Echocardiographic assessment of left ventricular diastolic function

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Conflicts of interest

• None
1. HFpEF accounts for about 50% of all cases of congestive heart failure

2. Prognosis of HFpEF appears to be almost as severe as for systolic heart failure.
Etiology of diastolic (HFpEF) vs systolic HF (HFrEF)

1. Patients with HFpEF have typically concentric LVH, with stiff arteries as stimulus to remodelling.

2. Patients with HFrEF typically eccentric LVH and is more often due to previous myocardial infarction.

3. Patients with HFpEF often have reduced long-axis shortening, indicating some reduction of systolic function.
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 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
Hallmarks of LV diastolic dysfunction

1. Slowing of *relaxation*

2. Weakening of *restoring forces*

3. Increased diastolic *stiffness*

- Increased LV diastolic pressure
Why are vigorous restoring forces and rapid relaxation important?

Cause negative early-diastolic LV pressures

Diastolic suction
Exercise in heart failure

Loss of diastolic suction results in elevated left atrial pressure

LV filling by suction

LV filling by "pushing"

Normal heart

Heart failure

Rest
Exercise

Rest
Exercise

Modif. From Little et al. In Smiseth, European Cardiology 2012
Echo-Doppler Modalities for Assessing Diastolic Function

- Mitral velocities
- TR jet
- LVH?
- Atrial volume

OA Smiseth, 2013.
Tissue Doppler

LV lengthening velocity (e’)

OA Smiseth, 2011
LV early-diastolic lengthening velocity (e')
Pulsed Doppler (peak velocities)

Myocardial velocities (cm/s)

ECG
e’ by TDI color Mode (mean velocities)
Mechanism of velocity spikes during the isovolumic phases

Early systolic shortening closes mitral valve

LV volume increases as aortic valve closes

Early systolic shortening interrupted by MVC

Late systolic lengthening interrupted by AVC

LV dimension

Myocardial velocity

ECG

What determines e’?
Is it only relaxation?

Myocardial velocities

ECG

OA Smiseth, 2011.
**Relationship between \( e' \) and \( \tau \)**

- **Experimental study**
  \[ Y = 10 - 0.07x \]
  \[ R = -0.83 \]
  \[ P < 0.001 \]

- **Clinical studies**
  \[ y = 14.70 - 0.15x \]
  \[ r = -0.56 \]

  Sohn et al. JACC 30: 474-80, 1997

- **Atrial fibrillation**
  \[ y = -0.0014x + 0.1556 \]
  \[ r = -0.509, p = 0.007 \]


Nagueh et al., JACC 37: 278-85, 2001
Determinants of $e'$

**LV relaxation**

**Restoring forces**

**LV lengthening load**

**Decay in active fibre force:** Reduced actin-myosin interaction as cytosolic calcium is taken up by the sarcoplasmic reticulum.

**Passive recoil:** Restoring forces are generated during systole, and the myocardium recoils passively in diastole, similar to a compressed spring.

**Left atrial pressure at onset filling:** Represents a force which pushes blood into the ventricle, thereby causing LV lengthening.

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)

Y = 1.55 + 1.47X
R = 0.86
N = 100
Transmitral filling velocities
ECG

Pressure (mmHg)

Mitral gradient (mmHg)

Mitral velocity (cm/s)

Left ventricle

Left atrium

Mitral gradient

Mitral velocity

OA Smiseth. Can J Cardiol 17: 1167-76, 2001
Restrictive filling

- Increased E-velocity due to elevated filling pressures
- Because of stiff ventricle mitral flow decelerates rapidly.
- Increased E/A ratio.

Sign of advanced heart disease and poor prognosis.

From Little et al., Circ., 1995

\[ K_{LV} = \text{LV chamber stiffness} \]
Restrictive filling
Deceleration time
Impaired Relaxation
Mitral velocities
Pseudonormalization
Progressive diastolic dysfunction
Or is it completely normal?

Pulmonary venous velocities
Pulmonary vein flow and pressures – intraoperative study

LV pressure (mmHg)

Left atrial pressure (mmHg)

Pulmonary vein flow (L/min)

ECG
A duration 125 ms

PVa duration 120 ms

Appleton et al., JACC 1993

A duration 125 ms

PVa duration 165 ms
- A 2 to 3 mm sample volume is placed >0.5 cm into the pulmonary vein.
- The major technical problem is LA wall motion artifacts, caused by atrial contraction.
Estimation of pulmonary artery systolic pressure

Pressure gradient from TR jet + estimate of right atrial pressure
Calculation of PA systolic pressure using the TR jet.
Intraventricular filling
Intraventricular flow
Propagation velocity (Vp)


Flow Propagation Velocity: \( V_p \)
LV twist
LV twist (torsion)
LV twist (torsion)
Apical rotation

Remme et al. 2006
Speckle Tracking Echocardiography vs MRI-tagging

Apical rotation

Basal rotation

Rotation (°)

Rotation by MRI
Rotation by echocardiography

Determinants of LV untwisting rate

A Opdahl ... OA Smiseth. Circulation 2012;126:1441-1451
Recommendations for the Evaluation of Left Ventricular Diastolic Function by Echocardiography
Nagueh SF, Appleton CP, Gillebert TC, Marino PN, Oh JK, Smiseth OA, Waggoner AD, Flachskampf FA, Pellikka PA, Evangelisa A.

In pts with reduced EF:

- E/A < 1 and E ≤ 50 cm/s
  - Normal LAP

- E/A ≥ 1 - < 2, or E/A < 1 and E > 50 cm/s
  - Normal LAP
  - E/e’ (average e’) < 8
    - PAS < 35 mmHg
    - Ar – A < 0 ms
    - S/D > 1
    - E/Vp < 1.4
    - Two of these below limit
  - Elevated LAP

- E/A ≥ 2, DT < 150 ms
  - Elevated LAP
  - E/e’ (average e’) > 15
    - PAS > 35 mmHg
    - Ar – A ≥ 30 ms
    - S/D < 1
    - E/Vp ≥ 2.5
    - Two of these above limit
Estimation of LV filling pressures
When normal EF

- Elevated LAP suggested by
  - PA systolic pressure $> 35$ mmHg
  - $E/e'$ (average) $> 15$
  - $Ar - A \geq 30$ ms
  - Enlarged left atrium
Estimation of LV filling pressures

• When moderate/severe mitral insufficiency:
  Elevated LAP suggested by
  - PA systolic pressure > 35 mmHg
  - Ar – A ≥ 30 ms elevated LAP

• When atrial fibrillation:
  Elevated LAP suggested by
  - PA systolic pressure > 35 mmHg
  - E decelleration time < 150 ms
  - E/e’ > 15
Transmitral flow velocity

Mitral annulus velocity

E/e’ ratio

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

Tricuspid regurgitation velocity

Pulmonary venous flow velocity

Natriuretic peptides

Cardiac structural changes

Normal values virtually excludes heart failure

Elevated in most patients with diastolic heart failure, but not sufficient stand alone evidence

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

Smiseth et al., European Cardiology 2012
What to report?

- May report grade: Difficult if the referring physician is not familiar with the grading and therefore does not know what to do for the patient.

- Indicate in the report whether indices indicate elevated or normal filling pressure

- In patients with unexplained heart failure symptoms, indicate in the report if symptoms may be due to diastolic dysfunction
Take home messages 1

✓ Diastolic function should be evaluated in heart failure patients with *preserved systolic function*:
  - To obtain objective evidence for diastolic dysfunction.
  - To estimate LV filling pressure.

✓ Diastolic function should be evaluated in heart failure patients with *reduced systolic function*:
  - To estimate of LV filling pressure.

✓ The report to the referring physician should be simple and practical
Take home messages 2

- Do not trust single indices

- Look for consistency between several echocardiographic measures

- In some cases the examination in non-conclusive with regard to filling pressure