Speckle Tracking Echocardiography

Principles and Applications

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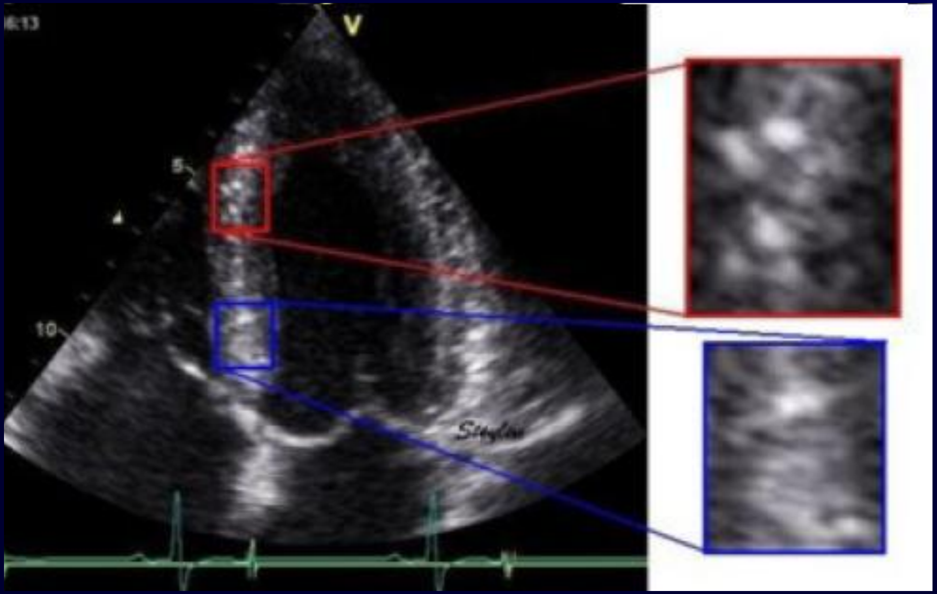
EAE Course, Bucharest, April 2010

Speckle tracking echocardiography (STE)

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



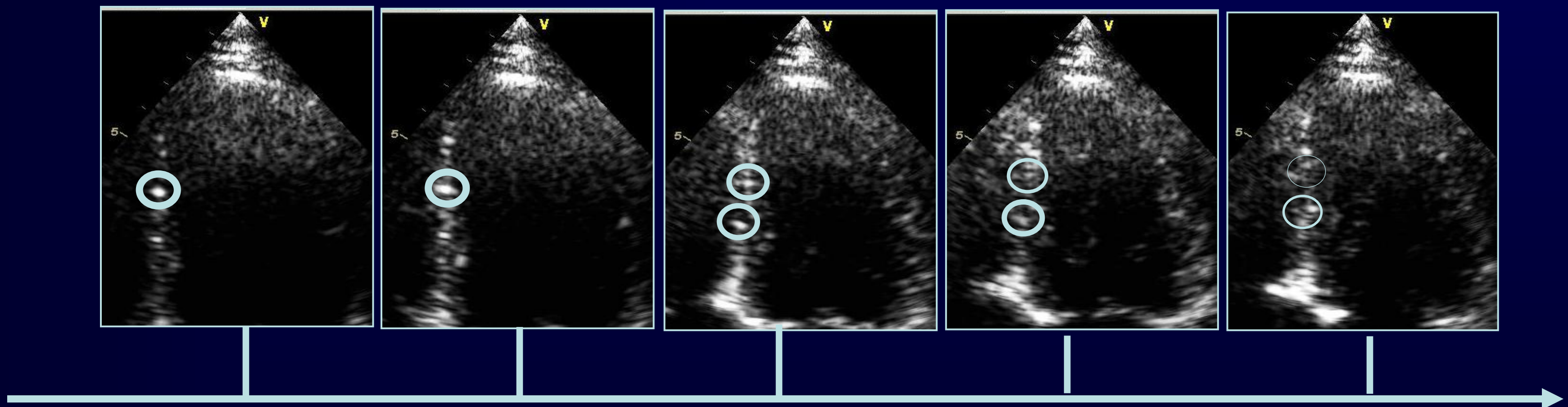
- **speckle formation:**

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.

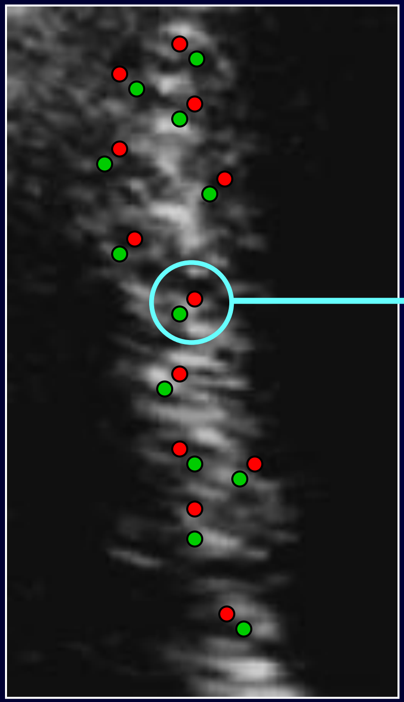


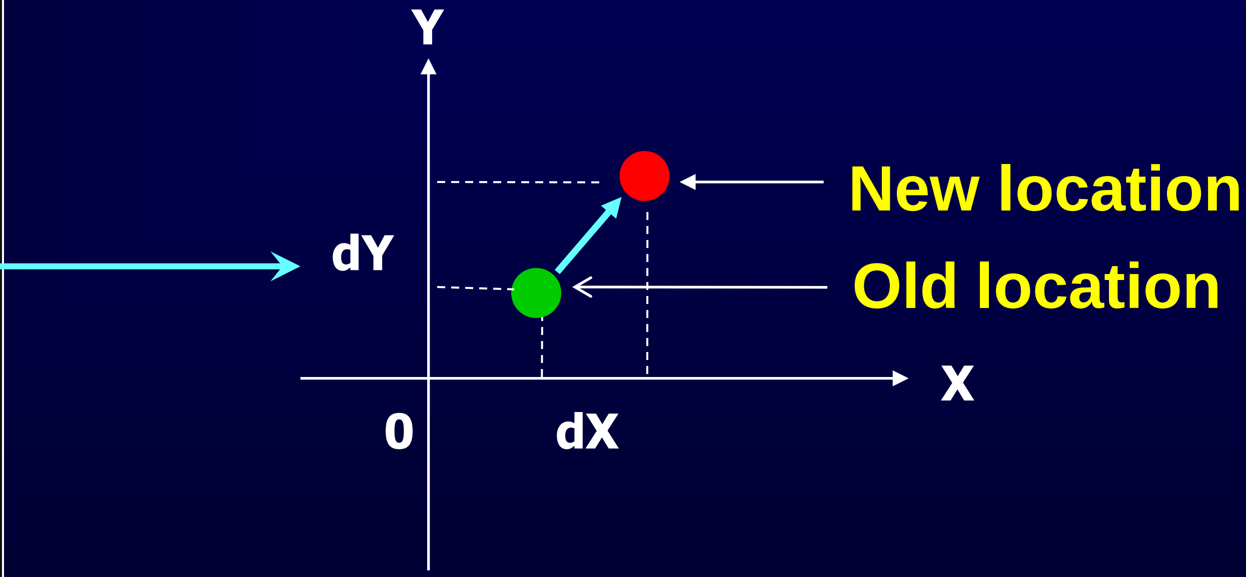
Time (sequential frames)

Local Velocities

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

<u>2D velocity vector</u>: (Vx, Vy) = (dX, dY) / Frame Time





Angle-independent technique !

STE - Pros

- angle independent technique
  - assesment 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*

J Am Soc Echocardiogr 2004

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 Stoylen, 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,† Asbjørn Støylen, MD, PhD,*‡ Halfdan Ihlen, MD, PhD,† João A. C. Lima, MD, FACC,§ Otto A. Smiseth, MD, PhD, FACC,† Stig A. Slørdahl, MD, PhD*‡

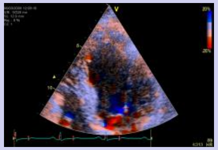
Trondheim and Oslo, Norway; and Baltimore, Maryland

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

Ingul CB, et al. J Am Soc Echocardiogr 2005
Amundsen BH, et al. J Am Coll Cardiol 2006
Becker M, et al. Heart 2005

TDI versus STE strain

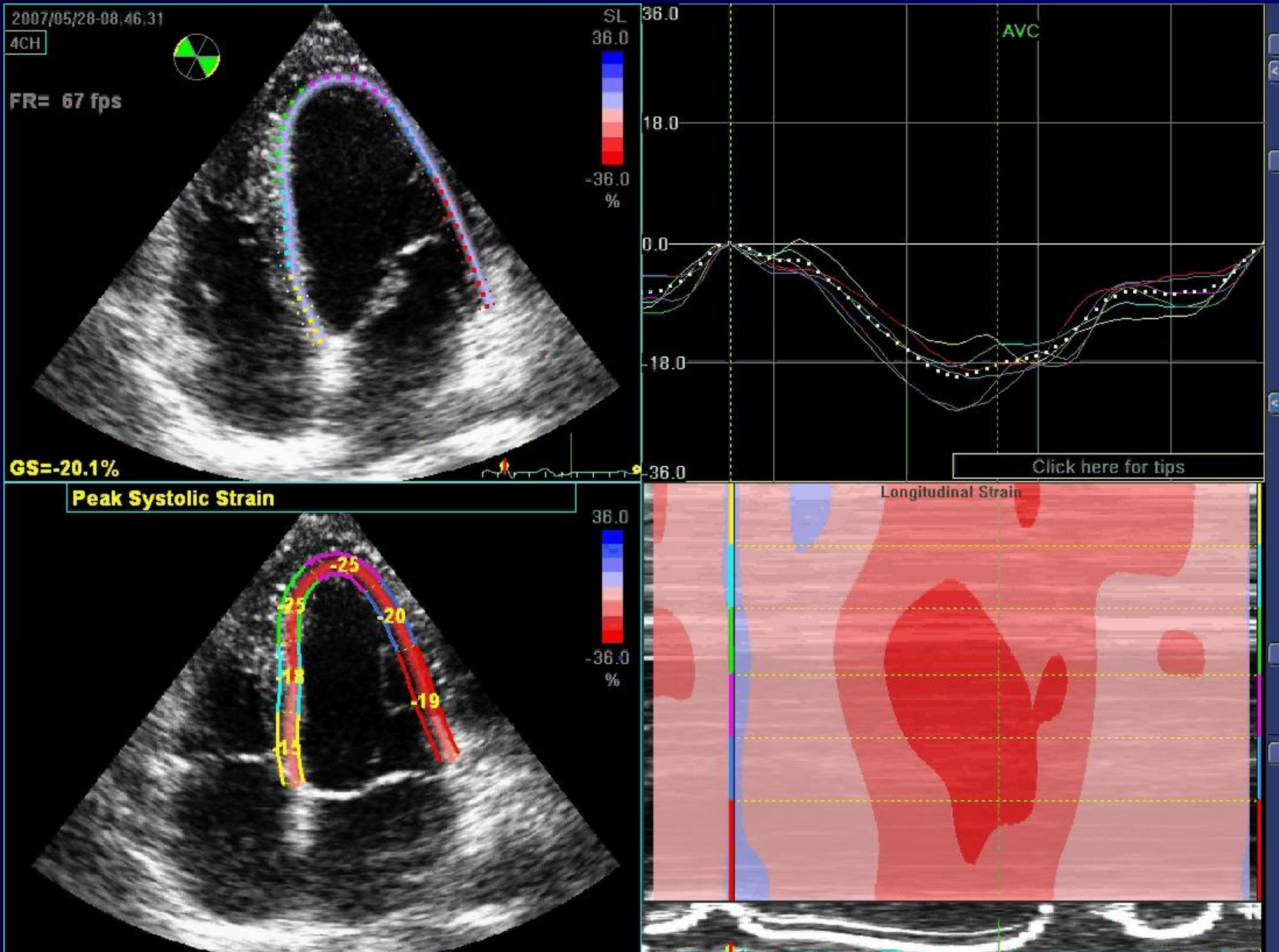


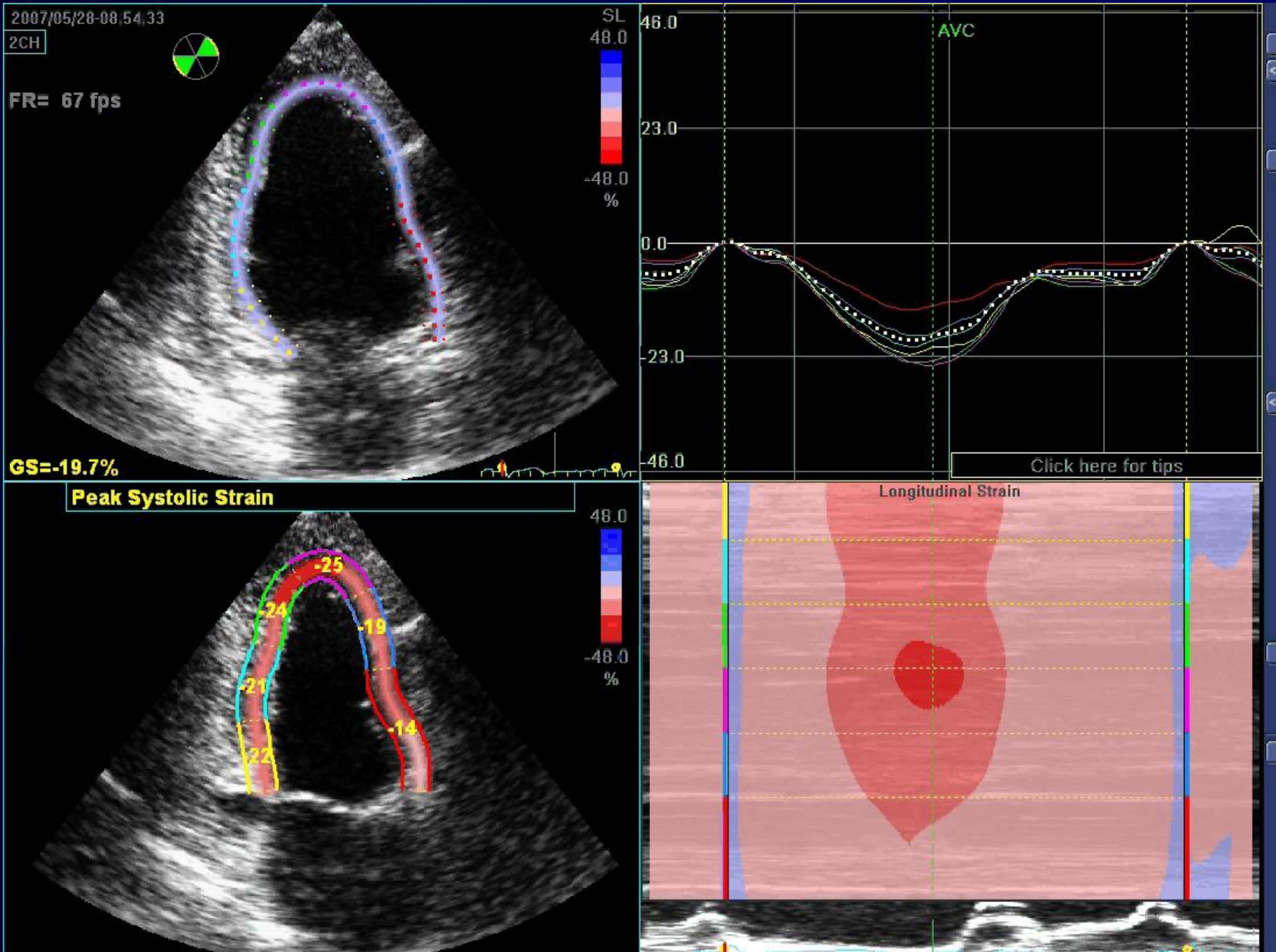
TDI STRAIN

- 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


2007/05/28-08.46.31
4CH
FR= 67 fps
SL
36.0
-36.0
%
GS=-20.1%
36.0
18.0
0.0
-18.0
-36.0
AVC
Click here for tips
Peak Systolic Strain
-25
-25
-20
-18
-19
-15
Longitudinal Strain



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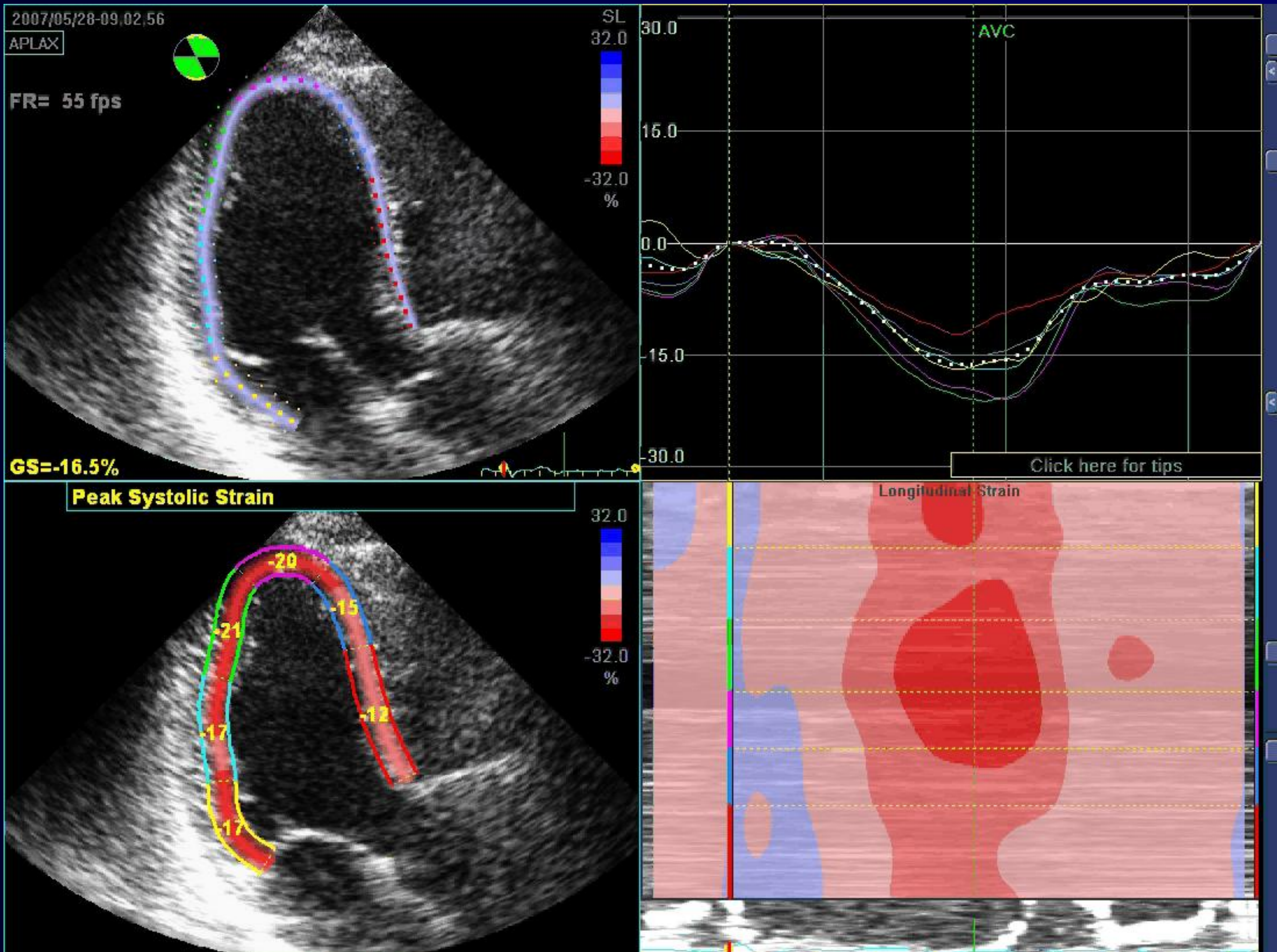
2CH
FR= 67 fps
SL
48.0
-48.0
%
GS=-19.7%
46.0
23.0
0.0
-23.0
-46.0
AVC
Click here for tips
Peak Systolic Strain
-25
-24
-19
-21
-14
-22
Longitudinal Strain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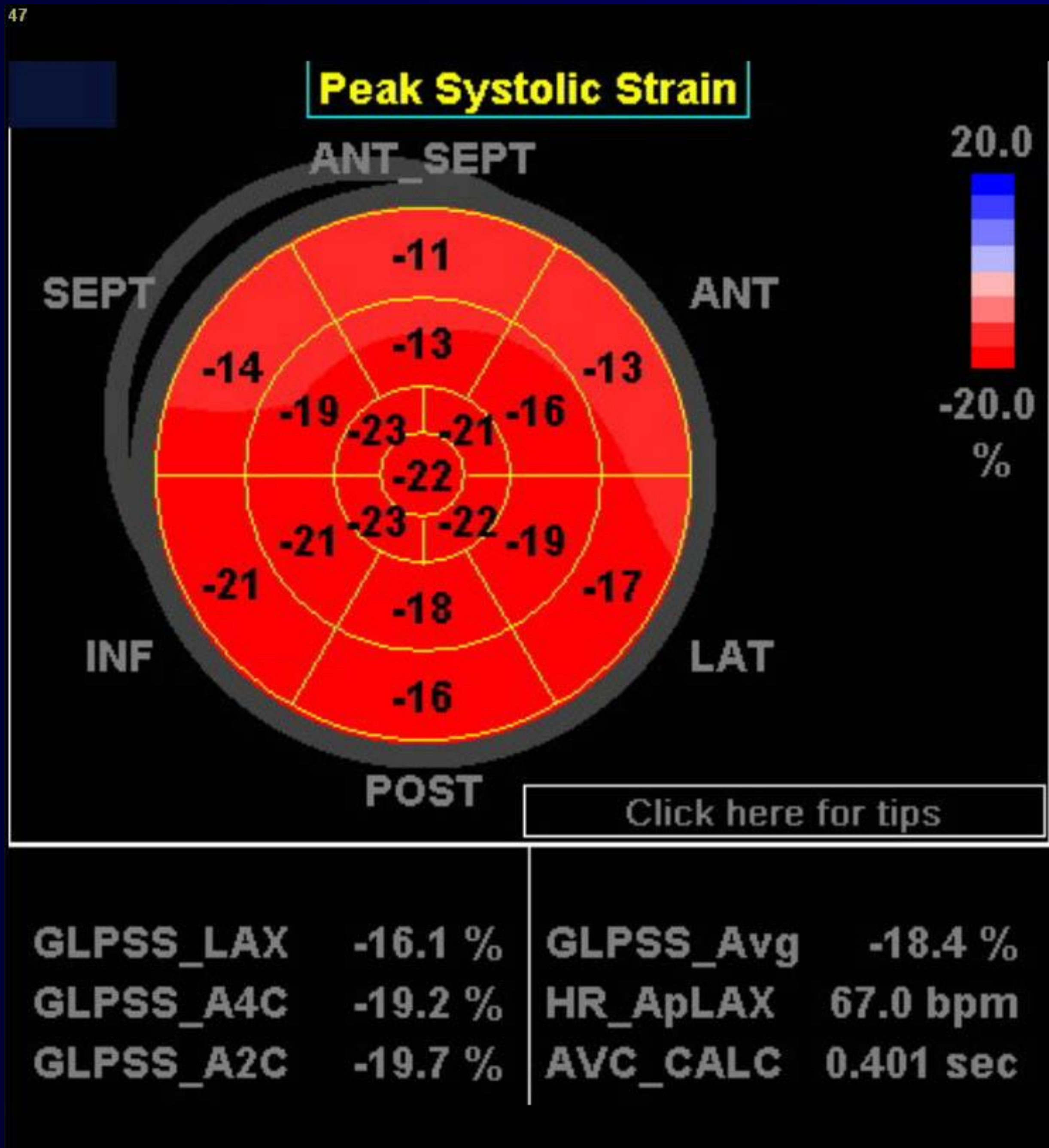
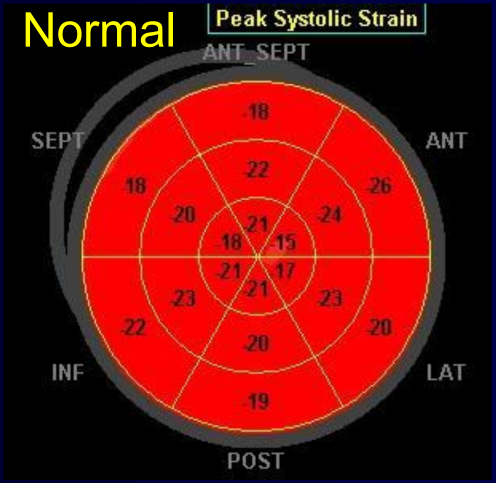
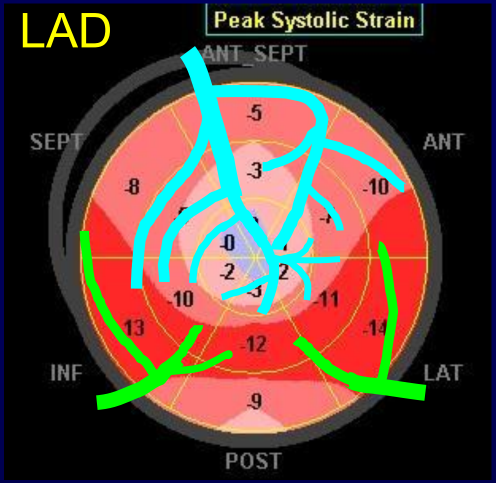
APLAX
FR= 55 fps
SL
32.0
-32.0
%
GS=-16.5%
30.0
15.0
0.0
-15.0
-30.0
AVC
Click here for tips
Peak Systolic Strain
32.0
-32.0
%
-20
-21
-15
-17
-12
-17
Longitudinal Strain

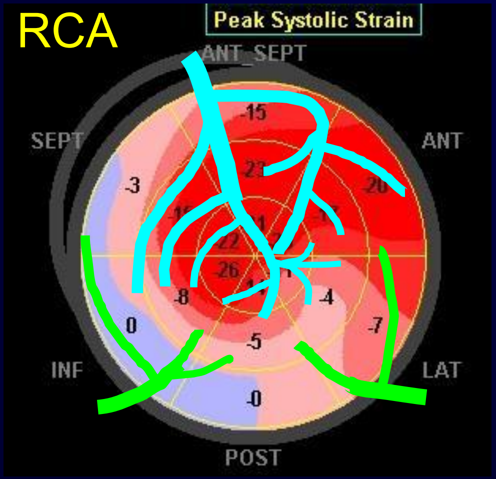


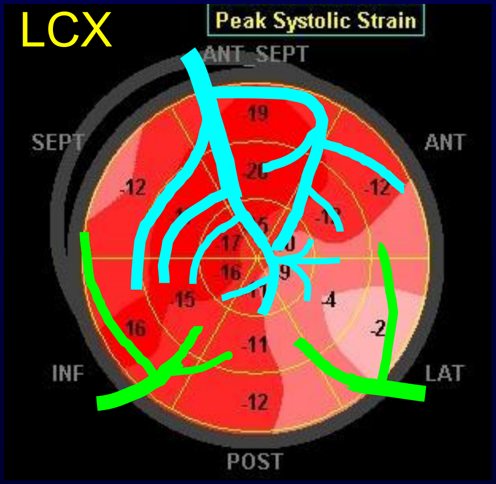
47
Peak Systolic Strain
ANT_SEPT
SEPT
ANT
INF
LAT
POST
-11
-13
-14
-19
-23
-21
-16
-13
-22
-23
-22
-21
-19
-21
-18
-17
-16
20.0
-20.0
%
Click here for tips
GLPSS_LAX -16.1 %
GLPSS_A4C -19.2 %
GLPSS_A2C -19.7 %
GLPSS_Avg -18.4 %
HR_ApLAX 67.0 bpm
AVC_CALC 0.401 sec

Acute MI Typical Patterns



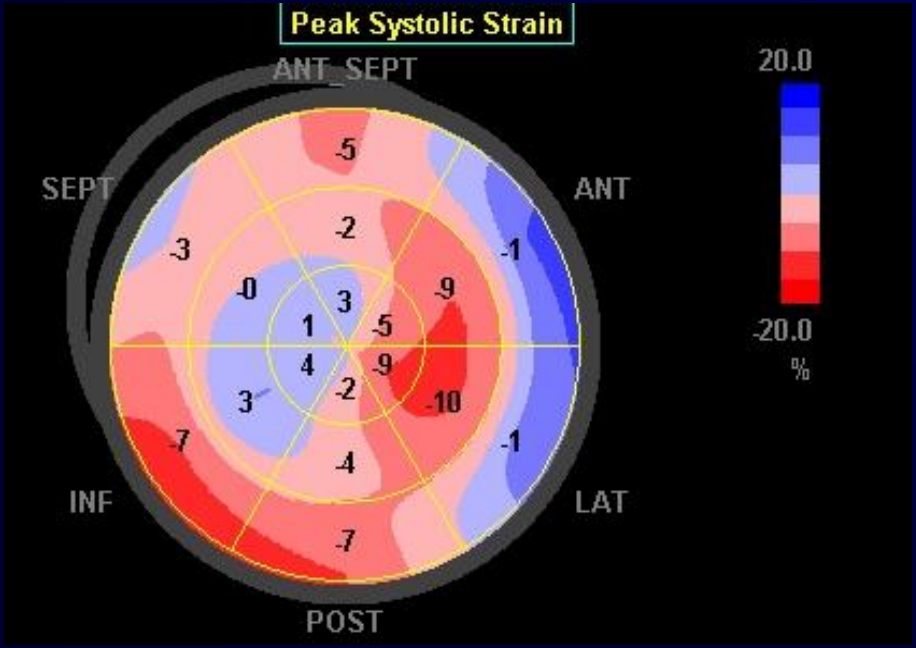




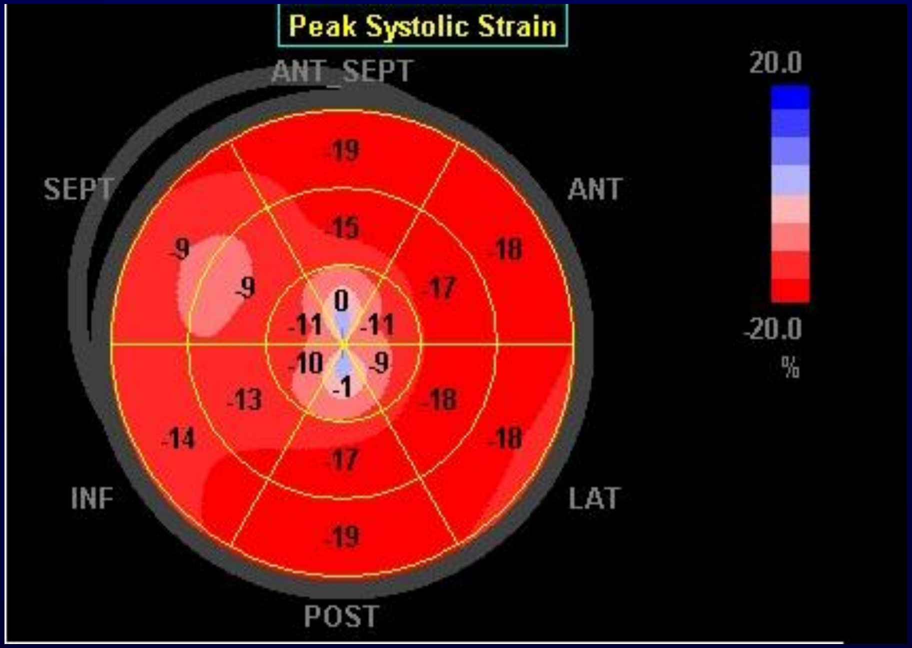


Follow-Up: Myocarditis

Before recovery



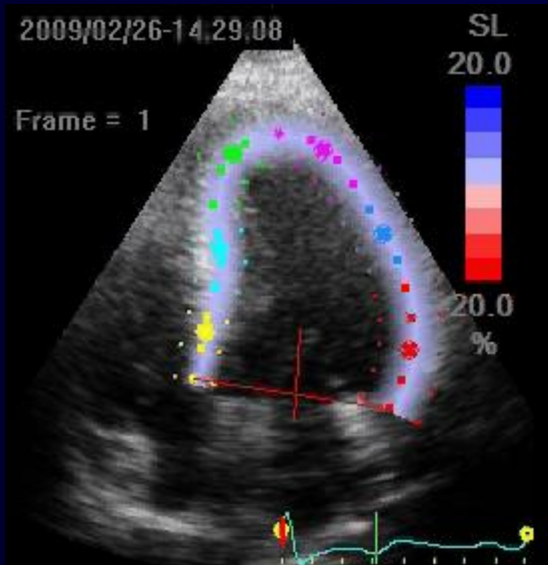
After recovery

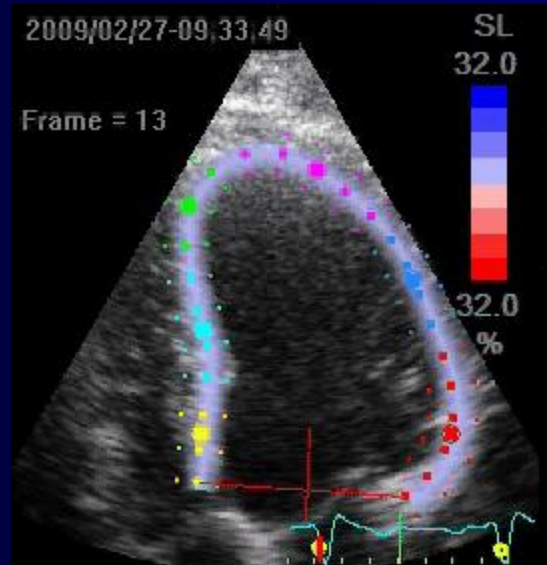


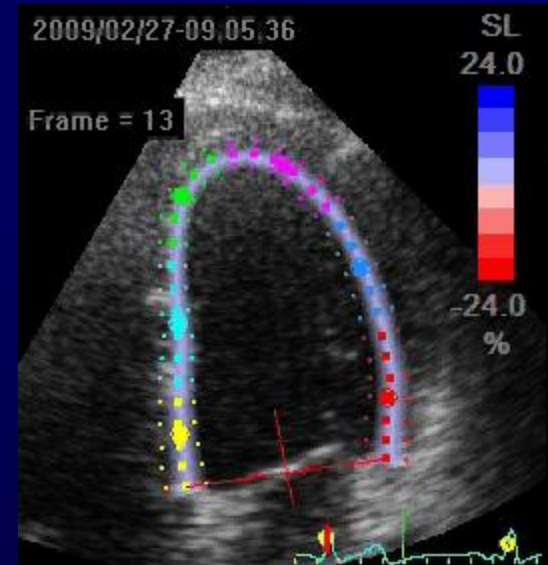
Courtesy of Dr. M. Feinberg

Global longitudinal strain in HCM

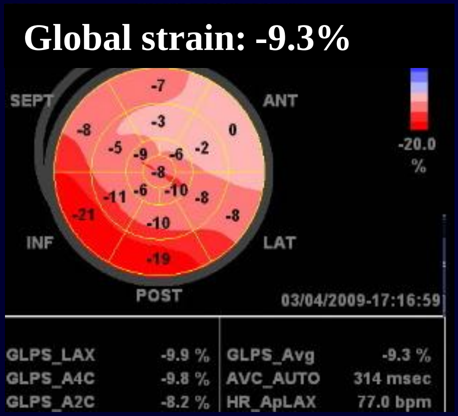
Father	1st son	2nd son

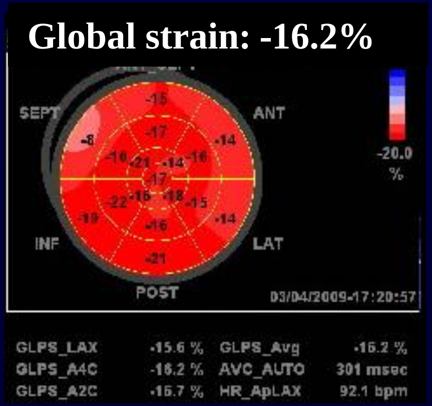


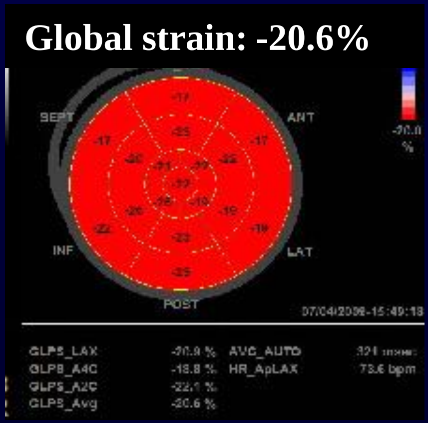




HCM	Subclinical dysfx	Normal





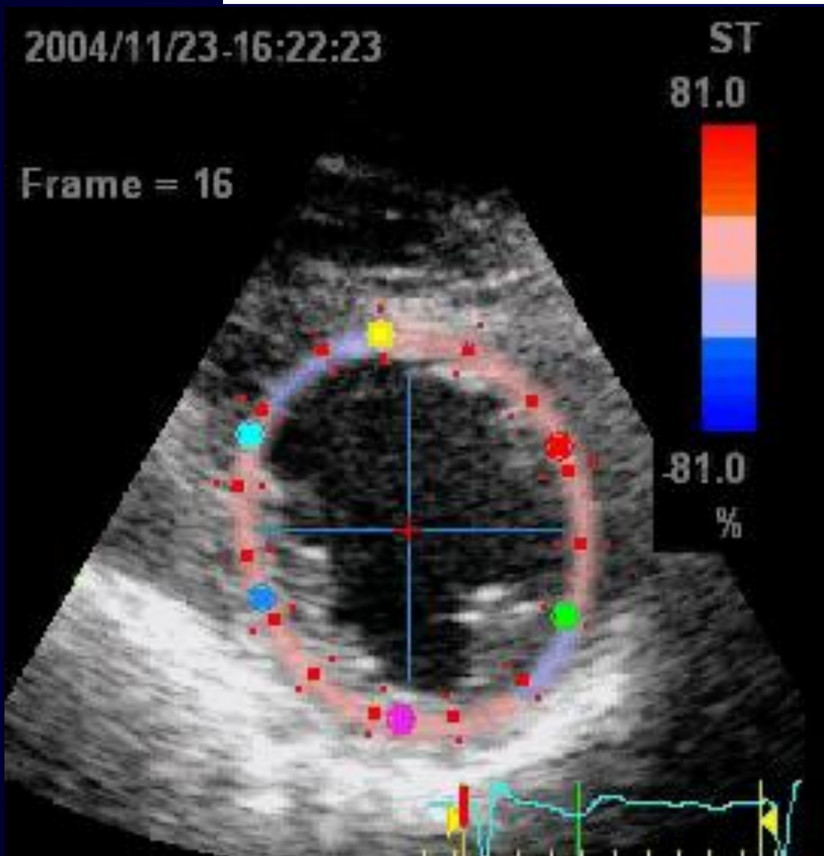


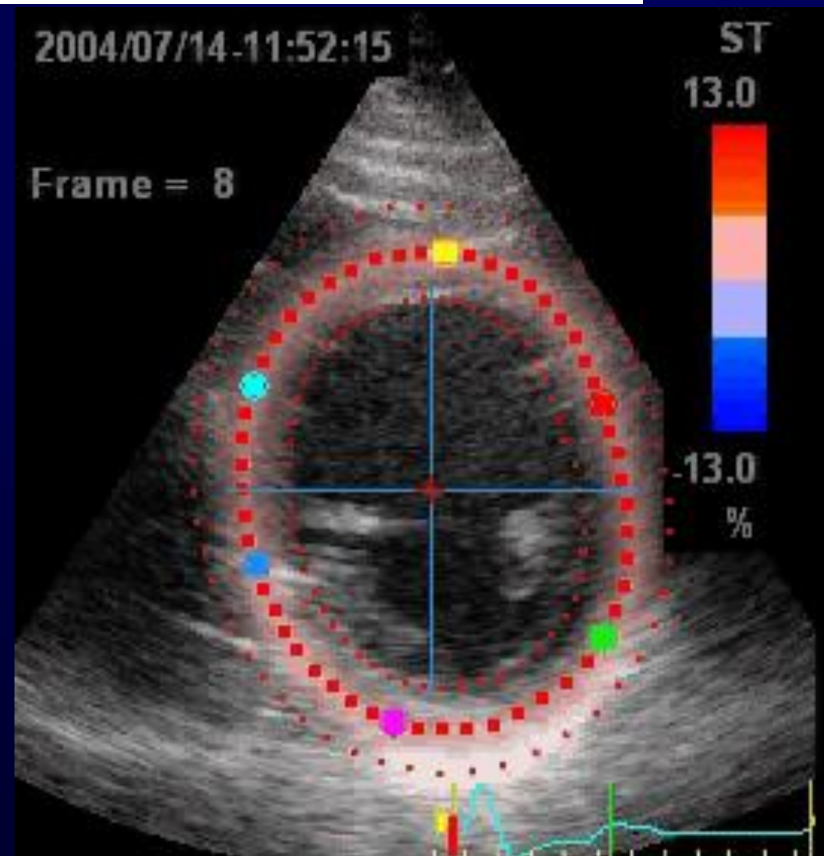
Courtesy of Dr. M. Rosca

STE – Cardiac Resynchronization Therapy

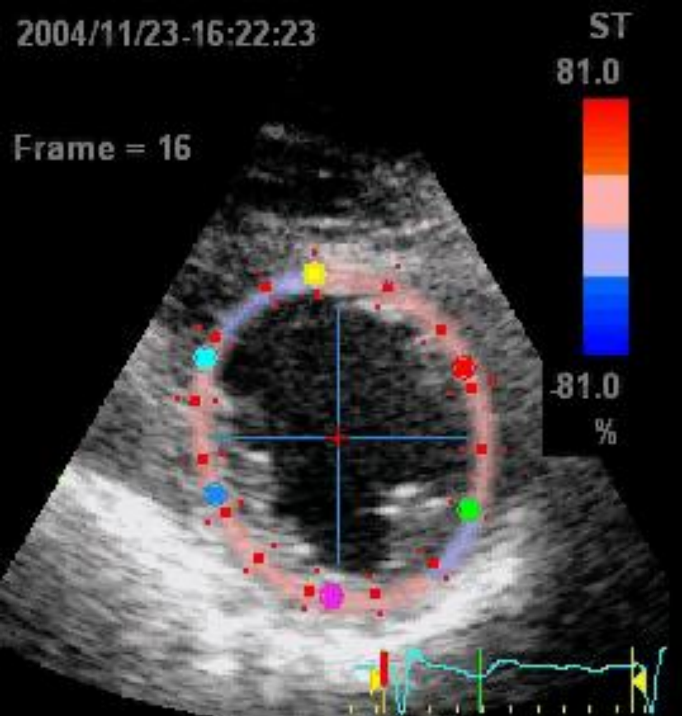
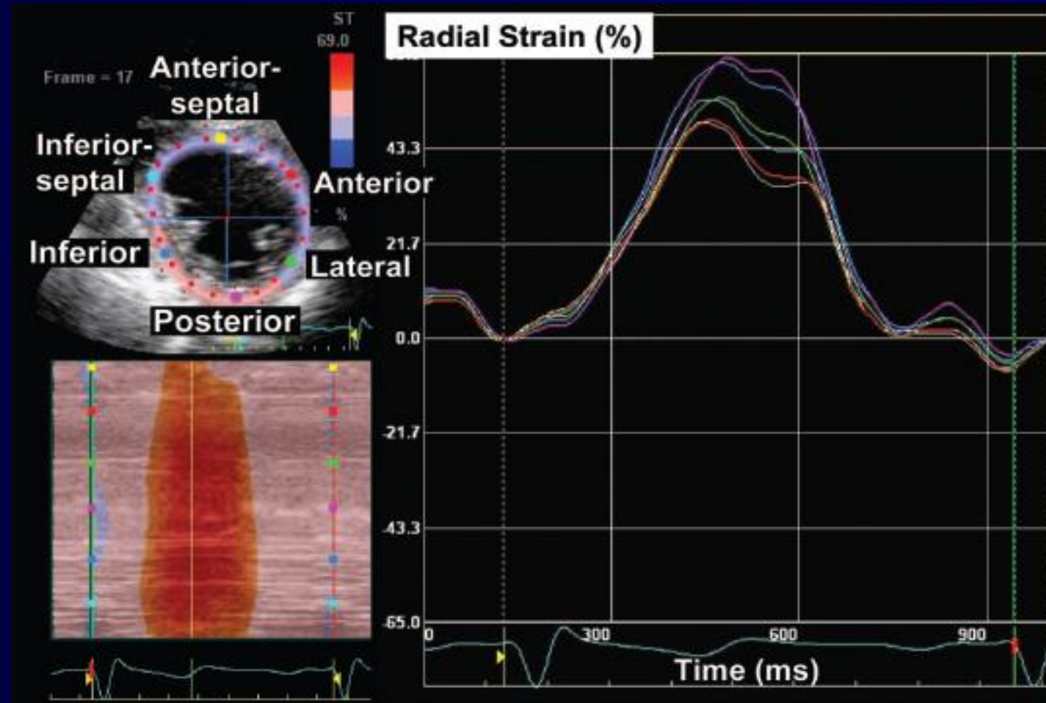
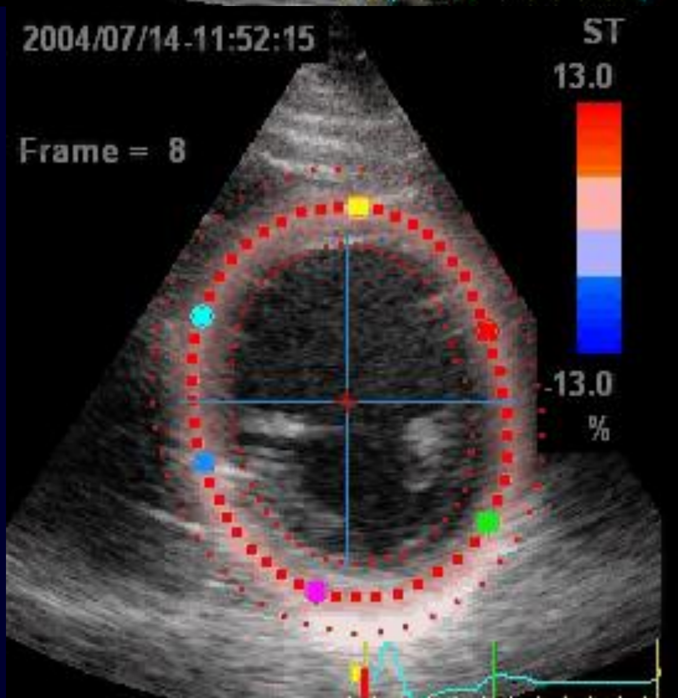
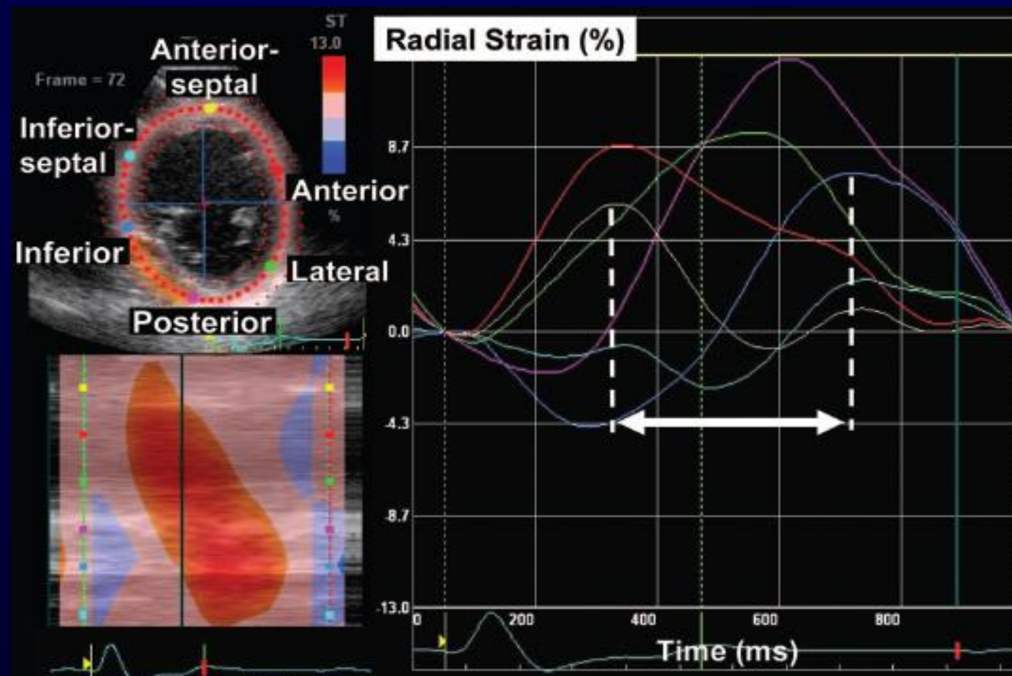
Novel Speckle-Tracking Radial Strain From Routine Black-and-White Echocardiographic Images to Quantify Dyssynchrony and Predict Response to Cardiac Resynchronization Therapy

Matthew S. Suffoletto, MD; Kaoru Dohi, MD; Maxime Cannesson, MD; Samir Saba, MD; John Gorcsan III, MD





Circulation 2006;113:960-8.

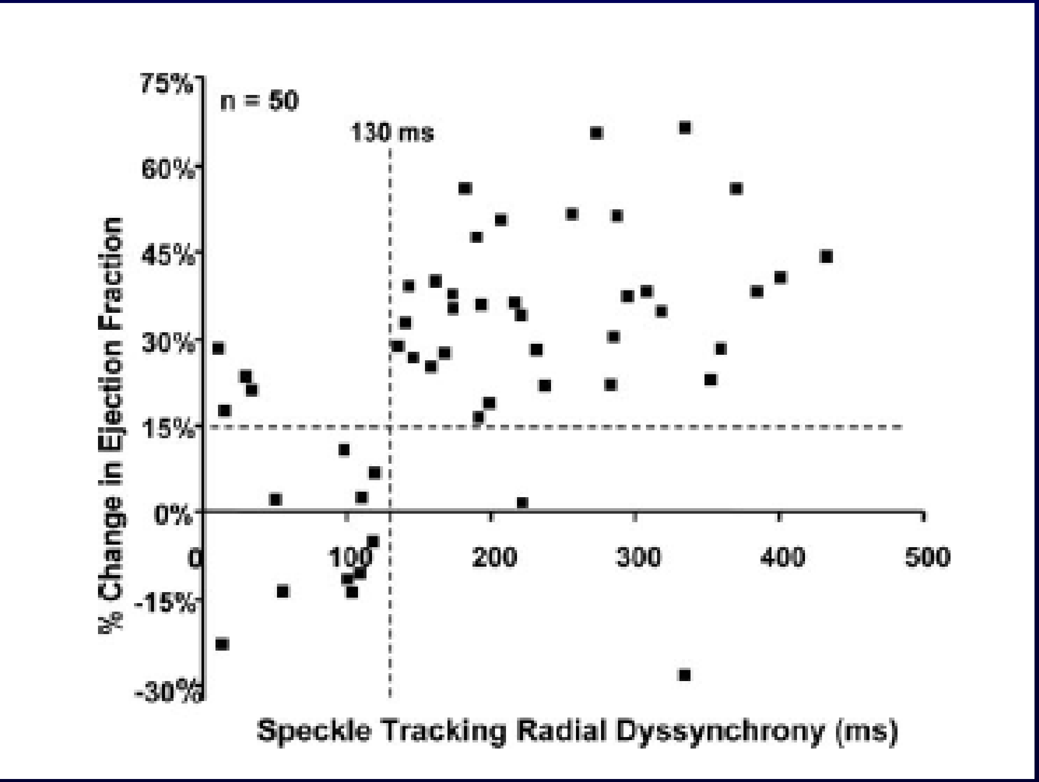

2004/11/23-16:22:23
ST
81.0
Frame = 16
-81.0
%

ST
69.0
Frame = 17
Anterior-
septal
Inferior-
septal
Anterior
Inferior
Lateral
Posterior
Radial Strain (%)
43.3
21.7
0.0
-21.7
-43.3
-65.0
0
300
600
900
Time (ms)

2004/07/14-11:52:15
ST
13.0
Frame = 8
-13.0
%

ST
13.0
Frame = 72
Anterior-
septal
Inferior-
septal
Anterior
Inferior
Lateral
Posterior
Radial Strain (%)
8.7
4.3
0.0
-4.3
-8.7
-13.0
0
200
400
600
800
Time (ms)

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 ≥130 ms (by STE) predicted:
- immediate increase in stroke volume ≥ 15% in response to CRT
- improvement in EF (≥ 15%) in a subgroup (n =50) followed for 8±5 months

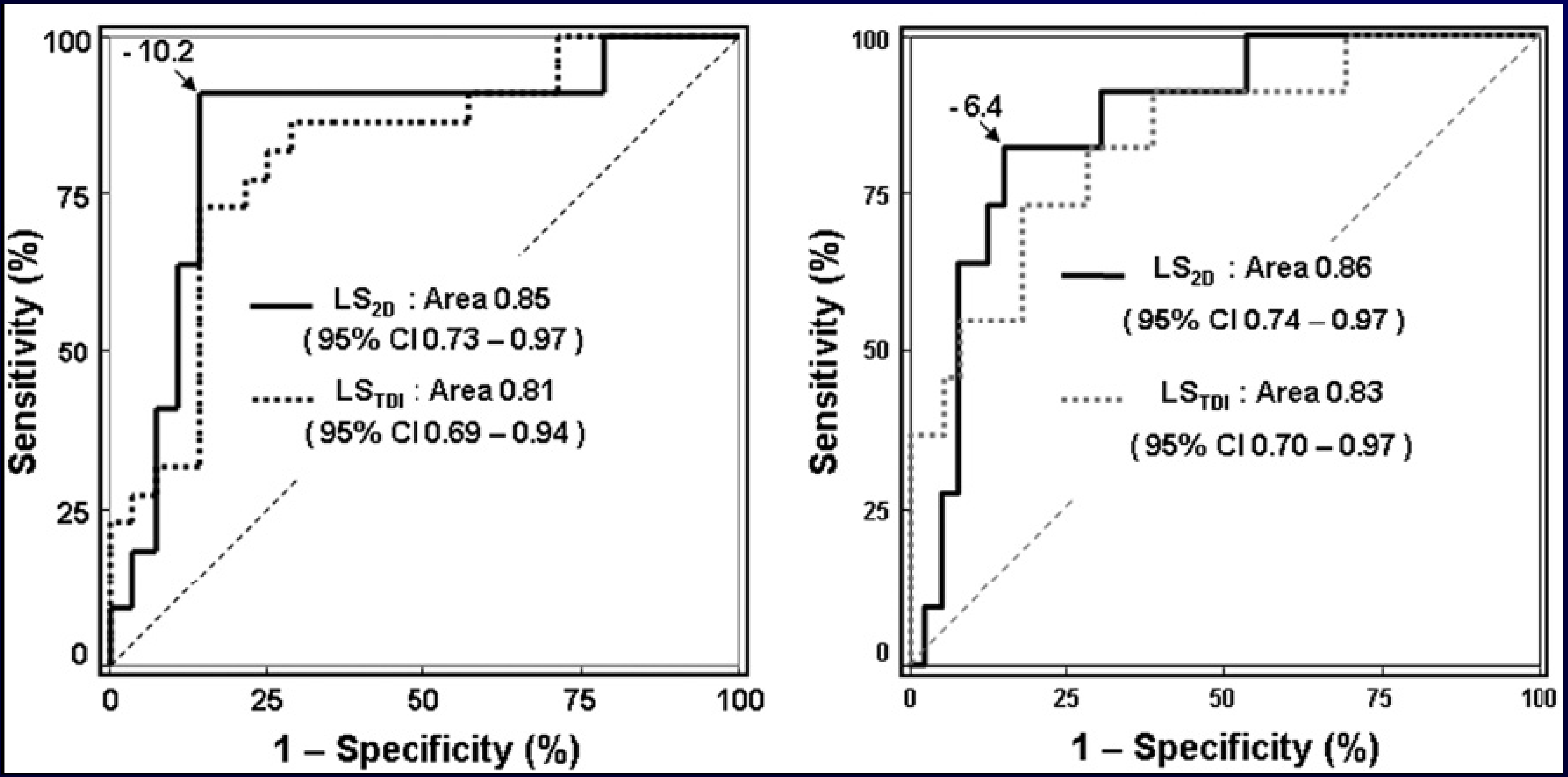


Suffoletto MS, et al. Circulation 2006;113:960–8.

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

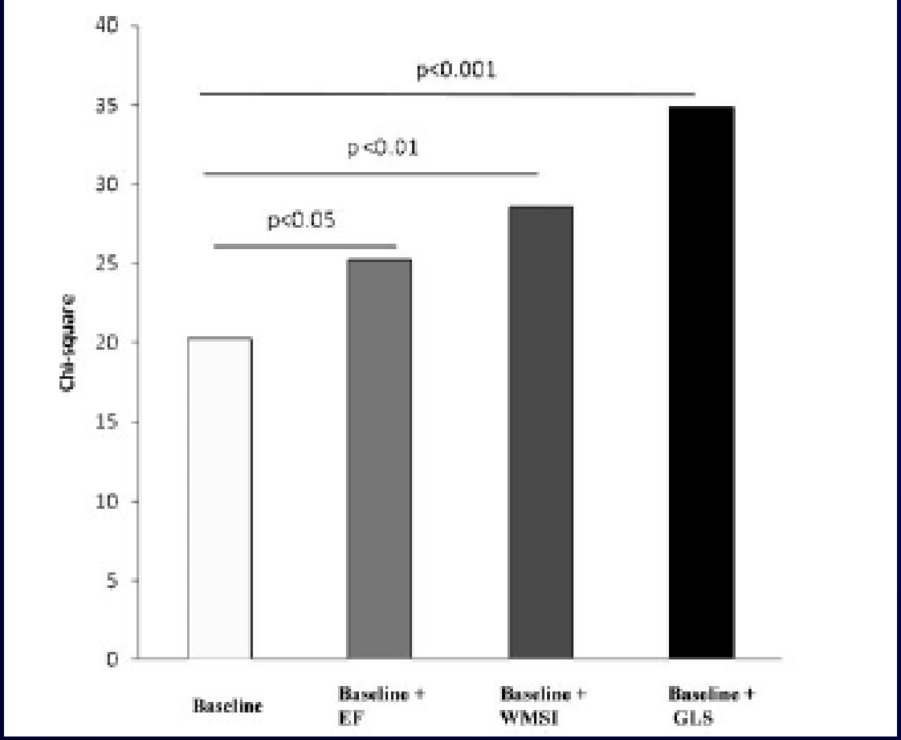
Prediction of LV remodelling

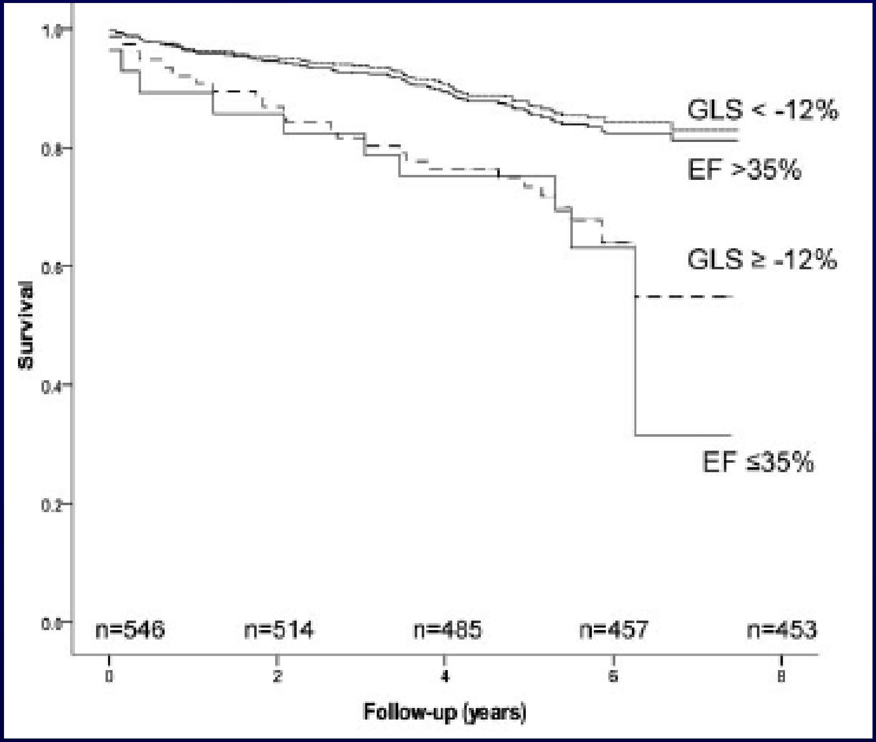
Prediction of adverse CV events



Park IH *et al*. J Am Soc Echocardiogr 2008

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

Stanton T *et al.* Circ Cardiovasc Imaging. 2009

LV rotation by STE : validation

Clinical 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-Miklovic, 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

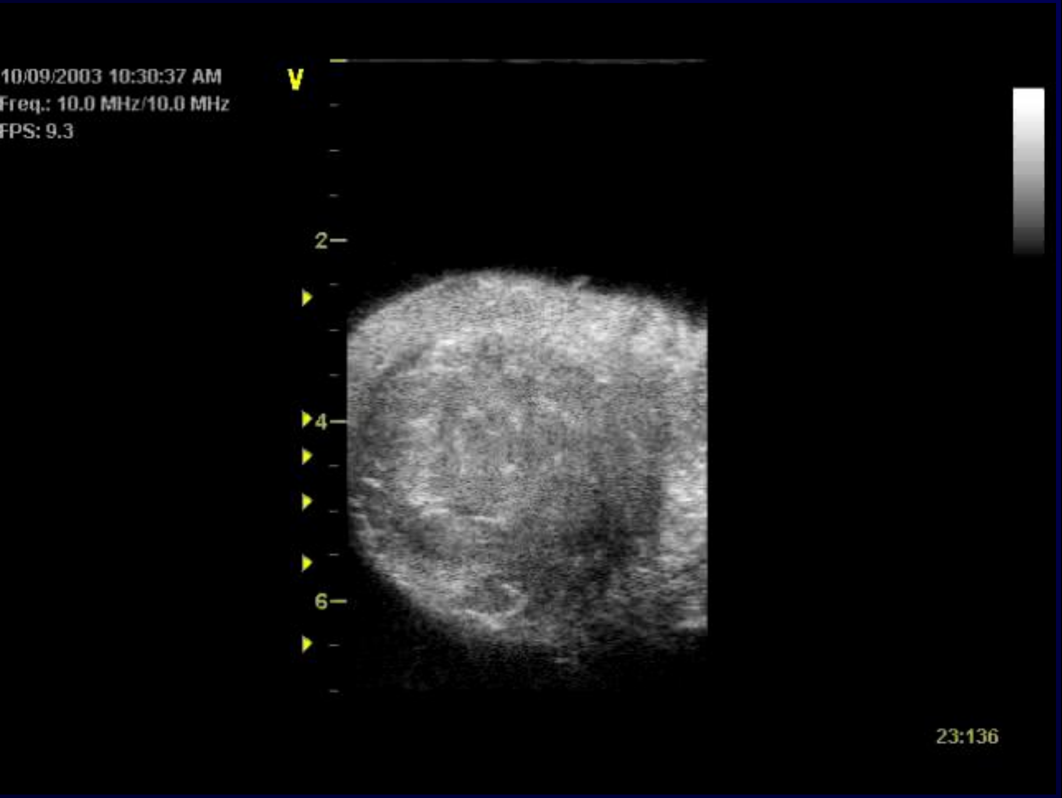
New Noninvasive Method for Assessment of Left Ventricular Rotation

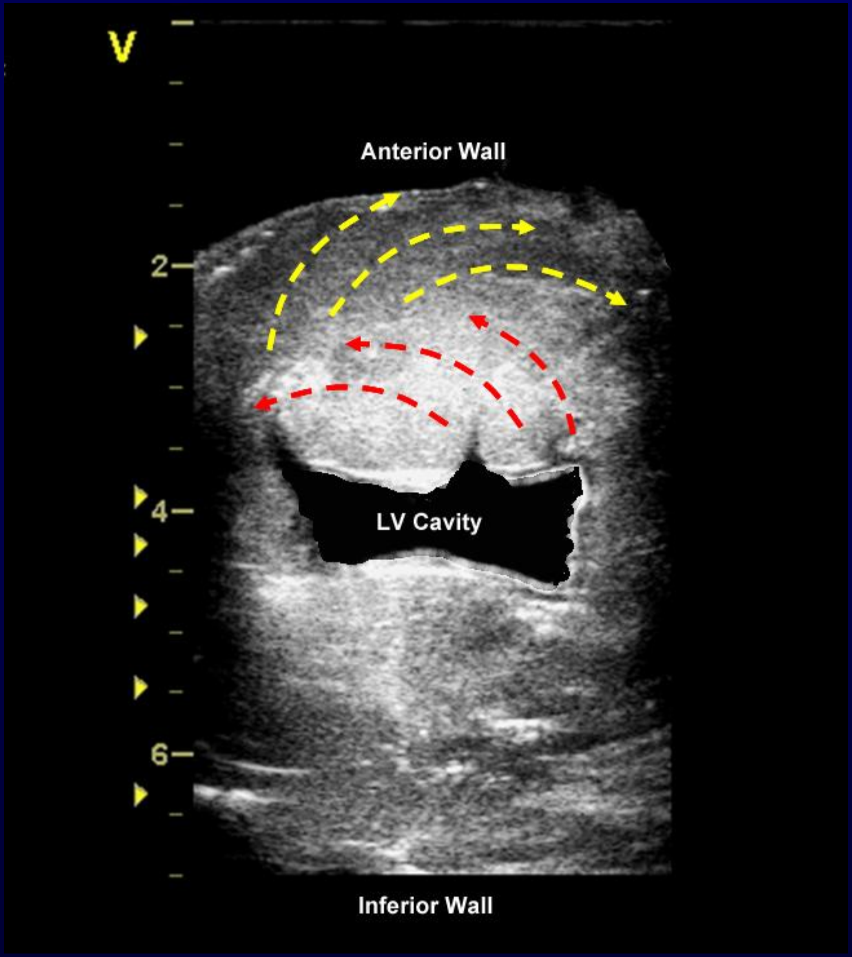
Speckle Tracking Echocardiography

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

Notomi Y *et al*. J Am Coll Cardiol 2005.
Helle-Valle T *et al*. Circulation 2006.

Myocardial fiber arrangement

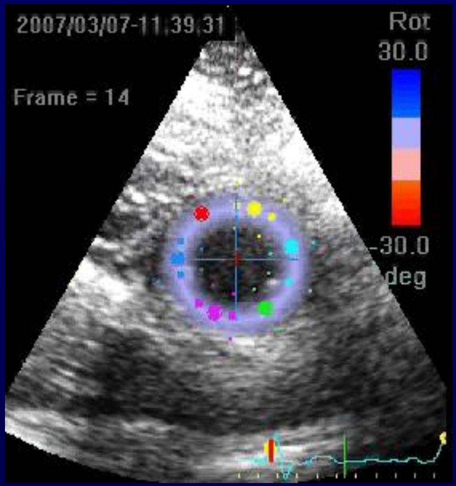




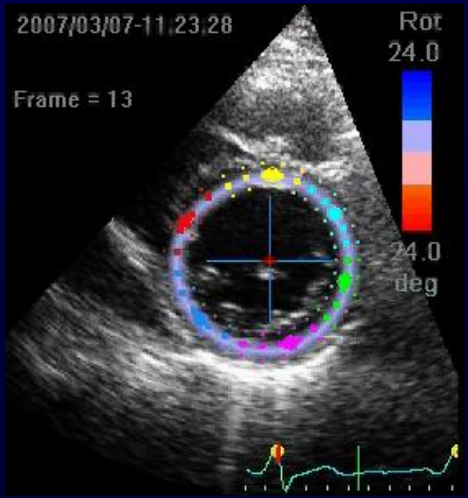
Sengupta PP *et al*. J Am Coll Cardiol 2006

Left ventricular torsion

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



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



Twist (º) = apical rot – basal rot

$$\text{Torsion (º/cm)} = \frac{\text{Twist}}{\text{Apex-to-base length}}$$

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

Table 1 Reported Values for Torsion in Normals of Similar Age

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

DTI = Doppler tissue imaging.

Wide variability in the reported values for resting systolic torsion

Weyman AE. The Year in Echo. *J Am Coll Cardiol* 2007

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

Opdahl A et al. *J Am Soc Echocardiogr* 2008

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}

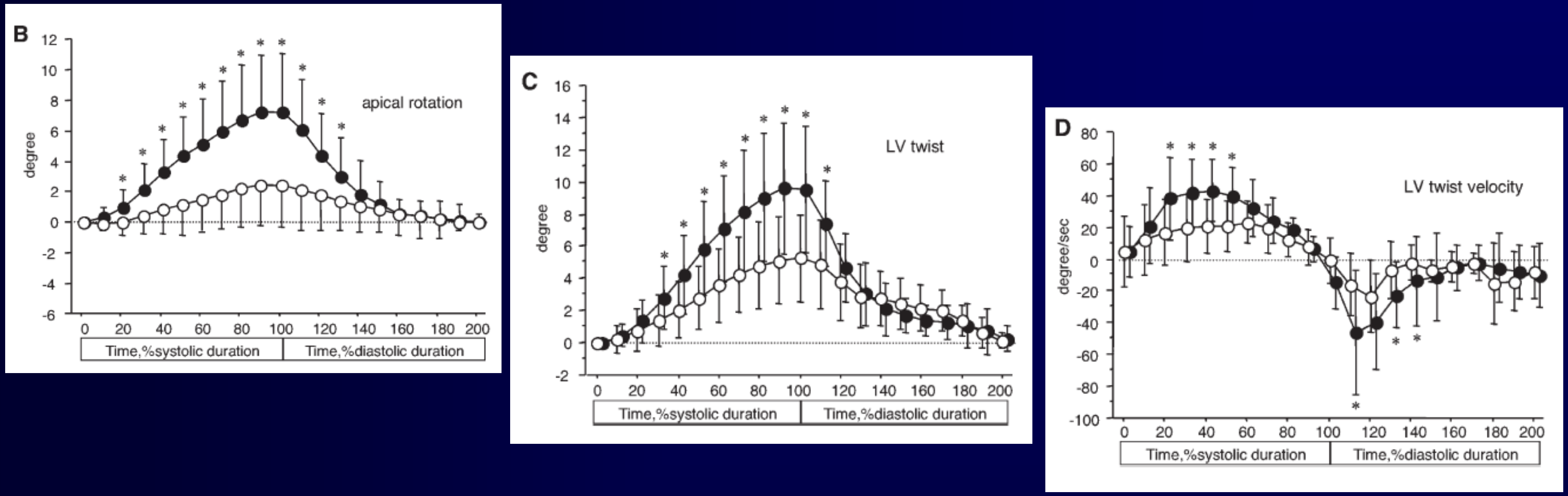
- **At exercise, all parameters failed to normalize**

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

Takeuchi M et al. *J Am Soc Echocardiogr* 2007

Aortic stenosis

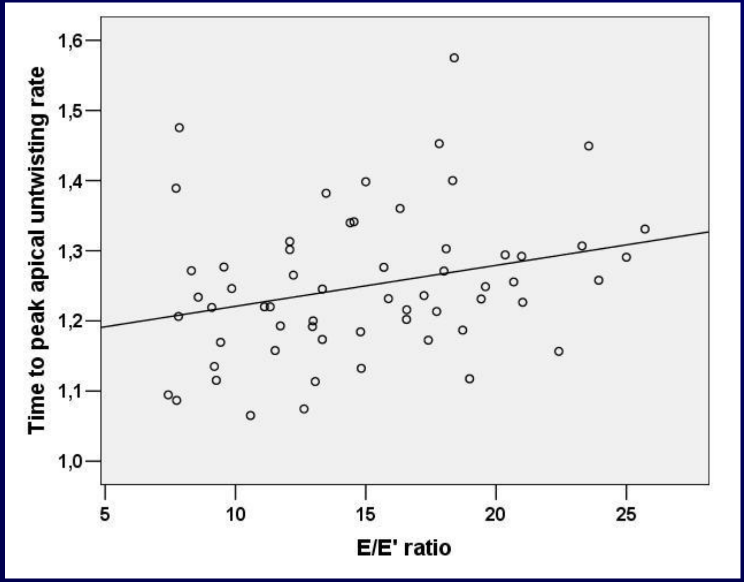
	Controls (n=40)	AS (n=61)	p value
Peak apical rotation (°)	15.7±5.9	21.0±7.6	<0.001
Peak basal rotation (°)	-6.2±2.9	-6.7±3.2	0.4
Twist (°)	20.8±6.8	26.5±9.1	0.001
LV twist rate (°/s)	118±35	137±55	0.006
Peak systolic torsion (°/cm)	2.7±0.9	3.4±1.3	0.002
LV peak untwisting rate (°/s)	-143±48	-158±59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

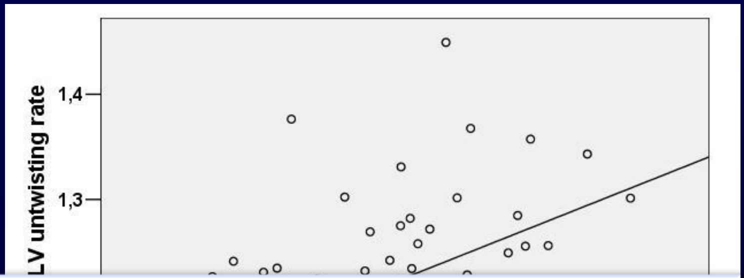
Popescu BA, Calin A, *et al.* Eur J Echocardiogr 2010

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)



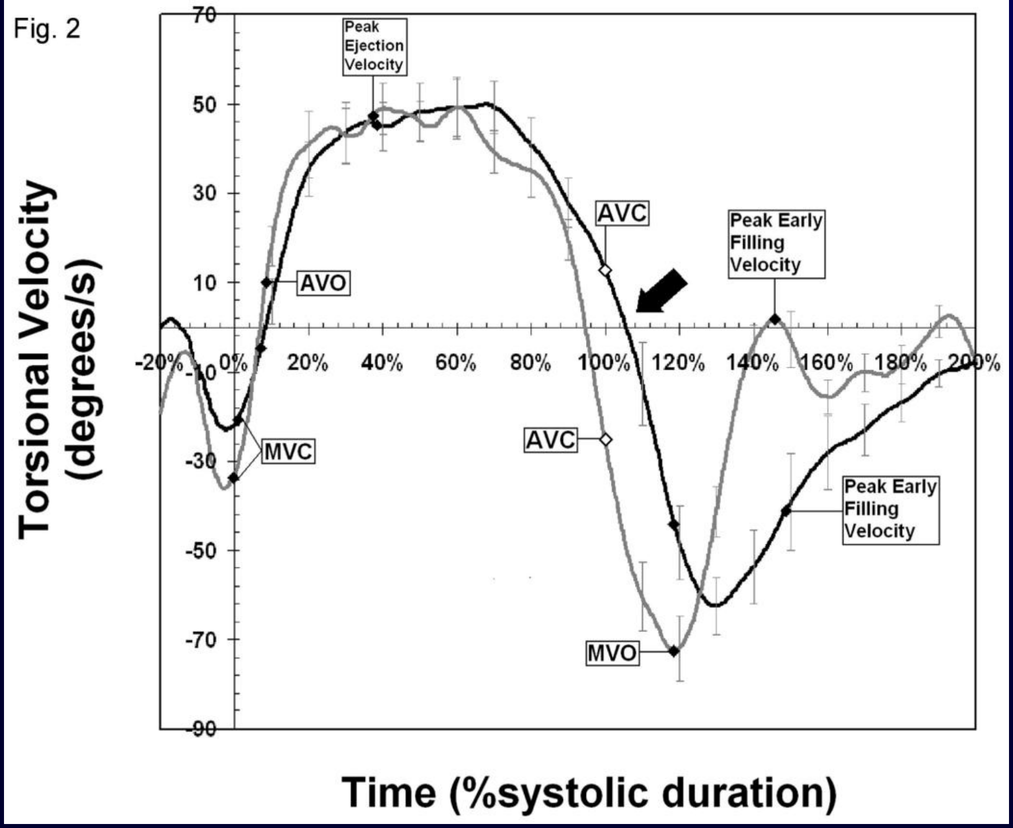


*In patients with severe AS and preserved LVEF there is a **significant relationship between delayed LV untwisting and increased filling pressures,** suggesting a role for impaired LV untwisting in the pathophysiology of diastolic dysfunction in AS*

Popescu BA, Calin A, *et al.* Eur J Echocardiogr 2010

LV torsion by STE in mitral regurgitation

- **38 pts with mod–severe MR (MVP) vs 30 controls**
- **LV remodeling and MR degree correlated with:**



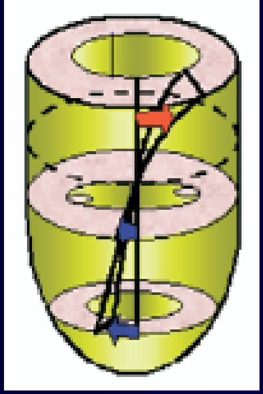
- **reduced LV torsion**
- **reduced untwisting velocity**
- **delayed onset of untwisting**

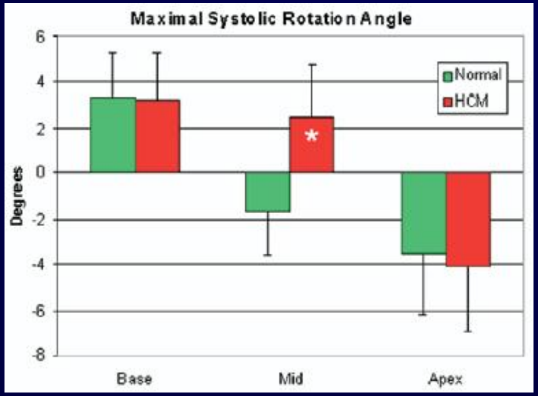
Borg A, et al. *Heart* 2008

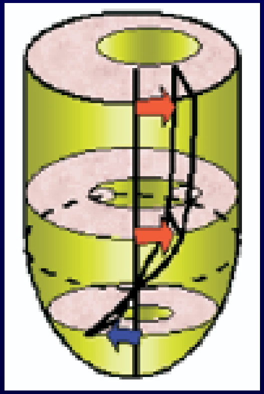
Hypertrophic cardiomyopathy (HCM)

- 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

Normal







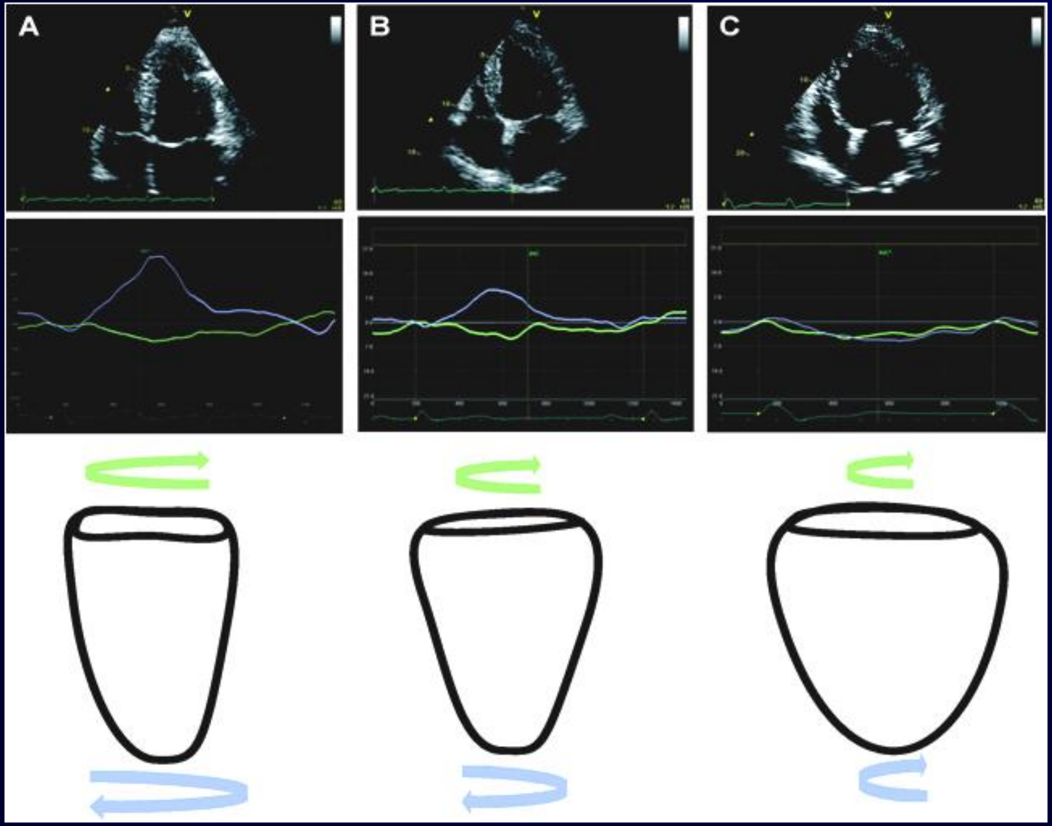
HCM

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

Carasso S, et al. *J Am Soc Echocardiogr* 2008
Notomi Y, et al. *Circulation* 2006

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)

Popescu BA, Beladan C, et al. *Eur J Heart Failure* 2009

Dilated cardiomyopathy

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

Popescu BA, Beladan C, et al. *Eur J Heart Failure* 2009

Dilated cardiomyopathy

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

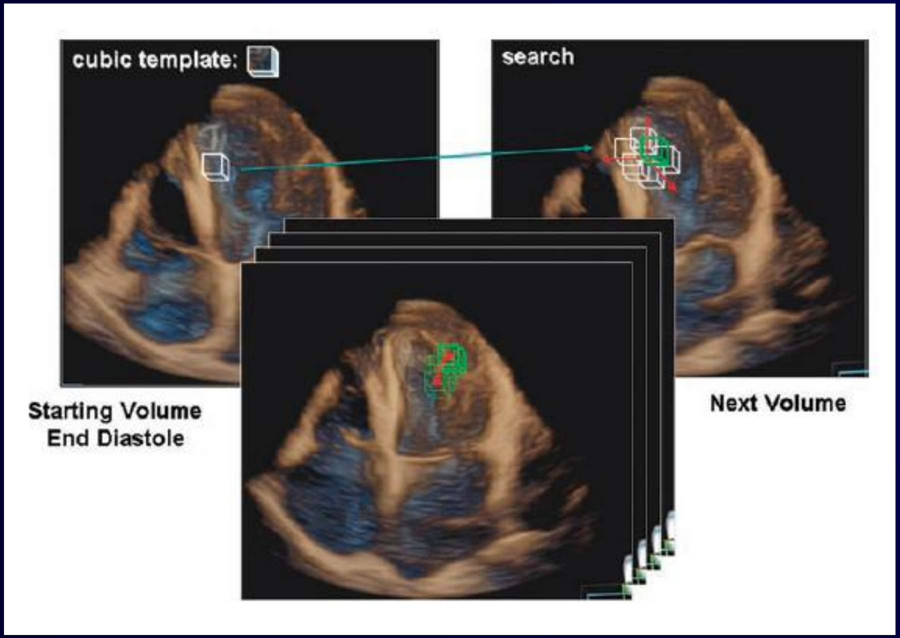
- **significant LV remodeling**
- **increased electrical dyssynchrony**
- **reduced systolic function**
- **increased filling pressures**

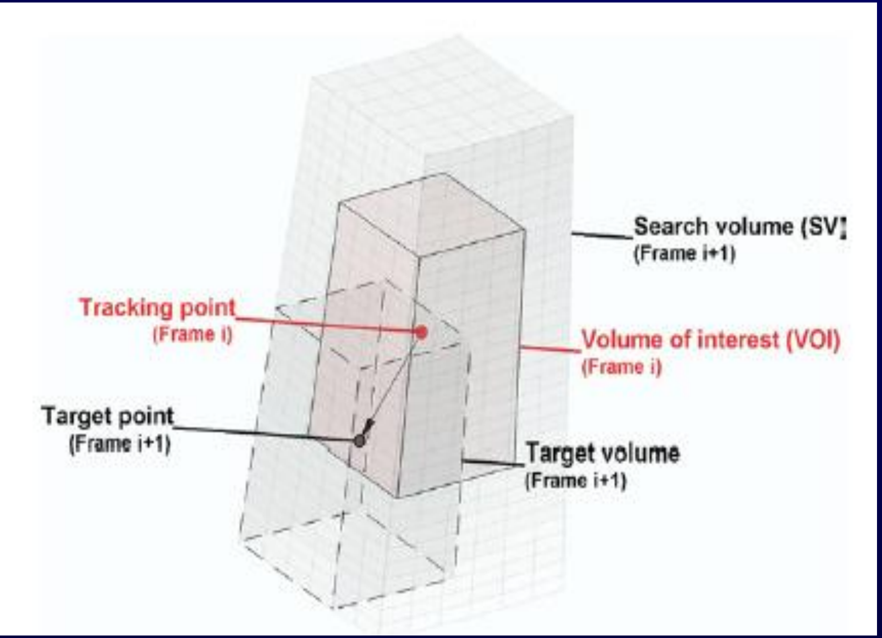
Indicating a more advanced disease stage

***Eur J Heart Failure* 2009**

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
Crosby J *et al.* Ultrasound in Med. & Biol 2009

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