The Basics of Systolic Function

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Relations with Industry: GE, Abbott, Edwards (honoraria)
If you can’t measure it, it doesn’t exist.

–AN DeMaria
Which is More Remarkable??

That a hollow muscular shell can eject 100 mL at 140 mmHg

That this same hollow muscular shell can fill with 100 mL at 10 mmHg

That it can fill with 100 mL at 10 mmHg in <200 msec during exercise
Systolic and Diastolic Function

Myocardium to Ventricle

Tissue Elastance

Activation

Stress/strain Relationship

Geometry

Pressure-Volume Curve

LV Volume

LV Pressure

Systole

Diastole

20g

20g

h
Transition from Systole to Diastole

P-V Curves as a Function of Time

Pressure (mmHg) vs. Volume (mL)
Myocardial Architecture is Complex

Fitted transmural fiber field


Peter Hunter
Fiber Orientations

Epicardium

Mid-wall

Endocardium

Left-handed helix

Circumferential

Right-handed helix

Myocyte Organization

Courtesy of Peter Hunter
Mechanics of the Heart

Our Imaging Planes Are Not Fiber-Oriented

base-apex shortening  +  circumferential shortening  +  axial twist (shear)  =  wall thickening

MRI

Subendocardial Strains

Complex combinations of linear and shear strains
So you can see it’s pretty complicated

And that’s BEFORE we get serious with the physics and math!

### Reaction-diffusion
\[
\frac{\partial C}{\partial t} + \mathbf{u} \cdot \nabla C = -\nabla \cdot (-k \nabla C) + f_s
\]

### Fluid flow
\[
\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\frac{1}{\rho} \nabla p + \nu \nabla^2 \mathbf{u}
\]

### Finite elasticity
\[
\tau^{ij} |_t = f^j \quad \tau^{ij} = f_2 (e_{ij})
\]
\[
e_{ij} = \frac{1}{2} (\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i})
\]

### Electro-magnetic
\[
\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon} \quad \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}
\]
\[
\nabla \cdot \mathbf{B} = 0 \quad \nabla \times \mathbf{B} = \mu (J + \varepsilon \frac{\partial \mathbf{E}}{\partial t})
\]

### Galerkin finite element method
\[
\int_{V_0} T^{\alpha \beta} F^j_{\beta} \delta v_j |_\alpha \ dV_0 = \int_{V_0} \rho_0 (b^j - f^j) \delta v_j \ dV_0 + \int_{S_2} p_{(appl)} \frac{g^{3M}}{\sqrt{g^{33}}} \frac{\partial x_j}{\partial \xi_M} \delta v_j \ dS
\]
\[
\int_{V_e} \int \int \left( \sqrt{T_3 - 1} \right) \psi^p \sqrt{G(\xi)} \ d\xi_3 d\xi_2 d\xi_1 = 0
\]
\[
\frac{1 - T/T_0}{T/T_0 + a} = \sum_{i=1,3} A_i \int_{-\infty}^{t} e^{-\alpha_i(t-\tau)} \dot{\lambda}(\tau) d\tau
\]
The Heart is an Elegantly Complex Machine

Fiber Sheet Oriented LV Strain Model

Any echo measure of systolic function is mere approximation.
Quantitation in Echocardiography

• Systolic function
  – Dimensions, volumes and ejection fraction
  – Stroke volume and cardiac output
  – 3D methods

• Advanced methods
  – Strain imaging
M-Mode Estimation of Volumes and EF

\[ V = \frac{7.0}{(2.4+D)}D^3 \]

\[ EF = \frac{[EDD^2 - EDD^2]}{EDD^2 + Apex (0, 5, 10\%)} \]

Lang et al. JASE 2005; 18: 1840-63
Quantification of Stroke Volume

2-D Echo Volumetric Assessment

LVEDV 105 ml
LVESV 78 ml

Stroke volume = 27 ml; ejection fraction = 26%
Biplane Methods

Better in Asymmetric Ventricles

Lang et al. JASE 2005; 18: 1840-63
Simple Methods Still Give Insight

Impact of Thrombolysis (T+/-) and Vessel Patency (P+/-) on Ejection Fraction Post MI

Popovic et al. Circulation 1994; 90: 800-807
Contrast Helps with Quantitation

“Polar bear in a snowstorm”

Ah, better!
Contrast Improvs Estimation of LV Volume Yields Results Closer to CT/MR
Quantitation in Echocardiography

• **Systolic function**
  – Volumes and ejection fraction
  – Stroke volume and cardiac output
  – 3D methods
• **Advanced methods**
  – Strain imaging
**Volume Calculation**

\[ \pi r^2 = A = \text{Area (cm}^2\text{)} \]

\[ \frac{V \text{ (cm/sec)}}{t \text{ (sec)}} = TVI = \text{Stroke distance (cm)} \]

---

**Volume of a Cylinder**

\[ \text{Area (cm}^2\text{)} \times \text{distance (cm)} = \text{Volume (cm}^3\text{)} \]

---

**Stroke Volume**

\[ TVI \times A_{LVOT} \]
Measurement of Flow in LVOT
Measurement of Flow in RVOT
Automated Calculation of Cardiac Output

Apical Long-Axis View

\[ SV = \pi \int \int r \, v(r,t) \, dr \, dt \]

Sun et al, Circulation 1997; 95: 932-939
Accuracy of ACM

LVOT SV vs Pulsed Doppler

Stroke Volume by ACOM (ml)

Difference in Stroke Volume (ACOM-PWAO, ml)

Sun et al, Circulation 1997; 95: 932-939
Mitral Regurgitation
Measurement Current Peak
Volume PISA 13.33 13.33 cm²
Aliasing Velocity 0.32 0.32 m/s
Inst Flow Rate 428.23 428.23 ml/s
Peak RF -- -- %
VTI 1.64 1.64 m
ERO 0.87 0.87 cm²
Peak Regurg Vol 142.45 142.45 ml
Automated 3D Flow More Accurate Than 2D

A

\[ y = 25.4 + 0.62x \]

\[ r = 0.66 \]

\[ p < .0001 \]

B

\[ y = 30.3 + 0.56x \]

\[ r = 0.62 \]

\[ p < .0001 \]

C

\[ y = 10.2 + 0.88x \]

\[ r = 0.91 \]

\[ p < .0001 \]

D

\[ y = 15.7 + 0.84x \]

\[ r = 0.93 \]

\[ p < .0001 \]
Quantitation in Echocardiography

• **Systolic function**
  – Volumes and ejection fraction
  – Stroke volume and cardiac output
  – 3D methods

• **Advanced methods**
  – Strain imaging
We Really Have Come a Long Way…
Nine-Plane Visualization of 3D Echo

Quantitation similar to MRI
Normal 3D LV Volumes

Table 3 Normal values for LV parameters obtained with 3DE

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects</td>
<td>166</td>
<td>410</td>
<td>978</td>
<td>226</td>
</tr>
<tr>
<td>Ethnic makeup of population</td>
<td>Scandinavian</td>
<td>Japanese</td>
<td>51% European white, 49% Asian Indian</td>
<td>White European</td>
</tr>
<tr>
<td>EDVi (mL/m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men, mean (LLN, ULN)</td>
<td>66 (46, 86)</td>
<td>50 (26, 74)</td>
<td>White: 49 (31, 67); Indian: 41 (23, 59)</td>
<td>63 (41, 85)</td>
</tr>
<tr>
<td>Women, mean (LLN, ULN)</td>
<td>58 (42, 74)</td>
<td>46 (28, 64)</td>
<td>White: 42 (26, 58); Indian: 39 (23, 55)</td>
<td>56 (40, 78)</td>
</tr>
<tr>
<td>ESVi (mL/m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men, mean (LLN, ULN)</td>
<td>29 (17, 41)</td>
<td>19 (9, 29)</td>
<td>White: 19 (9, 29); Indian: 16 (6, 26)</td>
<td>24 (14, 34)</td>
</tr>
<tr>
<td>Women, mean (LLN, ULN)</td>
<td>23 (13, 33)</td>
<td>17 (9, 25)</td>
<td>White: 16 (8, 24); Indian: 15 (7, 23)</td>
<td>20 (12, 28)</td>
</tr>
<tr>
<td>EF (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men, mean (LLN, ULN)</td>
<td>57 (49, 65)</td>
<td>61 (53, 69)</td>
<td>White: 61 (49, 73); Indian: 62 (52, 72)</td>
<td>62 (54, 70)</td>
</tr>
<tr>
<td>Women, mean (LLN, ULN)</td>
<td>61 (49, 73)</td>
<td>63 (55, 71)</td>
<td>White: 62 (52, 72); Indian: 62 (52, 72)</td>
<td>65 (57, 73)</td>
</tr>
</tbody>
</table>

EDVi, LV EDV index; ESVi, LV ESV index; LLN, lower limit of normal; NR, not reported; RT3DTTE, real-time 3D TTE; SVi, LV stroke volume index; ULN, upper limit of normal.

Modified with permission from Bhave et al.¹³ LLN and ULN are defined as mean ± 2 SDs.
Conditions Where LV Volume/Function are Critical

• **Cardiomyopathy**
  – Indications for ICD and BiV pacing

• **Oncology**
  – Monitoring effects of chemotherapy

• **Valvular heart disease**
  – Monitoring progression in aortic and mitral regurgitation
Practical Barriers to 3D Echocardiography

• How to manage the workflow
  – Extensive experience/comfort in 2D acquisition and review
  – 3D acquisition and analysis are separate tasks: 1 or 2 sonographers?
  – Is 3D software integrated into review software or separate?
  – DICOM format only recently approved (but little penetration into the market now and the files are huge)
Practical Barriers to 3D Echocardiography

• How to pay for this
  – Currently no separate CPT code for 3D echo
  – Most billing done under CPT’s 76376 and 76377
# Medicare Reimbursement

<table>
<thead>
<tr>
<th>Modality</th>
<th>Tech</th>
<th>Prof</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D echo</td>
<td>414.42</td>
<td>70.40</td>
<td>484.82</td>
</tr>
<tr>
<td>3D add-on</td>
<td>Bundled</td>
<td>41.74</td>
<td>41.74</td>
</tr>
</tbody>
</table>

Actual 3D reimbursement averages ~$38
Would Separate 3D Echo code be Beneficial?

• Not necessarily
  – Imaging (and particularly echo) under intense scrutiny for rapidly rising utilization
  – The pie is not getting bigger, so an increase in one piece will mean a decrease in another piece
  – Comprehensive 3D echo code might lead to a devaluation in 2D reimbursement
3D Echocardiography
Strategies for Clinical Use

- Transthoracic echo (LV volumes)
  - Identified key indications for 3D volumes (cardio-oncology, device implantation, valve regurgitation)
  - Core group of sonographers trained for mechanics ‘pod’
  - Database modified to code 3D volumes

- Transesophageal echo (visualizing 3D structures)
  - Repeated training on acquisition and vendor software
  - Sonographer to assist less trained staff and fellows
  - Expectation that 3D will be done on all valve cases
Growth in 3D Volumes with Time

Number of TTE studies with 3D volumes

Year

'09  '10  '11  '12  '13

0  500  1000  1500  2000  2500  3000
So……

Contrast: good
3D volumes: good
Contrast + 3D: great?

Not so fast.
Reproducibility of Echocardiographic Techniques for Sequential Assessment of Left Ventricular Ejection Fraction and Volumes

Application to Patients Undergoing Cancer Chemotherapy

Paaladinesh Thavendiranathan, MD, MSc, Andrew D. Grant, MD, Tomoko Negishi, MD, Juan Carlos Plana, MD, Zoran B. Popović, MD, PhD, Thomas H. Marwick, MD, PhD, MPH

Cleveland, Ohio

• Patients seen in cardio-oncology clinic
  – Exams with 2D and 3D echo without and with contrast
  – Up to 5 exams over one year

• 56 patients selected with constant GLS
  – What was variability of each EF estimation method?
Temporal Variability in EF

3D volumes were most reproducible

Universal contrast worsened this

Use contrast when you need it!

JACC 2013; 64: 77-84
Quantitation in Echocardiography

• **Systolic function**
  – Volumes and ejection fraction
  – Stroke volume and cardiac output
  – 3D methods

• **Advanced methods**
  – Strain imaging
Myocardial Strain: What is It??

Strain: dimensionless index of change in length

Strain ($\varepsilon$) = \( \frac{L - L_0}{L_0} \)

LV strain may offer a pure index of regional LV function but is difficult to measure.
From Sarcomere to Stroke Volume
A Little Goes a Long Way!

Diastole

- 50 mL
- 1.0 cm

Systole

- 20 mL
- 1.4 cm

\[ \Delta SL = 13\% \]
\[ \varepsilon_{epi} = -7\% \]
\[ \varepsilon_{mid} = -15\% \]
\[ \varepsilon_{endo} = -26\% \]
\[ \varepsilon_{rad} = +37\% \]
\[ EF = 60\% \]
Longitudinal Strain by Speckle Tracking

Normal Subject
Longitudinal Strain
Dilated Cardiomyopathy
• 242 normal patients from Cleveland, Brisbane and Aachen, age 18-80

• Imaged with GE Vivid 7 and analyzed with EchoPAC
Global Longitudinal Strain is $-18.6 \pm 1.5\%$

*Absolute Strain Rate Falls With Age*

Marwick et al. JACC Imaging 2009; 2: 80-84
Clinical Applications of Strain Imaging

- **Coronary artery disease**
  - Detection and sizing of myocardial infarction
  - Detection of myocardial ischemia
  - Assessment of myocardial viability
  - Prediction of post-MI arrhythmias

- **Detection of subclinical LV dysfunction**
  - Chemotherapy
  - Valvular heart disease

- **Cardiomyopathy**
  - Amyloid
MRI vs Echo Strain for Infarct Size

Large infarct

Medium infarct

115 g

36 g

Gjesdal et al. Circ Img 2008; 1: 189-96
Detection of 30 g MI Size

Gjesdal et al. Clinical Science 2007; 113: 287-96
Clinical Applications of Strain Imaging

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• *Cardiomyopathy*
  – Amyloid

• *Assessment of RV function*
Strain Imaging Diastolic Index

SI-DI = % of systolic wall thickening lost in the first 1/3 of diastole:

\[(A-B)/A\]

Ishii et al. JACC 2009; 53: 698-705
60-year-old Male: Exertional Angina
Radial Strain Before and After Exercise

Ishii et al. JACC 2009; 53: 698-705
60-year-old Male: Effort Angina

Left coronary artery
(#7: 99% #9:90% stenosis)

Right coronary artery

Ishii et al. JACC 2009; 53: 698-705
Predictive Accuracy of SI-DI for Detecting Coronary Stenoses

Ishii et al. JACC 2009; 53: 698-705
Clinical Applications of Strain Imaging

- **Coronary artery disease**
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- **Cardiomyopathy**
  - Amyloid
- **Assessment of RV function**
Assessment of Myocardial Viability

Improvement in Ejection Fraction vs Resting Radial Strain and MRI Markers

Becker et al. JACC 2008; 51: 1473-81
Prediction of Regional and Global Recovery
vs Resting Radial Strain and MRI Markers

Becker et al. JACC 2008; 51: 1473-81
Post-Systolic Strain vs Recovery of Function Post NSTEMI

Initial pattern
LCx occlusion

Post-PCI

\[ r = -0.61 \]
\[ p < 0.001 \]
Clinical Applications of Strain Imaging

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- **Cardiomyopathy**
  - Amyloid

- **Assessment of RV function**


Myocardial Mechanical Dispersion
85 patients after myocardial infarction with ICD

Mechanical Dispersion Assessed by Myocardial Strain in Patients After Myocardial Infarction for Risk Prediction of Ventricular Arrhythmia

Kristina H. Haugaa, MD,*† Marit Kristine Smørsrud, MD,*† Torkel Steen, MD, Ph.D.; Erik Kongsgaard, MD, Ph.D.; Jan Pål Loennechen, MD, Ph.D.; Terje Skjaerpe, MD, Ph.D.; Jens-Uwe Voigt, MD, Ph.D.; Rik Willems, MD, Ph.D.; Gunnar Smith, MD; Otto A. Smiseth, MD, Ph.D.; Jan P. Amlie, MD, Ph.D.; Thor Edvardsen, MD, Ph.D.*
Oslo and Trondheim, Norway; and Leuven, Belgium

2.3 (0.6-5.5) years follow up

Haugaa et al. JACC Img 2010; 3: 247-56
Myocardial Mechanical Dispersion

85 patients after myocardial infarction with ICD

2.3 (0.6-5.5) years follow up

Haugaa et al. JACC Img 2010; 3: 247-56
• 85 post MI patients meeting ICD criteria
• Followed until arrhythmia requiring appropriate ICD intervention
  – No difference in EF: 34±11% vs 35±9%
  – Mechanical dispersion: 85±29 msec vs 56±13 msec, p<0.001

Haugaa et al. JACC Img 2010; 3: 247-56
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  - Amyloid

- **Assessment of RV function**
Can Echo and Biomarkers Predict Chemo-Induced LV Dysfunction?

Questionnaire/ Echocardiogram / Biomarkers

Baseline 3 mo (post Anthracyclines) 6 mo 9 mo 12 mo 15 mo

Anthracyclines Trastuzumab Paclitaxel Trastuzumab

Assessment of Echocardiography and Biomarkers for the Extended Prediction of Cardiotoxicity in Patients Treated With Anthracyclines, Taxanes, and Trastuzumab

Heloisa Sawaya, MD, PhD; Igal A. Sebag, MD; Juan Carlos Plana, MD; James L. Januzzi, MD; Bonnie Ky, MD, MSCE; Timothy C. Tan, MBBS, PhD; Victor Cohen, MD; Jose Banchs, MD; Joseph R. Carver, MD; Susan E. Wiegers, MD; Randolph P. Martin, MD; Michael H. Picard, MD; Robert E. Gerszten, MD; Elkan F. Halpern, PhD; Jonathan Passeri, MD; Irene Kuter, MD; Marielle Scherrer-Crosbie, MD, PhD

Sawaya et al. AJC 2011; 107: 1375-80
ROC Curves for 3 Month Findings to Predict 6 Month Cardiotoxicity

Sawaya et al. AJC 2011; 107: 1375-80
EXPERT CONSENSUS STATEMENT

Expert Consensus for Multimodality Imaging Evaluation of Adult Patients during and after Cancer Therapy: A Report from the American Society of Echocardiography and the European Association of Cardiovascular Imaging

Juan Carlos Plana, MD, FASE, Chair, Maurizio Galderisi, MD, FESC, Co-Chair, Ana Barac, MD, PhD, Michael S. Ewer, MD, JD, Bonnie Ky, MD, FASE, Marielle Scherrer-Crosbie, MD, PhD, FASE, Javier Ganame, MD, PhD, FASE, Igal A. Sebag, MD, FASE, Deborah A. Agler, RCT, RDGS, FASE, Luigi P. Badano, MD, PhD, FESC, Josc Banchs, MD, FASE, Daniela Cardinale, MD, PhD, FESC, Joseph Carver, MD, Manuel Cerqueira, MD, Jeanne M. DeCara, MD, FASE, Thor Edvardsen, MD, PhD, FESC, Scott D. Flamm, MD, MBA, Thomas Force, MD, Brian P. Griffin, MD, Guy Jerusalem, MD, PhD, Jennifer E. Liu, MD, FASE, Andreia Magalhães, MD, Thomas Marwick, MBBS, PhD, MPH, Liza Y. Sanchez, RCS, FASE, Rosa Sicari, MD, PhD, FESC, Hector R. Villarraga, MD, FASE, and Patrizio Lancellotti, MD, PhD, FESC, Cleveland, Ohio; Naples, Padua, Milan, and Pisa, Italy; Washington, District of Columbia; Houston, Texas; Philadelphia, Pennsylvania; Boston, Massachusetts; Hamilton, Ontario and Montreal, Quebec, Canada; Chicago, Illinois; Oslo, Norway; Liège, Belgium; New York, New York; Lisbon, Portugal; Hobart, Australia; Rochester, Minnesota

(J Am Soc Echocardiogr 2014;27:911-39.)

Key Points

- Myocardial deformation (strain) can be measured using DTI or 2D STE. The latter is favored because of a lack of angle dependency.
- GLS is the optimal parameter of deformation for the early detection of subclinical LV dysfunction.
- Ideally, the measurements during chemotherapy should be compared with the baseline value. In patients with available baseline strain measurements, a relative percentage reduction of GLS of <8% from baseline appears not to be meaningful, and those >15% from baseline are very likely to be abnormal.
- When applying STE for the longitudinal follow-up of patients with cancer, the same vendor-specific ultrasound machine should be used.
Clinical Applications of Strain Imaging

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  - Valvular heart disease

- **Cardiomyopathy**
  - Amyloid

- **Assessment of RV function**
Increased Strain After Percutaneous AVR
Impact of Strain on Post MVr LV function
233 Pts, Prediction of 12+ month LVEF<50%

GLS = - 19.9%
90% sensitivity, 79% specificity

Predictors of LV dysfunction

<table>
<thead>
<tr>
<th>Predictor</th>
<th>OR</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GLS</td>
<td>&lt;19.9%</td>
</tr>
<tr>
<td>LVESD&gt;40mm</td>
<td>6.7</td>
<td>0.003</td>
</tr>
<tr>
<td>EF&lt;60%</td>
<td>2.6</td>
<td>0.069</td>
</tr>
<tr>
<td>Symptoms</td>
<td>2.4</td>
<td>0.165</td>
</tr>
<tr>
<td>AF</td>
<td>2.0</td>
<td>0.210</td>
</tr>
</tbody>
</table>

\[ \chi^2 = 69.1, \ p<0.001 \]

GLS accounted for 3.3x more variance than EF

Witkowski et al. EHJ-CVI 2013; 14 :69-76
Clinical Applications of Strain Imaging

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- **Cardiomyopathy**
  - Amyloid

- **Assessment of RV function**
Relative ‘apical sparing’ of longitudinal strain using two-dimensional speckle-tracking echocardiography is both sensitive and specific for the diagnosis of cardiac amyloidosis

Dermot Phelan, Patrick Collier, Paaladinesh Thavendiranathan, Zoran B Popović, Mazen Hanna, Juan Carlos Plana, Thomas H Marwick, James D Thomas
Amyloid: Apex > 2x Base & Mid

Phelan, Collier et al. Heart 2012; 98: 1442-1448
Differentiation of Amyloid, HHD, and HCM

Value of Strain Maps

• 20 level 3 echo readers reviewed 24 cases of “LVH”
  – 8 amyloid, 8 HTN, 8 HCM
• Full echo Doppler data presented but NOT strain or clinical info
  – Readers chose 1 of 3 dx, and listed their confidence
• Exercise repeated some weeks later with recorded cases, now including GLS and strain maps
• Reader concordance improved with strain data ($\kappa = 0.28$ to 0.57)
• Reader confidence improved with strain data ($p<0.001$)
• Reader accuracy improved with strain data (65% to 82%, $p<0.001$)
  – Especially for amyloid!

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Read</strong></td>
<td>40</td>
<td>84</td>
<td>70</td>
<td>55</td>
<td>75</td>
</tr>
<tr>
<td><strong>Strain Read</strong></td>
<td>86</td>
<td>95</td>
<td>92</td>
<td>92</td>
<td>94</td>
</tr>
</tbody>
</table>

$P < 0.001$  $0.002$  $< 0.001$  $< 0.001$  $< 0.001$

Phelan, et al. JASE 2014; 27: 888-95
Effect of Combined Systolic and Diastolic Functional Parameter Assessment for Differentiation of Cardiac Amyloidosis From Other Causes of Concentric Left Ventricular Hypertrophy

Dan Liu, MD*; Kai Hu, MD*; Markus Niemann, MD; Sebastian Herrmann, MD; Maja Cikes, MD, PhD; Stefan Störk, MD, PhD; Philipp Daniel Gaudron, MD; Stefan Knop, MD; Georg Ertl, MD; Bart Bijnens, PhD; Frank Weidemann, MD

25 cases each of amyloid, Fabry, Friedreich ataxia, HTN and controls
Emerging Applications

Transmural strain

3D strain

Seo et al, Circ Img 2009; 2: 451-9

N = 108
Y = 0.89X - 4.80
R = 0.90
P < 0.001
Normal reference values of left ventricular strain using three-dimensional speckle tracking echocardiography: results from a multicentre study

Sebastiaan A. Kleijn1*, Natesa G. Pandian2, James D. Thomas3, Leopoldo Perez de Isla4, Otto Kamp1, Michel Zuber5, Petros Nihoyannopoulos6, Tamas Forster7, Hans-Joachim Nesser8, Annette Geibel9, Willem Gorissen10, and Jose L. Zamorano11


• 303 healthy subjects, 18-82 years
  – 10 centers in 8 countries (US, Spain, Germany, Netherlands, Hungary, Switzerland, UK, Austria)
  – All Caucasian, 156M, 147F
  – 3D strain using Toshiba

• Results
  – Minor gender difference (GLS)
  – Significant age effect (GLS falls, others rise)
  – Area strain most reproducible (5% relative standard error), vs GLS 8%, GCS 6%, and GRS 15%
    » Segmental strain worse (11-28%)
Achilles Heel: 
*Intervendor Reproducibility*
Imagine This Situation...

61 yr. old real estate agent
Avid bowler, no symptoms
AVA = 0.85 cm²
Peak/mean grad. = 72/46 mm Hg

No surgery now, follow-up in one year
One Year Later

*Our Bowler Returns for Follow-Up*

Staff: “Wait…we can’t image him on the GE machine”
Sonographer: “Why not. It’s a good machine.”
Staff: “That’s irrelevant. We studied him on an ATL machine last year, and we know ATL and GE give different gradients. He always needs to be studied with an ATL.”
Sonographer: “But we got rid of the ATL last week.”
Staff: “Uh, oh……”
Intervendor Reproducibility in Normals

Normal Range of Left Ventricular 2-Dimensional Strain
– Japanese Ultrasound Speckle Tracking of the Left Ventricle (JUSTICE) Study –
Kiyohiro Takigiku, MD; Masaaki Takeuchi, MD; Chisato Izumi, MD;
Satoshi Yuda, MD; Konomi Sakata, MD; Nobuyuki Ohte, MD; Kazuaki Tanabe, MD;
Satoshi Nakatani, MD on behalf of the JUSTICE investigators

V1: GE
V2: Philips
V3: Toshiba

Vendor 1 vs 2
Vendor 1 vs 3
Vendor 2 vs 3

Circ J 2012; 76: 2623-32
Great Collaboration Between EACVI and ASE

Luigi Badano  Jim Thomas
Standardization in Several Settings

Reliability of the reference method

Synthetic data

First focus of the task force

In vitro models

Experimental Animals

In vivo (patients)

Level of realism of the data set

All ‘levels’ have benefits and require attention

Courtesy Jan D’Hooge
Tracking examples

Courtesy Jan D’Hooge
Definitions for a Common Standard for 2D Speckle Tracking Echocardiography: Consensus Document of the EACVI/ASE/Industry Task Force to Standardize Deformation Imaging

Jens-Uwe Voigt,† Gianni Pedrizzetti,† Peter Lysyansky,† Tom H. Marwick, Hélène Houle, Rolf Baumann, Stefano Pedri, Yasuhiro Ito, Yasuhiko Abe, Stephen Metz, Joo Hyun Song, Jamie Hamilton, Partho P. Sengupta, Theodore J. Kolas, Jan d’Hooge, Gerard P. Aurigemma, James D. Thomas,† and Luigi Paolo Badano†, Leuven, Belgium; Trieste, Genova, and Padova, Italy; New York, New York; Haifa, Israel; Hobart, Australia; Mountain View, California; Unterschleissheim, Germany; Tokyo and Tochigi-ken, Japan; Andover and Worcester, Massachusetts; Seoul, Korea; Ann Arbor, Michigan; and Cleveland, Ohio

- Agreement on
  - Nomenclature
  - Display
  - Timing of end-diastole
  - Timing of end-systole
  - Mathematical definition of strain
  - Regions of interest
Two-dimensional speckle tracking echocardiography: standardization efforts based on synthetic ultrasound data

Jan D’hooge¹, Daniel Barbosa¹, Hang Gao¹, Piet Claus¹, David Prater², Jamie Hamilton³, Peter Lysyansky⁴, Yasuhiko Abe⁵, Yasuhiro Ito⁶, Helene Houle⁷, Stefano Pedri⁸, Rolf Baumann⁹, James Thomas¹⁰, Luigi P. Badano¹¹

on behalf of the EACVI/ASE/Industry Task Force to Standardize Deformation Imaging

![Graph showing data points for different conditions: Normal (20%->60% Noise), LVH (20%->60% Noise), Exercise (20%->60% Noise), Dilated (20%->60% Noise).]
Head-to-Head Comparison of Global Longitudinal Strain Measurements among Nine Different Vendors
The EACVI/ASE Inter-Vendor Comparison Study

Konstantinos E. Farsalinos, MD, Ana M. Daraban, MD, Serkan Ünlü, MD, James D. Thomas, MD, PhD, Luigi P. Badano, MD, PhD, and Jens-Uwe Voigt, MD, PhD, Leuven, Belgium; Chicago, Illinois; and Padua, Italy

One week: 22nd - 26th April 2013, Leuven

7 machines: Esaote, GE, Hitachi-Aloka, Philips, Samsung, Siemens, Toshiba, MyLab Alpha, Vivid E9, Prosound Alpha7 CV, iE 33, EKO 7, SC 2000, Artida

2 independent softwares: Epsilon, Tomtec, Epsilon, EchoInsight, Image Arena
Inter-Vendor Comparison Study

• Energetics: 7 machines (1000 W)
  21 persons (250 W)
  12 kW power + heat!
Mean GLS Values

All Vendors

JASE 2015; 28: 1171-81
Regression Analysis

All Vendors vs Average Values

Hitachi-A.  
\[ y = 0.94x + 0.22 \]  
\[ R^2 = 0.85 \]

Esaote  
\[ y = 1.01x - 0.52 \]  
\[ R^2 = 0.86 \]

GE  
\[ y = 1.10x + 0.38 \]  
\[ R^2 = 0.88 \]

Philips  
\[ y = 1.01x + 0.84 \]  
\[ R^2 = 0.88 \]

Samsung  
\[ y = 1.03x + 1.76 \]  
\[ R^2 = 0.89 \]

Siemens  
\[ y = 1.03x - 0.06 \]  
\[ R^2 = 0.89 \]

Toshiba  
\[ y = 0.90x - 1.00 \]  
\[ R^2 = 0.86 \]

Epsilon  
\[ y = 0.85x - 1.99 \]  
\[ R^2 = 0.84 \]

Tomtec  
\[ y = 1.13x + 0.39 \]  
\[ R^2 = 0.88 \]
Interobserver Variability, GLS vs EF

- EF is worst!

Intervendor Variability, GLS vs Other Parameters

- GLS is best!
Improvement in Strain Concordance between Two Major Vendors after the Strain Standardization Initiative

Hong Yang, BMed, Thomas H. Marwick, MBBS, PhD, MPH, Nobuaki Fukuda, MD, Hiroki Oe, MD, PhD, Makoto Saito, MD, PhD, James D. Thomas, MD, PhD, and Kazuaki Negishi, MD, PhD, Hobart, Australia; Takasaki and Okayama, Japan; and Chicago, Illinois

A. Between Vendors comparison

B. Within Vendors comparison

Overall $P<.0001$

Overall $P<.0001$

Yang et al. JASE 2015; 28: 642-8
Strain Standardization Task Force

Next Steps

• **Regional longitudinal strain**
• **Circumferential and radial strain**
• **RV strain**
• **Atrial strain**
• **Strain from 3D echoes**
**Inter-Vendor Clinical Study**  
**Round 2**

**One week:** 20th - 24th April 2015, Leuven

**7 machines:**  
- Esaote  
- GE  
- Hitachi-Aloka  
- Philips  
- Samsung  
- Siemens  
- Toshiba

**Esaote**  
**GE**  
**Hitachi-Aloka**  
**Philips**  
**Samsung**  
**Siemens**  
**Toshiba**

**MyLab Alpha**  
**Vivid E9**  
**Prosound Alpha7 CV**  
**iE 33**  
**EKO 7**  
**SC 2000**  
**Artida**

**2 independent softwares:**  
- Epsilon  
- Tomtec  
- EchoInsight  
- Tomtec  
- Image Arena

**Subjects:**  
- 63 pts, many with regional dysfunction  
- All with MRIs with Gd  
- Focus on regional strain

*Courtesy of Jens-Uwe Voigt*
The Heart is an Elegantly Complex Machine

Fiber Sheet Oriented LV Strain Model

J. Hassan

P. Hunter
Thanks!