Echocardiography
Looking at Left Ventricular Ejection Fraction and Beyond

George Le-Bert, DO, FACC
Baptist Heart Specialists
Case

68y man with DM, HTN, obesity, and paroxysmal atrial fibrillation presents with class 2 dyspnea on exertion for months.

Intermittent LE edema

+ PND, orthopnea

ECG: NSR 84, LVH, LAD, LAA

Regadenoson MPI with EF > 70%, no ischemia
Echo

- Normal LV size and systolic function, EF 65%
- Concentric LVH (Moderate LVH with Grade 2 or Pseudonormal diastolic dysfunction)
- Normal RV size and systolic function
- Mild RA/Moderate LA enlargement
- Mild MR/TR
- Mild pulmonary hypertension, PASP = 40mmHg
CLINICAL EXAM UNRELIABLE IN DIFFERENTIATING SYSTOLIC VS DIASTOLIC DYSFUNCTION
## Prevalence of Specific Symptoms and Signs in Systolic vs. Diastolic Heart Failure

<table>
<thead>
<tr>
<th></th>
<th>Diastolic Heart Failure (EF &gt; 50%)</th>
<th>Systolic Heart Failure (EF &lt; 50%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symptoms</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyspnea on exertion</td>
<td>85</td>
<td>96</td>
</tr>
<tr>
<td>Paroxysmal nocturnal dyspnea</td>
<td>55</td>
<td>50</td>
</tr>
<tr>
<td>Orthopnea</td>
<td>60</td>
<td>73</td>
</tr>
<tr>
<td><strong>Physical examination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jugular venous distension</td>
<td>35</td>
<td>46</td>
</tr>
<tr>
<td>Rales</td>
<td>72</td>
<td>70</td>
</tr>
<tr>
<td>Displaced apical impulse</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>$S_3$</td>
<td>45</td>
<td>65</td>
</tr>
<tr>
<td>$S_4$</td>
<td>45</td>
<td>66</td>
</tr>
<tr>
<td>Hepatomegaly</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Edema</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td><strong>Chest Radiograph</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiomegaly</td>
<td>90</td>
<td>96</td>
</tr>
<tr>
<td>Pulmonary venous hypertension</td>
<td>75</td>
<td>80</td>
</tr>
</tbody>
</table>

Zile and Brutsaert Circulation 2002;105:1387-93
Determinants of Myocardial Performance

**Filling**
- ED volume

**Emptying**
- EF<sub>effective</sub>

\[ \text{Stroke volume} = \text{EF}_{\text{effective}} \times \text{EF} \]

**Diastolic function**
- LV distensibility
- Relaxation

**Systolic function**
- Contractility
- Afterload
- Preload

**Cardiac output**
- Heart rate

The heart failure spectrum

Heart failure trigger

NYHA

eccentric

concentric

ventricular remodeling

Heart failure Phenotype

Architectural & functional LV adaptation

Interplay of complex signaling processes

Relative prevalence of "disease modifiers" (= patients' biological traits & co-morbidities)

biomarker

immune responses

ischemia

glucose insulin

leptin

strain

estrogen

infection (%)
coronary failure (%)
type I diabetes (%)
type II diabetes (%)
obesity (%)
hypertension (%)
female gender (%)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVPWs</td>
<td>1.5 cm</td>
</tr>
<tr>
<td>LVIDs</td>
<td>2.8 cm</td>
</tr>
<tr>
<td>IVS</td>
<td>1.5 cm</td>
</tr>
<tr>
<td>LVPWd</td>
<td>1.1 cm</td>
</tr>
<tr>
<td>LVIDd</td>
<td>5.1 cm</td>
</tr>
<tr>
<td>IVSd</td>
<td>1.1 cm</td>
</tr>
<tr>
<td>EDV (MM-Teich)</td>
<td>124 ml</td>
</tr>
<tr>
<td>IVS/LVPW (MM)</td>
<td>1.0</td>
</tr>
<tr>
<td>IVS % (MM)</td>
<td>36 %</td>
</tr>
<tr>
<td>FS (MM-Teich)</td>
<td>45 %</td>
</tr>
<tr>
<td>ESV (MM-Teich)</td>
<td>30 ml</td>
</tr>
<tr>
<td>EF (MM-Teich)</td>
<td>76 %</td>
</tr>
<tr>
<td>LVPW % (MM)</td>
<td>36 %</td>
</tr>
</tbody>
</table>
Left Ventricular Wall Thickness

Potential Pitfalls

- Oblique images
- Non-perpendicular measurement
- Aberrant muscle bundles/chordae
- Excessive trabeculations
- Asymmetric RWMA and thinning
- Arrhythmia
- Use subcostal window if parasternal inadequate
LV Mass

- LV Mass Formulas
- LV Mass / BSA = LV Mass Index
- Linear Method for LV Mass:

\[ 0.8 \times \left( 1.04 \left[ (IVSd + LVIDd + PWTd)^3 - (LVID)^3 \right] \right) + 0.6g \]

Devereux RB, et al.
Am J Cardiol 57: 450, 1986
# Left Ventricular Mass and Geometry

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th></th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference range</td>
<td>Mildly abnormal</td>
<td>Moderately abnormal</td>
</tr>
<tr>
<td><strong>LV dimension</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV diastolic diameter</td>
<td>3.9–5.3</td>
<td>5.4–5.7</td>
<td>5.8–6.1</td>
</tr>
<tr>
<td>LV diastolic diameter/BSA, cm/m²</td>
<td>2.4–3.2</td>
<td>3.3–3.4</td>
<td>3.5–3.7</td>
</tr>
<tr>
<td>LV diastolic diameter/height, cm/m</td>
<td>2.5–3.2</td>
<td>3.3–3.4</td>
<td>3.5–3.6</td>
</tr>
<tr>
<td><strong>LV volume</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV diastolic volume/BSA, mL/m²</td>
<td>35–75</td>
<td>76–86</td>
<td>87–96</td>
</tr>
<tr>
<td>LV systolic volume, mL</td>
<td>19–49</td>
<td>50–59</td>
<td>60–69</td>
</tr>
<tr>
<td>LV systolic volume/BSA, mL/m²</td>
<td>12–30</td>
<td>31–36</td>
<td>37–42</td>
</tr>
</tbody>
</table>
## Left Ventricular Mass and Geometry

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th></th>
<th></th>
<th></th>
<th>Men</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Linear Method</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV mass/BSA, g/m²</td>
<td>43–95</td>
<td>96–108</td>
<td>109–121</td>
<td>≥122</td>
<td>49–115</td>
<td>116–131</td>
<td>132–148</td>
<td>≥149</td>
</tr>
<tr>
<td>LV mass/height, g/m</td>
<td>41–99</td>
<td>100–115</td>
<td>116–128</td>
<td>≥129</td>
<td>52–126</td>
<td>127–144</td>
<td>145–162</td>
<td>≥163</td>
</tr>
<tr>
<td>LV mass/height³/², g/m²</td>
<td>18–44</td>
<td>45–51</td>
<td>52–58</td>
<td>≥59</td>
<td>20–48</td>
<td>49–55</td>
<td>56–63</td>
<td>≥64</td>
</tr>
<tr>
<td>Relative wall thickness, cm</td>
<td>0.22–0.42</td>
<td>0.43–0.47</td>
<td>0.48–0.52</td>
<td>≥0.53</td>
<td>0.24–0.42</td>
<td>0.43–0.46</td>
<td>0.47–0.51</td>
<td>≥0.52</td>
</tr>
<tr>
<td>Septal thickness, cm</td>
<td>0.6–0.9</td>
<td>1.0–1.2</td>
<td>1.3–1.5</td>
<td>≥1.6</td>
<td>0.6–1.0</td>
<td>1.1–1.3</td>
<td>1.4–1.6</td>
<td>≥1.7</td>
</tr>
<tr>
<td>Posterior wall thickness, cm</td>
<td>0.6–0.9</td>
<td>1.0–1.2</td>
<td>1.3–1.5</td>
<td>≥1.6</td>
<td>0.6–1.0</td>
<td>1.1–1.3</td>
<td>1.4–1.6</td>
<td>≥1.7</td>
</tr>
<tr>
<td><strong>2D Method</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV mass/BSA, g/m²</td>
<td>44–88</td>
<td>89–100</td>
<td>101–112</td>
<td>≥113</td>
<td>50–102</td>
<td>103–116</td>
<td>117–130</td>
<td>≥131</td>
</tr>
</tbody>
</table>

BSA, Body surface area; LV, left ventricular; 2D, 2-dimensional.
Bold italic values: Recommended and best validated.
“... the use of use of linear measurements to calculate LV EF is not recommended for clinical practice.”

Chamber Quantification Writing Group. J Am Soc Echocardiogr 18: 1440, 2005
Visual Echo EF = 0.847 * RVG-EF + 1.87
r = 0.896
SEE = 8.69%
Echo EF calculation

Cardiovascular Ultrasound

Visually estimated ejection fraction by two dimensional and triplane echocardiography is closely correlated with quantitative ejection fraction by real-time three dimensional echocardiography.

Conclusion: Visual estimation of LVEF both using 2D and TP by an experienced reader correlates well with quantitative EF determined by RT3DE. There is an apparent trend towards a smaller variability using TP in comparison to 2D, this was however not statistically significant.
Left Ventricular Volume by 2-D Echo
Myocardial Border Detection vs Angiography

Angio outline

Echo outline

Columnae carnae bases enclosed by angiographic dye vs apices imaged by ultrasound
Diastolic HF

How to diagnose HFNEF

ESC recommendations 2007

 Symptoms or signs of heart failure

 Normal or mildly reduced left ventricular systolic function
  LVEF > 50%
  and
  LVEDVI < 97 mL/m²

 Evidence of abnormal LV relaxation, filling, diastolic distensibility, and diastolic stiffness

 Invasive Haemodynamic measurements
  mPCW > 12 mmHg
  or
  LVEDP > 16 mmHg
  or
  τ > 48 ms
  or
  b > 0.27

 Biomarkers
  NT-proBNP > 220 pg/mL
  or
  BNP > 200 pg/mL

 Biomarkers
  NT-proBNP > 220 pg/mL
  or
  BNP > 200 pg/mL

 Echo – bloodflow Doppler
  E/A<sub>50 yr</sub> < 0.5 and DT<sub>50 yr</sub> > 280 ms
  or
  Ard–Ad > 30 ms
  or
  LAVI > 40 mL/m²
  or
  LVMI > 122 g/m² (♀); > 149 g/m² (♂)
  or
  Atrial fibrillation

 TD

 E/E' > 15
  or
  15 > E/E' > 8

 TD

 E/E' > 8
Patterns of Diastolic Function

Mitral inflow
PV flow
TDE
CMM - Vp

NL (Young)  NL (Adult)  Delayed Relaxation  Pseudo normal  Restrictive
Estimation of Filling Pressures in Patients with 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/TE-e' >2
Normal LAP

LA volume ≥ 34 ml/m2
Ar – A ≥ 30 ms
Valsalva Δ E/A > 0.5
PAS >35 mmHg
IVRT/TE-e' <2
↑ LAP

Sep. E/e' > 15
or
Lat. E/e' > 12
or
Av. E/e' > 13
↑ LAP

Nageuh et al JASE 2009
Evaluation of LA Pressure from transmitral and PV flow

A. Normal: 6 - 12 mm Hg
B. Decr. Relax.: 8 - 14
C. Pseudo - nl 15 - 22
D. Restrictive > 22
LAP = 1.24[(E/e′) + 1.9]

Naguch 1999

LAP = E/e′ + 4
As LV filling pressure ↑

Mitral E ↑

Annulus E' ↓

E/E' ↑

PCWP (mm Hg)

\[ y = 1.9 + 1.24x \]

\[ r = 0.87 \]

\[ n = 60 \]

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

Survival

Year

P=0.03

No. at Risk

Reduced ejection fraction

Preserved ejection fraction

2424

1637

1350

1049

813

604

2166

1539

1270

1001

758

574

Prognosis of Diastolic Dysfunction by Doppler

Mortality, %

Diastolic Function
- Yellow: Moderate or Severe Dysfunction
- Blue: Mild Dysfunction
- Orange: Normal

Log rank P<0.001

No at Risk
- Normal: 1277
- Mild: 371
- Mod or Severe: 131

Year
0 1 2 3 4 5

Redfield et al., JAMA 289:194202, 2003
Trends in Diastolic Heart Failure

Patients with Preserved Ejection Fraction (%)

- Preserved ejection fraction: $r=0.81$, $P<0.001$
- Reduced ejection fraction: $r=0.33$, $P=0.23$

No. of Admissions

Owan et al., NEJM 2006;355:251-9.
Pulmonary Hypertension in Heart Failure With Preserved Ejection Fraction

A Community-Based Study

Carolyn S. P. Lam, MBBS,*† Véronique L. Roger, MD, MPH,* Richard J. Rodeheffer, MD,* Barry A. Borlaug, MD,* Felicity T. Enders, PhD,‡ Margaret M. Redfield, MD*

Rochester, Minnesota; and Singapore, Singapore

Objectives This study sought to define the prevalence, severity, and significance of pulmonary hypertension (PH) in heart failure with preserved ejection fraction (HFrEF) in the general community.

Background Although HFrEF is known to cause PH, its development is highly variable. Community-based data are lacking, and the relative contribution of pulmonary venous versus pulmonary arterial hypertension (HTN) to PH in HFrEF is unknown. We hypothesized that PH would be a marker of symptomatic pulmonary congestion, distinguishing HFrEF from pre-clinical hypertensive heart disease.

Methods This community-based study of 244 HFrEF patients (age 76 ± 13 years; 45% male) was followed up using Doppler echocardiography over 3 years. Control subjects were 719 adults with HTN without HF (age 66 ± 10 years; 44% male). Pulmonary artery systolic pressure (PASP) was derived from the tricuspid regurgitation velocity and PH defined as PASP > 35 mm Hg. Pulmonary capillary wedge pressure (PCWP) was estimated from the ratio of early transmirtal flow velocity to early mitral annular diastolic velocity.

Results In HFrEF, PH was present in 83% and the median (25th, 75th percentile) PASP was 48 (37, 56) mm Hg. PASP increased with PCWP (r = 0.21; p < 0.007). Adjusting for PCWP, PASP was higher in HFrEF than HTN (p < 0.001). The PASP distinguished HFrEF from HTN with an area under the receiver-operating characteristic curve of 0.91 (p < 0.001) and strongly predicted mortality in HFrEF (hazard ratio: 1.3 per 10 mm Hg; p < 0.001).

Conclusions PH is highly prevalent and often severe in HFrEF. Although pulmonary venous HTN contributes to PH, it does not fully account for the severity of PH in HFrEF, suggesting that a component of pulmonary arterial HTN also contributes. The potent effect of PASP on mortality lends support for therapies aimed at pulmonary arterial HTN in HFrEF. (J Am Coll Cardiol 2009;53:1119–26) © 2009 by the American College of Cardiology Foundation.
$P_{RV} = P_{RV-RA} + P_{RA}$

$P_{RV-RA}$ estimated by tricuspid regurgitation:

Velocity regurgitant jet $\rightarrow$ gradient of pressure RV - RA
(Bernoulli law: $P = 4V^2$)

- Max $V = 228$ cm/s
- Max $G = 21$ mmHg

$P_{RA}$
- Central venous pressure if available
- Estimation with IVC:

<table>
<thead>
<tr>
<th>IVC size</th>
<th>Collapsibility index</th>
<th>RA pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;17</td>
<td>50%</td>
<td>5</td>
</tr>
<tr>
<td>&gt;17</td>
<td>&gt;50%</td>
<td>10</td>
</tr>
<tr>
<td>&lt;50%</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>No collapse</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>
### Table 5: Classification of right atrial pressure

<table>
<thead>
<tr>
<th>Collapsibility</th>
<th>High</th>
<th>High</th>
<th>High</th>
<th>NL</th>
<th>NL</th>
<th>Low</th>
<th>Low</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size, cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of patients</td>
<td>25</td>
<td>12</td>
<td>2</td>
<td>3</td>
<td>17</td>
<td>4</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Mean RAP, mm Hg</td>
<td>3.4</td>
<td>3.3</td>
<td>4.5</td>
<td>4.3</td>
<td>6.1</td>
<td>12</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>0-5 mm Hg, %</td>
<td>84</td>
<td>100</td>
<td>50</td>
<td>67</td>
<td>47</td>
<td>0</td>
<td>29</td>
<td>33</td>
</tr>
<tr>
<td>5-10 mm Hg, %</td>
<td>12</td>
<td>0</td>
<td>50</td>
<td>33</td>
<td>35</td>
<td>0</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>10-15 mm Hg, %</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>75</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>&gt;15 mm Hg, %</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>43</td>
<td>33</td>
<td>30</td>
</tr>
<tr>
<td>Traditional RAP classification, mm Hg</td>
<td>0-5</td>
<td>5-10</td>
<td>-</td>
<td>0-5</td>
<td>5-10</td>
<td>-</td>
<td>10-15</td>
<td>15-20</td>
</tr>
<tr>
<td>Suggested RAP classification, mm Hg</td>
<td>0-5</td>
<td>0-5</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
<td>10-15</td>
<td>I</td>
<td>I</td>
</tr>
</tbody>
</table>

*Indeterminate; mean RAP, mean right atrial pressure (RAP) of patients in each subgroup; suggested RAP, recommendation for RAP range that patients within each subgroup would best be classified to have maximal accuracy; traditional RAP, RAP range patient with specific subgroup's inferior vena caval collapsibility and size would be assigned according to current guidelines.*

All patients were segregated into 1 of 9 subgroups depending on whether their collapsibility was high (>55%), low (<35%), or normal (35%-50%) and their inferior vena cava, small (<1.7 cm), normal (1.7-2.1 cm), or large (>2.1 cm).

**Optimal cutoffs to predict RAP >10 mm Hg**

*IVCDmax ≥20 mm, Collapsibility <40%*

# Table 3: Estimation of RA pressure on the basis of IVC diameter and collapse

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal (0-5 [3] mm Hg)</th>
<th>Intermediate (5-10 [8] mm Hg)</th>
<th>High (15 mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVC diameter</td>
<td>≤2.1 cm</td>
<td>≤2.1 cm</td>
<td>&gt;2.1 cm</td>
</tr>
<tr>
<td>Collapse with sniff</td>
<td>&gt;50%</td>
<td>&lt;50%</td>
<td>&lt;50%</td>
</tr>
<tr>
<td>Secondary indices of elevated RA pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Restrictive filling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Tricuspid E/E' &gt; 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Diastolic flow predominance in hepatic veins (systolic filling fraction &lt; 55%)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pulmonary Vascular Resistance

PVR = (mean PAP - mean PCWP)/C.O.

Another method

PVR = 10 (Peak TR Velocity/RVOT VTI + 0.16)

PVR = Wood’s units
TR Velocity = m/sec
Normal LA volume = Normal LA pressure
HbA1c of the atria
LA volume

Biplane Area-Length Method

- A1 = LA area, 4-chamber view
- A2 = LA area, 2-chamber view
- L1 and L2: length from mid plane of mitral annulus to superior LA
- L = LA length, L1 or L2 shorter

LA volume = \frac{(0.85 \times A1 \times A2)}{L}
<table>
<thead>
<tr>
<th>Normal</th>
<th>Mild</th>
<th>Mod</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>22±6</td>
<td>29-33</td>
<td>34-39</td>
<td>≥ 40</td>
</tr>
</tbody>
</table>

Indexed LA Volume vs Diastolic Function Grade

Indexed LA volume (mL/m²)

- Normal: n=44
- Abnormal Relaxation: n=28
- Pseudonormal: n=61
- Restrictive: n=7
