Systolic ventricular function – how to assess the left ventricle

Mark K. Friedberg, MD
Hospital for Sick Children, Toronto
Outline

• What is function
• Methods to assess LV function
  – Global function
  – Hemodynamics
  – Regional function

• Strain/strain rate and dyssynchrony will be covered in other lectures
Defining cardiac function?

• “ability of the heart to fill at a low enough pressure not to cause pulmonary congestion, then deliver a sufficient quantity of blood to the vasculature at a high enough pressure to perfuse the tissue, and to augment this performance during exercise.”

*Thomas, JACC 2006;48;2012-2025*
Quantifying function

One of the biggest challenges is deciding how best to quantify cardiac function!

- No measurable quantity corresponds to integrated functional assessment
- Surrogates approximate individual aspects of cardiac function.
- It depends on what question you ask.
A routine echo report (partial list)....

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVH (cm)</td>
<td>8.8 cm</td>
</tr>
<tr>
<td>LV EDV (ml)</td>
<td>127 ml</td>
</tr>
<tr>
<td>LV ES (cm)</td>
<td>3.0 cm</td>
</tr>
<tr>
<td>MVE Vel</td>
<td>0.51 ms</td>
</tr>
<tr>
<td>MV DecT</td>
<td>82 ms</td>
</tr>
<tr>
<td>LV Dec Slope</td>
<td>7.4 ms²</td>
</tr>
<tr>
<td>MV A Vel</td>
<td>0.53 ms</td>
</tr>
<tr>
<td>MV A/ V</td>
<td>1.15</td>
</tr>
<tr>
<td>MV ADur</td>
<td>1.70 ms</td>
</tr>
<tr>
<td>P Vel E</td>
<td>0.40 ms</td>
</tr>
<tr>
<td>P Vel D</td>
<td>0.54 ms</td>
</tr>
<tr>
<td>LVESVM (g)</td>
<td>231.80 g</td>
</tr>
<tr>
<td>LV Mass (g)</td>
<td>158.13 g</td>
</tr>
<tr>
<td>LV ET</td>
<td>218 ms</td>
</tr>
<tr>
<td>Vof mean</td>
<td>0.45</td>
</tr>
<tr>
<td>Vof mean (cont)</td>
<td>0.37</td>
</tr>
<tr>
<td>Vof mean corr</td>
<td>0.000</td>
</tr>
<tr>
<td>Time</td>
<td>0.77 s</td>
</tr>
<tr>
<td>HR</td>
<td>68 BPM</td>
</tr>
<tr>
<td>LAT</td>
<td>12.0 s</td>
</tr>
<tr>
<td>EF (Biol)</td>
<td>5%</td>
</tr>
<tr>
<td>EF (Iso)</td>
<td>5%</td>
</tr>
<tr>
<td>LVESVM OP (g)</td>
<td>167.90 g</td>
</tr>
<tr>
<td>LV Mass (g)</td>
<td>158.13 g</td>
</tr>
<tr>
<td>LV ET</td>
<td>218 ms</td>
</tr>
<tr>
<td>Vof mean</td>
<td>0.45</td>
</tr>
<tr>
<td>Vof mean (cont)</td>
<td>0.37</td>
</tr>
<tr>
<td>Vof mean corr</td>
<td>0.000</td>
</tr>
<tr>
<td>Time</td>
<td>0.77 s</td>
</tr>
<tr>
<td>HR</td>
<td>68 BPM</td>
</tr>
<tr>
<td>LAT</td>
<td>12.0 s</td>
</tr>
</tbody>
</table>

The images show various echocardiogram details and measurements, including ventricular dimensions, systolic and diastolic function parameters, and imaging modalities like M-mode, 2D and Doppler echocardiography.
It's like asking: what is the state of the global economy?
Assessment of global LV function

- Chamber function
- Hemodynamics
- Myocardial function
- Interactions (ventricular-vascular; ventricular-ventricular)
Function and Performance

AFTERLOAD

PRELOAD

CONTRACTILITY
Also need to consider...

- Acute versus chronic changes
- Adaptation (hypertrophy)
- Heart rate
‘Eyeball’ assessment still a prevalent method

Experienced operator
Quick and easy
Subjective
Subtle findings overlooked
Sometimes we can see the abnormality
Ejection phase indices

• Most common functional surrogate is the chamber volume ejected in systole:
  – ejection fraction % = EDV - ESV / EDV x 100

• M-mode
• 2-D
• 3-D
LV volumes themselves are important!

- End systolic volume
- End diastolic volume
- End systolic dimension
- End diastolic dimension

M-mode E point separation
Cardiomegaly

McMahon, Heart 2004;90:908
The shape of the ventricle is important!
Influence of geometry on function

- Ellipsoid is more efficient for ejecting blood compared to sphere
- Remodelling into spherical configuration is mechanically unfavourable

Normal LV
- Low stress at apex
- Thin apical wall
- Long axis shortening ++

Remodeled LV (increased pressure)
- High stress at apex
- Thick apical wall
- Long axis shortening -

Slide courtesy of Luc Mertens, MD
Geometrical assumptions

NORMAL LEFT VENTRICLE

WORST CASE VENTRICLE

SIMPSON'S RULE

LENGTH-DIAMETER

CYLINDER HEMI ELLIPSE

AREA-LENGTH

CYLINDER TRUNCATED CONE-CONE

2/3 AREA × LENGTH

CYLINDER-CONE

Picard, JASE, 2008
EF by Simpson's method and area length - method

\[ V = \pi 4 \times \sum_{i=1}^{N} a_i \times b_i \times L/N \]

A

\[ V = \frac{5}{6} \times \text{CSA} \times \text{Length} \]

Lopez, JASE 2010;23:465
Volumes and EF by biplane Simpson’s
Ejection fraction by 3-D

Volume(s)
EDV = 53.8 ml
 ESV = 18.7 ml

Calculation(s)
EF = 68.7 %
SV = 41.1 ml

Regional
Tmesv Sel-SD =
Tmesv Sel-D01 =
Tmesv Sel-SD =

Volume (ml)
0.1
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Time (sec)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
3D volume measurements are comparable to MRI

Sugeng, Circ. 2006;114:654
# M-mode/ 2D/ 3D vs MRI in children

## Table II. Correlation between MM, 2DE, 3DE, and CMR for measurements of LV indices

<table>
<thead>
<tr>
<th></th>
<th>LVEDV</th>
<th>LVESV</th>
<th>LVEF</th>
<th>LV mass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( r )</td>
<td>SEE</td>
<td>( P )</td>
<td>( r )</td>
</tr>
<tr>
<td>MM</td>
<td>0.87</td>
<td>15.28</td>
<td>&lt;.001</td>
<td>0.90</td>
</tr>
<tr>
<td>2D biplane</td>
<td>0.89</td>
<td>12.11</td>
<td>&lt;.001</td>
<td>0.90</td>
</tr>
<tr>
<td>3D (4-plane)</td>
<td>0.96</td>
<td>10.30</td>
<td>&lt;.001</td>
<td>0.95</td>
</tr>
<tr>
<td>3D (8-plane)</td>
<td>0.97</td>
<td>9.36</td>
<td>&lt;.001</td>
<td>0.97</td>
</tr>
<tr>
<td>3D (auto)</td>
<td>0.96</td>
<td>9.25</td>
<td>&lt;.001</td>
<td>0.93</td>
</tr>
</tbody>
</table>

SEE, Standard estimation error.

## Table III. Agreement between MM, 2DE, 3DE, and CMR for measurements of LV indices

<table>
<thead>
<tr>
<th></th>
<th>LVEDV</th>
<th>LVESV</th>
<th>LVEF</th>
<th>LV mass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MD</td>
<td>( P )</td>
<td>MD</td>
<td>( P )</td>
</tr>
<tr>
<td>MM</td>
<td>4.78 ± 14.14</td>
<td>( P = .07 )</td>
<td>2.4 ± 6.5</td>
<td>( P = .13 )</td>
</tr>
<tr>
<td>2D biplane</td>
<td>-7.87 ± 12.11</td>
<td>( P &lt; .05 )</td>
<td>-2.2 ± 4.8</td>
<td>( P = .15 )</td>
</tr>
<tr>
<td>3D (4-plane)</td>
<td>-6.88 ± 10.01</td>
<td>( P &lt; .05 )</td>
<td>-2.4 ± 3.45</td>
<td>( P = .13 )</td>
</tr>
<tr>
<td>3D (8-plane)</td>
<td>-6.83 ± 9.66</td>
<td>( P &lt; .05 )</td>
<td>-1.84 ± 3.29</td>
<td>( P = .17 )</td>
</tr>
<tr>
<td>3D (auto)</td>
<td>-6.93 ± 9.71</td>
<td>( P &lt; .05 )</td>
<td>-1.6 ± 3.87</td>
<td>( P = .31 )</td>
</tr>
</tbody>
</table>

\( MD \), Mean difference.
3D summation of discs in small LVs and CHD

Ejection fraction limitations

- **Technique limitations**
  - Visualization of endocardial borders (contrast)
  - LV is 3-dimensional; most models for calculation based on 2 dimensions (3D echo)

- **Physiologic limitations**
  - Preload dependency
  - Afterload dependency
  - Heart rate
Why do we still use EF?
Hemodynamics

• Blood flow is governed by conservation of:
  – Mass
  – Momentum
  – Energy.

• Blood is incompressible:
  – flow into a region = flow out of that region
  – continuity equation for measuring stroke volume & cardiac output.

\[ A_1 v_1 = A_2 v_2 \]
Mitral Valve Function

Functional MR is common and associated with outcome

New interventional devices and CRT to control LV remodeling increase importance of MR assessment.

Evaluate severity and mechanism.

Functional MR severity is difficult to assess (change during systole; variability, complex jet morphology).

Most severe in early systole. Reduced as LV volume decreases and MV leaflets are pushed back to annular plane.

Lang, JACC 2006; 48:2053–69

Volumetric methods may be useful to...
Assessment of myocardial contractility

- continuous acquisition of ventricular pressure and volume data during sudden preload change.
- end-systolic elastance and preload recruitable stroke work most popular.
Assessment of myocardial ‘global’ contractility

- Many studies have investigated non-invasive estimates of contractility without need for preload intervention.
- end-systolic elastance (from single beat)- complex combination of non-invasive BP, diastolic and systolic LV volumes, pre-ejection and ejection times, and EF.
- LV power (peak systolic flow x pressure/(EDV)²)
  - later work suggested that this type of correction is inadequate.

Myocardial contractility from M-mode?

EDV = EDVd³;

ESV = LVIDs³;

EF = (EDV−ESV)/EDV × 100%;

LV mass (in grams) = 0.8*[1.04{(PWTd + LVIDd + SWTd)³ − LVID³}] + 0.6.

SF = 100\frac{EDD−ESD}{EDD}

Myocardial contractility from M-mode?

- Corrected Velocity Circumferential Fiber Shortening (VCFc) = shortening fraction / heart rate-adjusted ejection time

$$E_{TC} = \frac{\text{ejection time}}{\sqrt{\text{ECG R-R interval}}}$$

- VCFc is evaluated in relation to afterload (end-systolic wall stress):

$$\text{ESWS} = \frac{1.35D_{ES} P_{ES}}{4h \left[ 1 + \frac{h}{D_{ES}} \right]}$$
VCFc-wall stress relation

Lopez, JASE 2010, adapted from Colan
Echo Doppler measures that correlate with contractility: $dP/dT$ from mitral regurgitation

- Sensitive to loading conditions
- Measurements of slope are very variable
Doppler measures that correlate with contractility

- systolic velocity acceleration in the LVOT
- early systolic intraventricular pressure drop along LVOT
- Isovolumic acceleration
- systolic strain rate

Isovolumic acceleration
Isovolumic acceleration is relatively load independent

Vogel, Circ 2002;105:1693
Other Doppler Indices

• Systolic time intervals
The myocardial performance index

Tei index
\[ \text{Tei index} = \frac{(a - b)}{b} \]
\[ = \frac{(ICT + IRT)}{ET} \]
MPI as contractility parameter is debatable

![Graph showing MPI changes with different conditions.

Table 1 Absolute and percentage changes in contractile indices compared with baseline values during modulation of inotropy

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Esmolol (1 mg/kg/min)</th>
<th>Dobutamine (10 μg/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPI</td>
<td>0.26 ± 0.13</td>
<td>0.31 ± 0.18</td>
<td>0.22 ± 0.11</td>
</tr>
<tr>
<td>Total isovolumic time (ms)</td>
<td>47 ± 22</td>
<td>54 ± 30</td>
<td>39 ± 20</td>
</tr>
<tr>
<td>Ejection time (ms)</td>
<td>183 ± 15</td>
<td>181 ± 16</td>
<td>175 ± 17*</td>
</tr>
<tr>
<td>dP/dt\text{max} (mm Hg/s)</td>
<td>1001 ± 240</td>
<td>966 ± 205</td>
<td>1569 ± 532***</td>
</tr>
<tr>
<td>Ees (mm Hg/ml)</td>
<td>2.38 ± 1.22</td>
<td>2.11 ± 1.10</td>
<td>3.71 ± 2.24*</td>
</tr>
<tr>
<td>dP/dt\text{min} (mm Hg/s)</td>
<td>−1027 ± 2.81</td>
<td>−988 ± 251</td>
<td>−1397 ± 338***</td>
</tr>
</tbody>
</table>

% change MPI          | 16.6 ± 27.4    | −4.4 ± 49             |
% change dP/dt\text{max} | −3.0 ± 5.8     | 55.6 ± 27***          |
% change Ees           | −14.8 ± 28.0   | 60.7 ± 63.5*          |

*p < 0.05, ***p < 0.001 as compared with baseline value.

Cheung MM, Eur Heart J 2004;25:2238
The systolic to diastolic duration ratio

Friedberg, AJC 2006;97:101
S:D ratio (by TDI) and outcome

Mondal, AHA, 2010
Contractile Reserve

• Systolic dysfunction more likely under stress.
• Regional dysfunction during stress can identify ischemic and nonischemic cardiomyopathy.
• In HF, contractile reserve, (dP/dt, EF%, cardiac output response) is related to outcome.
• Contractile reserve mirrors sympathetic dysfunction, which makes this an inexpensive surrogate for tests of sympathetic status.
Assessment of regional function

- Commonly assessed by LV 17-segment model
- Qualitative grade assigned to each segment (1-5).
- Method changed little from initial descriptions of wall motion abnormalities and is observer-dependent.

Lang JASE 2005;18: 1440
Heger, Circ 1979;60:531
Tissue Doppler Imaging

Normal DTI of lateral mitral annulus

Diastole

Systole

IVC

Peak

Systole

IVR
Why is tissue Doppler useful to study function?

- excellent temporal resolution (4 ms)
- instantaneous velocity of myocardial motion.
- velocity data can be post-processed for displacement, strain rate, and strain.
- interrogates function in 3-dimensions
- relatively load-independent
- information on timing contraction/relaxation.
Limitations of TDI

- only measure component of motion parallel to ultrasound beam
- velocity may reflect translation rather than actual local contraction
- motion due to tethering of adjacent normally contracting segments.
Links between systolic and diastolic function

• Torsion links between systole and diastole.
• Elastic energy stored during systole is released with sudden untwisting during isovolumic relaxation (Titin)
• Intraventricular pressure gradients are generated - filling proceeds at low pressure.
• Important in exercise when diastole shortened

Courtesy Piet Claus
Links between systolic and diastolic function

Controls - blue diamonds
DCM - pink squares
HCM - yellow triangles.

Mohammed, JASE 2009;22:145
LV contraction needs to be synchronous
Assessment of ventricular synchrony

• Separate lecture!
So which indices do we use for LV functional assessment?

- Ventricular volumes
- Ejection fraction
- Mitral regurgitation
- Tissue velocities
- Strain (AFI)
- Formal dyssynchrony assessment in certain patients
- We record VCFc/ wall stress-but don’t routinely use it in clinical decision making.
• The philosopher Arthur Schopenhauer believed that the most common folly of humans was to lose track of their original intent.
• So, as my original intent was to end the talk...!

Thank you