Diastolic Dysfunction in Echocardiography: Making It Meaningful

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Objectives

1. Review grading of diastolic dysfunction

2. Demonstrate integration of echo diastology with clinical evaluation

3. To show how diastology measurement in echocardiography can be more user friendly for the technician, reader and referring physician
Syllabus

- Definition of diastolic function, Phases of diastole
- Pathophysiology of diastolic dysfunction
- Grading of diastolic dysfunction
- Clinical correlation with elevated filling pressures
- Echo clues of elevated L heart filling pressures
- Doppler techniques / modalities, the Valsalva maneuver
- Diastology variables: Measurements and normal values
- Technical and clinical pitfalls in measurement
- Real echo cases
- Exercise Diastology
- Algorithms for diastology assessment
- Sample questions and answers
- Summary / Take home points
Diastolic Function

Diastolic function is one of the first functions to be compromised in heart disease.

Nearly half of patients who present in heart failure have a normal ejection fracture (EF)

Diastolic dysfunction increases with age.

Common conditions of DM, HTN and CAD contribute.
Phases of Diastole

Isovolumetric Relaxation (before MV opens)

Rapid early passive LV filling (during E wave)

Diastasis (LA and LV pressures almost equal so filling is mainly due to pulmonary venous flow with LA acting as passive conduit. Flow related to compliance. End of E to beginning of A)

Late slow active LV filling (during A wave)
Normal and abnormal diastolic function

1. Normal function involves a complex sequence of multiple interrelated events including:
   Relaxation, Suction, Pericardial restraint, Ventricular interaction, Atrial contraction, Chamber stiffness, Myocardial stress/strain relations.

2. Diastolic dysfunction is an abnormality of one or more than one of these events.

3. Diastolic dysfunction occurs when there is a change in LV filling and/or an increase in pressure when the heart fills.
Definition of Diastolic Dysfunction

Functional abnormality of diastolic relaxation, filling or distensibility

Systolic function (EF) is normal or abnormal

Clinical asymptomatic or not

Abnormal mechanical properties of heart

Present in all patients with heart failure

Zile and Brutsaert. Circulation 2002; 105: 1387-93
Ventricular dysfunction during diastole is governed by 2 main processes:

1. Abnormal relaxation then ...

2. Decreased compliance (increased stiffness)

Decreasing compliance (↑ stiffness) leads to elevated LA filling pressures and thus elevated early transmitral gradient as seen in E wave.
Pathophysiology of diastolic dysfunction

Transmitral Velocity and LV Filling Pressures

- Normal
- Normal LAP
- High LAP — Impaired Relaxation

mmHg

cm/s
Review: Grading of Diastolic Dysfunction

Figure 10-10 A more complicated grading system for left ventricular (LV) diastolic dysfunction that incorporates multiple mitral flow velocity variables, their response to Valsalva maneuver, pulmonary venous flow velocity variables and tissue Doppler imaging of the septal mitral annulus. These criteria have been used in epidemiologic studies to assess the asymptomatic prevalence of diastolic dysfunction in the community and also how LV diastolic dysfunction increases the risk for future adverse cardiac events. (From Redfield MM et al. Burden of systolic and diastolic ventricular dysfunction in the community: Appreciating the scope of the heart failure epidemic. JAMA 2003;289:194–202.)

Klein AL, Garcia MJ. Diastology Clinical approach to Diastolic Heart failure, 124.
Grading of diastolic dysfunction

Grade 1: Imp relaxation. Normal filling pressure

Grade 1A: Impaired relaxation & mild reduction in compliance with elevation in L heart filling pressures

Grade II: Pseudonormal. Mild-mod LV compliance. Mild-mod ↑ filling pressure

Grade III: Restrictive (reversible). ↓↓ compliance

Grade IV: Restrictive (irreversible) despite ↓ preload
Symptoms that match diastology grade

Grade I: No symptoms at rest. Dyspnea with increased HR (exertion), loss of atrial filling (atrial fibrillation)

Grade II: Moderate dyspnea with exertion. Pseudonormal filling pattern.

Grade III: Marked dyspnea with minimal exertion

Grade IV: Marked dyspnea with minimal exertion
Diastology Measurements

Left ventricular size, thickness and function
Left atrial size, volume, volume index
Real time Posterior Annulus relaxation in PLAX view
Doppler mitral inflow (E, A, E/A, DT, A dur)
Color M-mode mitral inflow (V_p, E/V_p)
TDI of mitral annulus (e’, E/e’)
Pulm. venous flow (S, D and Ar velocity, Ar dur-A dur)
Pulm. artery systolic & diastolic pressure (PASP, PADP)
IVRT, time interval T_{E-e’} (correlates to tau) & IVRT/ T_{E-e’}
Tissue doppler strain
Echo clues of increased LV filling pressure

- Reduced EF, dilated LV ⇒ diastolic dysfunction
- LA enlargement (no mitral valve disease nor A-fib)
- Mitral E/A ratio > 1.5
- Mitral deceleration time <160 ms
- Pulmonary vein S/D < 40% (systolic suppression)
- Shortening of DT of the diastolic D wave
- Pulmonary vein A wave reversal velocity > 35 cm/s
- Pulm vein Ar duration - mitral A duration >30 msec
- E/e′ ratio > 15
- Color M-mode flow propagation vel (Vp) < 45 cm/s
- \( \frac{E}{Vp} > 2.5 \)
Left atrial size

Largest LA size (in systole)

Trace annulus to annulus. Exclude MV tenting and Pulmonary veins.
Doppler of MV inflow

- Technically adequate signals: 94% of the time
- Pulse wave in apical 4 chamber
- Sample volume between mitral leaflet tips
- E wave (preload dependent) and A wave
- MV inflow doppler velocities and filling patterns correlate poorly with hemodynamics in pts with CAD, HCM with EF > 50% and in pts with EF > 45%
- L wave: low mid-diast MV inflow vel. (progressive fall in LV diastolic pressure from slow LV relaxation)
- Limitations in S-tach, 1*AVB, partially merged E and A with flow velocity at onset of A (E at A) > 20 cm/s
Valsalva Maneuver

- Technically adequate 61% of the time. Forceful expiration (approx. 40 mmHg) against a closed nose and mouth producing hemodynamics in 4 phases. Decreases venous return (preload) to L side of the heart
- LV preload is reduced in Phase II (strain phase)
- \textbf{Decrease in E/A by } \geq 0.5 \textbf{ in cardiac pts is highly specific for increased LV filling pressures.}
- Good effort: Decrease in peak E by 20 cm/s.
- Careful in computing E/A ratio with Valsalva. Absolute A is (Peak A-height of E at onset of A)
- Useful when diastology unclear after MV inflow and TDI (e’)

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3/26/2011
Valsalva in Grade II Diastolic dysfunction
Real Time 2D echo in Grade II
Grade II Diastolic dysfunction

Left Atrium Enlargement

TDI at lateral Mitral Annulus
Color M-mode Doppler of MV Inflow

Measurement of Propagation Velocity

James D. Thomas, M.D., F.A.C.C., Cleveland Clinic
Propagation velocity ($V_p$) in Color M-mode

- $V_p$ is the propagation velocity of the E wave
- Most reliable as an index of LV relaxation especially in dilated LVs and / or reduced EFs
- Normal $V_p > 45$ cm/s
- $E/V_p$ is a good measure of L heart filling pressures. Normal $< 1.4$ (dimensionless)
- $E/V_p > 2.5$ suggests elevated L heart filling pressures.
- $V_p$ seems to be less preload dependent
Tissue Doppler of Mitral Annulus

• Technically adequate signals: 97% of the time
• PW doppler in 4 chamb, minimal angulation (<20°)
• Septal, lateral annulus insertions (within 1 cm of)
• Early & late diast. relaxation vel. (e’ and a’ waves)
• Sweep speed of 50 to 100 mm/s
• End expiration, average of 3 cardiac cycles
• Lateral tissue doppler has the best correlation with LV filling pressures in pts with normal EFs
• Useful in A-fib, sinus tach, merged E and A
• Useful in diff. Constrictive Peric vs Restrictive CM
• Limitations with basal RWMA. Consider averaging

Myocardial wall velocities don’t pseudonormalize.
Tissue Doppler Imaging at Lateral annulus
e’, E/e’ and Left Heart Filling Pressures

• Although e’ is a good measure of relaxation and relatively preload independent, E/e’ is not so accurate as an index of filling pressures in normal patients. Caution with calculating E/e’ below in:

  • Significant annular calcification, Surgical rings
  • Mitral stenosis, Prosthetic mitral valves
  • Lateral e’: constrictive pericarditis

  • Septal e’: constrictive pericarditis

  • Mod-severe primary MR (normal relaxation)
Pulmonary Vein Doppler: Determinants of Waves

- Atrial contractility ↑
- LA pressure ↑
- LV stiffness ↑
- MV area ↓

- PVs1
  - Atrial contractility ↑
  - LA pressure ↑
  - LV stiffness ↑
  - MV area ↓

- PVs2
  - LV relaxation ↑
  - MV area ↓
  - MR ↑
  - Cardiac output ↑

- PVd
  - LV contractility ↑
  - Descent of annulus ↑
  - MR ↓

LA = left atrial; LV = left ventricular; PV = pulmonary vein; MV = mitral valve; MR = mitral valve regurgitation.
Adapted with permission from James D. Thomas, MD.
Pulmonary Vein Doppler: Real case
Pulmonary Vein Doppler Flow

• Technically adequate signals: 73% of the time

• Pulm venous (PV) flow analysis infers ranges of LV filling pressures

• Forward flow from the veins into the left atrium (LA) follows the development of PV-LA gradients during systole (S) and diastole (D)

• With normal LA pressure, systolic flow (S) dominance occurs.

• As LA pressure increases, antegrade systolic flow (S) decreases and the diastolic (D) wave becomes more prominent as the LA empties in diastole with a larger PV-LA gradient in diastole (D).

• After atrial contraction, a retrograde flow (atrial reversal or Ar) occurs from the LA into the PV

• The PVAr dur -Adur value correlates well with LVEDP
Isovolumetric Relaxation Time (IVRT)

- Period from AV closure to onset of MV inflow
- MV opens when LV pressure falls below that of LA
- CW in the LVOT simultaneously displaying end of aortic ejection and the onset of MV inflow.

- Impaired relaxation & delayed MV opening prolongs IVRT. Further decreased compliance shortens IVRT
- IVRT by itself has limited accuracy
- Preload is a confounder. As preload increases, it opposes the effect of impaired relaxation
Special conditions (A-fib, MR & MS)

A-fib: No A wave. No PV Ar wave. IVRT ≤ 65 ms, Septal E/e’ ≥11, E/Vp ≥ 1.4 (Color M-mode) suggest elevated L filling pressures.

MR (Moderate and severe): Elevation of peak E velocity and reductions in pulm venous systolic (S) flow wave and the S/D ratio. In severe MR, pulm venous systolic (S) flow reversal is seen in late systole. MR can induce changes in MV and PV flow patterns resembling advanced LV diastolic dysfunction. E/e’ > 15 applies only with ↓EF. IVRT/T_{E-e’} < 3 (normal EF) ⇒ elevated filling pressures

Mitral stenosis: The shorter the IVRT and the higher the peak E velocity, the higher is the early diastolic LA pressure. LA pressure is significantly elevated at end-diastole if mitral velocity remains > 1.5 m/s at this (A) point. E/e’ is not useful. IVRT/T_{E-e’} ratio correlates well with mean PCWP and LA pressure. Ratio < 4.2 accurately identifies filling pressures > 15 mmHg. IVRT < 60 ms: highly specific for high filling pressures
Real time echo case in Grade I
Mitral Valve inflow: Grade I
Exercise Diastology

- Resting echo may suggest a resting grade of diastolic dysfunction not correlating with the symptoms of a higher NYHA class of dyspnea
- Reduced e’ does not improve with exercise
- E velocity increases with exercise
- E/e’ as a surrogate of filling pressure will therefore increase with exercise
- Chronic grade II ⇒↑PASP/PADP. Do TR jet vel.
- Measure diastology e’ and E/e’ after the stress image acquisition for the ischemia work up.
Normal Ranges

- LA volume index < 28 ml/m2
- E/A 0.8 - 1.5
- DT 160-240 ms
- Septal e’ ≥ 0.08 m/s (age dependent ranges)
- Lateral e’ ≥ 0.10 m/s (age dependent ranges)
- E/e’ ≤ 8 (abnormal average E/e’ > 12)
- $V_p$ > 45 cm/s
- E/$V_p$ < 1.4
- PV Ar dur < A dur
- PV Ar velocity < 35 cm/s
- S ≥ D
- Peak Valsalva change in E/A ratio < 0.5
- IVRT 70-90 ms, IVRT/T $\frac{E-e’}{E-e’} > 2$
Some Pitfalls in Diastology Measurement

- Doppler MV inflow E velocity: Preload dependent
- Doppler MV inflow pattern: Unreliable in normal EF
- Partially fused E & A (E at A ≥ 0.2 m/s) may cause A to be artificially increased, falsely reducing E/A ratio
- Mid diastolic velocity (L wave) of delayed relaxation can cause overestimation of DT
- Underestimating LA volume reduces suspicion of LAP
- Color M-mode Vp unreliable in LV with normal EF/size and falsely normal in small LV (HCM, Amyloid)
- Regional WMA can confound septal, lateral e'
- Tethered nonviable wall segment falsely measures e'
- Atrial failure in restrictive diastolic dysfunction can cause PV Ar dur to be reduced instead of augmented
- Constrictive pericarditis can falsely increase septal e'
Review: Grading of Diastolic Dysfunction

**Figure 10-10** A more complicated grading system for left ventricular (LV) diastolic dysfunction that incorporates multiple mitral flow velocity variables, their response to Valsalva maneuver, pulmonary venous flow velocity variables and tissue Doppler imaging of the septal mitral annulus. These criteria have been used in epidemiologic studies to assess the asymptomatic prevalence of diastolic dysfunction in the community and also how LV diastolic dysfunction increases the risk for future adverse cardiac events. (From Redfield et al. *Burden of systolic and diastolic ventricular dysfunction in the community: Appreciating the scope of the heart failure epidemic*. JAMA 2003;289:194-202.)

Klein AL, Garcia MJ. Diastology Clinical approach to Diastolic Heart failure, 124.
Estimation of Filling Pressures in Normal EF

E/e’ < 8
(Sep, Lat, or Av.)

E/e’ 9-14

LA volume < 34 ml/m²
Ar – A < 0 ms
Valsalva Δ E/A < 0.5
PAS <30 mmHg
IVRT/T_{E-e’} >2

Normal LAP

LA volume ≥ 34 ml/m²
Ar – A ≥ 30 ms
Valsalva Δ E/A ≥ 0.5
PAS >35 mmHg
IVRT/T_{E-e’} <2

↑LAP

Sep. E/e’ ≥ 15
or
Lat. E/e’ ≥ 12
or
Av. E/e’ ≥ 13

↑LAP

Nagueh SF et al. JASE 2009;22:107-33
Estimation of Filling Pressures in Depressed EF

Nagueh SF et al. JASE 2009;22:107-33
For Questions 1-9, match each set of Doppler recordings with the most likely diagnosis. Each answer may be used once, more than once, or not at all.

**Diagnoses:**

A. Normal diastolic function for age  
B. Impaired early diastolic relaxation (mild diastolic dysfunction)  
C. Pseudo-normalization (moderate diastolic dysfunction)  
D. Decreased diastolic compliance (severe diastolic dysfunction)  
E. Elevated filling pressures  
F. Mitral regurgitation  
G. Atrial fibrillation  
H. Heart block

**Figure 7-25**

Otto CM, Schwaegler RG. , 2008
For Questions 1-9, match each set of Doppler recordings with the most likely diagnosis. Each answer may be used once, more than once, or not at all.

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A. Normal diastolic function for age
B. Impaired early diastolic relaxation (mild diastolic dysfunction)
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E. Elevated filling pressures
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H. Heart block
Self-Assessment Questions 3 - 4

For Questions 1-9, match each set of Doppler recordings with the most likely diagnosis. Each answer may be used once, more than once, or not at all.

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Self-Assessment Questions 5 - 6

For Questions 1-9, match each set of Doppler recordings with the most likely diagnosis. Each answer may be used once, more than once, or not at all.

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Self-Assessment Questions 7 - 8

**Diagnoses:**
A. Normal diastolic function for age
B. Impaired early diastolic relaxation (mild diastolic dysfunction)
C. Pseudo-normalization (moderate diastolic dysfunction)
D. Decreased diastolic compliance (severe diastolic dysfunction)
E. Elevated filling pressures
F. Mitral regurgitation
G. Atrial fibrillation
H. Heart block

**QUESTION 7**
Diagnosis ______

**QUESTION 8**
Diagnosis ______

Figure 7-31

Figure 7-32
How much diastology testing is enough?

What constitutes a Basic Diastolic Screen?

1. LV size and function
2. LA volume
3. E/A ratio and DT
4. e’, E/e’

When to do more?

1. Referral for diastology assessment
2. Referral for dyspnea
3. New pulm HTN
4. Abnormal basic screen findings
5. Indeterminate screen findings

Do what else?

Valsalva, A wave dur, Pulm veins, V_p, IVRT, PASP.
Algorithm to Grade Diastolic Dysfunction

**Practical Approach to Grade Diastolic Dysfunction**

- **Septal e’ ≥ 8**
  - Lateral e’ ≥ 10
  - LA < 34 ml/m²
  - **Normal function**

- **Septal e’ ≥ 8**
  - Lateral e’ ≥ 10
  - LA ≥ 34 ml/m²
  - **Normal function, Athlete’s heart, or constriction**

- **Septal e’ < 8**
  - Lateral e’ < 10
  - LA ≥ 34 ml/m²
  - E/A < 0.8
  - DT > 200 ms
  - Av. E/e’ ≤ 8
  - Ar-A < 0 ms
  - Val ΔE/A < 0.5
  - **Grade I**

- **E/A 0.8-1.9**
  - DT 160-200 ms
  - Av. E/e’ 9-12
  - Ar-A ≥ 30 ms
  - Val ΔE/A ≥ 0.5
  - **Grade II**

- **E/A ≥ 2**
  - DT < 160 ms
  - Av. E/e’ ≥ 13
  - Ar-A ≥ 30 ms
  - Val ΔE/A ≥ 0.5
  - **Grade III**

*Note: Nagueh SF et al. JASE 2009;22:107-33*
1. Diastology measurement is essential in a complete echo study
2. Diastolic dysfunction is graded I to IV with clinical correlates
3. Estimating LV filling pressures: Done well with integration
4. LV filling pressures (reduced EF): MV inflow as pillar
5. LV filling pressures (normal EF): TDI as pillar of algorithm
6. Be aware of confounders that limit stand-alone test validity
7. Understand the progression from abnormal relaxation to decreased compliance and then elevated left atrial pressure
Summary / Take home points (II)

8. Understand that loading conditions change diastology measures from study to study in the same patient.

9. Attention to echo clues before assessing LV filling pressures

10. Exercise diastology relevant to truly correlate with symptoms

11. TDI useful in A-fib, S-tach, 1*AVB, merging of the vital E and A

12. Loss of A wave in A-fib will decompensate grade I > grade II

13. Diastolic strain measurement is a new frontier

14. Reports should be worded for referring providers to understand

15. Diastology measurements by techs do not have to be a hassle

16. Be aware of the new nomenclature and updated algorithms
References


9. Little WC, Oh JK. Echocardiographic evaluation of diastolic function can be used to guide clinical care. Circulation. 2009;120(9):802-809.