Myocardial Imaging
Tissue Doppler and Strain Imaging

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mayo

DISCLOSURE

Relevant Financial Relationship(s)

None

Off Label Usage

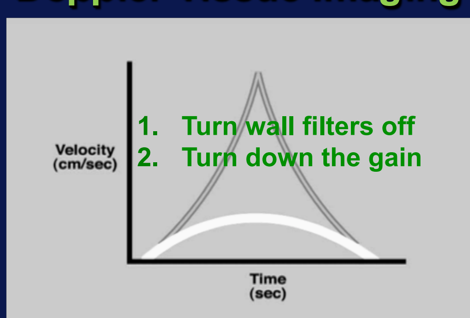
None

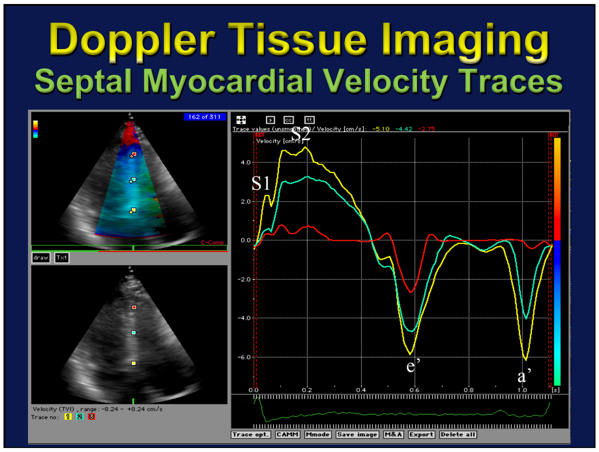
Myocardial Imaging
Objective way with which to quantify the minor amplitude and temporal subtleties in motion

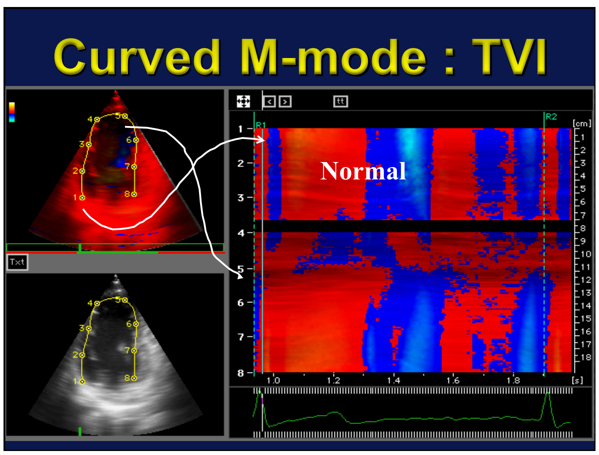
Objectives

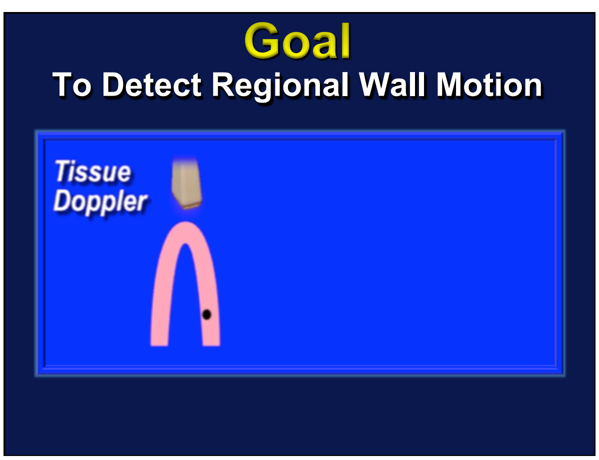
1. What is myocardial imaging?
2. Potential Clinical Applications
3. Impediments to widespread clinical adoption?

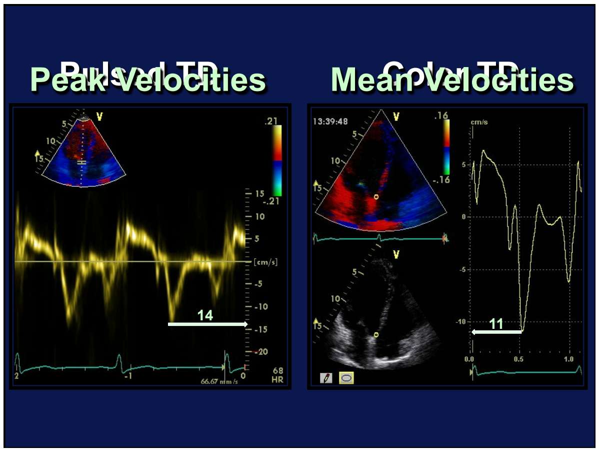
Doppler:
Doppler Tissue Imaging

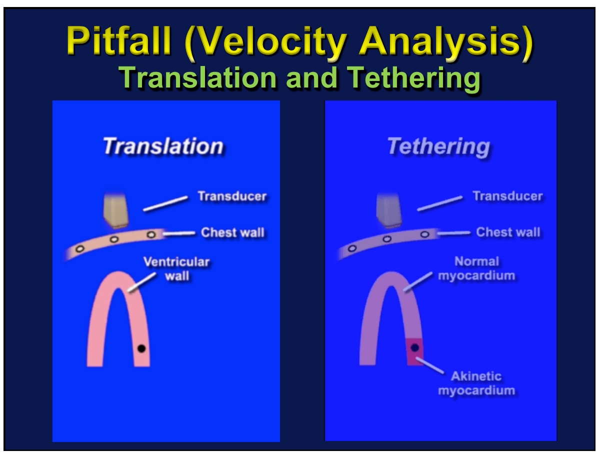



Doppler Tissue Imaging
Septal Myocardial Velocity Traces
S1
S2
e'
a'

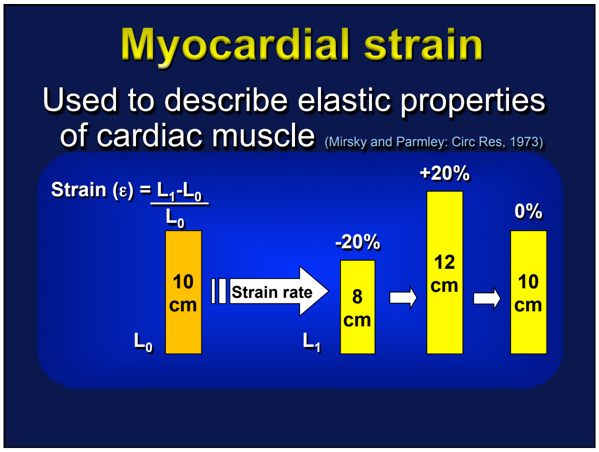

Curved M-mode : TVI
Normal

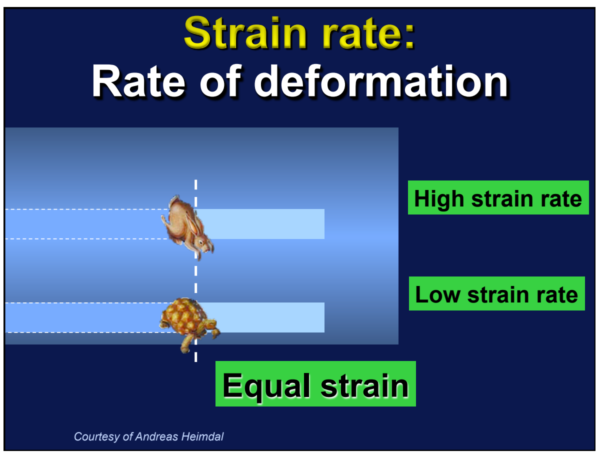

Goal
To Detect Regional Wall Motion
Tissue
Doppler

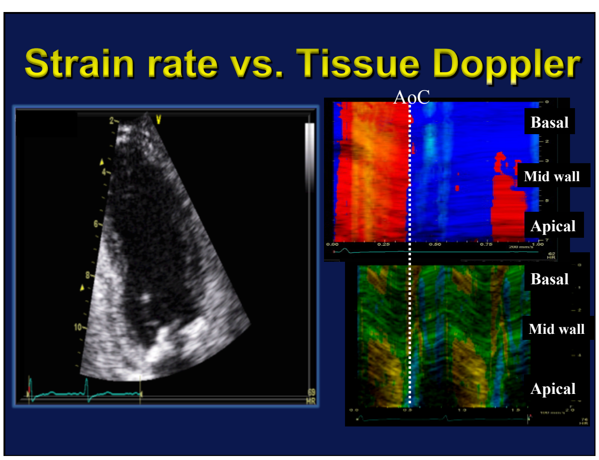

Peak Velocities
Mean Velocities
14
11


Pitfall (Velocity Analysis)
Translation and Tethering
Translation
Transducer
Chest wall
Ventricular wall
Tethering
Transducer
Chest wall
Normal myocardium
Akinetic myocardium


Strain = deformation resulting from applied force
Stress = force
Courtesy of Ted Abraham


Myocardial strain
Used to describe elastic properties of cardiac muscle (Mirsky and Parmley: Circ Res, 1973)
Strain (ε) = $\frac{L_1 - L_0}{L_0}$
10 cm
L_0
Strain rate
L_1
-20%
8 cm
+20%
12 cm
0%
10 cm


Strain rate:
Rate of deformation
High strain rate
Low strain rate
Equal strain
Courtesy of Andreas Heimdal


Strain rate vs. Tissue Doppler
AoC
Basal
Mid wall
Apical
Basal
Mid wall
Apical

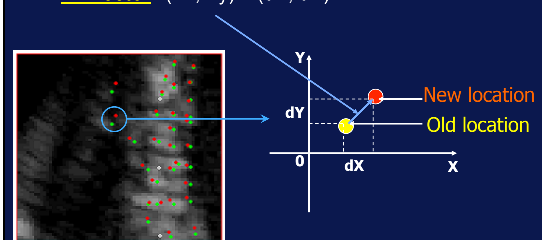
Feature "Speckle" Tracking
Doppler

Movement of the myocardium relative to the sample volume fixed in space

Acoustic pattern tracking
Speckle Tracking

Velocity is estimated as a shift of each object divided by time between successive frames (or multiplied by Frame Rate)-->

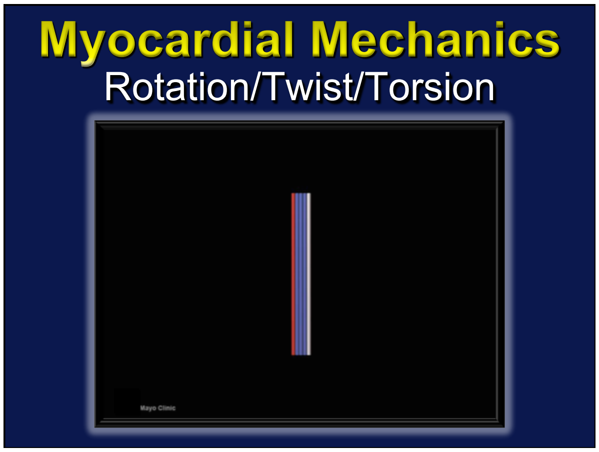
2D vector: (Vx, Vy) = (dX, dY) * FR

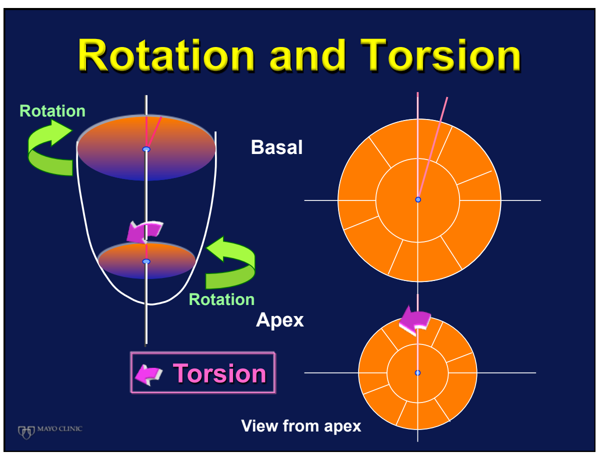


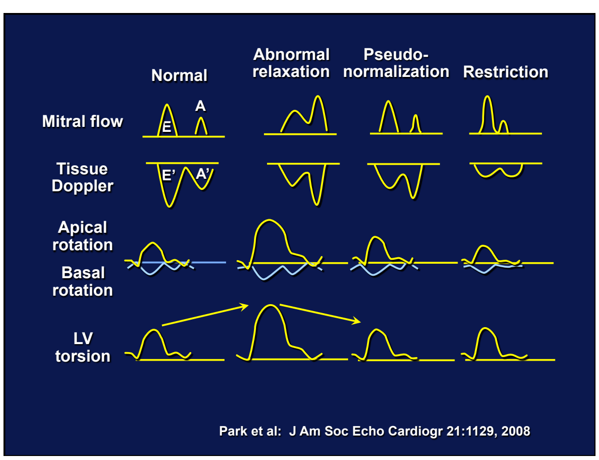
Courtesy Peter Lysysanksy

Doppler Independent Techniques (Speckle Tracking)
Potential Advantage?

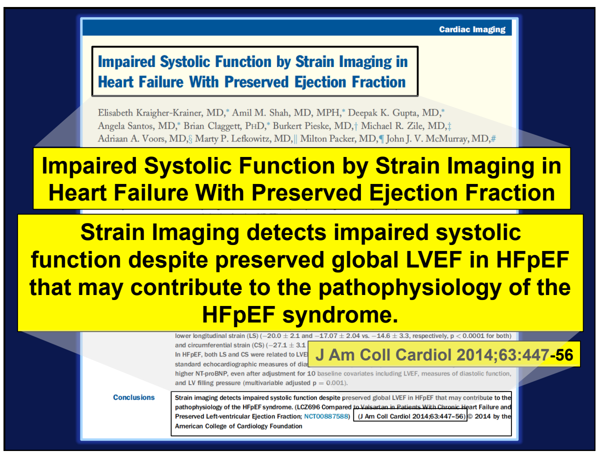
- Signal noise
- Speckle tracking by principle is angle independent
- Gray scale (standard views)
- Monitor strain in two rather than one dimension
- Minimal user input
- Assessment of rotation: derived from circumferential strain at different levels in the heart (NO fixed sample volume)

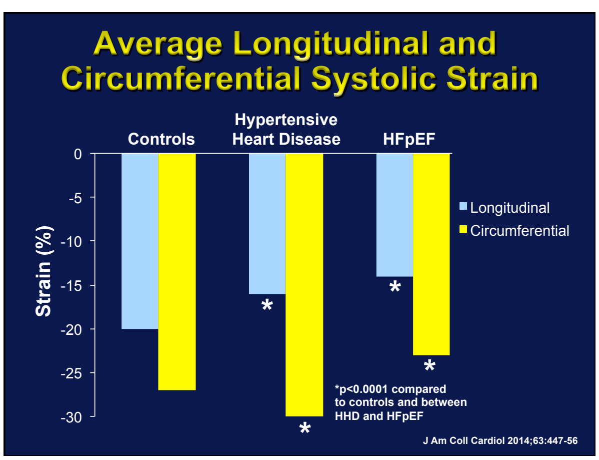

Myocardial Mechanics
Rotation/Twist/Torsion
Mayo Clinic

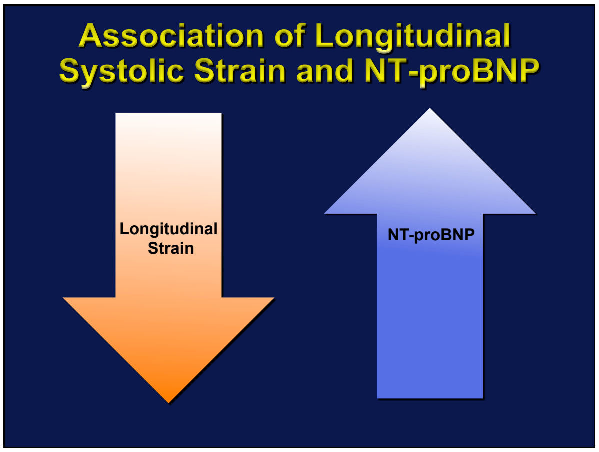

Rotation and Torsion
Rotation
Basal
Rotation
Apex
Torsion
View from apex
MAYO CLINIC


Normal
Abnormal relaxation
Pseudo-normalization
Restriction
Mitral flow
E
A
Tissue Doppler
E'
A'
Apical rotation
Basal rotation
LV torsion
Park et al: J Am Soc Echo Cardiogr 21:1129, 2008


Objective #2
Potential Clinical Applications


Cardiac Imaging
Impaired Systolic Function by Strain Imaging in Heart Failure With Preserved Ejection Fraction
Impaired Systolic Function by Strain Imaging in Heart Failure With Preserved Ejection Fraction
Strain Imaging detects impaired systolic function despite preserved global LVEF in HFpEF that may contribute to the pathophysiology of the HFpEF syndrome.
J Am Coll Cardiol 2014;63:447-56
Conclusions


Average Longitudinal and Circumferential Systolic Strain
Controls
Hypertensive Heart Disease
HFpEF
Strain (%)
0
-5
-10
-15
-20
-25
-30
Longitudinal
Circumferential
*p<0.0001 compared to controls and between HHD and HFpEF
J Am Coll Cardiol 2014;63:447-56


Association of Longitudinal Systolic Strain and NT-proBNP
Longitudinal Strain
NT-proBNP


Cardiovascular Business
Surviving Cancer, But at a Cost
Radiation & Chemo-induced Cardiovascular Diseases

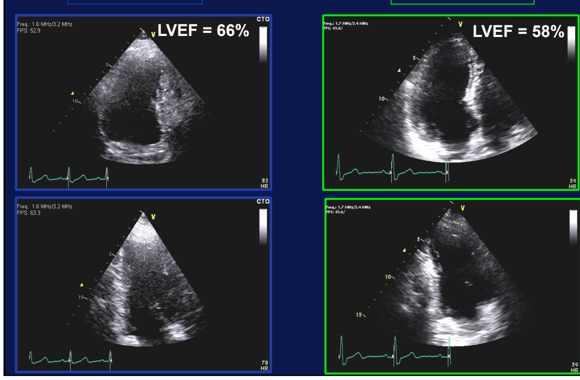

Cardio-Oncology
"The difficulty when dealing with cardiology side effects is that they can often mask themselves as normal effects from the cancer treatment itself..."

Case

- 76 year old male
- CMML/MDS with associated myeloid sarcoma skin lesions
- Experimental Chemotherapy ABT-348

Baseline

2 Months

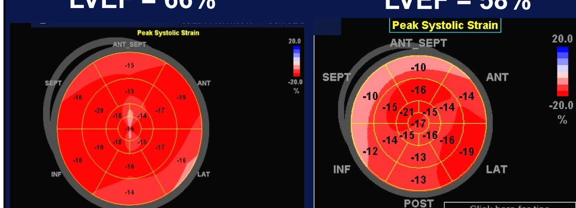


Baseline

LVEF = 66%

2 Months

LVEF = 58%



GLPSS Avg = -17.8%
Troponin T = 0.02

GLPSS Avg = -14.3%
Troponin T = 0.03

Early Detection and Prediction of Cardiotoxicity in Chemotherapy-Treated Patients

Heloisa Sawaya, MD, PhD[a], Igal A. Sebag, MD[d], Juan Carlos Plana, MD[f], James L. Januzzi, MD[a], Bonnie Ky, MD[g], Victor Cohen, MD[e], Sucheta Gosavi, MD[a], Joseph R. Carver, MD[g], Susan E. Wiegers, MD[g], Randolph P. Martin, MD[h], Michael H. Picard, MD[a], Robert E. Gerszten, MD[a], Elkan F. Halpern, PhD[c], Jonathan Passeri, MD[a], Irene Kuter, MD[b], and Marielle Scherrer-Crosbie, MD, PhD[a,*]

Anthracyclines and Trastuzumab

Can we predict a later (3 months) decline in LVEF?

- No decrease in GLS > 10% or elevated hsTnI have a 3% probability of a decrease in LVEF.
- If either a decrease in GLS or elevated hsTnI have a 9X increased risk for cardiotoxicity compared to those with no changes in either of these markers.

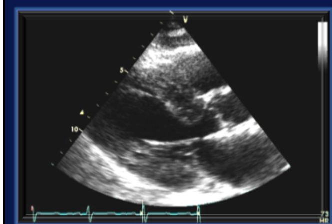
EXPERT CONSENSUS STATEMENT

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

- GLS is the optimal parameter of deformation for the early detection of subclinical LV dysfunction.
- 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.

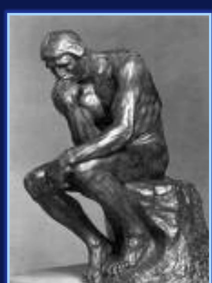
(J Am Soc Echocardiogr 2014;27:911-39.)

Thick Walls, Why?

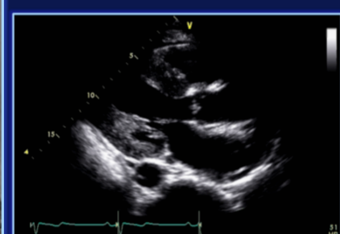


- Athlete
- HTN
- HCM
- Infiltrative
  - -amyloid
- Storage
  - -Fabry

HTN or HCM?



The Thinker
Auguste Rodin



Are They Really The Same?

CARDIAC MECHANICS IN PATIENTS WITH CARDIOMYOPATHY

Systolic Function Reserve Using Two-Dimensional Strain Imaging in Hypertrophic Cardiomyopathy: Comparison with Essential Hypertension

Hala Mahfouz Badran, MD, Naglaa Faheem, MD, Waleed Abdou Ibrahim, MD, Mohamed Fahmy Elnoamany, MD, Mohamed Elsedi, MSc, and Magdi Yacoub, MD,
Shebin, Alexandria, and Aswan, Egypt; London, United Kingdom

J Am Soc Echocardiogr 2013;26:1397-406

Background: Although patients with hypertrophic cardiomyopathy (HCM) have normal ejection fractions at rest, the investigators hypothesized that these patients have differentially abnormal systolic function reserves, limiting their exercise capacity compared with patients with hypertension (HTN).

Methods: Forty patients with HCM (mean age, 39.1 ± 12 years), 20 patients with HTN with LVH, and 33 healthy

Patients with HCM have significantly limited systolic function reserve and more dynamic dyssynchrony with exercise compared with those with HTN…

Results: In patients with HCM, resting values for longitudinal ε_{sys}, systolic strain rate, early diastolic strain rate, and atrial diastolic strain rate were significantly lower, while circumferential ε_{sys} and twist were higher, compared with patients with HTN and controls ($P < .0001$). Functional systolic reserve increased during exercise in controls (17 ± 6%), increased to a lesser extent in patients with HTN (10 ± 16%), and was markedly attenuated in patients with HCM (−23 ± 28%) ($P < .001$). At peak exercise, even with augmented circumferential ε_{sys} and twist in patients with HCM ($P < .01$) compared with those with HTN, both remained lower than in controls ($P < .001$). LV dyssynchrony was amplified during exercise in patients with HCM compared with those with HTN ($P < .001$). Within the entire population, exercise capacity was clearly correlated with systolic functional reserve. However when taken separately, it was mainly related to resting LV dyssynchrony and diastolic function in patients with HCM, whereas it was linked to age and LV wall thickness in those with HTN.

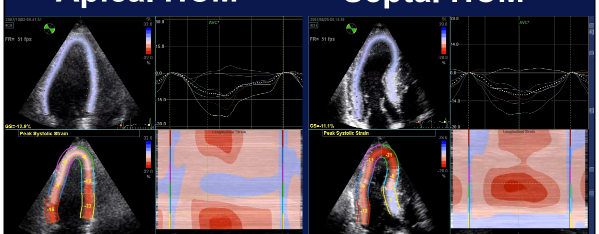
Conclusions: Patients with HCM have significantly limited systolic function reserve and more dynamic dyssynchrony with exercise compared with those with HTN. Two-dimensional strain imaging during stress may provide a new and reliable method to identify patients at higher cardiovascular risk. (J Am Soc Echocardiogr 2013;26:1397-406.)

HTN or HCM?

	Controls	HTN	HCM
Rest Strain (%)	-18.5 ± 2.0	-15.5 ± 3.7*	-13.5 ± 5.6**
Exercise Strain (%)	-23.1± 2.7	-17.7 ± 2.4*	-11.8 ± 4.9**
Rest TTP-SD (msec)	28 ± 7.5	28 ± 12.7	52 ± 28.9**
Exercise TTP-SD (msec)	20.9 ± 12	30 ± 20*	60 ± 37**

Identify "Regionality" of Myocardial Motion

Apical HCM | **Septal HCM**



Application of a Parametric Display of Two-Dimensional Speckle-Tracking Longitudinal Strain to Improve the Etiologic Diagnosis of Mild to Moderate Left Ventricular Hypertrophy

Dermot Phelan, MB, BCh, PhD, Paaladinesh Thavendiranathan, MD, MSc, Zoran Popovic, MD, PhD, Patrick Collier, MB, BCh, PhD, Brian Griffin, MD, James D. Thomas, MD, and Thomas H. Marwick, MBBS, PhD, MPH, *Cleveland, Ohio; Toronto, Ontario, Canada; Hobart, Australia*

Application of a Parametric Display of Two-Dimensional Speckle-Tracking Longitudinal Strain to Improve the Etiologic Diagnosis of Mild to Moderate Left Ventricular Hypertrophy

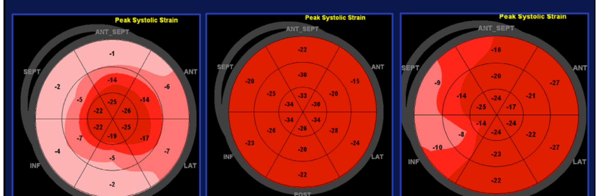
J Am Soc Echocardiogr 2014;27:888-95

these cohorts, and interpretation was repeated with the addition of the strain polar map.

Results: Baseline concordance among the readers was poor ($\kappa = 0.28$) and improved with the addition of strain data ($\kappa = 0.57$). Accuracy was improved with the addition of polar maps for the entire study cohort ($P < .001$), with 22% of cases reclassified correctly. The largest improvements in sensitivity (from 40% to 86%, $P < .001$), specificity (from 84% to 95%, $P < .001$), and accuracy (from 70% to 92%, $P < .001$) were seen for CA. The strain polar map significantly improved reader confidence in making the correct diagnosis overall ($P < .001$).

Conclusions: Regional variations in strain are easily recognizable, accurate, and reproducible means of differentiating causes of LVH. The detection of LVH etiology may be a useful clinical application for strain. (J Am Soc Echocardiogr 2014;27:888-95.)

Cardiac Amyloidosis	Hypertensive Heart Disease	Hypertrophic Cardiomyopathy



14mm	14mm	13mm

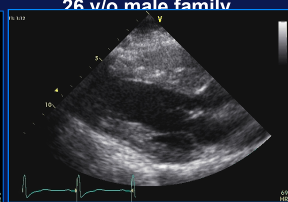
Mean Wall Left Ventricular Thickness

Pattern Recognition

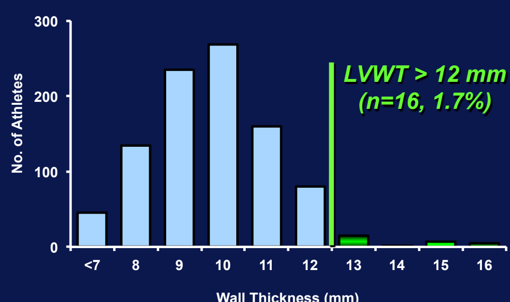
Athlete or HCM ?

30 y/o male professional Football player

26 y/o male family



Distribution of LVWT in 947 Elite Athletes?



Pelliccia et al N Engl J Med 1991;324:295

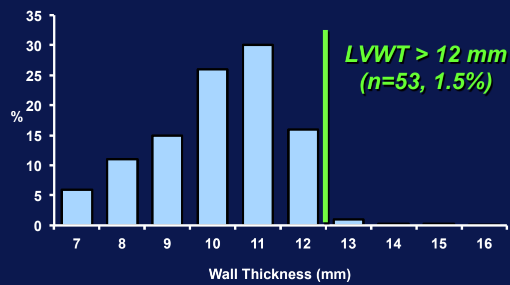
Distribution of LVWT in 947 Elite Athletes?

Of the 16 with LVWT > 12mm

- All had EDD >54mm
- All had normal LA dimension
- All were men, no women >11mm

Pelliccia et al N Engl J Med 1991;324:295

Distribution of LVWT in 3500 Elite Athletes?



Basavarajaiah et al. J Am Coll Cardiol 2008:51:1033

Distribution of LVWT in 3500 Elite Athletes?

Of the 53 with LVWT > 12mm

- 50 had EDD >58mm
- All had normal LA dimension and diastolic function
- All were men

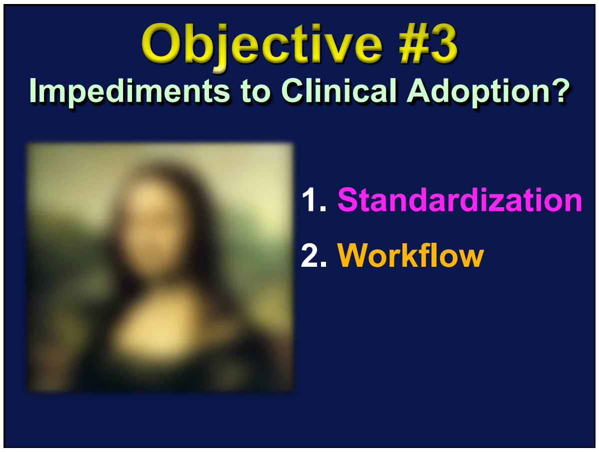
Basavarajaiah et al. J Am Coll Cardiol 2008:51:1033

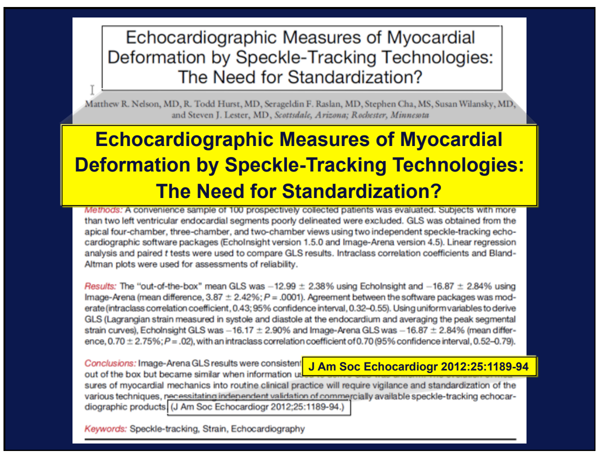
Athletes vs HCM

Gray Zone LVWT

	Criterion	*Sensitivity*	*Specificity*	*AUC*
LVRWT	<0.6	96	86	0.97
Septal e' (cm/sec)	>9	86	70	0.75
Long-endo ε (%)	<-15	79	67	0.72
Long-endo ε / LVRWT	<-30	82	95	0.94

Kansal MM et al. Am J Cardiol 2011;108(9):1322-6


Objective #3
Impediments to Clinical Adoption?
1. Standardization
2. Workflow


Echocardiographic Measures of Myocardial Deformation by Speckle-Tracking Technologies: The Need for Standardization?
Matthew R. Nelson, MD, R. Todd Hurst, MD, Serageldin F. Raslan, MD, Stephen Cha, MS, Susan Wilansky, MD, and Steven J. Lester, MD, Scottsdale, Arizona; Rochester, Minnesota
Echocardiographic Measures of Myocardial Deformation by Speckle-Tracking Technologies: The Need for Standardization?
Methods: A convenience sample of 100 prospectively collected patients was evaluated. Subjects with more than two left ventricular endocardial segments poorly delineated were excluded. GLS was obtained from the apical four-chamber, three-chamber, and two-chamber views using two independent speckle-tracking echocardiographic software packages (EchoInsight version 1.5.0 and Image-Arena version 4.5). Linear regression analysis and paired t tests were used to compare GLS results. Intraclass correlation coefficients and Bland-Altman plots were used for assessments of reliability.
Results: The "out-of-the-box" mean GLS was −12.99 ± 2.38% using EchoInsight and −16.87 ± 2.84% using Image-Arena (mean difference, 3.87 ± 2.42%; P = .0001). Agreement between the software packages was moderate (intraclass correlation coefficient, 0.43; 95% confidence interval, 0.32–0.55). Using uniform variables to derive GLS (Lagrangian strain measured in systole and diastole at the endocardium and averaging the peak segmental strain curves), EchoInsight GLS was −16.17 ± 2.90% and Image-Arena GLS was −16.87 ± 2.84% (mean difference, 0.70 ± 2.75%; P = .02), with an intraclass correlation coefficient of 0.70 (95% confidence interval, 0.52–0.79).
Conclusions: Image-Arena GLS results were consistent
out of the box but became similar when information u
sures of myocardial mechanics into routine clinical practice will require vigilance and standardization of the various techniques, necessitating independent validation of commercially available speckle-tracking echocardiographic products. (J Am Soc Echocardiogr 2012;25:1189-94.)
J Am Soc Echocardiogr 2012:25:1189-94
Keywords: Speckle-tracking, Strain, Echocardiography

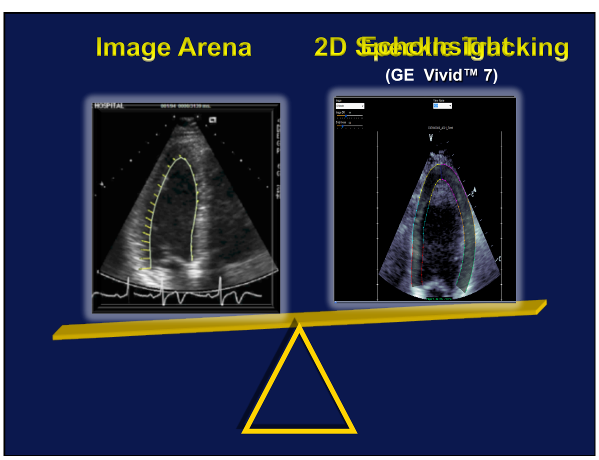
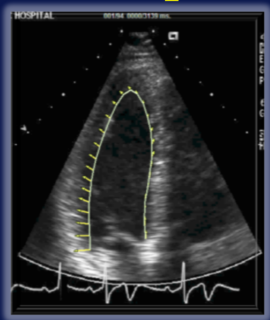
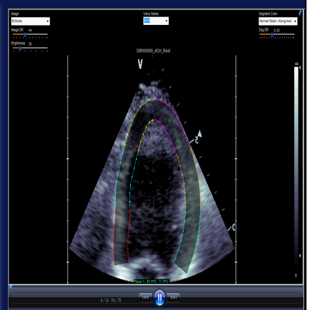


Image Arena
2D Speckle Tracking
(GE Vivid™ 7)

Image Area vs EchoInsight

GLS -16.87 ± 2.84% vs −12.99 ± 2.38%; p=0.0001





Need For Standardization

	Endocardium		Endocardium/Epicardium	
	Natural	Lagrangian	Natural	Lagrangian
Average of peaks				
Systole	-14.63±2.48†	-15.79±2.86†	-13.42± 2.22†	-14.39±2.53†
Systole/ diastole	-14.96±2.50†	-16.17±2.90*	-13.70± 2.24†	-14.71±2.57†
Peak of ave[illegible]				
Systole	[illegible]	[illegible]	[illegible]	[illegible]±2.75†
Systole/ diastole	-13.99±2.61†	-15.05±2.99†	-12.99± 2.38†	-13.91±2.69†

-16.17 vs -16.87; p=0.02

*Significant difference (P<.05) compared with Image-Arena GLS
†Significant difference (P<.001) compared with Image-Arena GLS

•J Am Soc Echocardiogr 2012:25:1189-94

REPRODUCIBILITY OF LEFT VENTRICULAR STRAIN

Head-to-Head Comparison of Global Longitudinal Strain Measurements among Nine Different Vendors
The EACVI/ASE Inter-Vendor Comparison Study

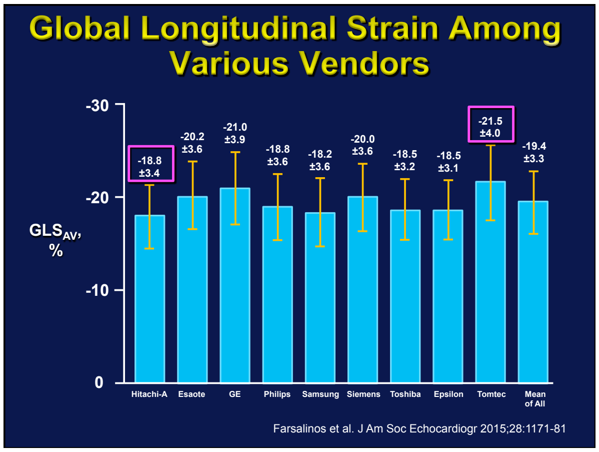
Konstantinos E. Farsalinos, MD, Ana M. Daraban, MD, Serkan Ünlü, MD, James D. Thomas, MD, Luigi P. Badano, MD, PhD, and Jens-Uwe Voigt, MD, PhD, *Leuven, Belgium; Chicago, Illinois; and Padua, Italy*

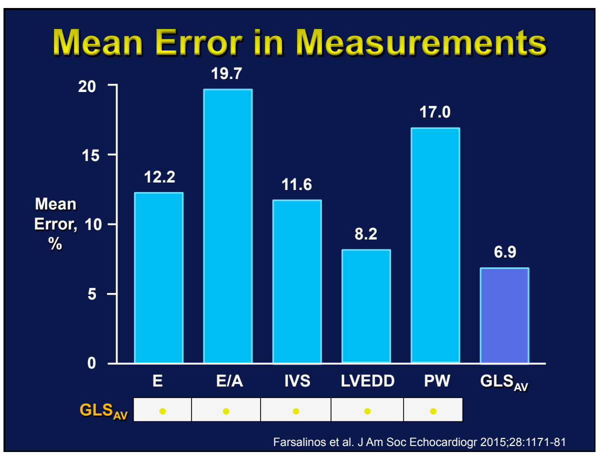
Background: This study was planned by the EACVI/ASE/Industry Task Force to Standardize Deformation Imaging to (1) test the variability of speckle-tracking global longitudinal strain (GLS) measurements among different vendors and (2) compare GLS measurement variability with conventional echocardiographic parameters.

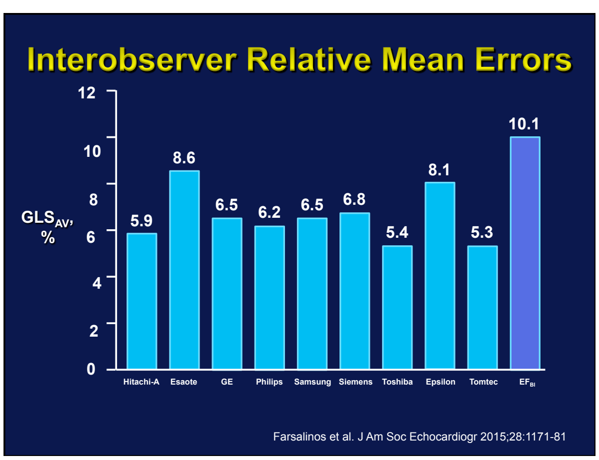
Methods: Sixty-two volunteers were studied using ultrasound systems from seven manufacturers. Each volunteer was examined by the same sonographer on all machines. Inter- and intraobserver variability was determined in a true test-retest setting. Conventional echocardiographic parameters were acquired for comparison. Using the software packages of the respective manufacturer and of two software-only vendors, endocardial GLS was measured because it was the only GLS parameter that could be provided by all manufactures. We compared GLS_{AV} (the average from the three apical views) and GLS_{4CH} (measured in the four-chamber view) measurements among vendors and with the conventional echocardiographic parameters.

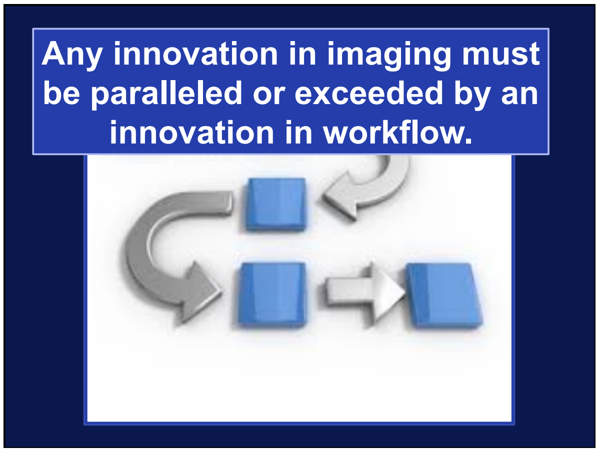
Results: Absolute values of GLS_{AV} ranged from 18.0% to 21.5%, while GLS_{4CH} ranged from 17.9% to 21.4%. The absolute difference between vendors for GLS_{AV} was up to 3.7% strain units ($P < .001$). The interobserver relative mean errors were 5.4% to 8.6% for GLS_{AV} and 6.2% to 11.0% for GLS_{4CH}, while the intraobserver relative mean errors were 4.9% to 7.3% and 7.2% to 11.3%, respectively. These errors were lower than for left ventricular ejection fraction and most other conventional echocardiographic parameters.

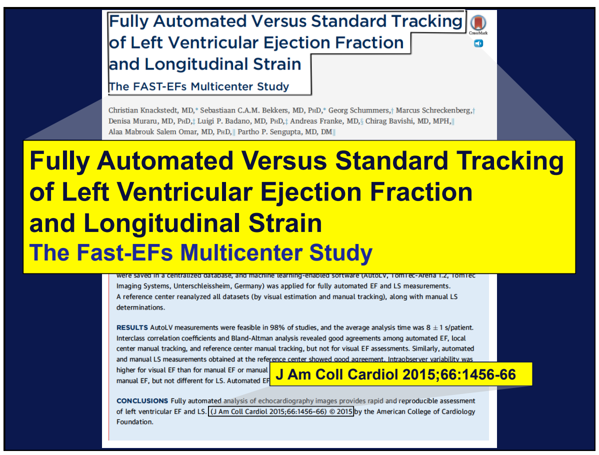
Conclusion: Reproducibility of GLS measurements was good and in many cases superior to conventional echocardiographic measurements. The small but statistically significant variation among vendors should be considered in performing serial studies and reflects a reference point for ongoing standardization efforts. (J Am Soc Echocardiogr 2015;28:1171-81.)

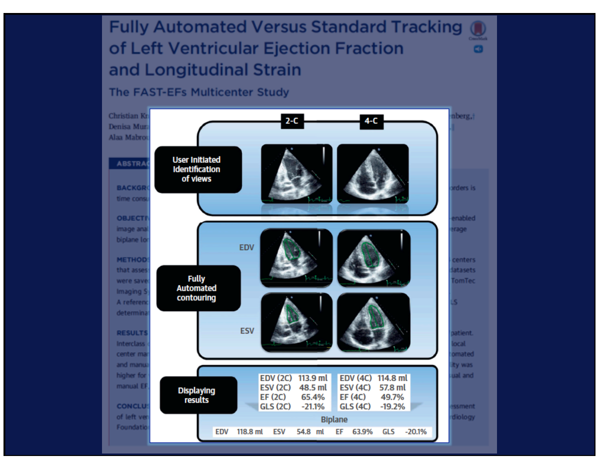

Global Longitudinal Strain Among Various Vendors
-30
-20
-10
0
GLSAV, %
-18.8 ±3.4
-20.2 ±3.6
-21.0 ±3.9
-18.8 ±3.6
-18.2 ±3.6
-20.0 ±3.6
-18.5 ±3.2
-18.5 ±3.1
-21.5 ±4.0
-19.4 ±3.3
Hitachi-A
Esaote
GE
Philips
Samsung
Siemens
Toshiba
Epsilon
Tomtec
Mean of All
Farsalinos et al. J Am Soc Echocardiogr 2015;28:1171-81


Mean Error in Measurements
20
15
10
5
0
Mean Error, %
12.2
19.7
11.6
8.2
17.0
6.9
E
E/A
IVS
LVEDD
PW
GLSAV
GLSAV
Farsalinos et al. J Am Soc Echocardiogr 2015;28:1171-81


Interobserver Relative Mean Errors
12
10
8
6
4
2
0
GLSAV, %
5.9
8.6
6.5
6.2
6.5
6.8
5.4
8.1
5.3
10.1
Hitachi-A
Esaote
GE
Philips
Samsung
Siemens
Toshiba
Epsilon
Tomtec
EFBi
Farsalinos et al. J Am Soc Echocardiogr 2015;28:1171-81


Any innovation in imaging must be paralleled or exceeded by an innovation in workflow.


Fully Automated Versus Standard Tracking of Left Ventricular Ejection Fraction and Longitudinal Strain
The FAST-EFs Multicenter Study
Fully Automated Versus Standard Tracking of Left Ventricular Ejection Fraction and Longitudinal Strain
The Fast-EFs Multicenter Study
J Am Coll Cardiol 2015;66:1456-66


Fully Automated Versus Standard Tracking of Left Ventricular Ejection Fraction and Longitudinal Strain
The FAST-EFs Multicenter Study
2-C
4-C
User Initiated Identification of views
Fully Automated contouring
EDV
ESV
Displaying results
EDV (2C) 113.9 ml
ESV (2C) 48.5 ml
EF (2C) 65.4%
GLS (2C) -21.1%
EDV (4C) 114.8 ml
ESV (4C) 57.8 ml
EF (4C) 49.7%
GLS (4C) -19.2%
Biplane
EDV 118.8 ml ESV 54.8 ml EF 63.9% GLS -20.1%

Fully Automated Versus Standard Tracking of Left Ventricular Ejection Fraction and Longitudinal Strain

The FAST-EFs Multicenter Study

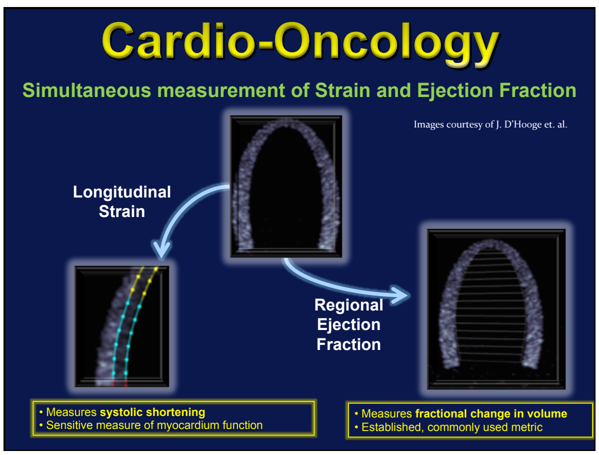
Christian Knackstedt, MD,* Sebastiaan C.A.M. Bekkers, MD, PhD,* Georg Schummers,† Marcus Schreckenberg,† Denisa Muraru, MD, PhD,‡ Luigi P. Badano, MD, PhD,‡ Andreas Franke, MD,§ Chirag Bavishi, MD, MPH,|| Alaa Mabrouk Salem Omar, MD, PhD,|| Partho P. Sengupta, MD, DM||

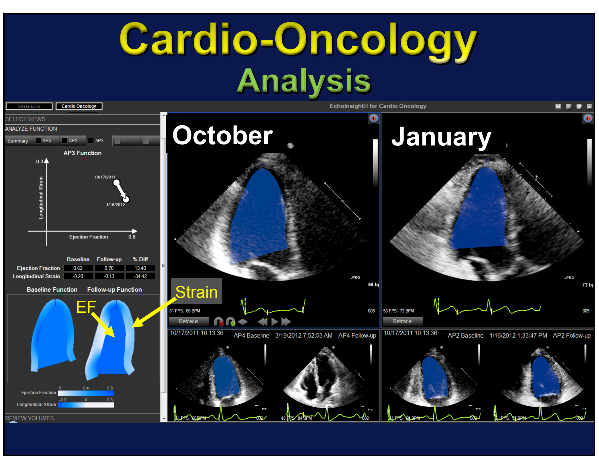
1. AutoLV measurements were feasible in 98% of studies.
2. Average analysis time was 8 ± 1 s/patient.
3. Interobserver variability was higher for both visual and manual EF, but not different for LS.

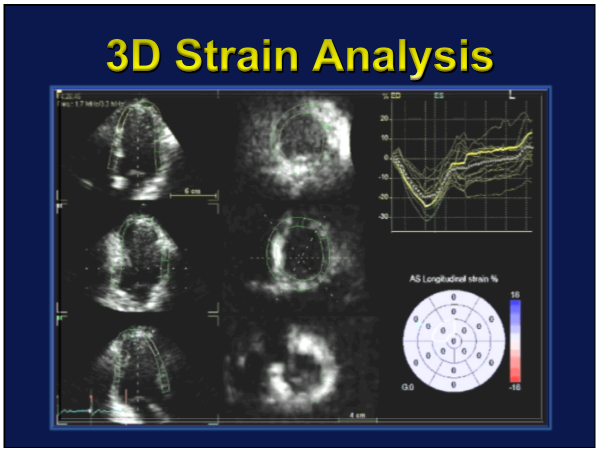
determinations.

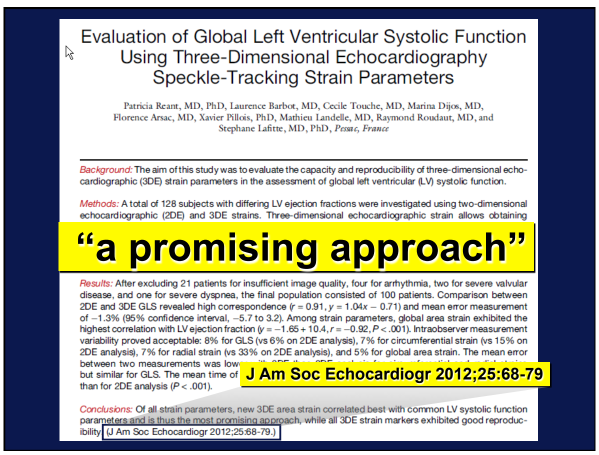
RESULTS AutoLV measurements were feasible in 98% of studies, and the average analysis time was 8 ± 1 s/patient. Interclass correlation coefficients and Bland-Altman analysis revealed good agreements among automated EF, local center manual tracking, and reference center manual tracking, but not for visual EF assessments. Similarly, automated and manual LS measurements obtained at the reference center showed good agreement. Intraobserver variability was higher for visual EF than for manual EF or manual LS, whereas interobserver variability was higher for both visual and manual EF, but not different for LS. Automated EF and LS had no variability.

CONCLUSIONS Fully automated analysis of echocardiography images provides rapid and reproducible assessment of left ventricular EF and LS. (J Am Coll Cardiol 2015;66:1456–66)








Evaluation of Global Left Ventricular Systolic Function Using Three-Dimensional Echocardiography Speckle-Tracking Strain Parameters

Patricia Reant, MD, PhD, Laurence Barbot, MD, Cecile Touche, MD, Marina Dijos, MD, Florence Arsac, MD, Xavier Pillois, PhD, Mathieu Landelle, MD, Raymond Roudaut, MD, and Stephane Lafitte, MD, PhD, *Pessac, France*

Background: The aim of this study was to evaluate the capacity and reproducibility of three-dimensional echocardiographic (3DE) strain parameters in the assessment of global left ventricular (LV) systolic function.

Methods: A total of 128 subjects with differing LV ejection fractions were investigated using two-dimensional echocardiographic (2DE) and 3DE strains. Three-dimensional echocardiographic strain allows obtaining

"a promising approach"

Results: After excluding 21 patients for insufficient image quality, four for arrhythmia, two for severe valvular disease, and one for severe dyspnea, the final population consisted of 100 patients. Comparison between 2DE and 3DE GLS revealed high correspondence ($r = 0.91$, $y = 1.04x - 0.71$) and mean error measurement of –1.3% (95% confidence interval, –5.7 to 3.2). Among strain parameters, global area strain exhibited the highest correlation with LV ejection fraction ($y = -1.65 + 10.4$, $r = -0.92$, $P < .001$). Intraobserver measurement variability proved acceptable: 8% for GLS (vs 6% on 2DE analysis), 7% for circumferential strain (vs 15% on 2DE analysis), 7% for radial strain (vs 33% on 2DE analysis), and 5% for global area strain. The mean error between two measurements was low… but similar for GLS. The mean time of … than for 2DE analysis ($P < .001$).

J Am Soc Echocardiogr 2012;25:68-79

Conclusions: Of all strain parameters, new 3DE area strain correlated best with common LV systolic function parameters and is thus the most promising approach, while all 3DE strain markers exhibited good reproducibility. (J Am Soc Echocardiogr 2012;25:68-79.)

Confucius

"It doesn't matter how slowly you go as long as you do not stop"