Assessment of left ventricular diastolic function

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Conflicts of interest

- None
Recommendations for the Evaluation of Left Ventricular Diastolic Function by Echocardiography

SF Nagueh, CP Appleton, TC Gillebert, P Marino, JK Oh, OA Smiseth, AD Waggoner, F Flachskampf, PA Pellika, A Evangelisa.

A diagnosis of heart failure with normal LV ejection fraction requires three obligatory conditions to be simultaneously satisfied:

1. Symptoms or signs of CHF

2. Normal or only slightly reduced LV systolic function
   \[ \text{EF} > 0.50 \]

3. Evidence of abnormal diastolic function
   - Invasive measures: LVEDP, \( \tau \), P-V curve
   - Doppler echocardiographic evidence
   - Natriuretic peptides

Exclude non-cardiac etiology: Pulmonary disease
Echo-Doppler Modalities for Assessing Diastolic Function

- Tissue Doppler
- Pulmonary venous velocities
- Mitral velocities
- Color M-mode

LVH?
Atrial size
Pulmonary venous velocities
TR jet

OA Smiseth, 2011.
Transmitral flow velocities

Reflect the transmitral pressure gradient
E-deceleration time

Reflects diastolic stiffness

Progressive diastolic dysfunction

Impaired Relaxation

Pseudonormalization

Restrictive filling

Mitral velocities

Mitral velocities  
A duration 125 ms

Pulmonary venous velocities  
PVa duration 120 ms

PVa duration 165 ms

Appleton et al., JACC 1993
Tissue Doppler echocardiography

Myocardial velocities (cm/s)

ECG

OA Smiseth, 2011.
# Staging of Diastolic Dysfunction

<table>
<thead>
<tr>
<th>Normal</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Mitral inflow" /></td>
<td><img src="image2" alt="Mitral inflow" /></td>
<td><img src="image3" alt="Mitral inflow" /></td>
<td><img src="image4" alt="Mitral inflow" /></td>
</tr>
<tr>
<td><img src="image5" alt="Mitral annulus velocity" /></td>
<td><img src="image6" alt="Mitral annulus velocity" /></td>
<td><img src="image7" alt="Mitral annulus velocity" /></td>
<td><img src="image8" alt="Mitral annulus velocity" /></td>
</tr>
</tbody>
</table>

- **Normal**
  - Mitral inflow: E, A
  - Mitral annulus velocity: e', a'
- **Mild**
  - Mitral inflow: E, A
  - Mitral annulus velocity: e', a'
- **Moderate**
  - Mitral inflow: E, A
  - Mitral annulus velocity: e', a'
- **Severe**
  - Mitral inflow: E, A
  - Mitral annulus velocity: e', a'

**Modified from Sohn et al., JACC 1997**
Determinants of $e'$

- LV relaxation
- Restoring forces
- Lengthening load (diastolic load)
Invasive measure of LV relaxation ($\tau$)

- ln PLV
- Pressure (mmHg)
- $\tau = 49$ msec
- LV $dP/dt$ (mmHg/sec)
- ln PLV
- Paorta
- PLV
- IVR

Smiseth et al, 2002.
Relationship between $e'$ and $\text{Tau}$

**Experimental study**

- **Nagueh et al., JACC 37: 278-85, 2001**
  - $Y = 10 - 0.07x$
  - $R = -0.83$
  - $P < 0.001$

**Clinical studies**

- **Sohn et al. JACC 30: 474-80, 1997**
  - $y = 14.70 - 0.15x$
  - $r = -0.56$

- **Atrial fibrillation**
  - $y = -0.0014x + 0.1556$
  - $r = -0.509$, $p = 0.007$
LV lengthening load (diastolic load)

LVP at mitral opening ($LVP_{MVO}$)
e'- relationship to lengthening load (LVP_{MVO})

R=0.83
P<0.001

- Baseline
- Dobutamine
- Ischemia
- Volume loading
- Caval constriction

Transmural LVP_{mvo} (mmHg) vs. e' (cm/s)

Opdahl et al, Circulation 2009
Restoring forces

Modified from www.phy-061062.blogspot.com
LV relaxation and restoring forces are independent determinants of e′.

**e′ vs rate of relaxation**

**e′ vs restoring forces**

Opdahl et al, Circulation 2009
Determinants of $e'$

- LV relaxation
- Restoring forces
- Lengthening load (diastolic load)
Is e’ determined by systolic function?

Since LV contractility determines end-systolic volume, which in turn determines restoring forces, e’ is modulated by systolic function.
Estimation of LV filling pressure by E/e’

Modified from Nagueh et al., Circulation 1998.

E/e’ > 15

E/e’ < 8

PCWP “normal”

PCWP elevated

PCWP (mmHg)

E/e’
Comparison between Doppler-based pressure estimates with left atrial pressure in heart failure patients with reduced EF (n=15) using a permanently implanted pressure sensor

ROC Curves for the Prediction of LAP $\geq$15 mm Hg Using Echo Doppler Indexes

“When serial testing was undertaken in these subjects, an E/e' 15 accurately detected an LAP elevated into the decompensated range, with an E/e' >18 essentially "ruling in" an elevated LAP and an E/e' <12 essentially excluding an elevated LAP”

Ritzema, J. L. et al. J Am Coll Cardiol Img 2011;4:927-934
<table>
<thead>
<tr>
<th>Variable</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>AUC (95% confidence intervals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral E/A ratio</td>
<td>82</td>
<td>82</td>
<td>0.87 (0.79-0.96)</td>
</tr>
<tr>
<td>IVRT</td>
<td>89</td>
<td>81</td>
<td>0.86 (0.73-0.99)</td>
</tr>
<tr>
<td>E/Vp</td>
<td>89</td>
<td>83</td>
<td>0.9 (0.81-0.99)</td>
</tr>
<tr>
<td>Average E/e’</td>
<td>89</td>
<td>91</td>
<td>0.92 (0.85-1)</td>
</tr>
<tr>
<td>PA systolic pressure by Doppler</td>
<td>85</td>
<td>92</td>
<td>0.89 (0.92-1)</td>
</tr>
<tr>
<td>LA maximum volume index</td>
<td>91</td>
<td>33</td>
<td>0.67 (0.52-0.83)</td>
</tr>
</tbody>
</table>

AUC i.e. area under the curve.

Nagueh et al., Circulation CV Imaging 2011
In pts with reduced EF:

Mitral E/A

- E/A < 1 and E ≤ 50 cm/s
  - E/e’ (average e’) < 8
    - PAS < 30 mmHg
    - Ar – A < 0 ms
    - S/D > 1
    - E/Vp < 1.4
    - Two of these past limit
  - Normal LAP

- E/A ≥ 1 - < 2, or E/A < 1 and E > 50 cm/s
  - E/e’ (average e’) > 15
    - PAS > 35 mmHg
    - Ar – A ≥ 30 ms
    - S/D < 1
    - E/Vp ≥ 2.5
    - Two of these past limit
  - Elevated LAP

- E/A ≥ 2, DT < 150 ms
  - Elevated LAP

Modified from Nagueh et al., Eur J Echocardiogr 2009;10:165-93
LV twist and untwist
LV twist and untwist
Apical rotation

Remme et al. 2006
Prognostic impact of TDI in a general population
The eas index: $e'/(a' x s')$

Kaplan–Meier survival curves by tertiles of the eas index. $N = 1036$

Mogelvang et al., Circulation 2009
Severe Transmitral flow velocity

Mitral annulus velocity

E/e’ ratio

Increasing E/e’ ratio
E/e’ > 15 is consistent with elevated LV filling pressure

Natriuretic peptides
Normal values virtually excludes heart failure
Elevated in most patients with diastolic heart failure, but not sufficient stand-alone evidence

Cardiac structural changes
Enlarged left atrium and LV hypertrophy supports the diagnosis diastolic heart failure

Modified from Textbook: Diastolic Heart Failure, eds OA Smiseth and M Tendera, Springer, 2008
Why evaluate diastolic function in heart failure patients with *preserved systolic function*:

- To obtain objective evidence for diastolic dysfunction.
- To estimate LV filling pressure.
- To obtain prognostic information.

Why evaluate diastolic function in heart failure patients with *reduced systolic function*:

- To estimate of LV filling pressure.
- To obtain prognostic information.