Echo assessment of the failing heart

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Cardiac function - definitions

**Cardiovascular function**: delivery of blood (oxygen) to tissues at a rate commensurate with oxygen consumption.

**Cardiac & ventricular function**: pump activity resulting in adequate amount of cardiac output at low filling pressures.

**Myocardial function**: phasic shortening and force generation followed by lengthening and force decay.
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.
LV contractile function

Active Force Development in the myocytes = *intrinsic contractility*

Cavity pressure development

Aortic Valve Opening

Ejection by wall deformation

- Geometry
- Fibre orientation
- Elasticity
- Afterload

Determinants of Function

AFTERLOAD

PRELOAD

CONTRACTILITY
Also need to consider...

• Acute versus chronic changes

• Adaptation (hypertrophy)

• Heart rate

• Interactions (ventricular-vascular; ventricular-ventricular)
A routine echo report (partial list)....
Is this enough?
‘Eyeball’ assessment still a prevalent method

- Experienced operator
- Quick and easy
- Subjective
- Subtle findings overlooked
‘Eyeball’ assessment: Newborn with cyanosis-this echo diagnosed critical PS (near atresia) intact septum

What is the LV function?
Sometimes the abnormality can be seen
Remodeling: Same SV with less contractility

McMahan, Heart 2004;90:908
Measurement of LV dimensions


Molina, Circ: HF 2013;6:1214

Friedberg, In progress
The shape of the ventricle is important!

Friedberg, In progress
Mitral regurgitation

Fernandes, Am J Cardiol. 2011 15;107(1517-21)
Ejection phase indices

- Fractional shortening
- Ejection fraction % = EDV - ESV/ EDV x 100

- M-mode
- 2-D
- 3-D
Ejection fraction by 3-D

Courtesy Manni Vannan, MD
Three-dimensional Echocardiography in Congenital Heart Disease: An Expert Consensus Document from the European Association of Cardiovascular Imaging and the American Society of Echocardiography

John Simpson, MBChB, MD, FESC, Leo Lopez, MD, FASE, Philippe Acar, MD, PhD, Mark K. Friedberg, MD, FASE, Nee S. Khoo, MBChB, H. Helen Ko, BS, ACS, RDMS, RDMS, RCCS, FASE, Jan Marek, MD, PhD, FESC, Gerald Marx, MD, FASE, Jackie S. McGhie, Folkert Meijboom, MD, David Roberson, MD, FASE, Annemien Van den Bosch, MD, PhD, Owen Miller, BMed, and Girish Shirali, MBBS, FASE, London, United Kingdom; Miami, Florida; Toulouse, France; Toronto, Ontario and Edmonton, Alberta, Canada; New York, New York; Boston, Massachusetts; Rotterdam and Utrecht, The Netherlands; Chicago, Illinois; and Kansas City, Missouri

Table 5 Results of published data comparing 3DE and MRI in patients with CHD and children

<table>
<thead>
<tr>
<th>Echocardiographic method</th>
<th>Population</th>
<th>n</th>
<th>Feasibility (%)</th>
<th>EDV correlation/ agreement with MRI</th>
<th>ESV correlation with MRI</th>
<th>EF correlation with MRI</th>
<th>LV mass</th>
<th>Mean difference EDV</th>
<th>Reproducibility (EDV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disk summation</td>
<td></td>
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</tr>
<tr>
<td>Altman et al.</td>
<td>Children and adults with functional single ventricle</td>
<td>12</td>
<td>$r = 0.98$</td>
<td>$r = 0.98$</td>
<td>Mean diff. 4.4 ± 10%</td>
<td>Mean diff. 5.8 ± 19 g</td>
<td></td>
<td>$-2.9 \pm 8.1$ mL</td>
<td></td>
</tr>
<tr>
<td>Soriano et al.</td>
<td>Children with functional single ventricle</td>
<td>29</td>
<td>$r = 0.96$</td>
<td>$r = 0.94$</td>
<td>$r = 0.84$</td>
<td>$r = 0.84$</td>
<td></td>
<td>$-3.8 \pm 13$ mL</td>
<td>Intra: ICC 0.99, Inter: ICC 0.97</td>
</tr>
<tr>
<td>Friedberg et al.</td>
<td>Children with CHD</td>
<td>35</td>
<td>$r = 0.96$</td>
<td>$r = 0.90$</td>
<td>$r = 0.75$</td>
<td>$r = 0.93$</td>
<td></td>
<td>$-0.49 \pm 2.6$ mL</td>
<td>Intra: ICC 0.98, Inter: ICC 0.97</td>
</tr>
<tr>
<td>Semi-automated border detection</td>
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<td></td>
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</tr>
<tr>
<td>Buet al.</td>
<td>Healthy children</td>
<td>19</td>
<td>$r = 0.97$</td>
<td>$r = 0.97$</td>
<td>$r = 0.97$</td>
<td>$r = 0.97$</td>
<td></td>
<td>$-6.83 \pm 9.66$ mL</td>
<td>Intra: 2.9 ± 3.0%, Inter: 7 ± 5%</td>
</tr>
<tr>
<td>Van den Bosch</td>
<td>Adults with CHD</td>
<td>32, 22</td>
<td>91</td>
<td>$r = 0.95$</td>
<td>$r = 0.97$</td>
<td>$r = 0.98$</td>
<td></td>
<td>$-6.83 \pm 9.66$ mL</td>
<td>Intra: ICC 0.96, Inter: ICC 0.92</td>
</tr>
<tr>
<td>Riehl et al.</td>
<td>Children and young adults with CHD</td>
<td>12</td>
<td>$r = 0.99$</td>
<td>$r = 0.93$</td>
<td>$r = 0.99$</td>
<td>$r = 0.93$</td>
<td></td>
<td>$-4.11 \pm 5.16$ mL</td>
<td>Intra: 0.4 ± 5.3%, Inter: 3.3 ± 4.3%</td>
</tr>
<tr>
<td>Lu et al.</td>
<td>Healthy children</td>
<td>19</td>
<td>$r = 0.96$</td>
<td>$r = 0.93$</td>
<td>$r = 0.98$</td>
<td>$r = 0.98$</td>
<td></td>
<td>$-6.93 \pm 9.71$ mL</td>
<td>Intra: 1.0 ± 5.2%, Inter: 3.2 ± 3.8%</td>
</tr>
<tr>
<td>Laser et al.</td>
<td>Healthy children and children with TOF</td>
<td>49</td>
<td>$r = 0.95$</td>
<td>$r = 0.91$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Intra: ICC 0.99, Inter: ICC 0.98</td>
</tr>
<tr>
<td>Poutanen et al.</td>
<td>Healthy children</td>
<td>30</td>
<td>$r = 0.80$</td>
<td>$r = 0.88$</td>
<td>$r = 0.80$</td>
<td>$r = 0.81$</td>
<td></td>
<td>$-4.0 \pm 19.6$ mL</td>
<td>Intra: ICC 0.92, Bias: -1.0 ± 13.0, Inter: ICC 0.83, Bias: 4.7 ± 17.6</td>
</tr>
<tr>
<td>Yanen et al.</td>
<td>Children with normal cardiac anatomy</td>
<td>71</td>
<td>$r = 0.88$</td>
<td>$r = 0.83$</td>
<td>$r = 0.83$</td>
<td>$r = 0.12$</td>
<td></td>
<td>$-24 \pm 32$ mL</td>
<td>Intra: ICC 0.98, Inter: ICC 0.88</td>
</tr>
</tbody>
</table>

JASE 2016
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?

Any name, any study, any year

Friedberg, In progress
Time intervals
Systolic time intervals

Active Force Development in the myocytes = intrinsic contractility

Cavity pressure development → Aortic Valve Opening

- Geometry
- Fibre orientation
- Elasticity
- Afterload

Ejection by wall deformation

Table:

<table>
<thead>
<tr>
<th></th>
<th>Slope (m/s²)</th>
<th>PViT (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.99</td>
<td>2.7</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>197.18</td>
</tr>
<tr>
<td>3</td>
<td>0.63</td>
<td>77.46</td>
</tr>
</tbody>
</table>

Graph: 3.0MHz, WP Med, Med
The myocardial performance index

Tei index
= \( \frac{a - b}{b} \)
= \( \frac{ICT + IRT}{ET} \)
The systolic to diastolic duration ratio

Friedberg, AJC 2006;97:101
Prognostic Implications of the Systolic to Diastolic Duration Ratio in Children With Idiopathic or Familial Dilated Cardiomyopathy
Tapas Mondal, Cameron Slorach, Cedric Manlhiot, Wei Hui, Paul F. Kantor, Brian W. McCrindle, Luc Mertens and Mark K. Friedberg

_Circ Cardiovasc Imaging_. 2014;7:773-780; originally published online August 19, 2014; doi: 10.1161/CIRCIMAGING.114.002120
Myocardial performance

Active Force Development in the myocytes = intrinsic contractility

Cavity pressure development

Aortic Valve Opening

Ejection by wall deformation

- Geometry
- Fibre orientation
- Elasticity
- Afterload
Tissue Doppler Imaging

Molina, Circ: HF 2013;6:1214
LV myocardial contraction

- shortens
- thickens
- twists along long axis
Longitudinal strain

Circumferential strain

Radial strain
Global strain

Courtesy B. Bijnens
Global Longitudinal Strain as a Major Predictor of Cardiac Events in Patients with Depressed Left Ventricular Function: A Multicenter Study

Aude Mignot, MD, Erwan Donal, MD, PhD, Amira Zaroui, MD, Patricia Reant, MD, Adrien Salem, MD, Cecile Hamon, MD, Severine Monzy, MD, Raymond Roudaut, MD, PhD, Gilbert Habib, MD, PhD, and Stéphane Lafitte, MD, PhD, Pessac, Marseille, and Rennes, France

![Graph showing survival analysis with GLS < -7% and GLS > -7%].

P < .00001 *

<table>
<thead>
<tr>
<th>Follow-up (days)</th>
<th>Number of patients</th>
<th>Number of survivors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>147</td>
</tr>
<tr>
<td></td>
<td>122</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td>244</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>366</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>488</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>610</td>
<td>109</td>
</tr>
</tbody>
</table>

GLS < -7%: 109, 105, 104, 100, 98, 98
GLS > -7%: 38, 29, 26, 22, 17, 11
Progressive LV dysfunction

- Pre-clinical dysfxn
- HFpEF
- HFrEF

Greater absolute magnitude

Reduction in circumferential function associated with HF

Early compensatory increase in circumferential function

Lower absolute magnitude

- Hypertension
- Diastolic relaxation
- Longitudinal deformation
- Circumferential deformation

Cikes M, Eur Heart J 2015; Shah AM, Eur Heart J 2012
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.
Diastolic function

• Filling at low pressures

• Better filling at high heart rates despite shorter filling times

• During exercise increase in filling at persistently low filling pressures
Mitral inflow
Delayed relaxation in HCM
Characterization of Left Ventricular Diastolic Function by Tissue Doppler Imaging and Clinical Status in Children With Hypertrophic Cardiomyopathy

Colin J. McMahon, MB, MRCPI; Sherif F. Nagueh, MD; Ricardo H. Pignatelli, MD; Susan W. Denfield, MD; William J. Dreyer, MD; Jack F. Price, MD; Sarah Clunie, RN; Louis I. Bezold, MD; Amanda L. Hays, MEd; Jeffrey A. Towbin, MD; Benjamin W. Eidem, MD

- Decreased e’
- Increased E/e’ ratio
  - Predicted SCD or VT in children
  - Inversely related to peak VO$_2$

McMahon, Circulation, 2004
HCM with restrictive physiology
**Table 2. Frequency of Normal Individual Diastolic Parameters in the Study Population by Cardiomyopathy Type According to Adult Cutoff Values and Pediatric Reference Data**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Normal Controls (n=50)</th>
<th>DCM (n=50)</th>
<th>RCM (n=16)</th>
<th>HCM (n=50)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adult</td>
<td>Pediatric</td>
<td>Adult</td>
<td>Pediatric</td>
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<tr>
<td>IVRT, %</td>
<td>94</td>
<td>100</td>
<td>64</td>
<td>62</td>
</tr>
<tr>
<td>PV S/D ratio, %</td>
<td>84</td>
<td>100</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>PV Ar, %</td>
<td>92</td>
<td>86</td>
<td>86</td>
<td>84</td>
</tr>
<tr>
<td>Ar−A, %*</td>
<td>92</td>
<td>92</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>DT, %</td>
<td>68</td>
<td>90</td>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td>E/A, %</td>
<td>58</td>
<td>100</td>
<td>30</td>
<td>86</td>
</tr>
<tr>
<td>E', %</td>
<td>100</td>
<td>100</td>
<td>30</td>
<td>46</td>
</tr>
<tr>
<td>E/E', %</td>
<td>90</td>
<td>100</td>
<td>26</td>
<td>44</td>
</tr>
<tr>
<td>LAVI score, %</td>
<td>98</td>
<td>98</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>
Systolic- diastolic coupling

Systolic-diastolic coupling in children with DCM

5y, DORV, progressive LV enlargement, AI dysfunction and exercise intolerance

QRS 130 msec
Summary

• Assessment of cardiac function is central to clinical management
• Echo is the mainstay of functional imaging
• Qualitative & quantitative measures should be used
• Well tested conventional measures should be combined with more recent modalities
• Often simple measures are very informative
• Systolic and diastolic function are tightly coupled and both should be assessed
• The reader’s role is to integrate multiple parameters into a comprehensive picture of function
THANK YOU