Echo Diastolic Exam
Established and Emerging Methods

Allan L Klein M.D.
Director, Center of Pericardial Diseases
Professor of Medicine
Heart and Vascular Institute
Cleveland Clinic
President, ASE

* No Conflicts to Declare
Diastology 2016

- Case presentation
- Pathophysiology
- Epidemiology
- Diseases
- Assessment
- Prognosis and Treatment
Diastolic Heart Failure
Diastology
Advanced Diastology?

- Tricuspid
- Mitral
- Hepatic Veins
- Pulmonary Veins
- Valsalva
Simplified Diastology
Pulling vs Pushing

Oh et al
Circ Cardiovasc Imaging 2011:4:444-455

Pull
Push
Assessment of Diastolic Function
Echo Methods

- Transmitral inflow
- Pulmonary venous flow
- Tissue Doppler Echo
- LA Volume Index
The Phases of Left Ventricular Filling

Ommen et al. Heart 2003
LV Inflow Measurements

Doppler Flow Patterns

Mitral Inflow

Pulmonary Vein

Impaired Relaxation  Pseudonormal  Restriction

Cohen et al, JACC 1996;27:1753-60
Survival in Idiopathic DCM
Deceleration Time

Werner et al Am J Cardiol;1994; 73:792-8
Assessment of LV Filling Pressure

The Different LA and LV Pressures

Appleton et al.
Tissue Doppler Imaging
PCWP vs E/Ea

\[ Y = 1.9 + 1.24X \]

\[ R = 0.87 \]

\[ N = 60 \]

## Mitral Flow Velocity / TDI Annular Patterns

<table>
<thead>
<tr>
<th>Mitral Flow</th>
<th>Normal</th>
<th>Relaxation abnormality</th>
<th>Pseudo-normalization</th>
<th>Restrictive physiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral Annulus Velocity</td>
<td>Normal</td>
<td>Relaxation abnormality</td>
<td>Pseudo-normalization</td>
<td>Restrictive physiology</td>
</tr>
</tbody>
</table>

- Normal: $E$, $A$
- Relaxation abnormality: $E_a$, $A_a$
- Pseudo-normalization: $E_a$, $A_a$
- Restrictive physiology: $E$, $A$
M-LVDP vs. Groups Defined by Values of Septal E/E’

Ommen et al. Circulation 2000
LA Volume

- LA volume measured using:
  1. Simpson’s Method
  2. Area-Length Method

\[ V = \frac{8A_1A_2}{3\pi L} \]

- Measurements were taken in apical 2 and 4 chamber views
  - End systole and End diastole
  - Excluding the left atrial appendage

LAVI = LAV/Body Surface Area
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. Naghieh, Chair, MD, FASE, Otto A. Simeth, Co-Chair, MD, PhD, Christopher P. Appleton, MD, Benjamin F. Byrd, III, MD, FASE, Hisham Dokainish, MD, FASE, Thor Edvardsen, MD, PhD, Frank A. Flachskampf, MD, PhD, FESC, Thierry C. Gillebert, MD, PhD, FESC, Allan L. Klein, MD, FASE, Patrizio Lancellotti, MD, PhD, FESC, Paolo Marino, MD, FESC, Jae K. Oh, MD, Bogdan Alexandru Popescu, MD, PhD, FESC, FASE, and Alan D. Waggoner, MHS, RDMS, Houston, Texas; Oslo, Norway; Phoenix, Arizona; Nashville, Tennessee; Hamilton, Ontario, Canada; Uppsala, Sweden; Ghent and Liège, Belgium; Cleveland, Ohio; Novara, Italy; Rochester, Minnesota; Bucharest, Romania; and St. Louis, Missouri

(J Am Soc Echocardiogr 2016;29:277-314.)
2016 Diastology Guidelines Update

Objectives

- 2009 ASE/EACVI guidelines were too complex to grade DF and estimate LV filling pressures
- Based on too many parameters and a lot of discrepancies
- Primary goal of 2016 update is to simplify
  - increase feasibility of use of the guidelines in clinical practice
2016 Diastology Guidelines Update
General Rules of Engagement

• Clinical, 2-D and Doppler findings not in isolation
  – Need to know clinical info, age and 2-D echo

• Quality and limitation of the Doppler signal and 2-D technique
  – Puts a lot of responsibility on sonographers
  – Need great 2-D and Doppler data
2016 Diastology Guidelines Update

**General Rules of Engagement**

- Single measurement within normal range does not necessarily equate with normal study
- **Consistency** between ≥ 2 of the indices
- Determine grade of diastolic function based on the presence or absence of elevated LV filling pressures as a first step
- Algorithms are increasing specificity
  - E/A <1 with no other findings is considered normal
- Multicenter studies are ongoing with validation
### Table III: Proportion of Normal Subjects with Abnormal LA Volume Index and Doppler Velocities

<table>
<thead>
<tr>
<th>Parameter</th>
<th>20-40 y</th>
<th>40-60 y</th>
<th>≥60 y</th>
<th>Global cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Male</td>
<td>Female</td>
<td>Total</td>
</tr>
<tr>
<td>Septal e’&lt;8 cm/s</td>
<td>2/317(1.2)</td>
<td>2/79(2.5)</td>
<td>1/91(1.1)</td>
<td>13/85(16.3)</td>
</tr>
<tr>
<td>Lateral e’&lt;10 cm/s</td>
<td>3/167(1.8)</td>
<td>1/75(1.3)</td>
<td>1/01(1.1)</td>
<td>13/182(15.7)</td>
</tr>
<tr>
<td>Average sept:-E’/E’&gt;15</td>
<td>0/155(0.0)</td>
<td>0/75(0.0)</td>
<td>0/131(0.8)</td>
<td>13/182(15.7)</td>
</tr>
<tr>
<td>Septal E’&gt;15</td>
<td>0/159(0.0)</td>
<td>0/75(0.0)</td>
<td>0/131(0.8)</td>
<td>13/182(15.7)</td>
</tr>
<tr>
<td>Lateral E’&gt;3</td>
<td>2/107(1.9)</td>
<td>0/48(0.0)</td>
<td>0/131(0.8)</td>
<td>13/182(15.7)</td>
</tr>
<tr>
<td>LA volume &gt;34 ml/m²</td>
<td>2/106(1.9)</td>
<td>0/48(0.0)</td>
<td>0/131(0.8)</td>
<td>13/182(15.7)</td>
</tr>
<tr>
<td>SPAP &gt;45 mmHg</td>
<td>0/159(0.0)</td>
<td>0/75(0.0)</td>
<td>0/131(0.8)</td>
<td>13/182(15.7)</td>
</tr>
</tbody>
</table>

**Proportion of Normal Subjects with Abnormal LAVI and Doppler Indices**

Caballero et al. Echocardiographic reference ranges for normal cardiac Doppler data: results from the NORRE study
Eur Heart J Cardiovascular Imaging 2015
Criteria for Diagnosis of LV Diastolic Dysfunction

Diagnosis of Diastolic Dysfunction in Patients with Normal LV EF

1. Average E/é > 14
2. Septal é velocity < 7 cm/s or Lateral é velocity < 10 cm/s
3. TR velocity > 2.8 m/s
4. LA volume index > 34 ml/m²

0 or 1 Positive
- Normal Diastolic Function

2 Positive
- Indeterminate

3 or 4 Positive
- Diastolic Dysfunction

Nagueh S. et al. ASE/EACVI 2016 Update
Estimation of LV Filling Pressures in Patients with Depressed LV EF or Normal EF and Diastolic Dysfunction

E/A ≤0.8 + E>50 cm/s or E/A >0.8 - <2

3 Criteria to be evaluated*
①Average E/é >14
②TR velocity >2.8 m/s
③LA vol. index >34 ml/m²

When only 2 criteria are available
1 Positive and 1 Negative

2 of 3 or 3 of 3 negative

Normal Lap, Grade I Diastolic Dysfunction
If Symptomatic

Cannot determine LAP and Diastolic Dysfunction Grade*
Consider CAD, or proceed to Diastolic Stress Test

2 of 3 or 3 of 3 positive

E/A ≥2

Lap, Grade II Diastolic Dysfunction

Lap, Grade III Diastolic Dysfunction

*LAP indeterminate if only 1 of 3 parameters available. Pulmonary vein S/D ratio <1 applicable to conclude elevated LAP in patients with depressed LVEF
How To Determine if Diastolic Dysfunction with Preserved EF is Present

• Known CV disease as coronary artery disease
  – Wall motion
• Pathologic LVH
• Hypertensive CV Disease
• Cardiomyopathy
  – Amyloid
• Established Diagnosis of HFpEF
## Grades of Diastolic Function

**Table 4** LV relaxation, filling pressures and 2D and Doppler findings according to LV diastolic function

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Grade I</th>
<th>Grade II</th>
<th>Grade III</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV relaxation</td>
<td>Normal</td>
<td>Impaired</td>
<td>Impaired</td>
<td>Impaired</td>
</tr>
<tr>
<td>LAP</td>
<td>Normal</td>
<td>Low or normal</td>
<td>Elevated</td>
<td>Elevated</td>
</tr>
<tr>
<td>Mitral E/A ratio</td>
<td>≥0.8</td>
<td>≤0.8</td>
<td>&gt;0.8 to &lt;2</td>
<td>&gt;2</td>
</tr>
<tr>
<td>Average E/e’ ratio</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>10–14</td>
<td>&gt;14</td>
</tr>
<tr>
<td>Peak TR velocity (m/sec)</td>
<td>&lt;2.8</td>
<td>&lt;2.8</td>
<td>&gt;2.8</td>
<td>&gt;2.8</td>
</tr>
<tr>
<td>LA volume index</td>
<td>Normal</td>
<td>Normal or increased</td>
<td>Increased</td>
<td>Increased</td>
</tr>
</tbody>
</table>
Diastolic Dysfunction

Limitations

• Atrial fibrillation

• Significant mitral valve disease
  – at least moderate MAC
  – any mitral stenosis
  – mitral regurgitation of > moderate severity
  – mitral valve repair or prosthetic mitral valve

• LV assist devices (LVAD)

• Left bundle branch block

• Ventricular paced rhythm
Diastology Clinical Report

What should be included in our reports?

• Status of LV filling pressures
  – normal, elevated or cannot be determined

• Grade of diastolic function
  – Grade 1, 2 and 3
54 Year Old Woman with Palpitations
Apical view

EF 60%
LAVI 23 ml/m2
TR 2.2 m/s
Mitral Inflow

E wave = 91 cm/s; E/A ratio 2.12
Tissue Doppler Imaging

Medial

Medial e’ = 11

Lateral

Lateral e’ = 13

average E/e’= 7.6
Criteria for Diagnosis of LV Diastolic Dysfunction

Diagnosis of Diastolic Dysfunction in Patients with Normal LV EF

1. Average E/é >14
2. Septal é velocity <7 cm/s or Lateral é velocity <10 cm/s
3. TR velocity >2.8 m/s
4. LA volume index >34 ml/m²

0 or 1 Positive → Normal Diastolic Function
2 Positive → Indeterminate
3 or 4 Positive → Diastolic Dysfunction
59 Year Old Man s/p AV Repair and Aortic Root Replacement and Pathologic LVH
Apical view

EF 59%
LAVI 35 ml/m²
TR 2.5 m/s
Mitrail Inflow

E wave 45 cm/s, E/A ratio 0.62
Tissue Doppler Imaging

Medial

Lateral

Medial $e' = 6$

Lateral $e' = 8$

average $E/e' = 6.4$
Estimation of LV Filling Pressures in Patients with Depressed LV EF or Normal EF and Diastolic Dysfunction

- **E/A ≤ 0.8 + E > 50 cm/s or E/A > 0.8 - <2**
  - 3 Criteria to be evaluated:
    1. Average E/é > 14
    2. TR velocity > 2.8 m/s
    3. LA vol. index > 34 ml/m²
  - When only 2 criteria are available:
    - 1 Positive and 1 Negative: Cannot determine LAP and Diastolic Dysfunction Grade*
    - 2 Positive: ↑Lap, Grade III Diastolic Dysfunction
  - 2 of 3 or 3 of 3 negative: Normal Lap, Grade I Diastolic Dysfunction
  - 2 of 3 or 3 of 3 positive: Consider CAD, or proceed to Diastolic Stress Test

*LAP indeterminate if only 1 of 3 parameters available. Pulmonary vein S/D ratio < 1 applicable to conclude elevated LAP in patients with depressed LVEF

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Nagueh S. et al. ASE/EACVI 2016 Update

Cleveland Clinic
47 Year Old Man with Shortness of Breath
Apical 2 chamber

EF 60%
LAVI 40 ml/m2,
TR 2.9 m/s
Mitral Inflow

E wave 90 cm/s, E/A ratio 1.8
Tissue Doppler Imaging

Medial

Lateral

e' = 5

e' = 7

average E/e' = 15
What Is The Diagnosis?

A. Constrictive Pericarditis
B. Fabry’s Disease
C. Amyloidosis
D. Hypertensive heart disease
What Is The Diagnosis?

A. Constrictive Pericarditis
B. Fabry’s Disease
C. Amyloidosis
D. Hypertensive heart disease
Estimation of LV Filling Pressures in Patients with Depressed LV EF or Normal EF and Diastolic Dysfunction

1. **E/A ≤ 0.8 + E > 50 cm/s or E/A > 0.8 - <2**
   - 3 Criteria to be evaluated:
     1. Average E/é > 14
     2. TR velocity > 2.8 m/s
     3. LA vol. index > 34 ml/m²
   - When only 2 criteria are available:
     - 2 positive
     - 1 positive and 1 negative
     - 2 negative
   - **Normal Lap, Grade I Diastolic Dysfunction**
   - Consider CAD, or proceed to Diastolic Stress Test

2. **E/A ≥ 2**
   - 2 of 3 or 3 of 3 positive
   - **Lap, Grade II Diastolic Dysfunction**

3. **E/A ≤ 0.8 + E ≤ 50 cm/s**
   - 2 of 3 or 3 of 3 negative
   - **Cannot determine LAP and Diastolic Dysfunction Grade**

4. **Lap, Grade III Diastolic Dysfunction**

*LAP indeterminate if only 1 of 3 parameters available. Pulmonary vein S/D ratio < 1 applicable to conclude elevated LAP in patients with depressed LVEF

Nagueh S. et al. ASE/EACVI 2016 Update
Key Points

• Hypertensive Heart Disease
• Severe concentric hypertrophy
• ACC/AHA CHF Stage C
• Diastolic heart failure (HFpEF)
  – Elevated LV filling pressures
  – Grade 2 diastolic dysfunction
  – Impaired global and regional strain
75 Year Old Man with Shortness of breath
Apical Views

EF 49%
LAVI 35 ml/m2
TR velocity 2.7 m/s
Mitral inflow

E wave 67 cm/s, E/A ratio 0.66
**Tissue Doppler Imaging**

**Medial**

- $e' = 4$

**Lateral**

- $e' = 5$

**Average E/e’ = 14.88**
Estimation of LV Filling Pressures in Patients with Depressed LV EF or Normal EF and Diastolic Dysfunction

E/A ≤ 0.8 + E > 50 cm/s or E/A > 0.8 - <2

3 Criteria to be evaluated*

① Average E/ε > 14
② TR velocity > 2.8 m/s
③ LA vol. index > 34 ml/m²

When only 2 criteria are available

2 of 3 or 3 of 3 positive

↑ Lap, Grade III Diastolic Dysfunction

2 positive

2 of 3 or 3 of 3 negative

2 negative

Normal Lap, Grade I Diastolic Dysfunction

If Symptomatic

Consider CAD, or proceed to Diastolic Stress Test

Cannot determine LAP and Diastolic Dysfunction Grade*

↑ Lap, Grade II Diastolic Dysfunction

1 Positive and 1 Negative

↑ Lap, Grade II Diastolic Dysfunction

E/A ≥ 2

↑ Lap, Grade II Diastolic Dysfunction

*LAP indeterminate if only 1 of 3 parameters available. Pulmonary vein S/D ratio < 1 applicable to conclude elevated LAP in patients with depressed LVEF
Key Points

• CAD with wall motion abnormalities
• EF 49%
• E/A ratio $\leq 0.8$ and $E > 50\text{ cm/s}$
  - $2/3$ criteria positive for Grade 2
• Elevated LV filling pressures
• Grade 2 diastolic function
## Special Populations

**Table 6** Assessment of LV filling pressures in special populations

<table>
<thead>
<tr>
<th>Disease</th>
<th>Echocardiographic measurements and cutoff values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Atrioventricular flutter</strong></td>
<td>Peak acceleration rate of mitral E velocity (≥1,900 cm/sec²)</td>
</tr>
<tr>
<td></td>
<td>IVRT (≤85 msec)</td>
</tr>
<tr>
<td></td>
<td>DT of pulmonary venous diastolic velocity (≥220 msec)</td>
</tr>
<tr>
<td></td>
<td>E'/Vp ratio (≥1.4)</td>
</tr>
<tr>
<td></td>
<td>Septal E'/E ratio (≥11)</td>
</tr>
<tr>
<td><strong>Sinus tachycardia</strong></td>
<td>Mitral inflow pattern with predominant early LV filling in patients with EFs &lt;50%</td>
</tr>
<tr>
<td></td>
<td>IVRT ≤70 msec is specific (79%)</td>
</tr>
<tr>
<td></td>
<td>Pulmonary vein systolic filling fraction ≤40% is specific (88%)</td>
</tr>
<tr>
<td></td>
<td>Average E'/E &gt;14 (this cutoff has highest specificity but low sensitivity)</td>
</tr>
<tr>
<td></td>
<td>When E and A velocities are partially or completely fused, the presence of a compensatory period after premature beats often leads to separation of E and A velocities which can be used for assessment of diastolic function</td>
</tr>
<tr>
<td><strong>HCM</strong></td>
<td>Average E'/E (≥14)</td>
</tr>
<tr>
<td></td>
<td>Ar-A (≥30 msec)</td>
</tr>
<tr>
<td></td>
<td>TR peak velocity (&gt;2.8 m/sec)</td>
</tr>
<tr>
<td></td>
<td>LA volume (&gt;34 mL/m²)</td>
</tr>
<tr>
<td><strong>Restrictive cardiomyopathy</strong></td>
<td>DT (&lt;140 msec)</td>
</tr>
<tr>
<td></td>
<td>Mitral E/A (≥2.5)</td>
</tr>
<tr>
<td></td>
<td>IVRT (&lt;50 msec high specificity)</td>
</tr>
<tr>
<td></td>
<td>Average E'/E (≥14)</td>
</tr>
<tr>
<td><strong>Noncardiac pulmonary hypertension</strong></td>
<td>Lateral E'/E can be applied to determine whether a cardiac etiology is the underlying reason for the increased pulmonary artery pressures</td>
</tr>
<tr>
<td></td>
<td>When cardiac etiology is present, lateral E'/E is &gt;13, whereas in patients with pulmonary hypertension due to a noncardiac etiology, lateral E'/E is &lt;8</td>
</tr>
<tr>
<td><strong>Mitrval stenosis</strong></td>
<td>IVRT (&lt;60 msec high specificity)</td>
</tr>
<tr>
<td></td>
<td>IVRT/T_E'&lt; (≤4.2)</td>
</tr>
<tr>
<td></td>
<td>Mitral A velocity (&gt;1.5 m/sec)</td>
</tr>
<tr>
<td><strong>MR</strong></td>
<td>Ar-A (≥30 msec)</td>
</tr>
<tr>
<td></td>
<td>IVRT (&lt;60 msec high specificity)</td>
</tr>
<tr>
<td></td>
<td>IVRT/T_E'&lt; (≤5.6) may be applied for the prediction of LV filling pressures in patients with MR and normal EFs</td>
</tr>
<tr>
<td></td>
<td>Average E'/E (≥14) may be considered only in patients with depressed EFs</td>
</tr>
</tbody>
</table>
Constriction vs Restriction

Algorithm

- Mitral inflow E/A > 0.8
- Dilated inferior vena cava
- NO → Constriction / Restriction Unlikely
- YES → Ventricular septal motion abnormality with respiration
- NO → Further imaging or cardiac catheterization if constrictive pericarditis still suspected
- YES → Mitral medial e’
  - >8 cm/s → Constrictive Pericarditis
  - 6 - 8 cm/s → Mixed Constriction Restriction
  - <6 cm/s → Restrictive Cardiomyopathy

Ancillary Findings
- DT <150ms
- IVRT <50ms
- PV Systolic Fraction <40%
- E/e’ > 15
- LAVI > 48 ml/m²

Mitral lateral e’ < medical e’ (Annulus Reversus)
- MOST LIKELY CONSTRUCTION

Hepatic vein expiratory end-diastolic reversal velocity / forward flow velocity ≥ 0.8
- DEFINITE CONSTRUCTION

Also possible in obstructive airway disease especially yonm patients (increase inspiratory SVC flow seen)
Diastology Guidelines Update

• Introduction
• 2009 guidelines
• 2016 updated guidelines
• Case presentations
• Specific diseases
• Diastology stress test
Diastology Stress Testing

• Definitely abnormal indicating diastolic dysfunction
  – 3 conditions are met
    – septal E/e’ ratio >15 or lateral E/e' >13, or average E/e'
      >14 with exercise
    – peak TR velocity > 2.8 m/sec with exercise
    – septal e' velocity is < 8 cm/s (lateral e' <10 cm/s) at
      baseline.

• Normal when E/e’ ratio (septal, lateral or average) is < 10 with
  exercise and peak TR velocity < 2.8 m/sec with exercise

• In the absence of these results, the test is considered
  indeterminate pressures at rest and with exercise
Diastology Stress Test

Mitral Flow

- Rest: $E = 72$ cm/sec
- Stress: $E = 106$ cm/sec

Mitral Annular Velocity

- Rest: $e' = 7$ cm/sec
- Stress: $e' = 6$ cm/sec

$E/e' = 9 > E/e' = 17.6$

5.1 METs (%predicted METs 82%)
Novel parameters

- Global longitudinal strain (GLS)
- Global longitudinal LV diastolic strain rate during IVRT (GLS IVR)
- IVRT/T $E_e'$
- LV untwisting rate
- LA systolic strain
Myocardial Strain: Muscle Deformation

Strain: dimensionless index of change in length

Strain $(\varepsilon) = \frac{L - L_0}{L_0}$

LV strain may offer a pure index of regional LV function but is difficult to measure.
2-D Strain

Peek Systolic Strain

Longitudinal Strain
Normal Strain and Torsion

Wringing a Towel: Systolic twist and Diastolic untwist

Counter-clockwise
Rotation as viewed from apex
Clockwise

Contraction

Apical
Basal

Systole
Diastole

Time

Systole
Diastole

Contraction

Clockwise

S
A
P
L

Counter-clockwise

Cleveland Clinic
Torsion from 2D Echo

Apical twist: 8°

Apical level

Basal level

Notomi et al. JACC 2005; 45:2034-41
LV Twist and Twisting Rate and Untwisting Rate

Control

Diastolic Dys

Systolic Dys

Increased restoring Forces in Diast Dys

Compensatory mechanism

Echo Diastolic Exam
Established and Emerging Methods
Take Home Points

• HFPEF is common and deadly
• Echo is main technique to assess diastolic filling
• Echo techniques include Doppler, TDI, LAVI and strain
• Diastology updated guidelines in place using new algorithms based on E/e’, LAVI and RVSP in patients with decreased EF and patients with myocardial pathology and preserve EF