Speckle Tracking Echocardiography
Principles and Applications

Bogdan A. Popescu

University of Medicine and Pharmacy
Bucharest, Romania

EAE Course, Bucharest, April 2010
Speckle tracking echocardiography (STE)

• A newly developed **non-Doppler technique** for the assessment of cardiac mechanics from routine gray-scale 2D images

  • **speckle formation**: scattering, reflection, and interference of the ultrasound beams in myocardial tissue

  • **natural acoustic markers**
Feature Selection

- Tracking the feature to the next frame is accomplished by surrounding the feature with a square of ~ 20 x 20 pixels and finding its position in the subsequent frame, optimizing the cross-correlation between them.
Local Velocities

- The local tissue velocity is estimated as a shift of distance divided by time between successive frames:

\[ \text{2D velocity vector: } (V_x, V_y) = \frac{(dX, dY)}{\text{Frame Time}} \]

- Angle-independent technique!
STI - Pros

- **angle independent technique**
  - assessment of regional LV function (2D)
    - (velocity, displacement, strain/strain rate)
  - assessment of **longitudinal**, **radial**, and **circumferential** strain
  - accurate assessment of LV rotation / torsion
- **good temporal resolution vs tagged MRI** (provided high frame rates are used)
- suitable for research as well as for clinical use
STE - Cons

- the quality of the recordings must be high to achieve correct tracking (good acoustic window, proper adjustment of frame rate, probe frequency, focus)

- out-of-plane motion: motion of the heart in the chest cavity, breathing (new features keep coming in as previous ones fade out) – *3D strain should solve this*

- speckle quality is sometimes suboptimal in the subepicardial layer of the LV (excluded from final analysis in some studies)
ST Echo - clinical applications

- **global LV systolic function:**
  
  LV volumes; LV ejection fraction; LV torsion

- **regional LV function:** displacement, strain, strain-rate

  longitudinal myocardial strain: apical recordings

  radial and circumferential strain: short-axis recordings

- **diastolic LV function:** LV untwisting

- **dyssynchrony assessment** (for CRT)

- **RV function**
Feasibility of Strain Analysis by Speckle Imaging

Two-dimensional Strain – A Novel Software for Real-time Quantitative Echocardiographic Assessment of Myocardial Function

Marina Leitman, MD, Peter Lysyansky, PhD, Stanislav Sidenko, Vladimir Shir, Eli Peleg, MD, Michal Binenbaum, Edo Kaluski, MD, FACC, Ricardo Krakover, MD, and Zvi Vered, MD, FACC, FESC, Haifa and Tel Aviv, Israel
Validation: Speckle Imaging Strain

Automated Analysis of Strain Rate and Strain: Feasibility and Clinical Implications
Charlotte Bjork Ingul, MD, Hans Torp, Dr Tech, Svein Arne Aase, MS, Sigrid Berg, MS, Asbjorn Stoelen, MD, PhD, and Stig A. Slordahl, MD, PhD, Trondheim, Norway

Noninvasive Myocardial Strain Measurement by Speckle Tracking Echocardiography
Validation Against Sonomicrometry and Tagged Magnetic Resonance Imaging
Brage H. Amundsen, MD,* Thomas Helle-Valle, MD,† Thor Edvardsen, PhD, MD,† Hans Torp, DRTECHN,* Jonas Crosby, MSc,* Erik Lyseggen, MD,† Asbjorn Stoelen, MD, PhD,*‡ Halfdan Ihlen, MD, PhD,† João A. C. Lima, MD, FACC,§ Otto A. Smiseth, MD, PhD, FACC,† Stig A. Slordahl, MD, PhD*‡ Trondheim and Oslo, Norway; and Baltimore, Maryland

Analysis of myocardial deformation based on pixel tracking in two dimensional echocardiographic images enables quantitative assessment of regional left ventricular function
M Becker, E Bilke, H Kühl, M Katoh, R Kramann, A Franke, A Bücker, P Hanrath and R Hoffmann

TDI versus STE strain

**TDI STRAIN**
- 1-dimensional
- Angle-dependent (limited segments)
- Limited spatial resolution
- High temporal resolution
- Less dependent on image quality
- Requires expert readers to ensure reliability of results
- Time consuming
- Higher interobserver reproducibility

**STE STRAIN**
- 2-dimensional
- Angle-independent (comprehensive)
- Better spatial resolution
- Lower temporal resolution
- Dependent on image quality
- Semi-automated analysis for less experienced observers
- Rapid
- Better reproducibility
Peak Systolic Strain

GLPSS_LAX  -16.1 %
GLPSS_A4C   -19.2 %
GLPSS_A2C   -19.7 %
GLPSS_Avg   -18.4 %
HR_ApLAX    67.0 bpm
AVC_CALC    0.401 sec
Acute MI Typical Patterns

**Normal**

**LAD**

**RCA**

**LCX**
Follow-Up: Myocarditis

Before recovery

After recovery

Courtesy of Dr. M. Feinberg
Global longitudinal strain in HCM

Father

HCM

Global strain: -9.3%

1\textsuperscript{st} son

Subclinical dysfx

Global strain: -16.2%

2\textsuperscript{nd} son

Normal

Global strain: -20.6%

Courtesy of Dr. M. Rosca
Novel Speckle-Tracking Radial Strain From Routine Black-and-White Echocardiographic Images to Quantify Dyssynchrony and Predict Response to Cardiac Resynchronization Therapy

Matthew S. Suffoletto, MD; Kaoru Dohi, MD; Maxime Cannesson, MD; Samir Saba, MD; John Gorcsan III, MD
STE – Cardiac Resynchronization Therapy

- STE applied to midventricular short-axis images to determine dyssynchrony diff. in time to peak radial strain

- 64 heart failure pts undergoing CRT

A baseline septal to posterior wall delay of $\geq 130$ ms (by STE) predicted:

- immediate increase in stroke volume $\geq 15\%$ in response to CRT
- improvement in EF ($\geq 15\%$) in a subgroup (n = 50) followed for 8±5 months

Prognostic Value of Longitudinal Strain After Primary Reperfusion Therapy in Anterior AMI

Prediction of LV remodelling

Prediction of adverse CV events

Prediction of All-Cause Mortality From Global Longitudinal Speckle Strain

546 consecutive pts followed for 5.2±1.5 years

GLS is a superior predictor of outcome to either EF or WMSI and may become the optimal method for assessment of global LV function

LV rotation by STE : validation

Measurement of Ventricular Torsion by Two-Dimensional Ultrasound Speckle Tracking Imaging

Yuichi Notomi, MD* Peter Lysyansky, PhD,‡ Randolph M. Setser, DSc,† Takahiro Shiota, MD, FACC,* Zoran B. Popović, MD,* Maureen G. Martin-Miklović, Joan A. Weaver, RT,* Stephanie J. Oryszak,* Neil L. Greenberg, PhD, FACC,* Richard D. White, MD,*† James D. Thomas, MD, FACC*

*Cleveland, Ohio; and Tirat Hacarmel, Israel

New Noninvasive Method for Assessment of Left Ventricular Rotation
Speckle Tracking Echocardiography

Thomas Helle-Valle, MD; Jonas Crosby, MSc; Thor Edvardsen, MD, PhD; Erik Lyseggen, MD; Brage H. Amundsen, MD; Hans-Jørgen Smith, MD, PhD; Boaz D. Rosen, MD; João A.C. Lima, MD; Hans Torp, DrTechn; Halfdan Ihlen, MD, PhD; Otto A. Smiseth, MD, PhD

Myocardial fiber arrangement

Sengupta PP et al. J Am Coll Cardiol 2006
Left ventricular torsion

= rotation (rot) of the apex relative to the base

- Apex: counterclockwise (+)
- Base: clockwise (-)

Twist (º) = apical rot – basal rot

Torsion (º/cm) = \( \frac{\text{Twist}}{\text{Apex-to-base length}} \)
Importance of cardiac torsion

• Torsion helps bring a uniform distribution of LV fiber stress and fiber shortening across the wall, increasing the efficiency of LV contraction - *role in ejection*

• Fiber twisting and shearing deform the matrix and result in storage of potential energy, which is subsequently utilized for diastolic recoil - *role in filling*

Arts T *et al.* Am J Physiol 1982
Sengupta PP *et al.* J Am Coll Cardiol Imaging 2008
LV torsion by STE: clinical studies

Although conceptually simple, torsion is more complex in practice.

Wide variability in the reported values for resting systolic torsion

**Table 1**

<table>
<thead>
<tr>
<th>Author</th>
<th>Method</th>
<th>Subjects (n)</th>
<th>Age (yrs)</th>
<th>Torsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeuchi et al. (9)</td>
<td>Speckle tracking</td>
<td>57</td>
<td>29 ± 6</td>
<td>6.7 ± 2.9°</td>
</tr>
<tr>
<td>Notomi et al. (8)</td>
<td>DTI</td>
<td>10</td>
<td>28 ± 3</td>
<td>8.7 ± 2.7°</td>
</tr>
<tr>
<td>Neilan et al. (10)</td>
<td>Speckle tracking</td>
<td>17</td>
<td>37 ± 9</td>
<td>10 ± 4°</td>
</tr>
<tr>
<td>Notomi et al. (3)</td>
<td>DTI</td>
<td>20</td>
<td>34 ± 7</td>
<td>11 ± 4°</td>
</tr>
<tr>
<td>Halle-Valle et al. (11)</td>
<td>Speckle tracking</td>
<td>29</td>
<td>33 ± 6</td>
<td>14.5 ± 3.2°</td>
</tr>
</tbody>
</table>

DTI = Doppler tissue imaging.
Apical rotation and LV function

- Both LV twist and apical rotation are more closely related to LV dP/dt_{max} than LV EF after ligation of either LAD or LCx artery

- Apical rotation by STE correlated well with LV twist over a wide range of loading conditions and inotropic states, and during myocardial ischemia

- Apical rotation measurement by STE is an effective noninvasive index of global LV contractility

Kim WJ et al. *Circ Cardiovasc Imaging* 2009
Exercise echo in HFNEF

In HFNEF - widespread abnormalities of both LV systolic and diastolic function that become more apparent on exercise:

• At rest lower values of - Longitudinal and radial strain
  - Apical rotation
  - Reduced and delayed untwisting
  - Mitral annular velocities

Correlated with peak VO$_{2max}$

• At exercise, all parameters failed to normalize

HFNEF is not an isolated disorder of diastole!

Tan YT. J Am Coll Cardiol 2009
Anterior myocardial infarction

30 pts with old anterior MI (>1 mo): 2 groups (LVEF ≥ 45%; < 45%)

LV apex is the main determinant of LV torsion and untwisting both in normal and diseased hearts

# Aortic stenosis

<table>
<thead>
<tr>
<th></th>
<th>Controls (n=40)</th>
<th>AS (n=61)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak apical rotation (°)</td>
<td>15.7±5.9</td>
<td>21.0±7.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Peak basal rotation (°)</td>
<td>-6.2±2.9</td>
<td>-6.7±3.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Twist (°)</td>
<td>20.8±6.8</td>
<td>26.5±9.1</td>
<td>0.001</td>
</tr>
<tr>
<td>LV twist rate (°/s)</td>
<td>118±35</td>
<td>137±55</td>
<td>0.006</td>
</tr>
<tr>
<td>Peak systolic torsion (°/cm)</td>
<td>2.7±0.9</td>
<td>3.4±1.3</td>
<td>0.002</td>
</tr>
<tr>
<td>LV peak untwisting rate (°/s)</td>
<td>-143±48</td>
<td>-158±59</td>
<td>0.18</td>
</tr>
<tr>
<td>Time to peak untwisting rate</td>
<td>1.23±0.09</td>
<td>1.21±0.08</td>
<td>0.2</td>
</tr>
<tr>
<td>LV peak apical untwisting rate (°/s)</td>
<td>-93±47</td>
<td>-115±55</td>
<td>0.04</td>
</tr>
<tr>
<td>Time to peak apical untwisting rate</td>
<td>1.19±0.12</td>
<td>1.25±0.1</td>
<td>0.015</td>
</tr>
<tr>
<td>LV peak basal untwisting rate (°/s)</td>
<td>64±20</td>
<td>70±23</td>
<td>0.18</td>
</tr>
<tr>
<td>Time to peak basal untwisting rate</td>
<td>1.21±0.09</td>
<td>1.20±0.11</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Aortic stenosis

Time to peak LV untwisting rate and time to peak apical untwisting rate were significantly related to:

- E/E’ ratio (septal and lateral)
- Indexed LA volume
- BNP levels (p<0.04 for all)

In patients with severe AS and preserved LVEF there is a significant relationship between delayed LV untwisting and increased filling pressures, suggesting a role for impaired LV untwisting in the pathophysiology of diastolic dysfunction in AS

LV torsion by STE in mitral regurgitation

- 38 pts with mod–severe MR (MVP) vs 30 controls
- LV remodeling and MR degree correlated with:
  - reduced LV torsion
  - reduced untwisting velocity
  - delayed onset of untwisting

Hypertrophic cardiomyopathy (HCM)

- Rotational pattern significantly different with respect to controls, with null velocity equatorial apically displaced, therefore reducing twist for most of the LV and increasing it at the apex.

- LV untwisting is delayed and does not augment significantly with exercise.

Dilated cardiomyopathy

- LV systolic rotation at both basal and apical levels and LV torsion are significantly reduced in pts, compared to controls (A)

- 2 different patterns of apical rotation:
  - normally directed
    (B - counterclockwise)
  - reversed
    (C - clockwise)

## Dilated cardiomyopathy

<table>
<thead>
<tr>
<th></th>
<th>DCM (+) (n=24)</th>
<th>DCM (-) (n=26)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men, n (%)</td>
<td>18 (75)</td>
<td>23 (88)</td>
<td>0.2</td>
</tr>
<tr>
<td>Age (years)</td>
<td>51 (13)</td>
<td>48 (13)</td>
<td>0.4</td>
</tr>
<tr>
<td>QRS duration (ms)</td>
<td>114 (33)</td>
<td>147 (38)</td>
<td>0.004</td>
</tr>
<tr>
<td>Mitral regurgitation degree (0-3)</td>
<td>1.3 (0.8)</td>
<td>1.8 (0.8)</td>
<td>0.03</td>
</tr>
<tr>
<td>LVEDV (ml/m\textsuperscript{2})</td>
<td>107 (44)</td>
<td>148 (66)</td>
<td>0.01</td>
</tr>
<tr>
<td>LVESV (ml/m\textsuperscript{2})</td>
<td>75 (40)</td>
<td>110 (51)</td>
<td>0.01</td>
</tr>
<tr>
<td>LV sphericity index</td>
<td>1.64 (0.19)</td>
<td>1.51 (0.20)</td>
<td>0.02</td>
</tr>
<tr>
<td>LV mass (g/m\textsuperscript{2})</td>
<td>173 (48)</td>
<td>213 (72)</td>
<td>0.02</td>
</tr>
<tr>
<td>LVFS (%)</td>
<td>18 (6)</td>
<td>14 (5)</td>
<td>0.01</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>33 (12)</td>
<td>26 (7)</td>
<td>0.02</td>
</tr>
<tr>
<td>Peak E’ (cm/s)</td>
<td>5.6 (1.9)</td>
<td>4.4 (1.7)</td>
<td>0.04</td>
</tr>
<tr>
<td>E/E’ ratio</td>
<td>14 (6)</td>
<td>19 (10)</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Dilated cardiomyopathy

Reversed apical rotation and loss of LV torsion in pts with DCM is associated with:

• significant LV remodeling
• increased electrical dyssynchrony
• reduced systolic function
• increased filling pressures

Indicating a more advanced disease stage
3D Speckle tracking approach

- Based on apical LV full volume datasets by RT3DE

- Block matching is done using a kernel defined by rectangular coordinates (VOI) which is tracked forward and backward during the cardiac cycle

Kawagishi T et al. Echocardiography 2008
Conclusions

- STE holds promise to increase accuracy and reduce interobserver variability in assessing regional LV function.
- STE may improve patient care while reducing health care costs through the early identification of subclinical disease.
- STE allows proper assessment of LV rotation and torsion.
- Standardization of acquisition and processing is essential for the proper use of this new technique.