Από την ρομαντική εποχή του M-mode στην ελικοειδή παραμόρφωση

Ηλίας Κ Καραμπίνος
Δ/ντής Γ’ Καρδιολογικής, ΕΥΡΩΚΛΙΝΙΚΗ
Physics of echocardiography: the basic principles

Echo Transmission from a "Moving" source

Echo Reflection
The road to echocardiography

L Spallanzani

J and P Curie

P Langevin

K.T. Dussik
Father of diagnostic echo
Inge Edler: the 'Father' of echocardiography

Co-operation with Hellmuth Herz
First echocardiogram M-Mode 1953
Basic principles of echocardiography: echo-tissue interactions

1. Reflection
2. Scattering
3. Refraction
4. Attenuation
5. Absorption and cavitation

Transducer

Skin

Tissue interface
Transducers

A Linear array probe

B Curved array probe

C Phased array probe
Basic principles of 2D-echocardiography. Phased Array Transducer: how it works.
Basic principles of 2D-echocardiography: from A, B Mode to Motion (m) Mode
Basic principles of 2D-echocardiography: from M-Mode to 2-D and image generation
Basic principles of Doppler echocardiography. The transducer

F.E. Barber et al 1974
Color Flow Doppler: another pulsed doppler.

2D and doppler data merged in an image

Towards a more Realistic Imaging.
Technology for realism

M.A. Brandestini et al 1978
Innovation in Echocardiography. 
Contrast echocardiography: improvement of tissue border delineation

- Left vent opacification for border enhancement
- Myocardial perfusion imaging
- Perfusion at resting state-stress is performed and perfusion imaging is done at peak stress
Innovations in 2D-echocardiography.  
2nd Harmonic: improvement of tissue border delineation

Ultrasound at a specific frequency causes tissues to vibrate at twice the frequency. The signal-to-noise ratio is dramatically improved.

much improved tissue border delineation
Innovation in Echocardiography.
3D echocardiography

3 dimensional objects are more realistic
3D echocardiography drawbacks: Small sector-Thin slice mode

Real-time data set (sector 30° x 60°)

Full-volume data set not real-time (sector 101° x 104°)
3D echocardiography drawbacks: showing 3D images on a 2D display
Innovation in Echocardiography: Tissue Doppler Imaging

Tissue Doppler...

![Diagram of Tissue Doppler Imaging](image)
Tissue Doppler Imaging: the importance of filters

Blood Doppler Signal
- High velocities (100cm/s)
- Wide band ($-fr/2, +fr/2$)
- Low energies ($TD/100$)

Tissue Doppler Signal
- Low velocities (10cm/s)
- Narrow band ($-fr/8, +fr/8$)
- High energies ($BD*100$)
These filters generated
Deformation Study...

• Strain
• Strain Rate
STRAIN definition

Strain is approximately equal to deformation.

Strain = Deformation resulting from applied force.
STRAIN definition

Strain can be **Negative**

\[ \text{Strain} = \frac{L_1 - L_0}{L_0} \times 100 \]
\[ = \frac{6 - 8}{8} \times 100 \]
\[ = -25\% \]

**systole**

Strain can be **Positive**

\[ \text{Strain} = \frac{L_1 - L_0}{L_0} \times 100 \]
\[ = \frac{8 - 5}{5} \times 100 \]
\[ = +60\% \]

**diastole**
Color Doppler myocardial imaging: a new technique for the assessment of myocardial function.

Sutherland GR, Stewart MJ, Groundstroem KW, Moran CM, Fleming A, Guell-Peris FJ, Riemersma RA, Fenn LN, Fox KA, McDicken WN.

Abstract
Color Doppler myocardial imaging is a new technique that has been developed specifically to allow color Doppler imaging of myocardial wall motion rather than blood pool imaging. Such a technique has the potential to interrogate velocities, accelerations, and Doppler signal strength within the myocardial wall. Moreover, the concomitant enhancement of the myocardial Doppler signal after an intravenous injection of a transpulmonary echocardiographic contrast agent could permit the noninvasive assessment of regional myocardial perfusion. Thus this new imaging modality could be a valuable adjunct to the ultrasound assessment of myocardial ischemia.

New method for evaluating left ventricular wall motion by color-coded tissue doppler imaging: In vitro and in vivo studies

MD, FACC Kunio Miyatake a, b, MD Masakazu Yamagishi a, b, BS Norio Tanaka a, b, MD Masaaki Uematsu a, b, MS Nobuo Yamazaki a, b, MS Yoshitake Mine a, b, MS Akihiro Sano a, b, PhD Makoto Hirama a, b

Measuring velocities of myocardial tissue..
M-mode colour Doppler tissue imaging

- Colour-encoded images of tissue motion along an M-mode interrogation line.
- High temporal and spatial resolution.
Tissue Velocity Imaging, curved M-Mode: the road to Deformation Study
Innovation in Echocardiography. Speckle tracking: the other road to Deformation Study


Global longitudinal strain: a novel index of left ventricular systolic function.

Reisner SA¹, Lysyansky P, Agmon Y, Mutlak D, Lessick J, Friedman Z.


Two-dimensional strain—a novel software for real-time quantitative echocardiographic assessment of myocardial function.


Measuring displacement of myocardial tissue...
Innovation in Echocardiography. Speckle tracking: the other road to Deformation Study

Measuring displacement of myocardial tissue...
TDI and ST Deformation Study... Indirectly (software aided)
Study of STRAIN by Speckle tracking technique

Direction of Motion

<table>
<thead>
<tr>
<th>Direction</th>
<th>Longitudinal</th>
<th>Radial</th>
<th>Circumferential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systole</td>
<td>Shortening = -ve</td>
<td>Thickening = +ve</td>
<td>Shortening = -ve</td>
</tr>
<tr>
<td>(Diastole)</td>
<td>(Lentheninga = +ve)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

longitudinal  radial  circumferential
Global Longitudinal Strain by Speckle Tracking

Display of GLS (Quad Format)

- Colour-encoded ROI (Parametric preview)
- Segmental/regional strain curves
- Curved anatomical Colour M-mode
- Peak segmental Strain map

Display of GLS (Bull’s Eye Plot)

Peak Systolic Strain
GLS -20%

- BLUE = +ve (lengthening)
- RED = -ve (shortening)
The generation of helical deformation study: a further step with ST

Vortex: a common natural structure
The generation of helical deformation study: a further step with ST

Subendocardium:
Apex to base, counterclockwise, right handed helix

Subepicardium:
Base to apex, clockwise, left handed helix
The generation of helical deformation study: a further step with ST

Twist = diff Rot(ap) to Rot(base)

Apex

Rotation (ap)

L (diast)

Base

Rotation (base)

Diast

Syst

Apical rotation

Basal rotation

Measuring angles...another aspect of contractility...
Requirements for Strain Imaging

- Hardware
- Software
- Good 2D imaging
- Experience
Limitation 1: variability

• Because of intervendor and intersoftware variability ...... serial assessment of GLS in individual patients should be performed using the same vendor’s equipment and the same software

peak GLS in the range of -20% can be expected in a healthy person, and the lower the absolute value of strain is below this value, the more likely it is to be abnormal.
Limitation 3: Image Quality

When regional tracking is suboptimal in more than two myocardial segments in a single view, the calculation of GLS should be avoided.
## Proposed diagnostic tools for the detection of cardiotoxicity

<table>
<thead>
<tr>
<th>Technique</th>
<th>Currently available diagnostic criteria</th>
<th>Advantages</th>
<th>Major limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echocardiography: - 3D-based LVEF</td>
<td>- LVEF: &gt;10 percentage points decrease to a value below the LLN suggests cardiotoxicity. &lt;br&gt; - GLS: &gt;15% relative percentage reduction from baseline may suggest risk of cardiotoxicity.</td>
<td>- Wide availability. &lt;br&gt; - Lack of radiation. &lt;br&gt; - Assessment of haemodynamics and other cardiac structures.</td>
<td>- Inter-observer variability. &lt;br&gt; - Image quality. &lt;br&gt; - GLS: inter-vendor variability, technical requirements.</td>
</tr>
<tr>
<td>Echocardiography: - 2D Simpson’s LVEF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Echocardiography: - GLS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear cardiac imaging (MUGA)</td>
<td>- &gt;10 percentage points decrease in LVEF with a value &lt;50% identifies patients with cardiotoxicity.</td>
<td>- Reproducibility.</td>
<td>- Cumulative radiation exposure. &lt;br&gt; - Limited structural and functional information on other cardiac structures.</td>
</tr>
<tr>
<td>Cardiac magnetic resonance</td>
<td>- Typically used if other techniques are non-diagnostic or to confirm the presence of LV dysfunction if LVEF is borderlines.</td>
<td>- Accuracy, reproducibility. &lt;br&gt; - Detection of diffuse myocardial fibrosis using T1/T2 mapping and ECVF evaluation.</td>
<td>- Limited availability. &lt;br&gt; - Patient’s adaptation (claustrophobia, breath hold, long acquisition times).</td>
</tr>
<tr>
<td>Cardiac biomarkers: - Troponin I</td>
<td>- A rise identifies patients receiving anthracyclines who may benefit from ACE-I-s. &lt;br&gt; - Routine role of BNP and NT-proBNP in surveillance of high-risk patient needs further investigation.</td>
<td>- Accuracy, reproducibility. &lt;br&gt; - Wide availability. &lt;br&gt; - High-sensitivity.</td>
<td>- Insufficient evidence to establish the significance of subtle rises. &lt;br&gt; - Variations with different assays. &lt;br&gt; - Role for routine surveillance not clearly established.</td>
</tr>
<tr>
<td>Cardiac biomarkers: - High-sensitivity Troponin I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac biomarkers: - BNP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac biomarkers: - NT-proBNP</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

www.escardio.org/guidelines
Clinical application of GLS

GLS Detects Early Subclinical Myocardial Dysfunction before LVEF

Drop of 10 points to LVEF <53%

Yes → CTRCD

Relative drop of GLS as compared to baseline

< 8%

No evidence of subclinical LV dysfunction

> 15%

Subclinical LV dysfunction*

A relative % reduction in the GLS of > 15% from baseline identifies subclinical LV dysfunction

* The data supporting the initiation of cardioprotection for the treatment of subclinical LV dysfunction is limited.

J Plana et al JASE 2014
Echocardiography has totally influenced our cardiological thinking regarding...

- Understanding heart physiology and pathophysiology
- Introducing new clinical practices
- Affecting clinical research
Echocardiography opened new roads in understanding heart physiology and pathophysiology

• Contribution to the understanding of normal cardiac function and the recognition of different pathological states

• The ability to measure structural and functional parameters, adding another layer to the depth of knowledge of the pathophysiology of disease
Echocardiography opened new roads introducing new clinical practices

- The only noninvasive imaging modality capable of providing dynamic views of the beating human heart in real time. REALISM

- It is almost unimaginable today to make a diagnosis of almost any cardiac pathology without ultrasound imaging. THE COR OF CARDIOLOGY

- QUICKNESS - IMMEDIACITY - DOCUMENTATION
ECHOCARDIOGRAPHY: a new tool for clinical research.

• Non invasive and safe method
• A method without biological effect
• Introduction of numerous new endpoints
• Endpoints pathophysiologicaly orientated thus revealing newer aspects of the diseases
The greatest disappointment ...

The “experiment” of PROSPECT study

Results of the Predictors of Response to CRT (PROSPECT) Trial

Eugene S. Chung, MD; Angel R. Leon, MD; Luigi Tavazzi, MD; Jing-Ping Sun, MD; Petros Nihoyannopoulos, MD; John Merlino, MD; William T. Abraham, MD; Stefano Ghio, MD; Christophe Leclercq, MD; Jeroen J. Bax, MD; Cheuk-Man Yu, MD, FRCP; John Gorcsan III, MD; Martin St John Sutton, FRCP; Johan De Sutter, MD, PhD; Jaime Murillo, MD

Circulation. 2008;117: 2608-2616
PROSPECT study: today seems naïve but by then it was very reasonable

<table>
<thead>
<tr>
<th>Echocardiographic Predictor</th>
<th>Description of Method</th>
<th>Echocardiography Method</th>
<th>Cutoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPWMD&lt;sup&gt;10&lt;/sup&gt;</td>
<td>Septal-posterior wall motion delay; M mode measured by parasternal short-axis view</td>
<td>M mode</td>
<td>≥130 ms</td>
</tr>
<tr>
<td>IVMD&lt;sup&gt;14&lt;/sup&gt;</td>
<td>Interventricular mechanical delay defined as the difference between left and right ventricular pre ejection intervals</td>
<td>Pulsed Doppler</td>
<td>≥40 ms</td>
</tr>
<tr>
<td>LVFT/RR&lt;sup&gt;14&lt;/sup&gt;</td>
<td>Left ventricular filling time (LVFT) in relation to cardiac cycle length (RR) as measured by transmitral Doppler echo expressed as percentage</td>
<td>Pulsed Doppler</td>
<td>≤40%</td>
</tr>
<tr>
<td>LPEI&lt;sup&gt;14&lt;/sup&gt;</td>
<td>Left ventricular pre ejection interval defined as the time interval between the beginning of QRS and beginning of left ventricular ejection by Doppler</td>
<td>Pulsed Doppler</td>
<td>≥140 ms</td>
</tr>
<tr>
<td>LLWC&lt;sup&gt;14&lt;/sup&gt;</td>
<td>Intraventricular dyssynchrony left lateral wall contraction defined as the presence of overlap between the end of lateral wall contraction (via M mode) and onset of LV filling (by Doppler echocardiography)</td>
<td>M mode and pulsed Doppler</td>
<td>Any overlap</td>
</tr>
<tr>
<td>Ts-(lateral-septal)&lt;sup&gt;15&lt;/sup&gt;</td>
<td>Delay between time to peak systolic velocity in ejection phase at basal septal and basal lateral segments</td>
<td>TDI</td>
<td>≥60 ms</td>
</tr>
<tr>
<td>Ts-SD&lt;sup&gt;11,13&lt;/sup&gt;</td>
<td>SD of time from QRS to peak systolic velocity in ejection phase for 12 left ventricular segments (6 basal and 6 middle)</td>
<td>TDI</td>
<td>≥32 ms</td>
</tr>
<tr>
<td>PVD&lt;sup&gt;16&lt;/sup&gt;</td>
<td>Peak velocity difference derived from subtracting the maximal from the minimal difference of time to peak velocity (excluding velocities occurring during isovolumic contraction time) for 6 segments at basal level</td>
<td>TDI</td>
<td>≥110 ms</td>
</tr>
<tr>
<td>DLC&lt;sup&gt;17,18&lt;/sup&gt;</td>
<td>Delayed longitudinal contraction measured in the 6 basal left ventricular segments with a systolic contraction component in early diastole by TDI and confirmed with strain rate imaging</td>
<td>TDI + SRI</td>
<td>≥2 basal segments</td>
</tr>
<tr>
<td>Ts-peak displacement</td>
<td>Maximum difference of time to peak systolic displacement for 4 segments</td>
<td>TDI</td>
<td>≥Median</td>
</tr>
<tr>
<td>Ts-peak (basal)</td>
<td>Maximum difference of time to peak systolic velocity for 6 segments at basal level</td>
<td>TDI</td>
<td>≥Median</td>
</tr>
<tr>
<td>Ts-onset (basal)</td>
<td>Maximum difference of time to onset of systolic velocity for 6 segments at basal level</td>
<td>TDI</td>
<td>≥Median</td>
</tr>
</tbody>
</table>
The “experiment” of PROSPECT study

- First large scale echo study with predefined aim to measure observer variability
- Echo indices to predict the response to CRT, defined clinical improvement and reduction of another echo parameter LVESV

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A very unexpected result!!!

A simple Measurement done in M-Mode, the method with the most spatial and temporal resolution, performed in expert centers had THE HIGHEST VARIABILITY!!!

Circulation. 2008;117: 2608-2616
Septal to Posterior Wall Motion Delay

PROSPECT: We can not measure time with precision and accuracy in M-Mode

Do you believe it?
Talking about reproducibility and repeatability, (inter/intra observer variability): pitfalls

✓ Sample Definition: combination of data acquisition and its subsequent measurement, or off-line measurement of already acquired data?

✓ Does the sample consist of a single measurement, or is it the mean of several measurements?

✓ Should observers be constrained by measuring the same cardiac cycle, or should they freely choose from several cardiac recorded cycles?

✓ Is the repeated measurement performed on the same a priori selected image, or does the observer selects an image from a specific clip?

Variability studies may have a lot of "noise"
Talking about reproducibility and repeatability, (inter/intra observer variability): pitfalls

✓ What if one study contains three individual single-beat clips while the other contains a single three-beat clip?

✓ What if different image depths, transducer frequencies, frame rates, post-processing algorithms were used in these three clips?

✓ what “observer” means: the sonographer, the supervisor, or the particular sonographer/supervisor pair?

Variability studies may have a lot of “noise”
Assessing Variability with different methods…
The importance of standard error

- LVEDD, control
- 1 SEM
- 95% CI ~2 SEM
- Minimum detectable difference ~3 SEM
- LVEDD, follow up

Gaussian error distribution curve of LVEDD measurements
Reproducibility in echocardiographic assessment of the left ventricular global and regional function, the HUNT study

Anders Thorstensen¹, Havard Dalen¹,², Brage Høyem Amundsen¹,³, Svein Arne Aase¹, and Asbjørn Stoylen¹,³

Table 1 Reproducibility of measurements of dimensions and global systolic function

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean, inter-observer</th>
<th>COR, inter-observer</th>
<th>Mean error, inter-observer (%)</th>
<th>Mean error, inter-analysers (%)</th>
<th>Mean error, intra-analysers (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVSd (Mm)</td>
<td>8.5 (1.1) mm</td>
<td>1.8 mm</td>
<td>12</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>LVPWd (Mm)</td>
<td>7.7 (1.1) mm</td>
<td>2.4 mm</td>
<td>12</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>LVIDd (Mm)</td>
<td>50 (5.3) mm</td>
<td>5.4 mm</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>MAE (Mm) mean</td>
<td>17 (1.1) mm</td>
<td>1.6 mm</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>MAE (cTDI) mean</td>
<td>15 (1.1) mm</td>
<td>2.2 mm</td>
<td>7</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>S'(pwTDI) mean</td>
<td>9.1 (2.0) cm/s</td>
<td>1.7 cm/s</td>
<td>8</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>S'(cTDI) mean</td>
<td>7.7 (1.4) cm/s</td>
<td>1.6 cm/s</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>EDV biplane</td>
<td>108 (24) mL</td>
<td>14 mL</td>
<td>12</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>ESV biplane</td>
<td>44 (9) mL</td>
<td>9 mL</td>
<td>10</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>EF biplane</td>
<td>0.59 (0.05)</td>
<td>0.07</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>FS</td>
<td>0.33 (0.06)</td>
<td>0.11</td>
<td>14</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>LVOT peak</td>
<td>1.0 (0.1) m/s</td>
<td>0.2 m/s</td>
<td>10</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Global S&lt;sub&gt;E&lt;/sub&gt; (2D-St)</td>
<td>−0.21 (0.02)</td>
<td>0.02</td>
<td>6</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Global SR&lt;sub&gt;S&lt;/sub&gt; (2D-St)</td>
<td>−1.1 (0.01) s&lt;sup&gt;−1&lt;/sup&gt;</td>
<td>0.2 s&lt;sup&gt;−1&lt;/sup&gt;</td>
<td>9</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
Reproducibility in echocardiographic assessment of the left ventricular global and regional function, the HUNT study

Anders Thorstensen¹*, Havard Dalen¹,², Brage Høyem Amundsen¹,³, Svein Arne Aase¹, and Asbjørn Stoylen¹,³

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</tr>
</thead>
<tbody>
<tr>
<td>E'(pwTDI)</td>
<td>14 (1.0) cm/s</td>
<td>3.4 cm/s</td>
<td>8</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>A'(pwTDI)</td>
<td>85 (2.5) cm/s</td>
<td>2.1 cm/s</td>
<td>9</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>74 (13) cm/s</td>
<td>12 cm/s</td>
<td>8</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>DT</td>
<td>175 (33) cm/s</td>
<td>10 cm/s</td>
<td>20</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>A</td>
<td>41 (12) cm/s</td>
<td>14 cm/s</td>
<td>18</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>E/A</td>
<td>2.0 (0.6)</td>
<td>0.35</td>
<td>22</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>IVRT</td>
<td>83 (9) ms</td>
<td>13 ms</td>
<td>17</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>E/E'(pwTDI)</td>
<td>5.4 (1.0) ms</td>
<td>1.3</td>
<td>11</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>PV S</td>
<td>55 (12) cm/s</td>
<td>12 cm/s</td>
<td>15</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>PV D</td>
<td>54 (7) cm/s</td>
<td>20 cm/s</td>
<td>16</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>PV S/D</td>
<td>1.0 (0.2)</td>
<td>0.38</td>
<td>12</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Global SRₑ</td>
<td>1.6 (0.1) s⁻¹</td>
<td>0.3 s⁻¹</td>
<td>7</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>(2D-St)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global SRₐ</td>
<td>0.8 (0.1) s⁻¹</td>
<td>0.3 s⁻¹</td>
<td>13</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>(2D-St)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

European Journal of Echocardiography (2010) 11, 149-156
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### Table 3 Reproducibility of S' (pwTDI)

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean, inter-observer</th>
<th>COR, inter-observer</th>
<th>Mean error, inter-observer (%)</th>
<th>Mean error, inter-analyser (%)</th>
<th>Mean error, intra-analyser (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S' (pwTDI) mean of 4</td>
<td>9.1 cm/s</td>
<td>1.7 cm/s</td>
<td>8</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>S' (pwTDI) mean of septal and lateral</td>
<td>9.2 cm/s</td>
<td>2.3 cm/s</td>
<td>11</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>S' (pwTDI) septal</td>
<td>8.4 cm/s</td>
<td>2.9 cm/s</td>
<td>13</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>S' (pwTDI) lateral</td>
<td>10.1 cm/s</td>
<td>2.1 cm/s</td>
<td>9</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>S' (pwTDI) inferior</td>
<td>8.7 cm/s</td>
<td>2.8 cm/s</td>
<td>15</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>S' (pwTDI) anterior</td>
<td>9.3 cm/s</td>
<td>2.7 cm/s</td>
<td>12</td>
<td>8</td>
<td>5</td>
</tr>
</tbody>
</table>

### Table 4 Reproducibility of E' (pwTDI)

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean, inter-observer</th>
<th>COR, inter-observer</th>
<th>Mean error, inter-observer (%)</th>
<th>Mean error, inter-analyser (%)</th>
<th>Mean error, intra-analyser (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E' (pwTDI) mean of 4</td>
<td>13.9 cm/s</td>
<td>3.4 cm/s</td>
<td>8</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>E' (pwTDI) mean of septal and lateral</td>
<td>14.1 cm/s</td>
<td>4.9 cm/s</td>
<td>15</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>E' (pwTDI) septal</td>
<td>12.8 cm/s</td>
<td>5.6 cm/s</td>
<td>19</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>E' (pwTDI) lateral</td>
<td>15.4 cm/s</td>
<td>5.5 cm/s</td>
<td>14</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>E' (pwTDI) inferior</td>
<td>13.6 cm/s</td>
<td>3.8 cm/s</td>
<td>10</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>E' (pwTDI) anterior</td>
<td>13.7 cm/s</td>
<td>3.6 cm/s</td>
<td>13</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>
Reproducibility in echocardiographic assessment of the left ventricular global and regional function, the HUNT study

Anders Thorstensen¹*, Havard Dalen¹,², Brage Høyem Amundsen¹,³, Svein Arne Aase¹, and Asbjørn Stoylen¹,³

Table 5  Reproducibility of systolic deformation indices obtained by two different applications

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean, inter-observer</th>
<th>COR, inter-observer</th>
<th>Mean Error, inter-observer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2D-St</td>
<td>D + St</td>
<td>2D-St</td>
</tr>
<tr>
<td>Global $S_E$</td>
<td>$-0.21$</td>
<td>$-0.19$</td>
<td>0.02</td>
</tr>
<tr>
<td>Global $S_R$</td>
<td>$-1.1 \text{ s}^{-1}$</td>
<td>$-1.2 \text{ s}^{-1}$</td>
<td>0.2 $\text{s}^{-1}$</td>
</tr>
<tr>
<td>Segmental $S_E$</td>
<td>$-0.21$</td>
<td>$-0.19$</td>
<td>0.07</td>
</tr>
<tr>
<td>Segmental $S_R$</td>
<td>$-1.1 \text{ s}^{-1}$</td>
<td>$-1.2 \text{ s}^{-1}$</td>
<td>0.5 $\text{s}^{-1}$</td>
</tr>
</tbody>
</table>

Mean, coefficient of repeatability (COR), and mean error of global and segmental end-systolic strain ($S_E$) and peak systolic strain rate ($S_R$). 2D-St, measurements by 2D-strain; D + ST, measurements by GcMat.
Eye and vision: a real analogue transducer...

Echocardiography is not an absolute analogue method
Echocardiography: Some piece of information may be lost

Comprehensible enough but not clear
Echocardiography: Some piece of information may be fused

Clear enough but not comprehensible

Hannah Hoch 1919
Novel techniques THE MAIN DRAWBACK: NOT for ALL pts, NOT by ALL cardiologists
You don't have to be a physicist to drive a car
A cardiologist must not be like a car driver, but rather like a pilot of an airplane....
Cardiologist’s Mind: The best filter

Decide about
• The quality of information
• What to measure
• How to measure
• The power of measurements
• The effect of measurements
The future: better imaging by better information collection and/or information processing

STATE-OF-THE-ART PAPERS

Ultrafast Cardiac Ultrasound Imaging
Technical Principles, Applications, and Clinical Benefits

Maja Cikes, MD, PhD,*† Ling Tong, PhD,* George R. Sutherland, MD,* Jan D’hooge, PhD*

Ultrasonic Superharmonic Imaging
Instead of conclusions...

Our Era remains Romantic. The romance of the novel techniques.

The expectations, the struggle, the hope and the dream....

of finding the Holy Grail of echocardiography

of becoming better doctors is always alive.
6. Clinical application of GLS, beyond EF

GLS Detects Early Subclinical Myocardial Dysfunction before LVEF

- Drop of 10 points to LVEF <53%
- Relative drop of GLS as compared to baseline
  - < 8%
  - > 15%
- No evidence of subclinical LV dysfunction
- Subclinical LV dysfunction

*a relative % reduction in the GLS of > 15% from baseline identifies subclinical LV dysfunction*

*The data supporting the initiation of cardioprotection for the treatment of subclinical LV dysfunction is limited.*

J Plana et al JASE 2014
## Proposed diagnostic tools for the detection of cardiotoxicity

<table>
<thead>
<tr>
<th>Technique</th>
<th>Currently available diagnostic criteria</th>
<th>Advantages</th>
<th>Major limitations</th>
</tr>
</thead>
</table>
| Echocardiography:  
- 3D-based LVEF  
- 2D Simpson’s LVEF  
- GLS | • LVEF: >10 percentage points decrease to a value below the LLN suggests cardiotoxicity.  
• GLS: >15% relative percentage reduction from baseline may suggest risk of cardiotoxicity. | • Wide availability.  
• Lack of radiation.  
• Assessment of haemodynamics and other cardiac structures. | • Inter-observer variability.  
• Image quality.  
• GLS: inter-vendor variability, technical requirements. |
| Nuclear cardiac imaging (MUGA) | • >10 percentage points decrease in LVEF with a value <50% identifies patients with cardiotoxicity. | • Reproducibility. | • Cumulative radiation exposure.  
• Limited structural and functional information on other cardiac structures. |
| Cardiac magnetic resonance | • Typically used if other techniques are non-diagnostic or to confirm the presence of LV dysfunction if LVEF is borderline. | • Accuracy, reproducibility.  
• Detection of diffuse myocardial fibrosis using T1/T2 mapping and ECVF evaluation. | • Limited availability.  
• Patient’s adaptation (claustrophobia, breath hold, long acquisition times). |
| Cardiac biomarkers:  
- Troponin I  
- High-sensitivity Troponin I  
- BNP  
- NT-proBNP | • A rise identifies patients receiving anthracyclines who may benefit from ACE-Irs.  
• Routine role of BNP and NT-proBNP in surveillance of high-risk patient needs further investigation. | • Accuracy, reproducibility.  
• Wide availability.  
• High-sensitivity. | • Insufficient evidence to establish the significance of subtle rises.  
• Variations with different assays.  
• Role for routine surveillance not clearly established. |
<table>
<thead>
<tr>
<th>First Author, Year (Ref. #)</th>
<th>Method</th>
<th>Cancer</th>
<th>n</th>
<th>Age, yrs</th>
<th>Women, %</th>
<th>Treatment</th>
<th>Echo Timing</th>
<th>Pre-Echo</th>
<th>Post-Echo</th>
<th>Vendor, Reproducibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stoodley et al. 2013 (32)*</td>
<td>STE</td>
<td>Breast</td>
<td>78</td>
<td>52 ± 10</td>
<td>98.7</td>
<td>Doxorubicin 81%, epirubicin 19%</td>
<td>Pre- and 1-week post-anthracycline, then at 6 and 12 months</td>
<td>GLS = −15.8 ± 2.4%</td>
<td>GLS = −17.0 ± 2.2%</td>
<td>GE, Interobserver GLS 90.9%, Intraobserver 9.9%</td>
</tr>
<tr>
<td>Stoodley et al. 2013 (33)*</td>
<td>STE</td>
<td>Breast</td>
<td>52</td>
<td>49 ± 9</td>
<td>100</td>
<td>Doxorubicin 77% epirubicin 23%</td>
<td>Pre- and 1-week post-anthracycline</td>
<td>e-SR = 1.0 ± 0.2/s</td>
<td>e-SR = 0.9 ± 0.2/s</td>
<td>GE, Interobserver and Intraobserver as mean difference (SD) for early 0.08 (0.12/s) and 0.01 (0.08/s) and late diastolic SR 0.06 (0.12/s) and 0.01 (0.08/s), GLS −1.73 (1.0%) and −0.86 (0.59%)</td>
</tr>
<tr>
<td>Zhang et al. 2012 (36)</td>
<td>TDI</td>
<td>Breast</td>
<td>60</td>
<td>54 ± 12</td>
<td>100</td>
<td>Epirubicin</td>
<td>Pre-treatment and at 7 days (post reaching 100, 200, 300, and 400 mg/m³)</td>
<td>LSR = −1.69 ± 0.64/s</td>
<td>LSR = −1.45 ± 0.36/s (at 200 mg/m³)</td>
<td>Phillips, Interobserver and Intraobserver as percentage of mean of 2 repeated measures: 10 ± 4% and 11.2% 3%</td>
</tr>
<tr>
<td>Notoki et al. 2012 (30)</td>
<td>STE</td>
<td>NHL, AML, ALL</td>
<td>25</td>
<td>58 ± 11</td>
<td>50</td>
<td>Anthracyclines</td>
<td>Pre-treatment and at 1 and 3 months</td>
<td>No values provided</td>
<td>Reduced torsion, twisting and untwisting rate, and GLS by 1 month</td>
<td>GE, Interobserver and Intraobserver variability as bias ±1.96 (SD) for LV torsion were −0.26° (1.59) and −0.21° (1.39)</td>
</tr>
<tr>
<td>Stoodley et al. 2011 (34)*</td>
<td>STE</td>
<td>Breast</td>
<td>52</td>
<td>49 ± 9</td>
<td>100</td>
<td>Doxorubicin and epirubicin</td>
<td>Pre- and 1-week post-anthracycline</td>
<td>GLS = −17.8 ± 2.1%</td>
<td>GLS = −16.3 ± 2.0%</td>
<td>GE, mean (SD) Interobserver and Intraobserver for GLS −1.73 (1.0%) and −0.86 (0.59%), GRS 5.0 (7.8%) and 3.4 (12.4%), GCS 1.48 (12.4%) and 1.62 (1.10%)</td>
</tr>
<tr>
<td>Casali et al. 2010 (28)</td>
<td>TDI</td>
<td>Multiple</td>
<td>49</td>
<td>68 ± 13</td>
<td>76</td>
<td>Epirubicin</td>
<td>Pre-treatment and at 7 days (post reaching 100, 200, 300, and 400 mg/m³)</td>
<td>LSR = −1.78 ± 0.24/s</td>
<td>LSR = −1.41 ± 0.31/s (by 200 mg/m³)</td>
<td>Toshiba, no data</td>
</tr>
</tbody>
</table>

**Table 1**: Summary of Studies That Have Used Advanced Myocardial Mechanics to Illustrate Early Myocardial Injury During Cancer Chemotherapy
### Table 3: Early Predictors of Cardiotoxicity

<table>
<thead>
<tr>
<th>Studies/First Author (Ref. #)</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallah-Rad et al. (44)</td>
<td>79%</td>
<td>82%</td>
<td>60%</td>
<td>92%</td>
</tr>
<tr>
<td>2% absolute (10.1% relative) decrease in LS</td>
<td>86%</td>
<td>81%</td>
<td>60%</td>
<td>95%</td>
</tr>
<tr>
<td>0.8% decrease in RS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sawaya et al. (41)†</td>
<td>78%</td>
<td>79%</td>
<td>50%</td>
<td>93%</td>
</tr>
<tr>
<td>10% decrease in GLS</td>
<td>67%</td>
<td>82%</td>
<td>50%</td>
<td>90%</td>
</tr>
<tr>
<td>Elevated hsTnl</td>
<td>55%</td>
<td>97%</td>
<td>83%</td>
<td>89%</td>
</tr>
<tr>
<td>10% decrease in GLS and elevated hsTnl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10% decrease in GLS or elevated hsTnl</td>
<td>89%</td>
<td>65%</td>
<td>40%</td>
<td>97%</td>
</tr>
<tr>
<td>Sawaya et al. (40)†</td>
<td>74%</td>
<td>73%</td>
<td>53%</td>
<td>87%</td>
</tr>
<tr>
<td>GLS &lt;19%</td>
<td>48%</td>
<td>73%</td>
<td>44%</td>
<td>77%</td>
</tr>
<tr>
<td>hsTnl &gt;30 pg/ml</td>
<td>35%</td>
<td>93%</td>
<td>67%</td>
<td>77%</td>
</tr>
<tr>
<td>LS &lt;19% and usTnl &gt;30 pg/ml</td>
<td>87%</td>
<td>53%</td>
<td>43%</td>
<td>91%</td>
</tr>
<tr>
<td>LS &lt;19% or usTnl &gt;30 pg/ml</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negishi et al. (42)‡</td>
<td>65%</td>
<td>95%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1.1% reduction in global GLS</td>
<td>82%</td>
<td>67%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3.6% reduction in global GLSR early diastole</td>
<td>73%</td>
<td>67%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6.4% reduction in global GLSR</td>
<td>96%</td>
<td>66%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Absolute GLS at 6 months &lt; −20.5%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Mornos et al. (39)§</td>
<td>71% × 5 reduction in GLS × LV twist</td>
<td>90%</td>
<td>82%</td>
<td>—</td>
</tr>
<tr>
<td>2.77% absolute (~13% relative) reduction in GLS</td>
<td>79%</td>
<td>73%</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>1.75% absolute reduction in apical rotation</td>
<td>70%</td>
<td>78%</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Baratta et al. (37)¶</td>
<td>86%</td>
<td>86%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>≥15% decrease in GLS</td>
<td>86%</td>
<td>69%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>≥10% decrease in GR</td>
<td>86%</td>
<td>69%</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>≥15% decrease in GLS AND ≥10% decrease in GR</td>
<td>71%</td>
<td>97%</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

Thavendiranathan et al. JACC Vol. 63, No. 25, 2014
Echocardiography opened new roads in understanding heart physiology and pathophysiology.

From experimental studies, hemodynamic data, or clinical theoretical approach to live demonstration.
5. Confirming Mechanical Dysynchrony as a parameter of heart failure pathophysiology
6. Relationship between EF and GL STRAIN

6. Prognostic implications of GLS, beyond EF

6. Helical myocardial deformation assessed by speckle tracking echocardiography
Emergency Conditions that bedside echocardiography can help

- Cardiac Arrest
- Unexplained hypotension
- Shortness of Breath
- Chest Pain
- Procedural Guidance for pericardiocentesis
Chest pain: Possibly detectable
Causes by ECHO

- AMI, ACS—regional wall motion abnormality
- Aortic Dissection—dilated Ao, visible intimal flap
- Pulmonary Embolism—dilated RV and IVC, visible thrombus in RV/PA
- Pericarditis with effusion—pericardial effusion
Shortness of Breath: acute or decompensated heart failure?

If heart failure confirmed, determine aetiology and start appropriate treatment
**Inferior vena cava assessment = Preload assessment**

- Normally IVC collapsed with inspiration
- Hypovolaemia: collapsed IVC
- RV infarction, Massive Pulmonary Embolism
- Cardiac Temponade: distended IVC and Loss of inspiratory Collapse
- Semi-quantitative estimation of Pulmonary Artery Pressure
Bedside hand-carried ultrasound by internal medicine residents for the identification of systolic dysfunction in patients admitted with decompensated heart failure

Razi et al, JASE 2011

- Sensitivity = 94%, specificity = 94%
  NPV = 88%, PPV = 97%
- The time interval between clinical assessment and availability of formal echocardiographic results was 22 ± 17 hours
POC echocardiography can be limited and intended to only answer focused, usually dichotomous questions
Hand-carried cardiac ultrasound reduces the need for standard echocardiography

- A definite diagnosis was established in 34/108 of them (31%)
- The overall agreement between HCU and SE for diagnosis of normal/abnormal echocardiograms was 73% (κ=0.4)
- A total cost saving of €2142 per 100 patients referred for echocardiography was estimated.

P Trambaiolo et al. Heart 2007;93:470-475
Basic principles of echocardiography: echo-tissue interactions

**Specular reflection**
- One direction

**Diffuse reflection**
- Multiple directions
  - Low amplitude

**Types of Echoes**

- **Specular**: echoes originating from relatively large, regularly shaped objects with smooth surfaces. These echoes are relatively intense and angle dependent. (i.e. IVS, valves)
- **Scattered**: echoes originating from relatively small, weakly reflective, irregularly shaped objects are less angle dependant and less intense. (i.e. blood cells)
Echomachines: from past till today

The Modalities of Echo

The following modalities of echo are used clinically:
1. Conventional echo
   Two-Dimensional echo (2-D echo)
   Motion- mode echo (M-mode echo)
2. Doppler Echo
   Continuous wave (CW) Doppler
   Pulsed wave (PW) Doppler
   Colour flow(CF) Doppler

All modalities follow the same principle of ultrasound
Differ in how reflected sound waves are collected and analysed
Recommendation 1. Pocket-size imaging devices do not provide a complete diagnostic echocardiographic examination.

Recommendation 2. Imaging assessment with pocket-size imaging devices should be reported as part of the physical examination of the patient.

Recommendation 3. With the exception of cardiologists who are certified for transthoracic echocardiography, specific training and certification is recommended for all users.

Recommendation 4. The patient has to be informed that an examination with the current generation of pocket-size imaging devices does not replace a complete echocardiogram.
A second level of variability

- **Reanalysis** different clips/frames from the same study are chosen for measurements
- **Test-retest variability**: the ultimate test of variability when the study is repeated a second time and remeasured
Limitation 4: Learning curve

minimum of 50 studies

The generation of helical deformation study: a further step with ST

Measuring angles...another aspect of contractility...

<table>
<thead>
<tr>
<th>Systolic</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apical rotation (°)</strong></td>
<td>Peak counterclockwise systolic rotation of the LV apical short-axis cross section as viewed from the apex</td>
</tr>
<tr>
<td><strong>Apical rotation rate (°/s)</strong></td>
<td>Peak velocity of apical counterclockwise rotation</td>
</tr>
<tr>
<td><strong>Basal rotation (°)</strong></td>
<td>Peak clockwise systolic rotation of the LV basal short-axis cross section level as viewed from the apex</td>
</tr>
<tr>
<td><strong>Basal rotation rate (°/s)</strong></td>
<td>Peak velocity of basal clockwise rotation</td>
</tr>
<tr>
<td><strong>LV twist (°)</strong></td>
<td>Peak difference in systolic rotations of LV apex and base as viewed from the apex</td>
</tr>
<tr>
<td><strong>LV torsion (°/cm)</strong></td>
<td>Normalized twist: twist angle divided by the distance between the measured locations of base and apex</td>
</tr>
<tr>
<td><strong>LV twist rate (°/s)</strong></td>
<td>Peak velocity of LVT</td>
</tr>
</tbody>
</table>
Focused POC echocardiography goals

- Assessment of pericardial effusion
- Assessment of global cardiac function
- Identification of marked right ventricular and left ventricular enlargement
- Intravascular volume assessment
- Assessment of extravascular lung water (B-lines)
- Guidance of pericardiocentesis
- Confirmation of transvenous pacing wire placement
Cardiologists have started to train non-cardiologists in particular aspects of echocardiography.
POC echocardiography training for novice non cardiologists: 2-30 hours

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Prior TTE Training</th>
<th>Training</th>
<th>Imaging Goals</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longjohn et al</td>
<td>Pediatric emergency physicians (n=2)</td>
<td>Minimal</td>
<td>2 hours didactic training; 15 practice POC TTEs</td>
<td>LV function (normal or diminished); IVC collapsibility; pericardial effusion</td>
<td>Agreement with cardiologist:LV function $\kappa=0.87$, IVC collapsibility $\kappa=0.73$, pericardial effusion $\kappa=0.77$</td>
</tr>
<tr>
<td>Razi et al</td>
<td>Internal medicine residents (n=3)</td>
<td>None</td>
<td>Image review (DVD with 50 sample TTEs); 20 practice POC TTEs</td>
<td>LV systolic dysfunction (LVEF&lt;40%)</td>
<td>Sensitivity 94%; Specificity 94%;</td>
</tr>
<tr>
<td>Lucas et al</td>
<td>Internal medicine hospitalists (n=8)</td>
<td>None</td>
<td>27 hours didactic and hands-on training; 34 practice POC TTEs</td>
<td>LV systolic dysfunction; severe mitral regurgitation; moderate/severe left atrial enlargement; moderate/severe LVH; pericardial effusion; IVC dilatation</td>
<td>LV systolic dysfunction:sensitivity 84%; specificity 87%; pericardial effusion: sensitivity 100%; specificity 95%</td>
</tr>
<tr>
<td>Croft et al</td>
<td>Internal medicine residents (n=9)</td>
<td>None</td>
<td>15 hours didactic training (including image review); 15 hours hands-on training</td>
<td>LV size; global/regional LV systolic function; valvular abnormalities; LVH; pericardial effusion</td>
<td>Diagnostic images obtained: 94%; Images interpreted correctly: 93%; Correct identification of major TTE findings: 92%, and minor findings: 78%</td>
</tr>
</tbody>
</table>
Transducer: the stethoscope of 21st century
Stress echocardiography: “watching” heart in real effort, real time

Ischemic Cascade in front of our eyes
1. Quantification of myocardial contractility — introduction of a common easy and friendly language: left ventricular ejection fraction
2. Confirming Heart failure with preserved ejection Fraction

Do not count only on contractility!
3. Confirming new pathophysiological entities

- remodeling
- viability
- stunned and hibernating myocardium
4. Introducing new approaches for assessing severity of valvulopathies

- Revised old terms: AVA, MVA, GRADIENTS

- Introducing new terms: ERO, RV, RF
Echocardiography opened new roads introducing new clinical practices
# Results of the Predictors of Response to CRT (PROSPECT) Trial

Eugene S. Chung, MD; Angel R. Leon, MD; Luigi Tavazzi, MD; Jing-Ping Sun, MD; Petros Nihoyannopoulos, MD; John Merlino, MD; William T. Abraham, MD; Stefano Ghio, MD; Christophe Leclercq, MD; Jeroen J. Bax, MD; Cheuk-Man Yu, MD, FRCP; John Gorcsan III, MD; Martin St John Sutton, FRCP; Johan De Sutter, MD, PhD; Jaime Murillo, MD

<table>
<thead>
<tr>
<th>Echocardiography Type</th>
<th>Dyssynchrony Measure</th>
<th>Echocardiograms, (yield) %</th>
<th>CCS</th>
<th>LVESV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sensitivity, %</td>
<td>Specificity, %</td>
</tr>
<tr>
<td>M mode</td>
<td>SPWMD</td>
<td>71.7</td>
<td>55.4 (43.3–62.3)</td>
<td>50.0 (39.1–60.9)</td>
</tr>
<tr>
<td>Pulsed Doppler</td>
<td>IVMD</td>
<td>92.4</td>
<td>55.2 (48.9–61.4)</td>
<td>56.4 (46.9–65.6)</td>
</tr>
<tr>
<td></td>
<td>LVFT/RR</td>
<td>85.3</td>
<td>36.3 (30.2–42.7)</td>
<td>76.6 (67.5–84.3)</td>
</tr>
<tr>
<td></td>
<td>LPEI</td>
<td>94.6</td>
<td>66.3 (60.2–72.0)</td>
<td>47.1 (38.0–56.4)</td>
</tr>
<tr>
<td>M mode + Doppler</td>
<td>LLWC</td>
<td>60.7</td>
<td>6.3 (3.2–11.0)</td>
<td>91.7 (82.7–96.9)</td>
</tr>
<tr>
<td>TDI, published</td>
<td>Ts (Lat-Sep)</td>
<td>66.8</td>
<td>42.4 (34.4–50.7)</td>
<td>56.9 (44.7–68.6)</td>
</tr>
<tr>
<td></td>
<td>Ts-SD</td>
<td>50.0</td>
<td>74.1 (65.2–81.8)</td>
<td>35.3 (22.4–49.9)</td>
</tr>
<tr>
<td></td>
<td>PVD</td>
<td>81.4</td>
<td>67.6 (60.3–74.3)</td>
<td>37.8 (27.8–48.6)</td>
</tr>
<tr>
<td>TDI + SRI</td>
<td>DLC</td>
<td>81.1</td>
<td>41.7 (34.4–49.2)</td>
<td>60.4 (49.6–70.5)</td>
</tr>
<tr>
<td>TDI, median value used as cutoff</td>
<td>Ts-peak displacement</td>
<td>37.4</td>
<td>54.8 (43.5–65.7)</td>
<td>56.1 (39.7–71.5)</td>
</tr>
<tr>
<td></td>
<td>Ts-peak basal</td>
<td>82.0</td>
<td>51.9 (44.4–59.3)</td>
<td>53.8 (43.1–64.4)</td>
</tr>
<tr>
<td></td>
<td>Ts-onset basal</td>
<td>82.0</td>
<td>54.1 (46.6–61.5)</td>
<td>60.4 (49.6–70.5)</td>
</tr>
</tbody>
</table>
Basic principles of Doppler echocardiography

Doppler equation: $f_d = 2f_t \cdot V(\cos \theta) / c$
Innovation in Echocardiography. Contrast echocardiography: improvement of tissue border delineation

Principle of Contrast Echo Ultrasound-Contrast Interaction

- Gas bubbles are highly compliant
- Bubbles in an acoustic field resonate at the ultrasound frequency
- Differentiating the contrast echo from ordinary tissue forms the basis contrast echo

![Acoustic Power and Microbubble Responses]

A. High Power (>0.5)
B. Low Power (0.2-0.4)
C. Very Low Power (<0.1)
Physics of echocardiography: the fundamentals. Period, Frequency, Velocity, Wave length

\[ V = W \times F \]
Hypertension trials

- Evaluation of treatment effects on LV mass.
- Effects of treatment on systolic and diastolic LV function.

<table>
<thead>
<tr>
<th>Study</th>
<th>References</th>
<th>Echo participants</th>
<th>Echo sites</th>
<th>Echo Frequency</th>
<th>Length, year</th>
<th>Study aims</th>
<th>Principal findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA Cooperative Studies:</td>
<td>144</td>
<td>587</td>
<td>15</td>
<td>Baseline, 1, 2 years</td>
<td>1</td>
<td>LV mass reduction in participants on competing single-drug assignments for mild-moderate hypertension</td>
<td>Diuretic effective for decreasing LV mass and LA size; diuretic, captopril, atenolol for LV mass</td>
</tr>
<tr>
<td>Monotherapy in Hypertension TOMHS (Treatment of Mild Hypertension Study)</td>
<td>94</td>
<td>902</td>
<td>4</td>
<td>Baseline, annually for 4 years</td>
<td>4</td>
<td>LV mass reduction with monotherapy vs dietary-hygienic control</td>
<td>All treatments associated with decrease in LV mass. Diuretic greater than other drugs at 1 year</td>
</tr>
<tr>
<td>Isradipine vs hydrochlorothiazide</td>
<td>145</td>
<td>134</td>
<td>18</td>
<td>Baseline, 6 mo, 12 mo, 2 weeks after drug withdrawal</td>
<td>.5</td>
<td>Isradipine vs hydrochlorothiazide monotherapy for LV mass and LA dimension reduction</td>
<td>Decreased LV mass and LA size with hydrochlorothiazide, not with isradipine.</td>
</tr>
<tr>
<td>LIFE (Losartan Intervention for Endpoint Reduction in Hypertension)</td>
<td>241</td>
<td>754</td>
<td>47</td>
<td>Baseline, 1, 2, 3, 4, and 5 years</td>
<td>4.8</td>
<td>Losartan vs atenolol for LV mass reduction; prognostic significance of LV mass reduction</td>
<td>Greater LV mass reduction with losartan than with atenolol. Strong predictive value of lower on-treatment LV mass for outcome.</td>
</tr>
</tbody>
</table>
The impact from PROSPECT study...

- Reduction of confidence regarding novel echo indices
- Reduction of enthusiasm regarding involving in another subspecialty
- What do we measure?
- Can we rely on our measurements?
The Austrian C. A. Doppler (1803-1853) worked out the mathematical relationship between the frequency shift of sound and the relative motion of the sound source and the observer, a theory tested in practice in 1845 by C. H. D. Buys Ballot (1817 - 1890) in Utrecht.

Investigation of blood flow velocity using Doppler frequency shifts to measure motion of cardiac structures, and later of the velocity of red blood cells, started with the work of S. Satomura and his colleagues in 1957.

The pulsed-wave Doppler technique was almost simultaneously introduced by P. N.T. Wells, P. A. Peronneau et al. and D. W. Baker.

The method allowed depth selection for blood flow velocity interrogation, but the major step forward for its clinical acceptance was its combination with imaging: the duplex scanner published by F. E. Barber et al. in 1974.

Simultaneously, another major breakthrough in Doppler came in 1979, when Holen and then Hatle noted that a modified Bernoulli equation could be used to detect pressure gradients.

In 1978, the Swiss-born M. A. Brandestini et al. produced a 128-channel digital multigate Doppler instrument, allowing the imaging of cardiac structures and blood flow in colour and in real-time.
Innovation in Echocardiography: Deformation Study
Transducer became a non invasive “catheter” for estimating intracavitary pressures
Coronary flow Reserve: an invasive functional coronary angiogram
Echomachines were brought in the Emergency Depts
Point of Care echocardiography

Echomachines were brought in the Intensive Care Units
Emergency echocardiography: the European Association of Cardiovascular Imaging recommendations

Aleksandar N. Neskovic, Andreas Hagendorff, Patrizio Lancellotti, Fabio Guarracino, Albert Varga, Bernard Cosyns, Frank A. Flachskampf, Bogdan A. Popescu, Luna Gargani, Jose Luis Zamorano, and Luigi P. Badano, on behalf of the European Association of Cardiovascular Imaging

Table 8  ‘ABCD approach’ in performing emergency echocardiography

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Awareness</td>
</tr>
<tr>
<td></td>
<td>• Fight against routine</td>
</tr>
<tr>
<td></td>
<td>• Think beyond apparent explanations</td>
</tr>
</tbody>
</table>

| B | Be Suspicious |
|   | • Referral diagnosis may be misleading |
|   | • Never trust, confirm |

| C | Comprehensiveness |
|   | • Do as complete examination as suitable |
|   | • Careful interpretation |

| D | Double R<sup>a</sup> |
|   | • The study should be recorded and reviewed |
|   | • Team work is crucial |

<sup>a</sup>Record and Review.
Pocket Mobile Echocardiography: The Next-Generation Stethoscope?

Nuno Cardim[^1,2^], Havard Dalen[^3,4,5^], Jens-Uwe Voigt[^6^], Adrian Ionescu[^7^], Susanna Price[^8^], Aleksandar N. Neskovic[^9,10^], Thor Edvardsen[^11^], Maurizio Galderisi[^12^], Rosa Sicari[^13^], Erwan Donal[^14,15^], Alexandros Stefanidis[^16^], Victoria Delgado[^17^], Jose Zamorano[^18,19^], and Bogdan A. Popescu[^20^]

### Table 2  Different types of ultrasound

<table>
<thead>
<tr>
<th>Ultrasonic studies</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard or conventional echocardiography</td>
<td>Standard or conventional echocardiography, which acquires a well-defined examination, including morphological and functional echocardiography, which acquires a well-defined examination</td>
</tr>
<tr>
<td>Emergency echocardiography</td>
<td>Emergency environments in the assessment of</td>
</tr>
<tr>
<td>Goal-oriented echocardiography</td>
<td></td>
</tr>
<tr>
<td>Point-of-care ultrasonography (POCUS)</td>
<td></td>
</tr>
<tr>
<td>Focused cardiac ultrasound (FoCUS)</td>
<td></td>
</tr>
</tbody>
</table>

[^1]: Missing information
[^2]: Missing information
[^3]: Missing information
[^4]: Missing information
[^5]: Missing information
[^6]: Missing information
[^7]: Missing information
[^8]: Missing information
[^9]: Missing information
[^10]: Missing information
[^11]: Missing information
[^12]: Missing information
[^13]: Missing information
[^14]: Missing information
[^15]: Missing information
[^16]: Missing information
[^17]: Missing information
[^18]: Missing information
[^19]: Missing information
[^20]: Missing information
### Epidemiological and Observational Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of participants</th>
<th>No. of Echo sites</th>
<th>Echo frequency</th>
<th>Population; follow-up</th>
<th>Year echo performed</th>
<th>Study aims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framingham</td>
<td>4950+</td>
<td>1</td>
<td>Per examination cycle</td>
<td>Population-based CVD, original cohort and descendants; &gt;20 years</td>
<td>1981-present</td>
<td>Assessment of LV mass, function, chamber size</td>
</tr>
<tr>
<td>Olmstead County (Mary)</td>
<td>2942</td>
<td>1</td>
<td>Twice</td>
<td>Elderly &gt;65 years; 14-year follow-up</td>
<td>1990, 1995</td>
<td>Population-based assessment of systolic and diastolic dysfunction</td>
</tr>
<tr>
<td>Cardiovascular Health Study (CHS)</td>
<td>5888</td>
<td>4</td>
<td>Twice; 5-year interval</td>
<td>Elderly &gt;65 years; 14-year follow-up</td>
<td>1990, 1995</td>
<td>Population-based assessment of LV mass, systolic and diastolic function, chamber size. Comparison with wide array of clinical and biomedical variables.</td>
</tr>
<tr>
<td>CARDIA</td>
<td>1189</td>
<td>4</td>
<td>Twice; 5-year interval</td>
<td>Age 23-35 years; approximately 14-year follow-up</td>
<td>1990, 1995</td>
<td>Population-based assessment of systolic and diastolic dysfunction</td>
</tr>
<tr>
<td>Baltimore Longitudinal Aging Study (BLA)</td>
<td>1100+</td>
<td>1</td>
<td>Multiple</td>
<td>Age 21-90 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helsinki Aging Study</td>
<td>577</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strong Heart Family Study</td>
<td>3600+</td>
<td>3</td>
<td>Once: 4th Strong Heart Study exam / Strong Heart Family Study (some Strong Heart Study participants reexamined)</td>
<td>White &amp; African-American hypertensive adults from population-based sources</td>
<td>1996-1990</td>
<td>Heritability and genetic linkage of LV hypertrophy and dysfunction</td>
</tr>
<tr>
<td>HyperGEN exam</td>
<td></td>
<td></td>
<td></td>
<td>American Indians in large 3-generation families, CV events after examination</td>
<td>2001-2003</td>
<td>Heritability and genetic linkage of LV hypertrophy and dysfunction; LV-arterial relations (with carotid ultrasound)</td>
</tr>
</tbody>
</table>

 Provided important cross-sectional and longitudinal information on relationships between cardiac structure and function, determined echocardiographically, with clinical expressions of disease and with clinical outcome.
American Society of Echocardiography
Recommendations for Use of
Echocardiography in Clinical Trials

A Report from the American Society of
Echocardiography’s Guidelines and
Standards Committee and The Task Force on
Echocardiography in Clinical Trials

Writing Committee: John S. Gottdiener, MD (Chair), James Bednarz, BS, RDCS,
Richard Devereux, MD, Julius Gardin, MD, Allan Klein, MD, Warren J. Manning, MD,
Annitta Morehead, BA, RDCS, Dalane Kitzman, MD, Jae Oh, MD, Miguel Quinones, MD,
Nelson B. Schiller, MD, James H. Stein, MD, and Neil J. Weissman, MD