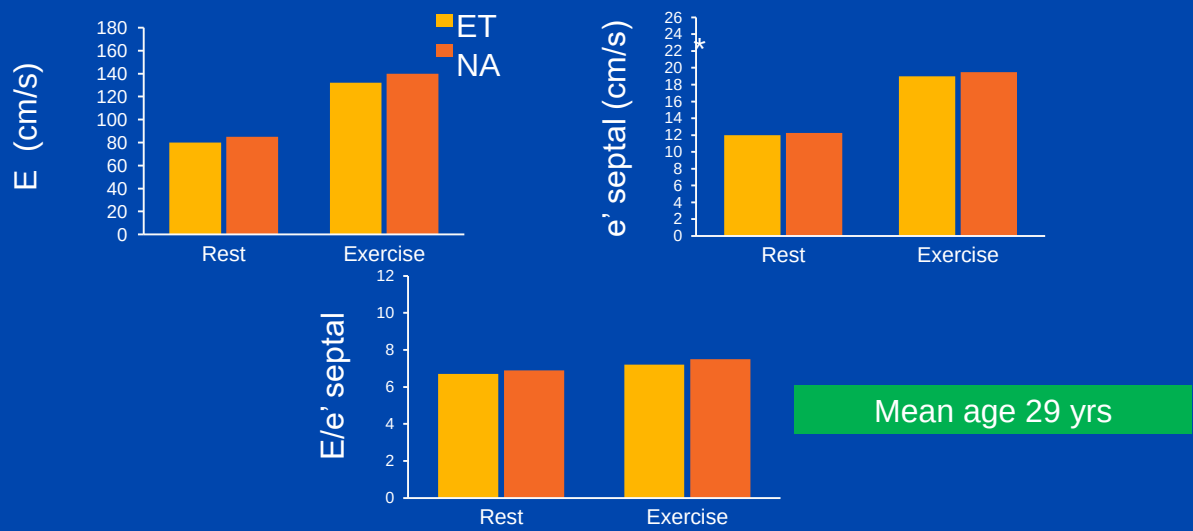
	Baseline	Exercise
E (cm/s)	73±19	90±25
A (cm/s)	69±17	87±22
DT (ms)	192±40	176±42
e′ (cm/s)	12±4	15±5
E/e′	6.7±2.2	6.6±2.5

Mean age 59±14 yrs

Ha J et al: AJC, 2003

LV Diastolic Function at Rest and With Stress

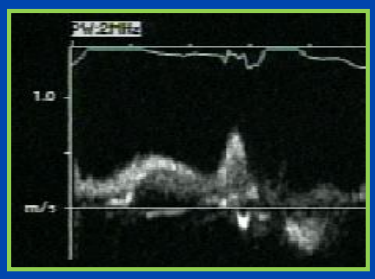
Diastolic Stress Echoin the Young: Nonathletic (NA) and Endurance-Trained (ET) Healthy Subjects



Mean age 29 yrs

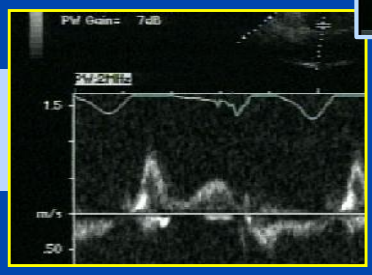
Bruengger et al: JASE, 2014

Exertional Dyspnea



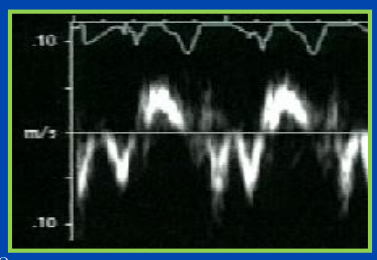
E = 50

DT = 250



E = 85

DT = 140

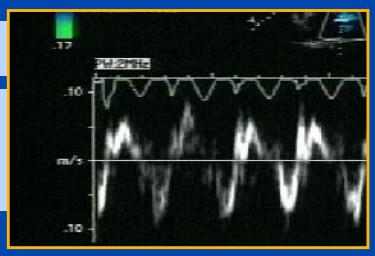


e' = 7

E/e' = 7

TR = 2.4

Baseline



e' = 7

E/e' = 12

TR = 3.8

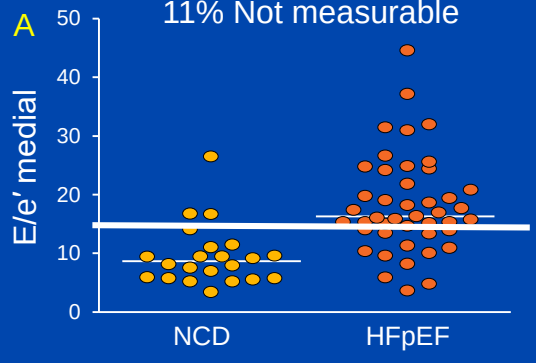
Supine Bike

Echo Hemodynamics During Exercise
E/e' at Sub- and Maximal Exercise
HFpEF = PCWP > 25 mmHg

Submaximal (20W)

P<0.0001

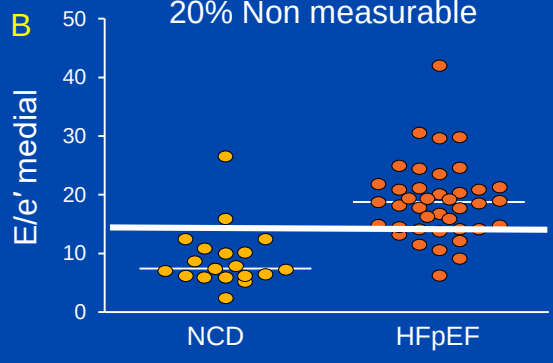
11% Not measurable



Peak

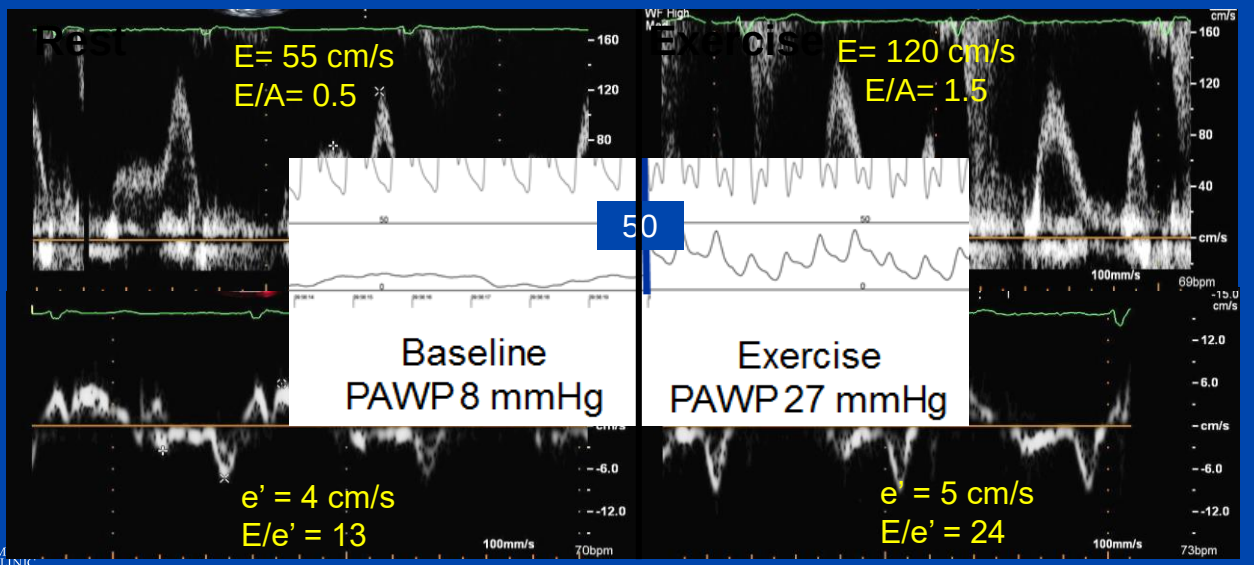
P<0.0001

20% Non measurable



Obokata M et al: Circ 135:825-838, 2017

78 year old male with exertional dyspnea
Diastolic Exercise Test

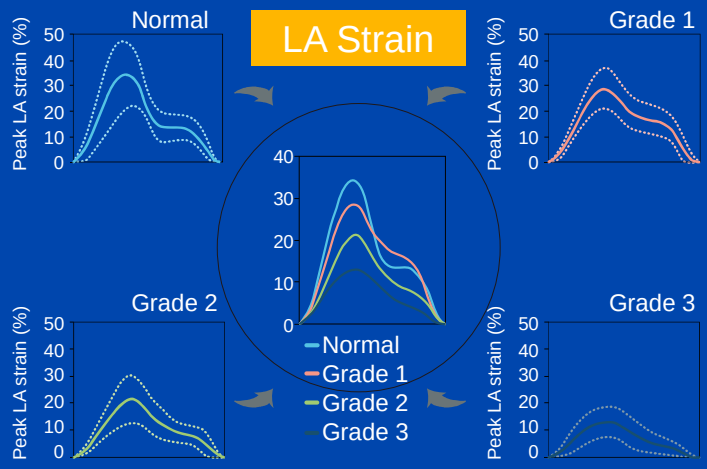


The 2016 Guideline can be improved !

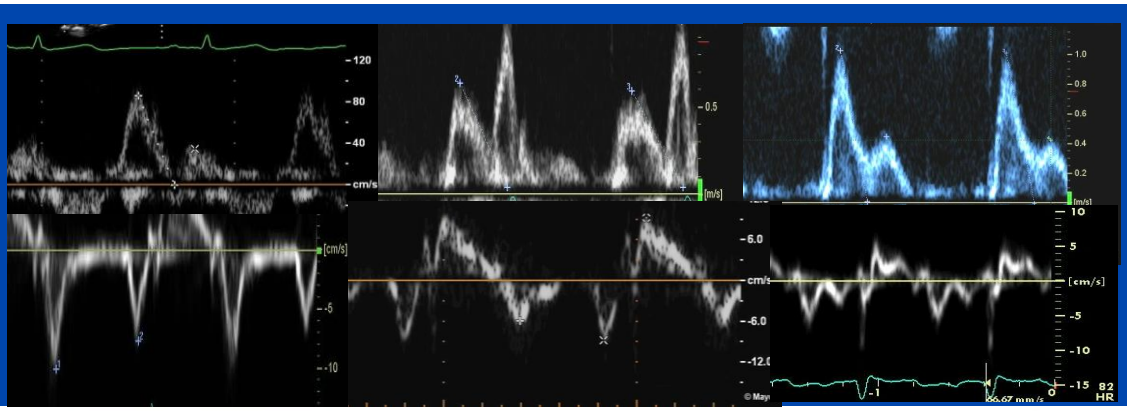
- Cut-off values are based on the asymptomatic elderly
- Confusion between diastolic dysfunction and increased filling pressure
- Early or compensated diastolic dysfunction (Grade 1) can be classified as normal diastolic function
- Adjudication of diastolic dysfunction by clinical and 2-D imaging data may not be reliable or available
- There are 2 separate algorithms
- Additional promising parameters (LA Strain)

Left atrial volume index (LAVI) and LA strain

- Overlap of LAVI among normal and abnormal diastolic function (26% abnormal in Almeida study; EHJ Imaging 2018)
- LA volume measurement can be technically challenging
- LAVI does not regress much as LVFP gets normalizes, but LA strain does. (Huynh et al JASE 2015)



Singh et al: JACC Imaging 10:735, 2017

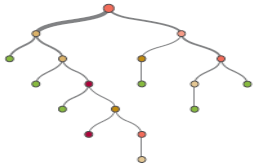
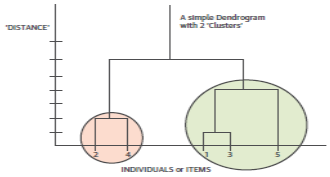


	Normal	Grade 1	Grade 2	Grade 3
PV	S D			
IVRT	80 -120 m sec	> 120 m sec	< 80 m sec	< 80 m sec
LAS*	37 ±13 %	29 ± 8 %	22 ± 9 %	13 ± 6 %
LVS*	- 19 ± 1 %	- 14 ± 2 %	- 16 ± 2 %	- 13 ± 4 %

Phenotypic Clustering of Left Ventricular Diastolic Function Parameters

Patterns and Prognostic Relevance

Megan Cummins Lancaster, MD, PhD,[a] Alaa Mabrouk Salem Omar, MD, PhD,[a,b,c] Sukrit Narula, BS,[a] Hemant Kulkarni, MD,[d] Jagat Narula, MD, PhD,[a] Partho P. Sengupta, MD, DM[a,e]

Method	Guideline-based DD Classification	Cluster Analysis of DD variables
		
Data need	A priori knowledge, DD variables with identified importance	Unlabeled variables
Grouping of data	Univariate classification, each split based upon known cutoff points from normal data range	Multivariate analysis based upon associations between all variables. Subjects organized into groups which are similar in several variables
Advantages	1. Simple to understand and interpret 2. Requires little data preparation	1. No need for a priori knowledge 2. Captures natural structure of data
Clinical Validation	Survival analysis showed modest separation of clinical outcomes, overlap seen particularly for indeterminate group	Survival analysis showed significant separation of clinical outcomes for identified groups

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Lancaster et al. JACC Imaging 2018

Diastolic Function Assessment Take Home Point #1

- LV myocardial relaxation is reduced in all stages of diastolic dysfunction
- Mitral annulus e' velocity reflects myocardial relaxation
- Normal e' = Normal diastolic function
- Algorithm #1 separates normal filling from elevated filling pressure
- Initial assessment of diastolic functon is based on
  - E', E/e', TR velocity, and LAVI

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Diastolic Function Assessment
Take Home Message #2

- Grade 1 diastolic dysfunction is the best pattern for the patients with Heart Failure
- Evidence for diastolic dysfunction needs an objective evidence
  - Hypertension
  - Cardiomyopathy
  - Old age
  - DM

The best evidence is reduced relaxation
Reduced e'
L wave
Prolonged IVRT

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Clinical Applications of Diastolic Function Assessment

- Estimation of Filling Pressure at Rest and with Exercise
  - Diagnosis of Heart Failure (with Preserved LVEF)
  - Evaluation of Dyspnea
- Identification of Myocardial Disease
  - Amyloid vs HCM vs Athlete's Heart vs Hypertension
  - Distinction between Restrictive CM and Constriction
- Prognosis
  - Myocardial Infarction
  - Myocardial Diseases
  - Aortic Stenosis

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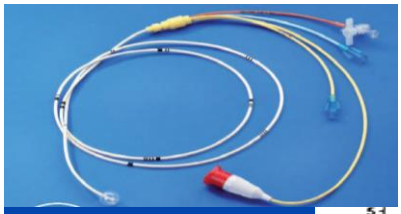
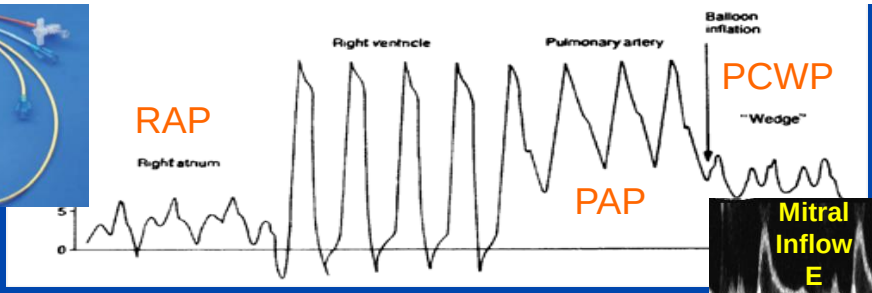
Editorial

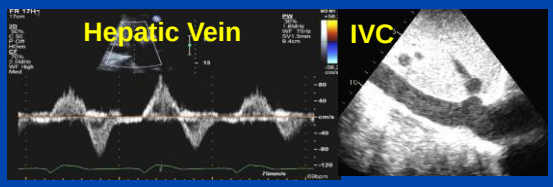
Echocardiography as a Noninvasive Swan-Ganz Catheter

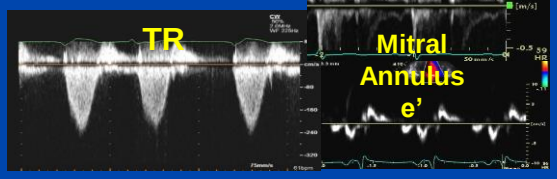
Jae K. Oh, MD

E/e' = PAWP









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Oh Circulation June 2005

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Questions & Discussion