Echo Board Review: Tissue Doppler & Strain Imaging

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Presenter Disclosures

Consultant/ Speakers bureaus	No Disclosures
Research funding	No Disclosures
Stock ownership/Corporate boards-employment	No Disclosures
Off-label uses	None

Q1: What signal processing steps are required to transform a regular PW Doppler to a high-fidelity tissue Doppler signal?

A. Turn off high pass filter > decrease receiver gain > decrease scale > Turn on low pass filter

B. Turn on high pass filter > decrease receiver gain > decrease scale > Turn off low pass filter

C. Turn off high pass filter > increase receiver gain > increase scale > Turn on low pass filter

D. Turn on high pass filter > increase receiver gain > increase scale > Turn off low pass filter

Q2: Which of the following statements is most accurate regarding Tissue Doppler Imaging (TDI) and Speckle Tracking Echocardiography (STE)

A. Unlike pulsed wave TDI, 2D-color TDI measurements are not angle dependent and as such may yield higher velocities

B. Both STE and TDI methods allow for evaluation of longitudinal, circumferential, radial, and twist/torsional strain

C. It is conventional to report Eulerian strain but LaGrangian Strain rate

D. Both STE and TDI methods allow calculation of Strain, Strain Rate, Velocity, and Displacement

Q3: Regarding strain measurements by Speckle tracking echocardiography:

A. Lagrangian and Eulerian strain calculations start to diverge when values drop below 15%

B. Strain is first calculated as the spatial derivative of displacement, then strain rate is obtained as the temporal derivative of strain

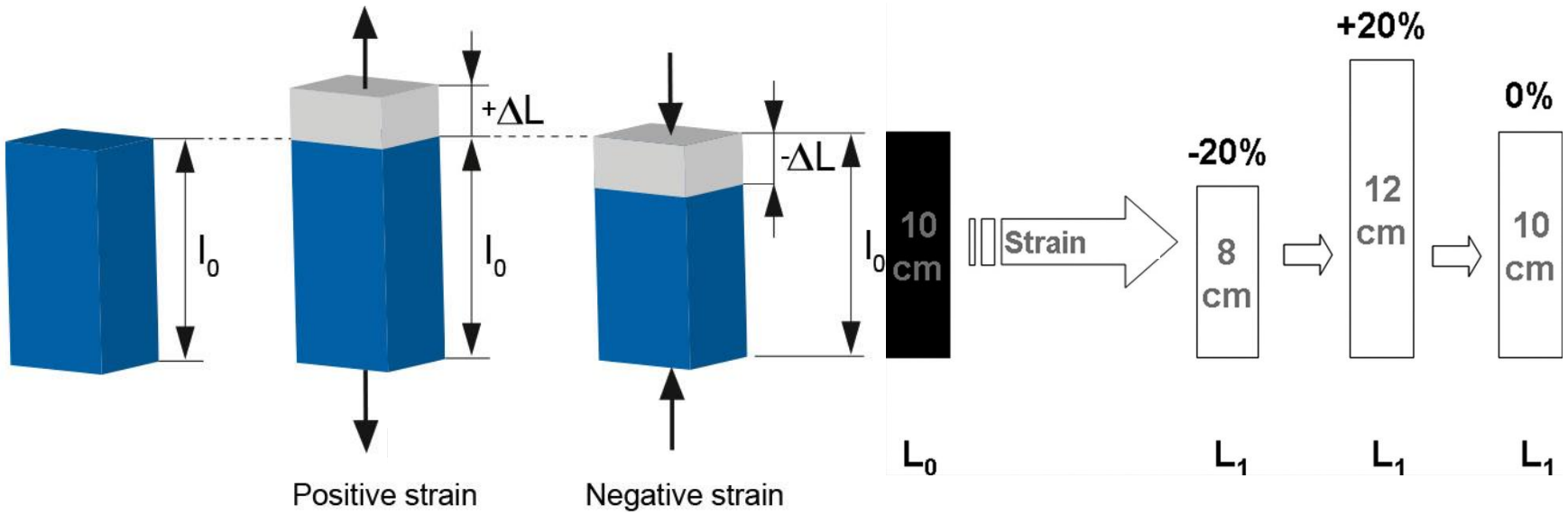
C. Strain rate is first calculated by as the spatial derivative of velocity, then strain is obtained by temporal integration of strain rate

D. When making strain measurements, most processing software utilize the peak of the QRS complex as a marker of end diastole and the midpoint of the T wave as a marker of end systole

Learning Objectives

1. Discuss the basic principles of strain and myocardial deformation imaging
2. Describe tissue Doppler imaging (TDI) and speckle tracking echocardiography (STE) techniques and list some of the main clinical applications for strain imaging
3. Explain the relationship between strain, strain rate, velocity, and displacement
4. Discuss the main technical challenges and barriers to widespread clinical adoption of strain imaging and relate to the need for standardization

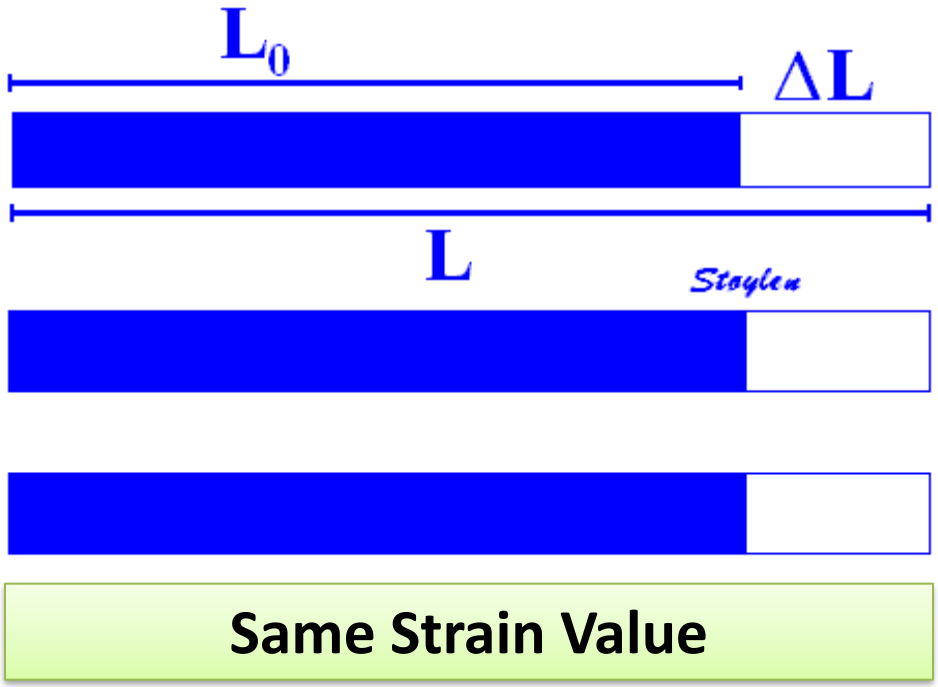
Strain = Deformation



$$\text{Strain} = \frac{Lo-L}{Lo} = \frac{\Delta L}{Lo}$$

Strain = Differential displacement of an object expressed as % (-ve ➔ shortening; +ve ➔ elongation)

Strain rate = rate by which the deformation occurs



Higher Strain Rate

Lower Strain Rate

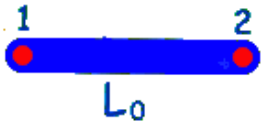
Same Strain Value

$$\text{Strain rate} = \frac{\varepsilon}{\Delta t} = \frac{\Delta L/Lo}{\Delta t} = \frac{\Delta L/\Delta t}{Lo} = \boxed{\frac{\Delta V}{Lo}}$$

Strain rate = Differential velocities of an object expressed in s^{-1} (-ve ➔ shortening; +ve ➔ elongation)

Motion vs. Deformation

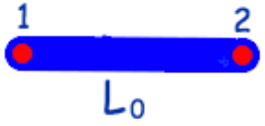
A



$V1 = V2 = 0,\ SR = 0$

No motion & No deformation

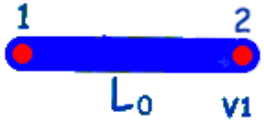
B



$V1 = V2 \neq 0,\ SR = 0$

Motion but No deformation

C



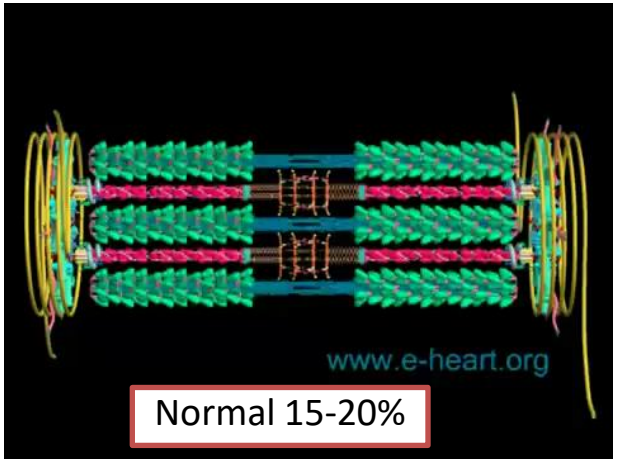
$V1 = 0,\ V2 \neq 0,\ V1 \neq V2,\ SR \neq 0$

Minimal motion but significant deformation

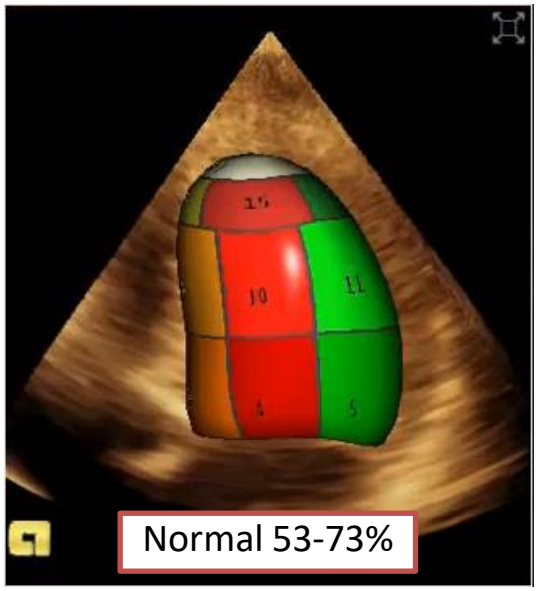
Motion & deformation

There can be motion (velocity & displacement) without deformation, but no deformation without differential motion

LV chamber deformation is determined by myofiber architecture



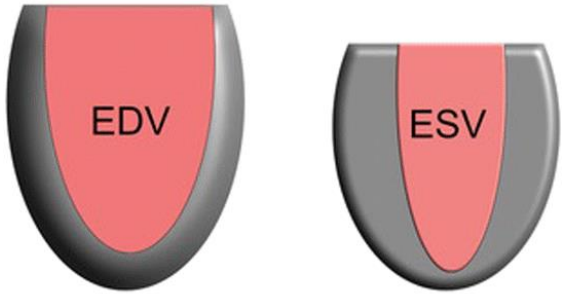
Fiber Architecture



$$\text{Strain} = \frac{L_o - L}{L_o} = \frac{\Delta L}{L_o}$$

- 3D LV myocardial deformation is the result complex electrical and mechanical interconnection of all fibers throughout the wall
- Myocardial fiber arrangement and interaction is integral to transform linear myocyte strain into an adequate stroke volume

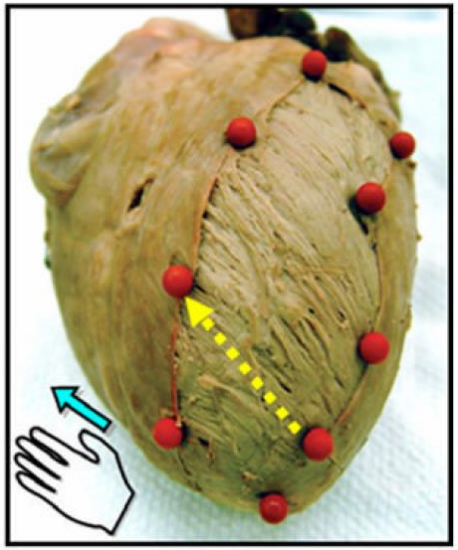
End-Diastole End-Systole

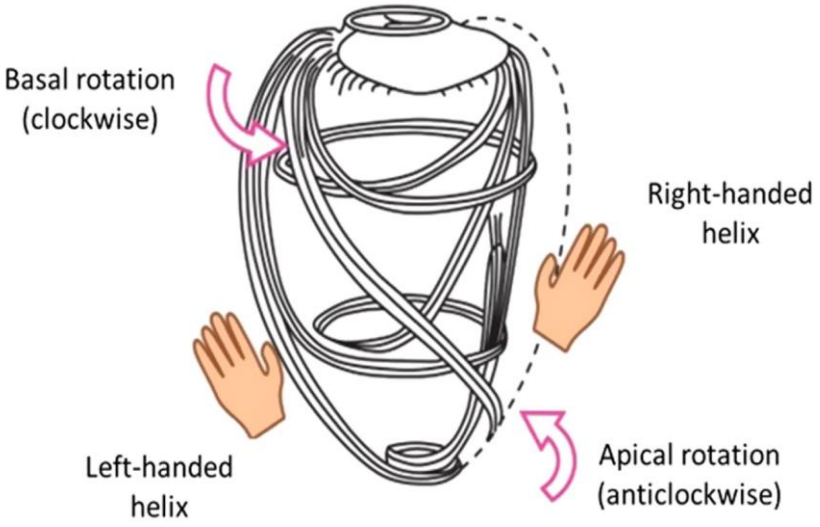


$$\text{LVEF} = \frac{\text{EDV-ESV}}{\text{EDV}} \times 100$$

Cardiac Muscle Fiber Orientation

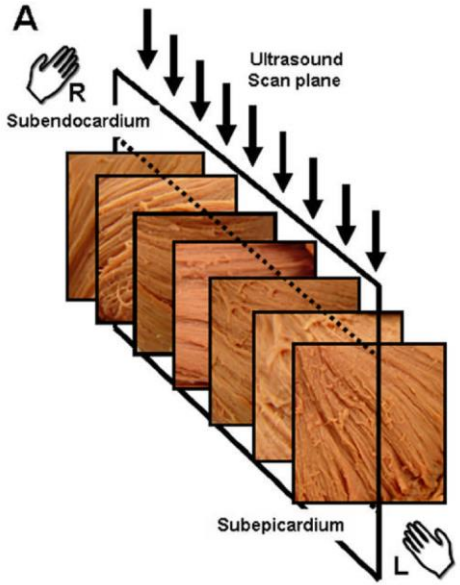
Epicardium [L]



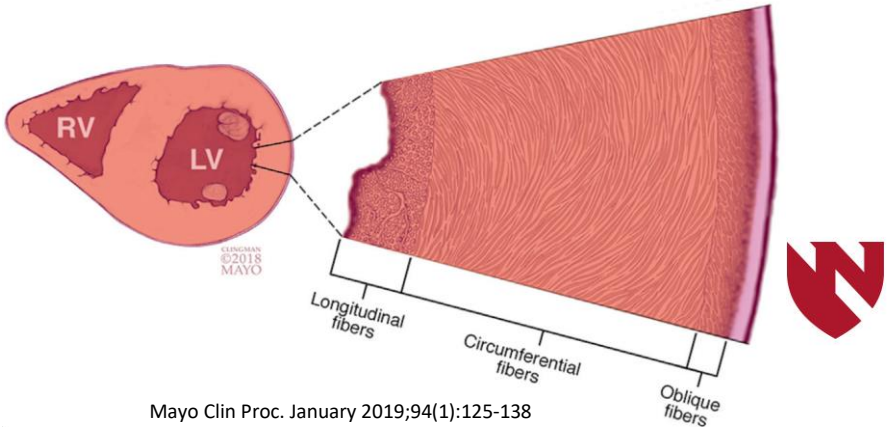


Endocardium [R]

Journal of Cardiovascular Ultrasound 2011 **19** 1–6.



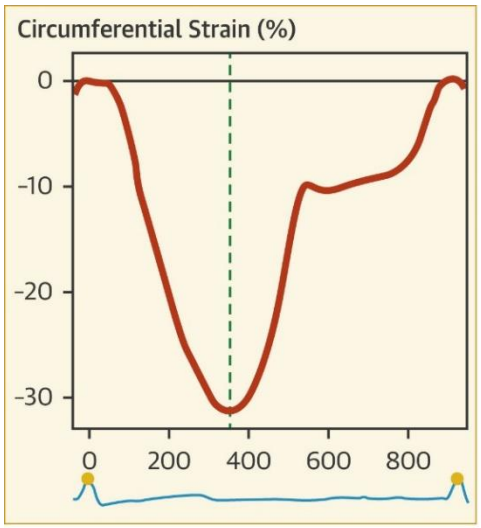
Fibers in the sub-endocardium are arranged in right-handed helix, then smoothly transition to a transverse circular arrangement in the midmyocardium and then finally a left-handed helix in the epicardium

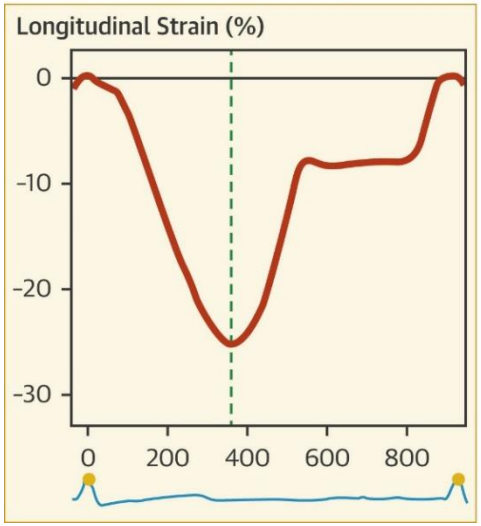


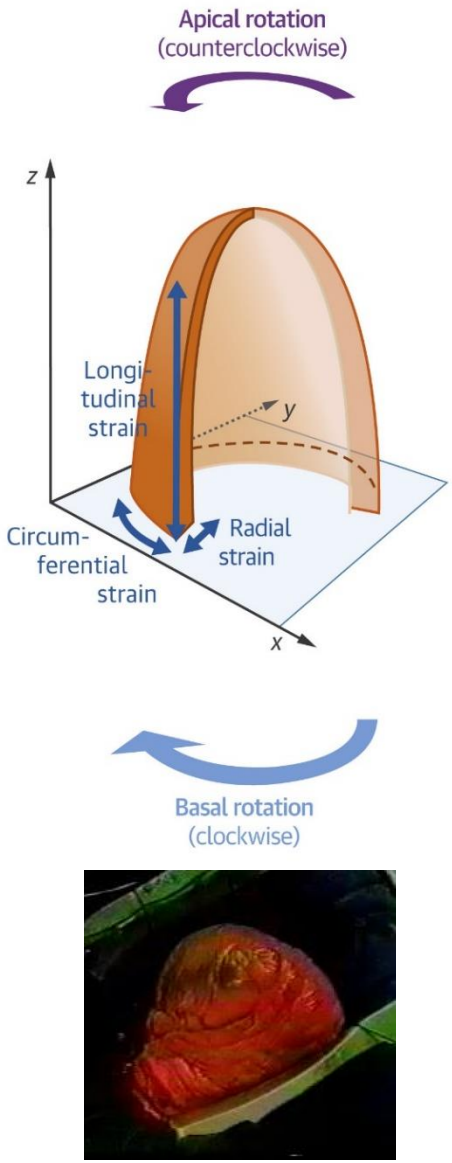
J Am Soc Echocardiogr. 2007 May ; 20(5): 539–551.

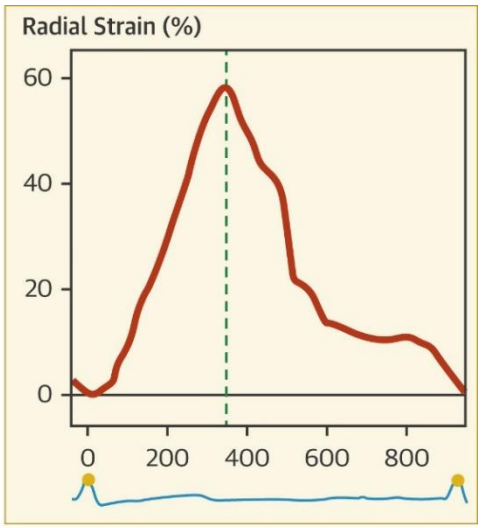
Mayo Clin Proc. January 2019;94(1):125-138

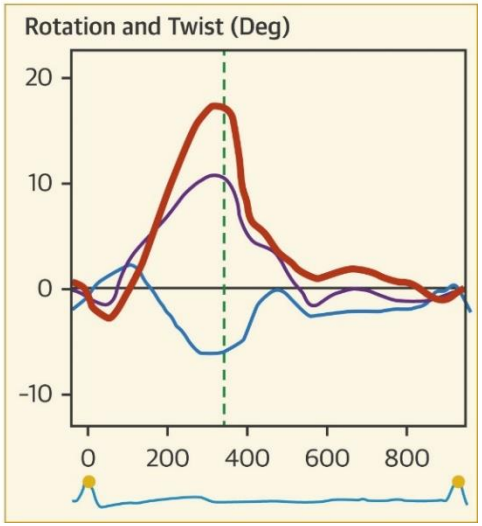
Principle myocardial deformations









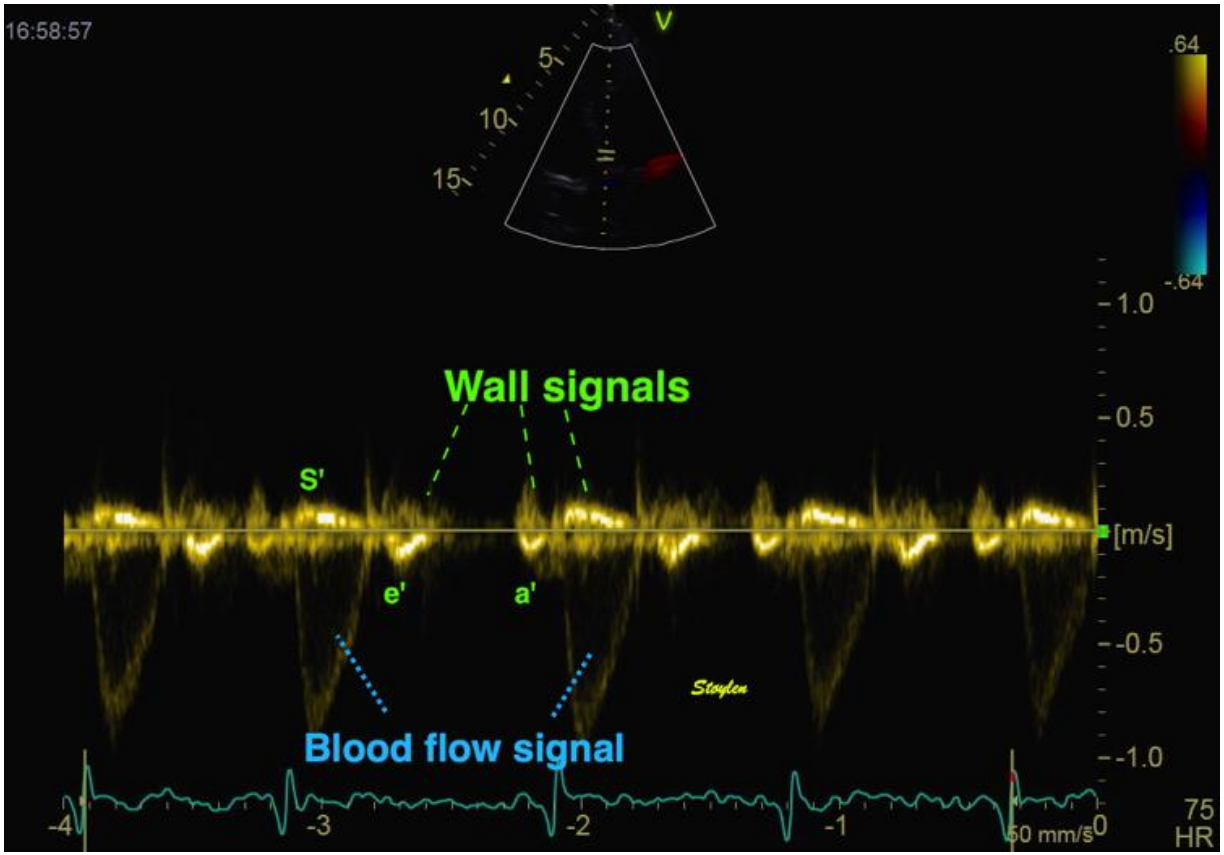


JACC Cardiovasc Imaging. 2019 Sep;12(9):1849-1863

LV & RV Deformation Mechanics

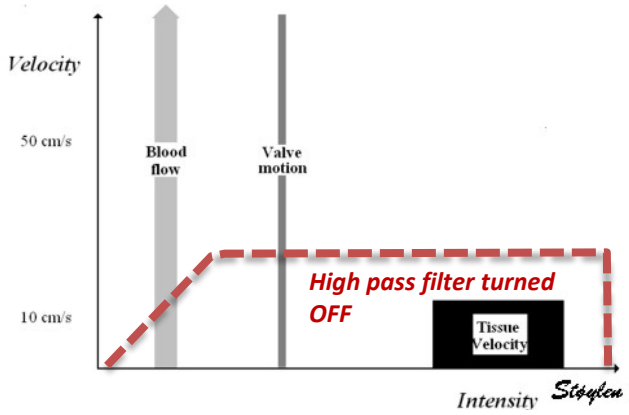
- LV systole ➔ –ve Longitudinal, –ve Circumferential, & +ve Radial strain
- Differential timing of subendocardial fibers prior to subepicardial fibers and larger radius of the subepicardial fibers contributes to LV Twist
- Deformation of the interventricular septum (largely controlled by LV fibers) is integral to RV contraction and stroke volume
- LV deformation causes traction of RV-free wall at its septal insertion points
- RV myocardium consists of deep longitudinal (subendocardial) fibers and superficial circumferential (subepicardial) fibers, however key overall RV deformation involves shortening of the longitudinal fibers during systole
- RV free wall radial strain is smaller in magnitude compared to LV
- Currently no evidence of powerful RV twist mechanics
- Circumferential and radial RV deformation is currently not routinely measured due to technological limitations in tracking RV thin walls and reduced influence on RV function

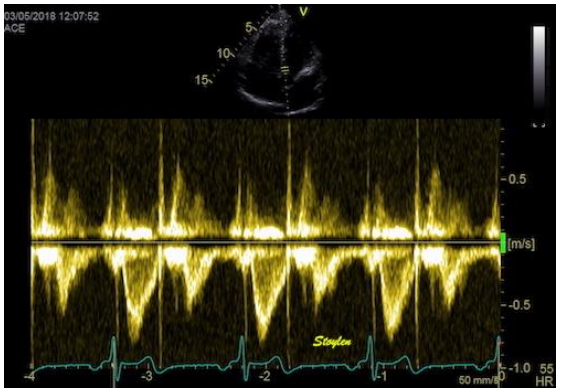
Spectral Doppler Echocardiography



- **Blood** (low density and fast) ➔ High Doppler velocity + low signal intensity
- **Tissue** (high density and slow) ➔ Low Doppler velocity + high signal intensity

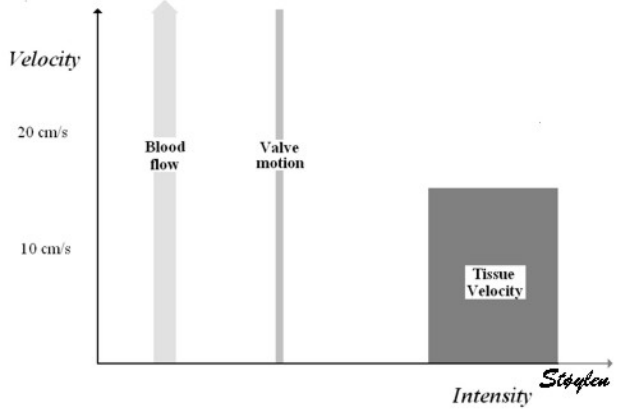
Tissue Doppler – Signal Processing

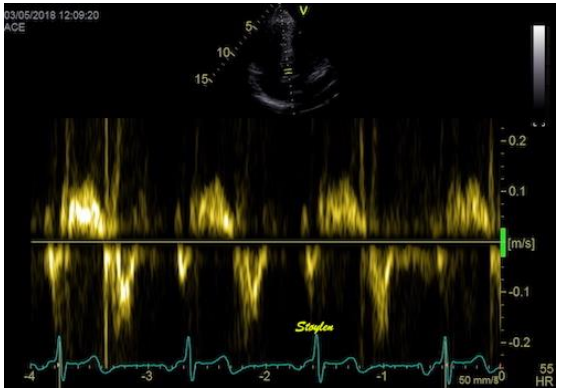


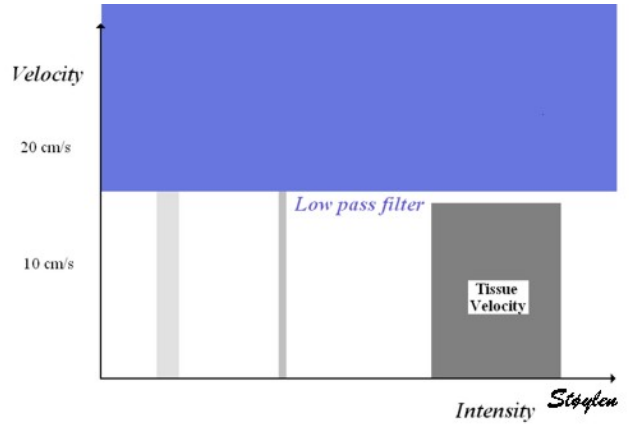


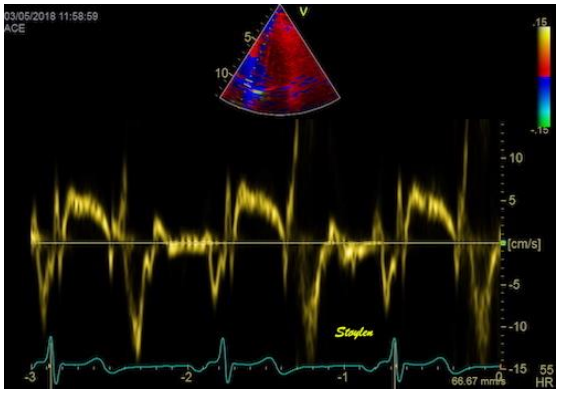
Turn off high pass filter

↓ Gain
↓ Scale





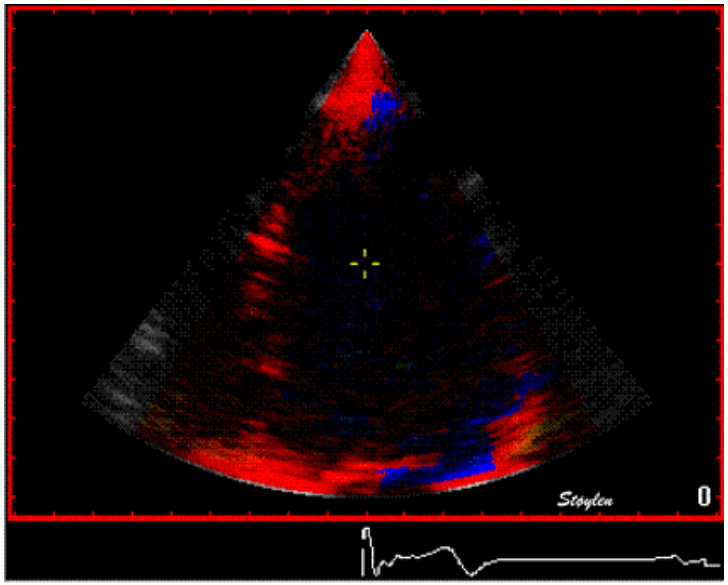




Apply Low Pass Filter*

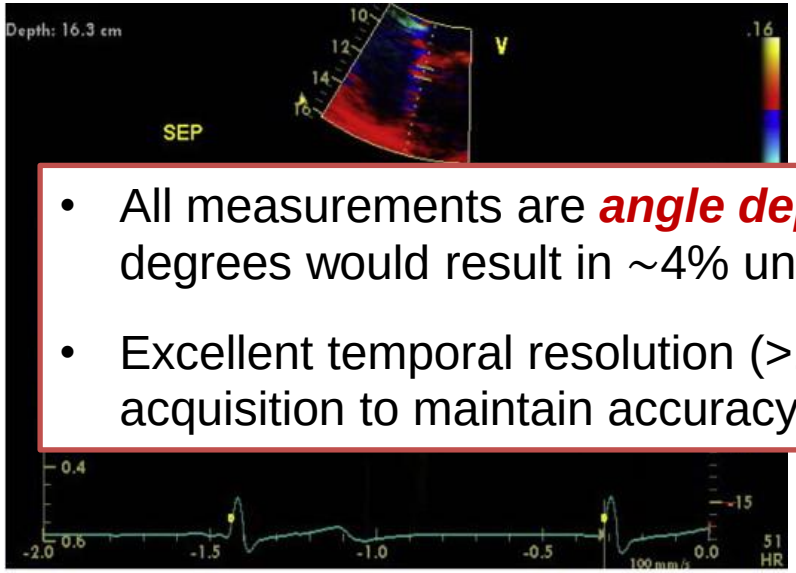
*Preferable but not absolutely necessary

Color (TDI) Tissue Doppler Imaging

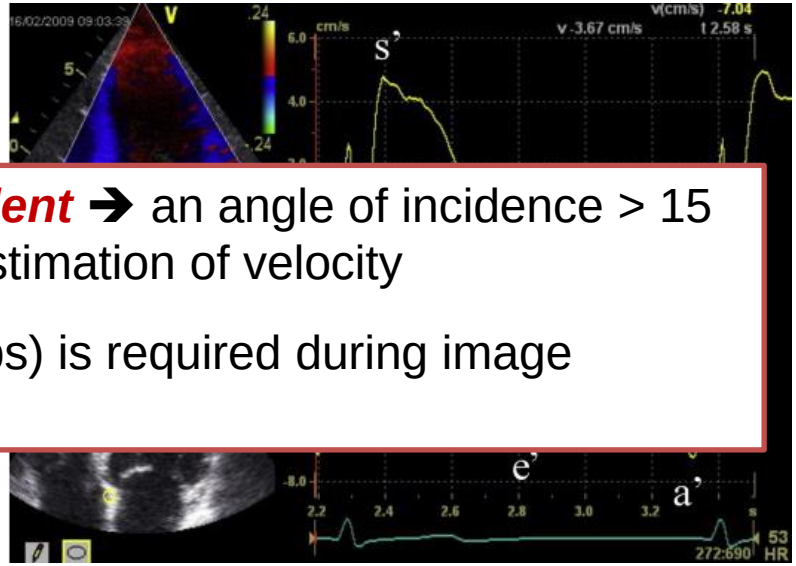


- Measures tissue Doppler velocity along the ultrasound beams while filtering out blood/cavity signals
- Velocity data is acquired in “near-simultaneous” manner over the imaging sector using very low line density, and a higher Multi-Line Acquisition (MLA) techniques
- Tissue velocities are then color coded and superimposed on full B-mode 2D sector to generate parametric color image in which each pixel represents the velocity relative to the transducer
- Velocity data is utilized for anatomical-guided numerical analysis such as: Velocity-time curves or Color Anatomical M-Mode

Pulsed-Wave TDI



2D Color-coded TDI



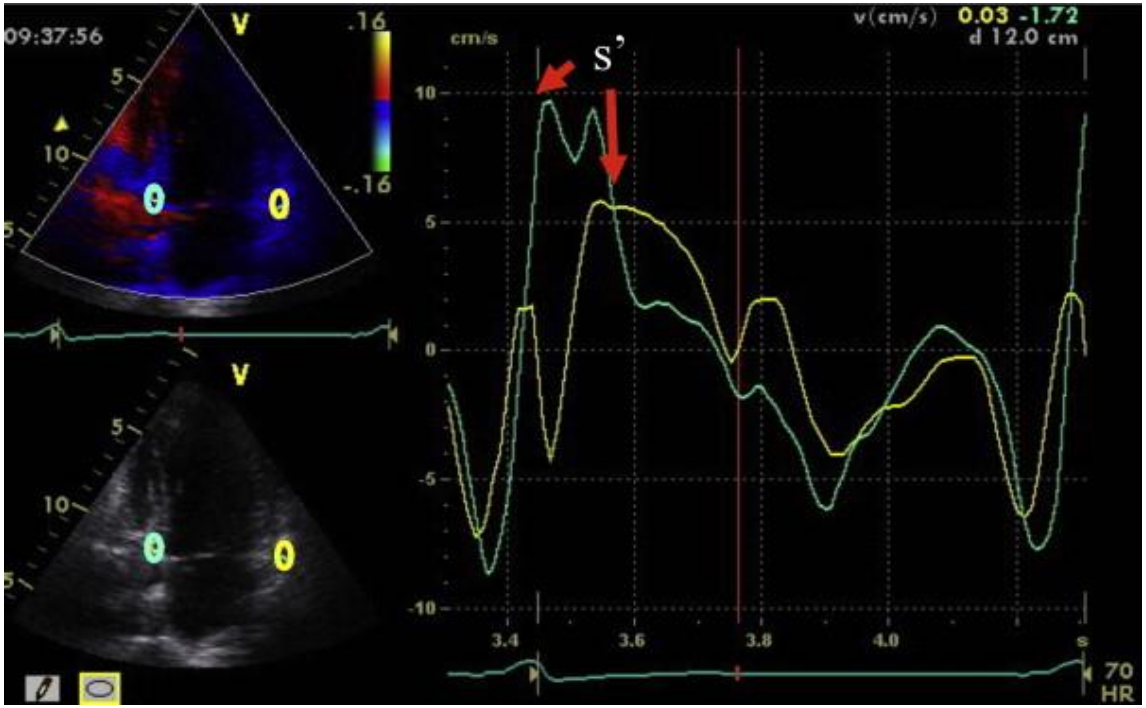
- All measurements are ***angle dependent*** ➔ an angle of incidence > 15 degrees would result in ~4% underestimation of velocity
- Excellent temporal resolution (>100fps) is required during image acquisition to maintain accuracy

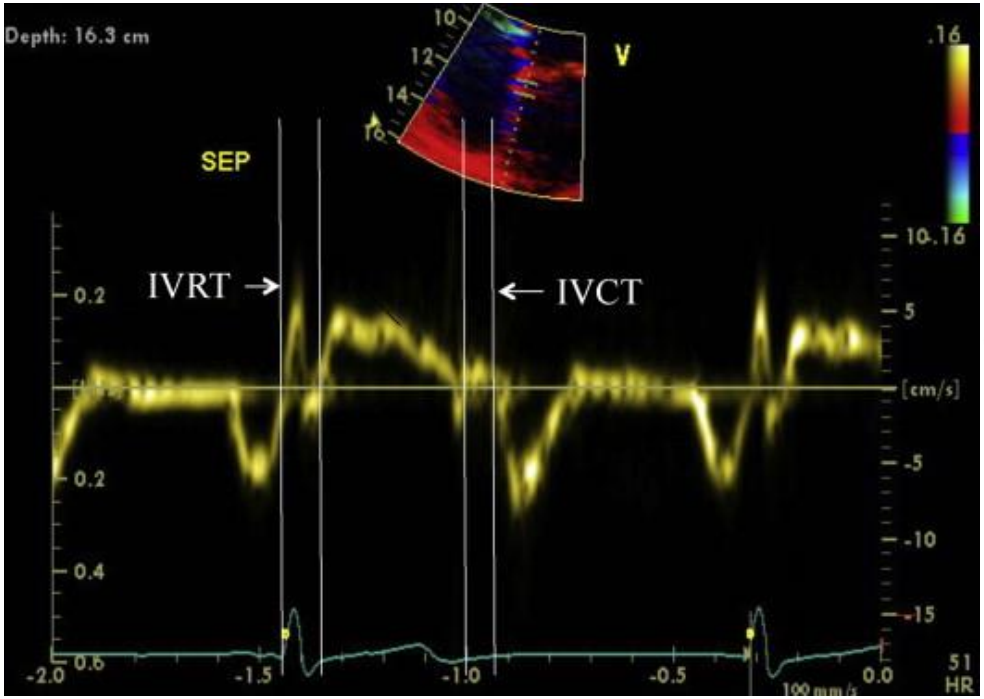
- ***High*** Temporal resolution (250 puses/sec)
- Measures ***peak*** instantaneous longitudinal velocity from single segment
- Myocardial velocities ***higher*** by ~20% compared to color TDI
- ***Online*** analysis of velocity curves
- Displays velocity curves of ***specific*** segment under interrogation

- ***Lower*** temporal resolution (50-150 frames/sec)
- Measures regional ***mean*** velocities
- ***Lower*** myocardial velocities compared to PW TDI
- ***Off-line*** analysis of velocity curves
- Allows ***simultaneous*** comparison of ***different*** segments

Heart, Lung and Circulation (2015) 24, 224–233

The time to peak s' velocity can be measured, and segmental heterogeneity can be ascertained using CTDI





Additionally, isovolumic contraction and relaxation periods can be identified

Heart, Lung and Circulation (2015) 24, 224–233

Table 1 Normal reference range of TDI values in healthy adults (mean ± SD).

	s'(cm/s)	e' (cm/s)	a' (cm/s)	E/e'	e'/a'
Septal velocity	8.1 ± 1.5	8.6 ± 1.9	9.5 ± 2.4	8.7 ± 2.2	1 ± 0.7
Lateral velocity	10.2 ± 2.4	12.2 ± 3	11.3 ± 2.9	6.3 ± 1.9	1.5 ± 0.6
Average septal + lateral	9.2 ± 1.7	10.4 ± 2.2	10.4 ± 2.7	7.5 ± 1.9	1.3 ± 0.7

Adapted from Chahal N.S, Lim T.K et al. Eur J Echocardiogr 2010, Garcia, M. J, Rodriguez L et al AHJ 1996, Pai R.G and Gill K.S JASE 1998.

Table 2 Normal age related values for Doppler-derived diastolic measurements.

	16-20(yrs.)	21-40 (yrs.)	41-60 (yrs.)	>61(yrs.)
Septal é (cm/s)	14.9 ± 2.4	15.5 ± 2.7	12.2 ± 2.3	10.4 ± 2.1
Septal é/á ratio	2.4	1.6 ± 0.5	1.1 ± 0.3	0.85 ± 0.2
Lateral é (cm/s)	20.6 ± 3.8	19.8 ± 2.9	16.1 ± 2.3	12.9 ± 3.5
Lateral é/á ratio	3.1	1.9 ± 0.6	1.5 ± 0.5	0.9 ± 0.4

Modified from Nagueh, S. F., C. P. Appleton, et al. 2009. Eur J Echocardiogr **10**(2): 165-193.

- ***Septal*** TD velocities are normally ***lower*** than ***lateral*** TD velocities
- TDI-derived myocardial velocities are affected by normal ***aging***
- There is a ***decrease*** in s' and e' velocities along with a corresponding increase in a' velocity with age

TDI shown to be useful for screening and detection of subclinical myocardial dysfunction, and for evaluating the efficacy of therapeutic interventions

Marker of disease

- LV systolic dysfunction
- Diastolic dysfunction
- LV dyssynchrony
- Right ventricular function
- Atrial function

Evaluation and prognostication of coronary artery disease

Detection of early myocardial alterations in primary & secondary myocardial disorders

- Hypertrophic cardiomyopathy
- Dilated Cardiomyopathy
- Ischemic cardiomyopathy
- Constrictive vs. restrictive cardiomyopathy

Heart, Lung and Circulation (2015) **24**, 224–233
1443-9506/04/$36.00
http://dx.doi.org/10.1016/j.hlc.2014.10.003

REVIEW

Tissue Doppler Imaging in Echocardiography: Value and Limitations

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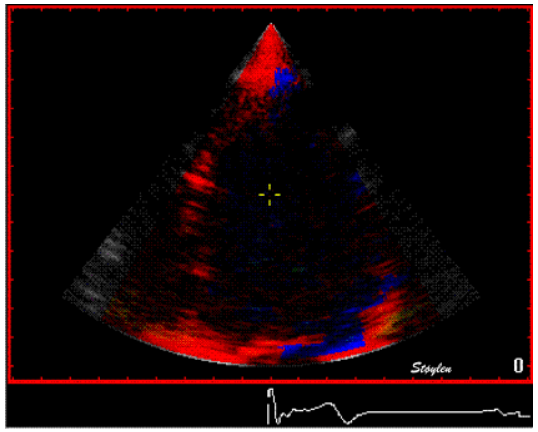
Received 15 October 2014; accepted 15 October 2014; online published-ahead-of-print 28 October 2014

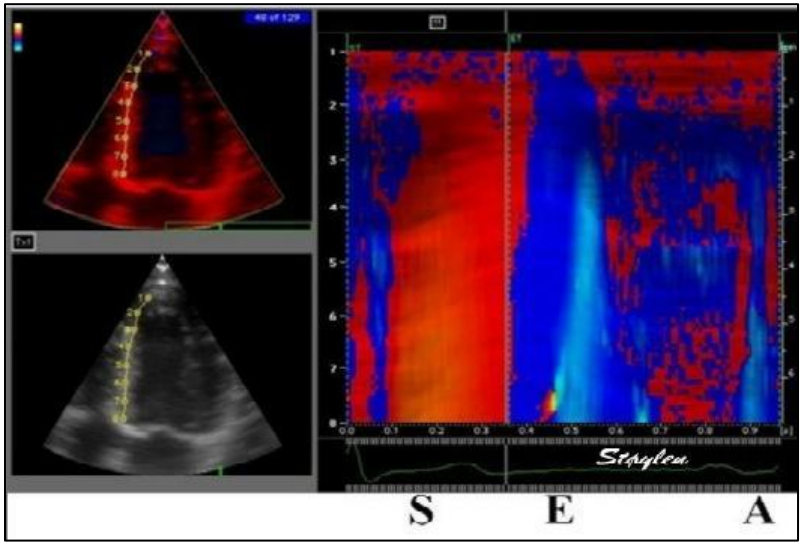
Tissue Doppler imaging (TDI) is a useful echocardiographic technique to evaluate global and regional myocardial systolic as well as diastolic function. It can also be used to quantify right ventricular and left atrial function. Recent studies have demonstrated its utility as a diagnostic as well as prognostic tool in different cardiac conditions including coronary artery disease, heart failure (both systolic and diastolic), valvular heart disease, cardiomyopathies as well as constrictive pericarditis. TDI measurements are also helpful to identify patients who will benefit from cardiac resynchronisation therapy. Even though it is reproducible and relatively easy to obtain, it is underutilised in routine clinical practice. TDI is readily available on most commercially available echocardiographic systems, and we recommend that TDI be used for routine clinical echocardiographic evaluation of patients.

Keywords Tissue Doppler imaging • Colour tissue Doppler imaging • Myocardial contraction velocity • Left ventricular systolic function • Left ventricular diastolic function

Color TDI data display

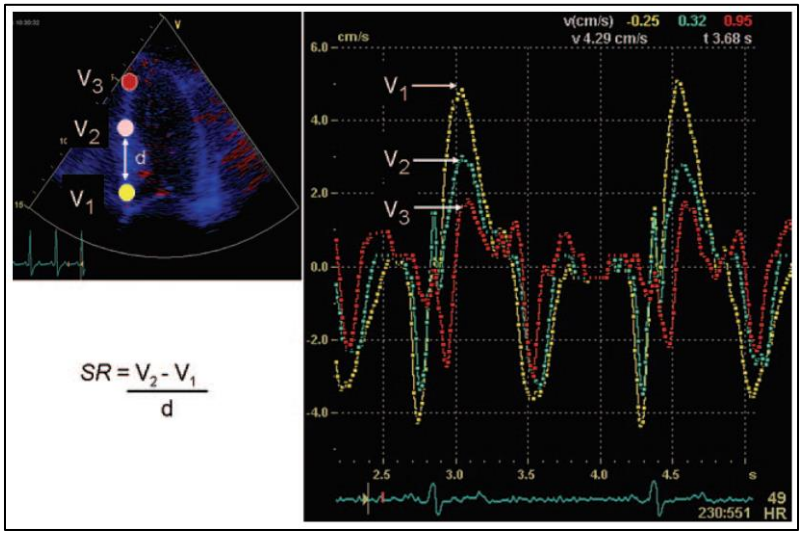


Color Anatomical M-Mode (CAMM)



NTNU Norwegian University of Science and Technology
Faculty of Medicine > Department of Circulation and Imaging

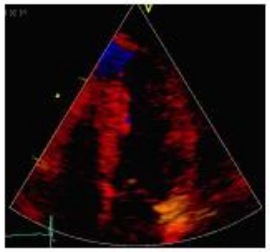
Velocity-Time Curves



Circulation. **2007;116:2597-2609**

- Tissue velocity ***decreases*** form the LV base to the apex
- Measuring tissue velocity at a single point relative to the transducer does ***not*** fully capture true myocardial mechanics
- Tissue velocity may be influenced by cardiac ***translational*** motion and myocardial ***tethering***

Assessment of myocardial motion & deformation parameters w TDI



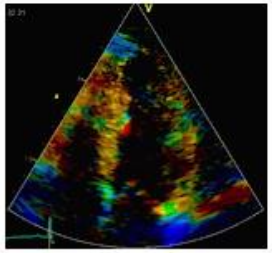
Velocity

Spatial derivation

$$SR = \frac{\partial V}{\partial d}$$

Spatial integration

$$V = \int SR\,\partial d$$



Strain rate

Temporal integration

$$D = \int V \partial t$$

$$V = \frac{\partial D}{\partial t}$$

Temporal derivation

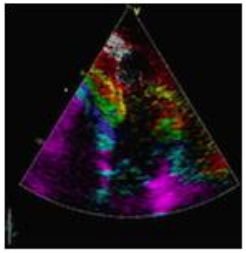
No direct Conversion

Temporal integration

$$\varepsilon = \int SR \partial t$$

$$SR = \frac{\partial \varepsilon}{\partial t}$$

Temporal derivation



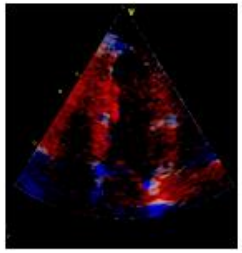
Displacement

Spatial derivation

$$\varepsilon = \frac{\partial D}{\partial d}$$

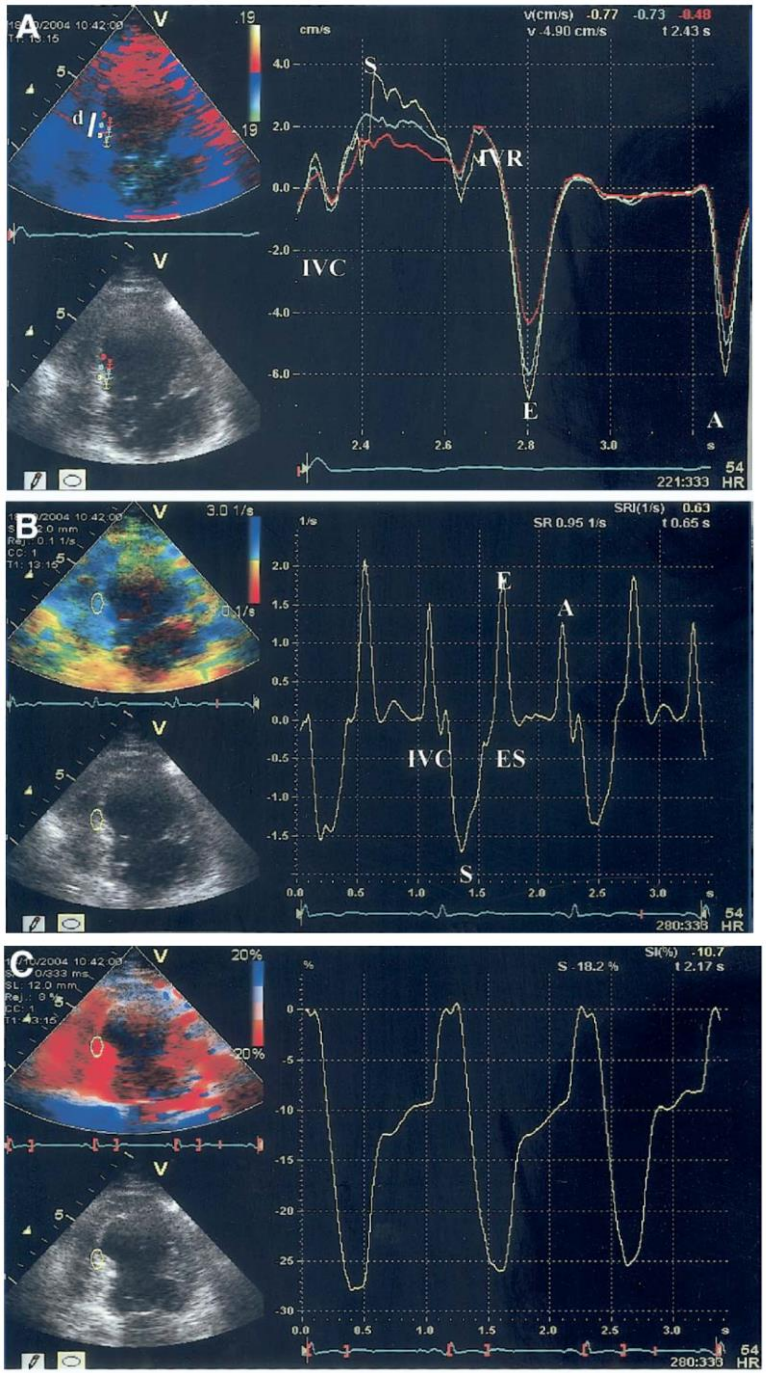
Spatial integration

$$D = \int \varepsilon \partial d$$



Strain

All 3 parameters can be derived form 1 velocity dataset



Step 1

A series of velocity curves (comprising isovolumic contraction [IVC], systolic [S] and diastolic [E and A] components) show a velocity gradient along a length of the wall

Step 2

A regression calculation between adjacent tissue velocity data points along this length generates the strain rate curve

Step 3

Integration of the strain rate data is then used to calculate strain

J Am Coll Cardiol 2006;47:1313–27

Limitations to the derivation of strain rate from tissue velocity

Problem	Solution
Signal noise	Ensure clean velocity signal (avoid reverberations on two-dimensional echocardiography) Use harmonic imaging Avoid aliasing on TVI signal (use adequate pulse repetition) Track sample volume to left ventricular wall to avoid cavity signal
Underestimation	Use high frame rate
Angle dependence	Align axis of movement with scan line Narrow sector
Through-plane motion	Caution with interpretation of events late after QRS
Respiratory drift	Acquire in end-expiration

TVI = tissue velocity imaging.

J Am Coll Cardiol 2006;47:1313–27

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TVI = tissue velocity imaging.

Widespread clinical adoption of TDI strain was also limited by analysis time and considerable intraobserver and interobserver variability

J Am Coll Cardiol 2006;47:1313–27

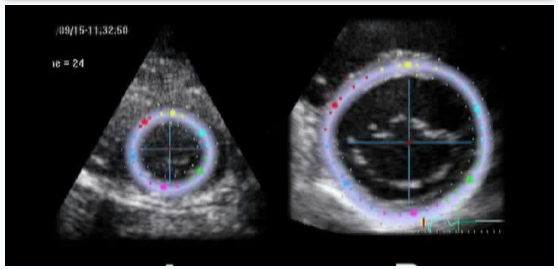
Acoustic Pattern (Speckle) Tracking

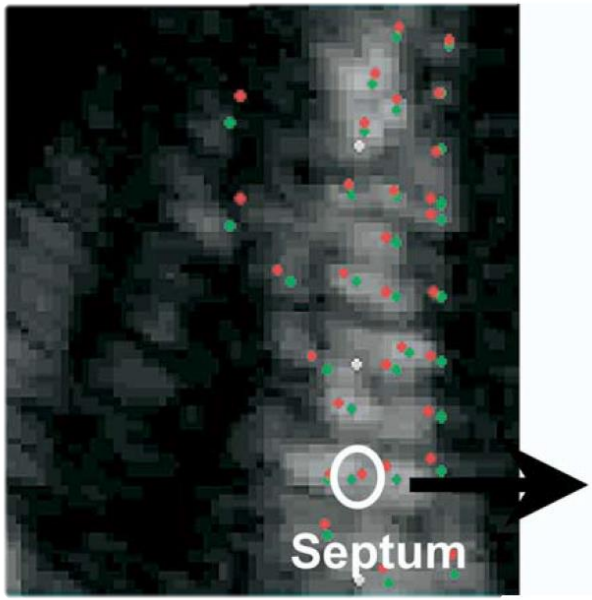
Velocity is estimated as a shift of each speckle divided by time between successive frames (or multiplied by Frame Rate)

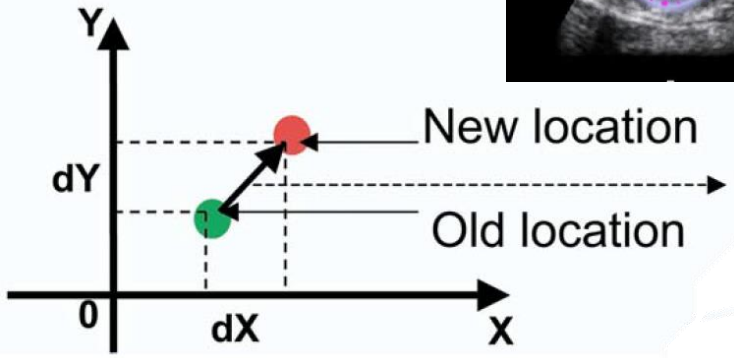
2D vector:(Vx, Vy) = (dX, dY) * FR

Improved signal noise levels, less angle dependency, & freedom to assess strain using regular B-Mode datasets in 2D, rather than a single dimension locked along the scan line

Allows assessment of rotational mechanics

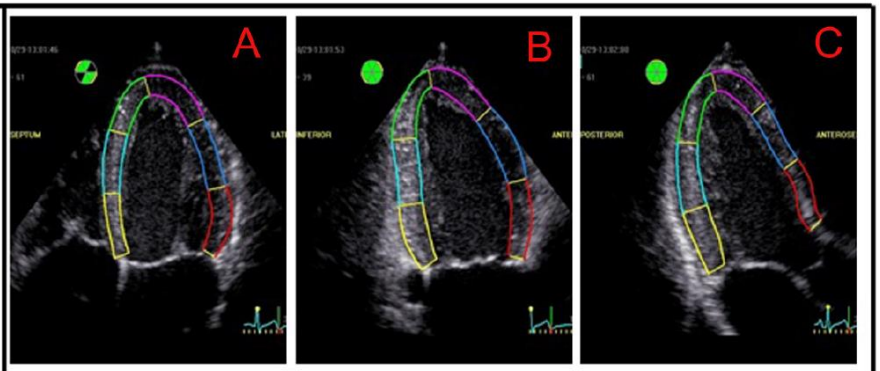
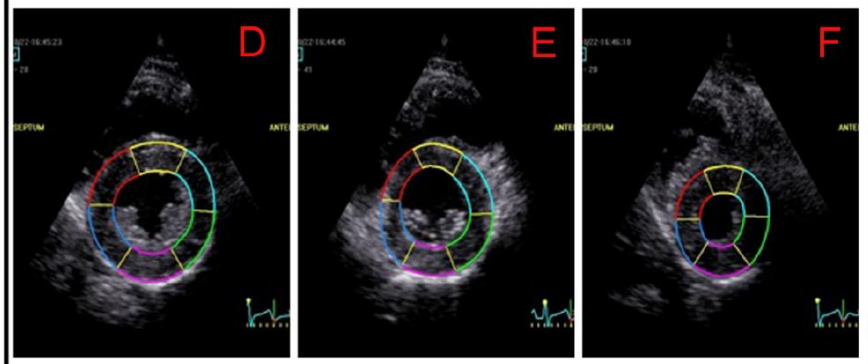
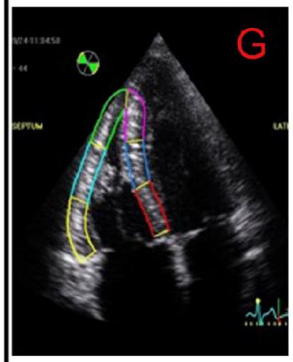






J Am Coll Cardiol 2006;47:1313–27

Standardized views for Speckle Tracking Echocardiography (STE)

LV Apical Views	
LV PSAX Views	
RV Apical View	

GLS (marker of longitudinal fiber shortening) assessed from the apical window using standard 4CH, 2CH, and 3CH views

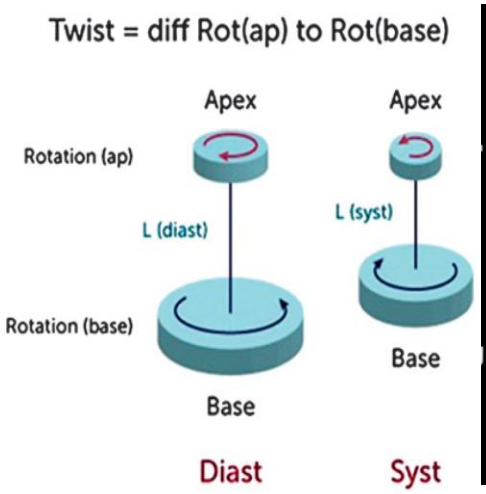
GCS (marker of circumferential fiber shortening) and **GRS** (marker of fiber thickening) assessed from the PSAX images at basal, mid, and apical levels

RV GLS vs **RV FWLS**

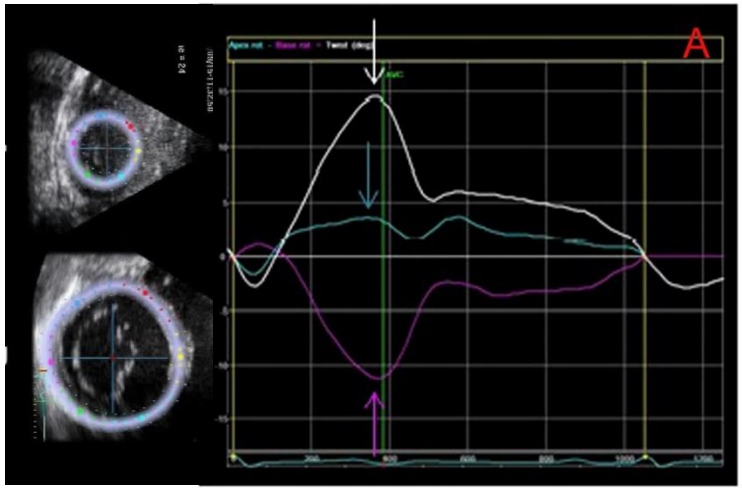
- Free wall > septal strain
- ROI septum and free wall, but report RV FWLS

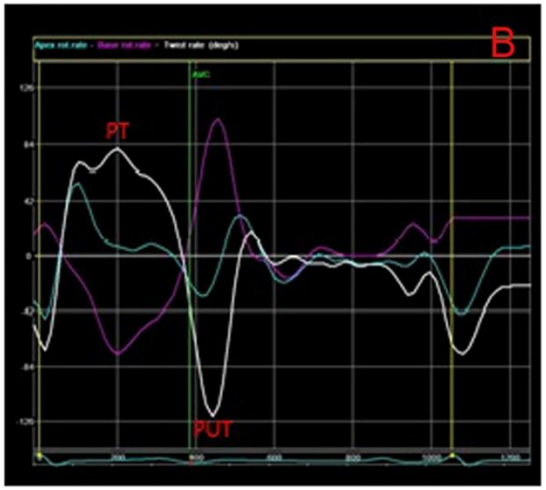
Echo Res Pract. 2019 Jun 13;6(3):R87-R98.

LV rotation, twist and torsion



Heart 2010;96:716e722

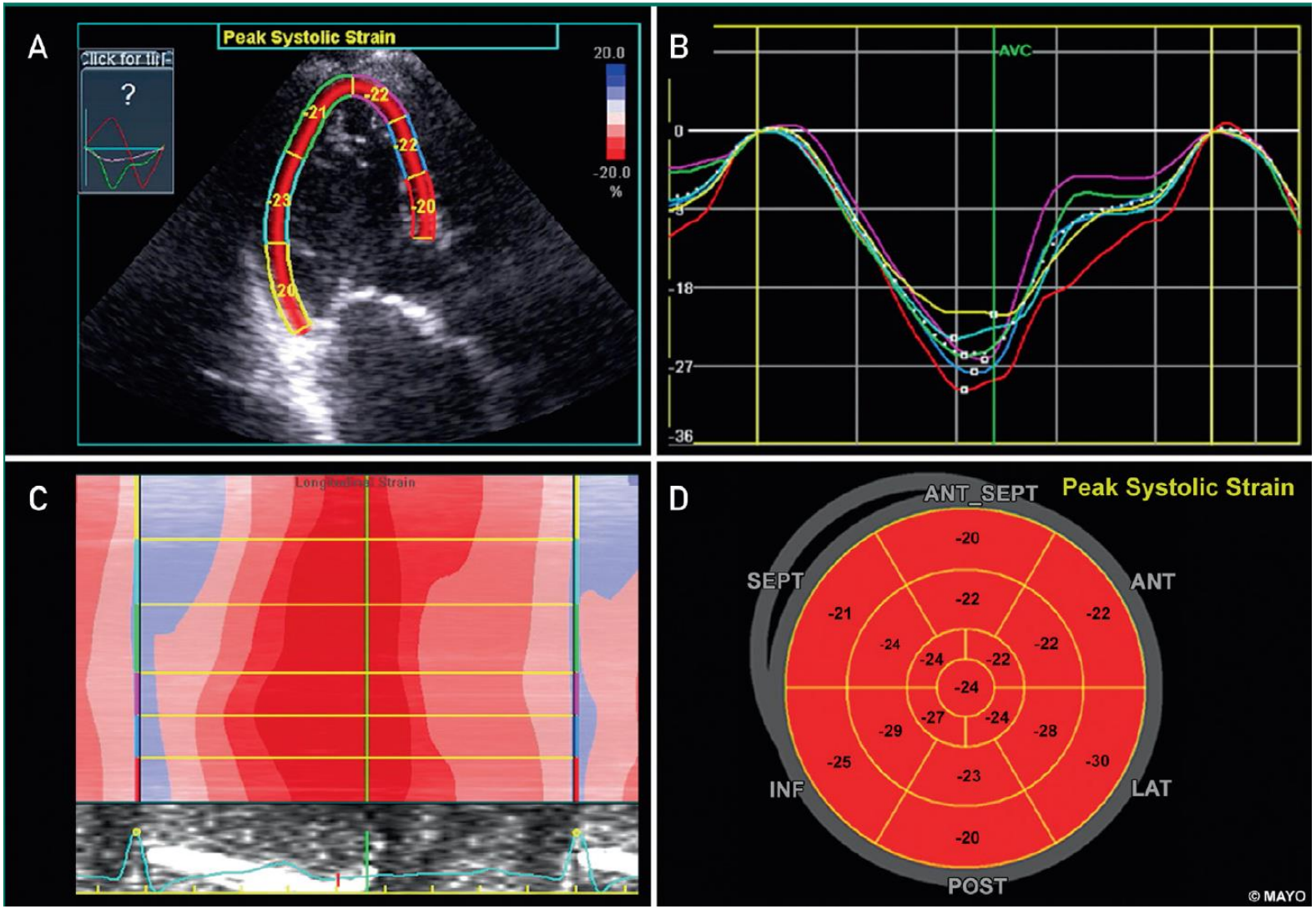




Echo Res Pract. 2019 Jun 13;6(3):R87-R98.

- Rotation of the myocardium around LV long axis is expressed in degrees
- When viewed from the apex during systole:
  - The base rotates in a clockwise direction (negative value)
  - The apex rotates in an anticlockwise direction (positive value)
- **Twist (°)** is defined as the difference in apical and basal systolic rotation when viewed from the apex
- **Torsion (°/cm)** is calculated as the twist angle divided by distance between base and apex

Normal 2D STE Strain



Mayo Clin Proc. January 2019;94(1):125-138

2D STE vs LVEF for assessment of LV systolic function

- LV ***systolic*** function as measured by EF is result of ***combined*** longitudinal and circumferential myofiber shortening
- ***GLS*** reflects ***longitudinal*** myofiber shortening, which are most ***vulnerable*** to myocardial disease because of their subendocardial location
- GCS reflects ***mid-wall*** (circumferential) myofiber shortening which are typically affected in more clinically ***advanced*** myocardial disease
- ***GCS*** has ***greater*** (~1.6-fold) effect on ***LVEF*** compared to GLS and may compensate for reduction in GLS to maintain LVEF
- Reduced LV cavity size or increased wall thickness reduces the amount of longitudinal and circumferential shortening required to maintain the LVEF ➔ ***in diseases with concentric remodeling/hypertrophy phenotype, LVEF may be preserved despite reductions in GLS and GCS***
- In patients with ***impaired*** LVEF, GLS and LVEF have a ***linear*** relationship
- In patients with ***preserved*** LVEF >50%, GLS and LVEF may exhibit a ***curvilinear*** relationship ➔ GLS may be more sensitive to detect early subclinical myocardial dysfunction before LVEF declines

Potential clinical applications

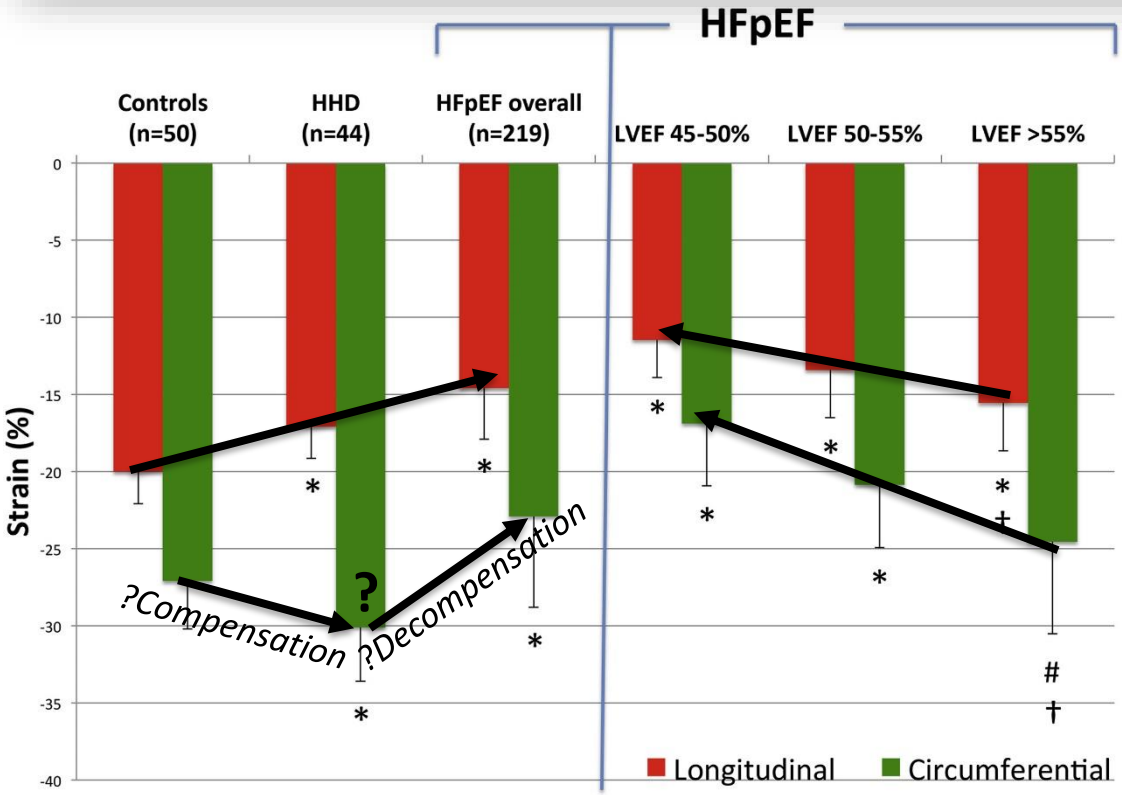
Two-dimensional GLS remains the predominant tool for clinical application because of its ease of use, reproducibility, time efficiency, and simplicity. Currently, GCS and GRS have limited clinical application and are predominantly research tools.

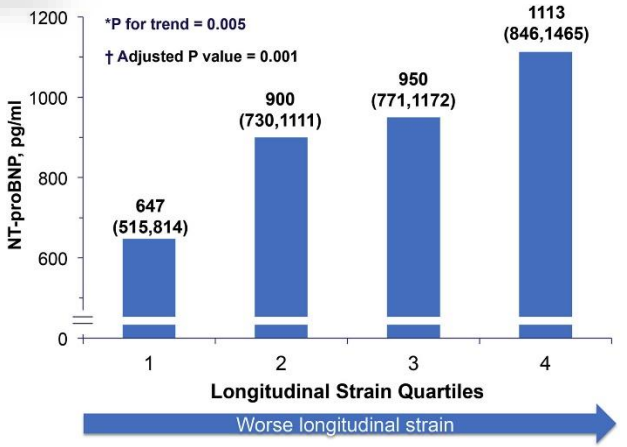
Cardiac Imaging

Impaired Systolic Function by Strain Imaging in Heart Failure With Preserved Ejection Fraction

Elisabeth Kraigher-Krainer, MD,* Amil M. Shah, MD, MPH,* Deepak K. Gupta, MD,* Angela Santos, MD,* Brian Claggett, PHD,* Burkert Pieske, MD,† Michael R. Zile, MD,‡ Adriaan A. Voors, MD,§ Marty P. Lefkowitz, MD,|| Milton Packer, MD,¶ John J. V. McMurray, MD,# Scott D. Solomon, MD,* for the PARAMOUNT Investigators

- 219 HFpEF patients from HFpEF PARAMOUNT trial
- 50 normal controls
- 44 pts with HHD but no HF





***Lower LS** was modestly associated with **higher NT-proBNP**, even after adjustment for 10 baseline covariates including LVEF, measures of diastolic function, and LV filling pressure*

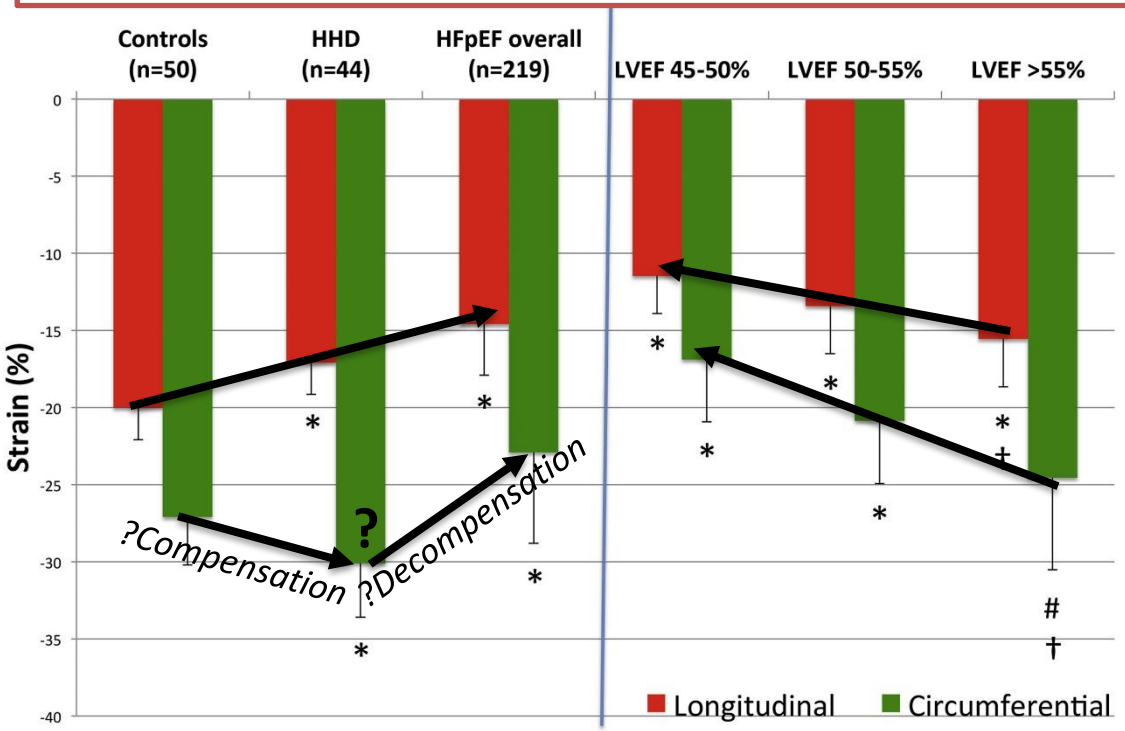
Compared to both normal controls and hypertensive heart disease patients, the HFpEF patients demonstrated significantly lower longitudinal and circumferential strain

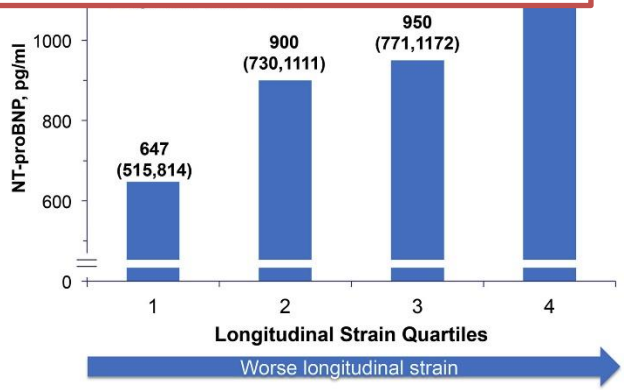
J Am Coll Cardiol 2014;63:447–56

Impaired Systolic Function by Strain Imaging in Heart Failure With Preserved Ejection Fraction

- 219 HFpEF patients from HFpEF PARAMOUNT trial
- 50 normal controls

Strain imaging detects impaired systolic function despite preserved global LVEF in HFpEF and that may contribute to the pathophysiology of the HFpEF syndrome





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Global Longitudinal Strain to Predict Mortality in Patients With Acute Heart Failure

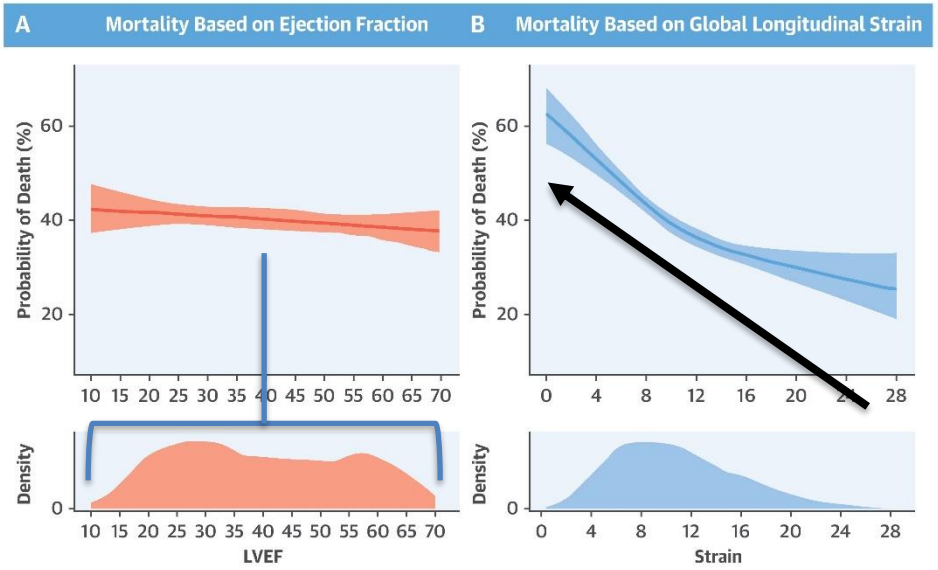
Jin Joo Park, MD, PhD,[a] Jun-Bean Park, MD, PhD,[b] Jae-Hyeong Park, MD, PhD,[c] Goo-Yeong Cho, MD, PhD[a]

4,172 consecutive pts w acute HF

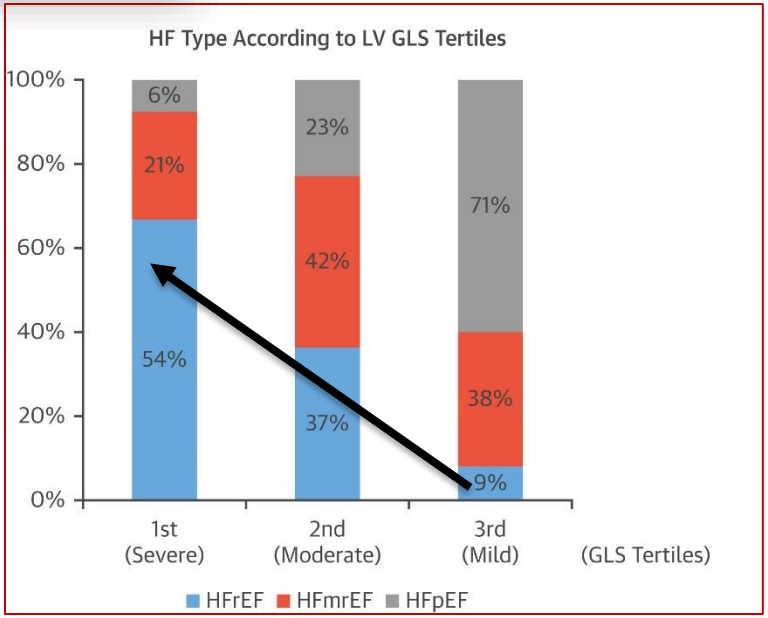
- HFrEF, HFmEF, HFpEF
- Mild, mod, severe GLS

5-year all-cause mortality

CENTRAL ILLUSTRATION: Prognostic Value of Strain in Acute Heart Failure: Probability Plot for 5-Year All-Cause Mortality



Park, J.J. et al. J Am Coll Cardiol. 2018;71(18):1947-57.



The proportion of patients with HFrEF increased as GLS decreased.

- Patients with HFrEF had slightly higher mortality than those with HFmEF or HFpEF, whereas patients with reduced strain had significantly higher mortality
- In multivariable analysis, each 1% increase in GLS was associated with a 5% decreased risk for mortality
- Patients with moderate and severe GLS reductions had higher mortality, but LVEF was not associated with mortality

J Am Coll Cardiol 2018;71:1947–57

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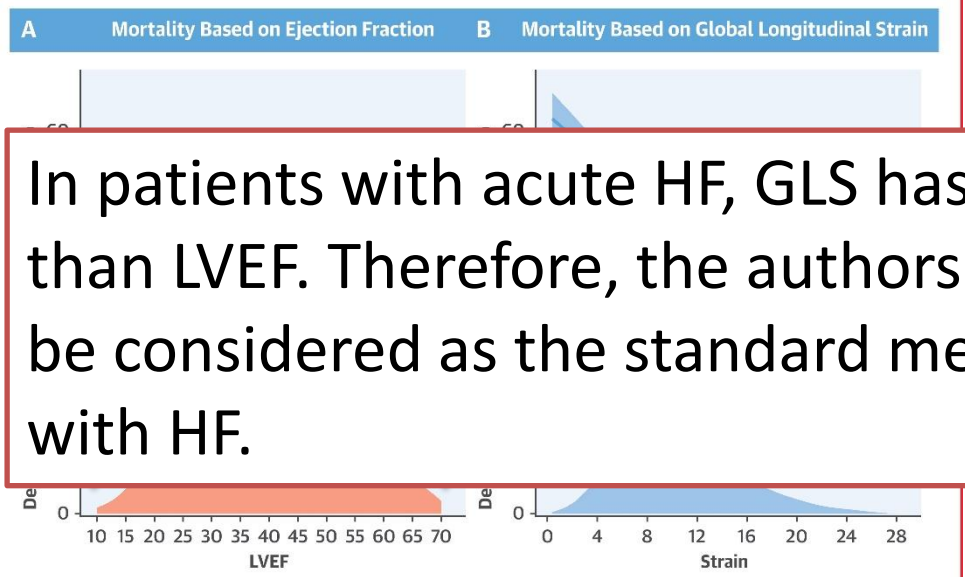

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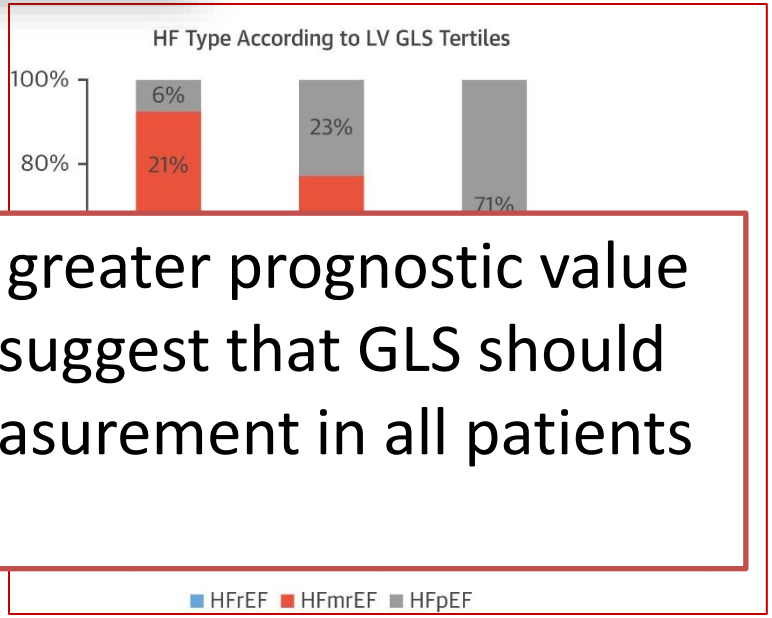

The proportion of patients with HFrEF increased as GLS decreased.

In patients with acute HF, GLS has greater prognostic value than LVEF. Therefore, the authors suggest that GLS should be considered as the standard measurement in all patients with HF.

- Patients with HFrEF had slightly higher mortality than those with HFmEF or HFpEF, whereas patients with reduced strain had significantly higher mortality
- In multivariable analysis, each 1% increase in GLS was associated with a 5% decreased risk for mortality
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J Am Coll Cardiol 2018;71:1947–57

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

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

Boston, Massachusetts (M.S.-C.); McMaster University, Hamilton, Ontario, Canada (J.G.); Jewish General Hospital and McGill University, Montreal, Quebec, Canada (I.A.S.); the University of Padua, Padua, Italy (L.P.B.); the European Institute of Oncology, Milan, Italy (D.C.); Abramson Cancer Center at the University of Pennsylvania, Philadelphia, Pennsylvania (J.C.); University of Chicago Medicine, Chicago, Illinois (J.M.D.C); Oslo University Hospital and the University of Oslo, Oslo, Norway (T.E.); Temple University, Philadelphia, Pennsylvania (T.F.); the University of Liege, Liege, Belgium (G.J. and P.L.); Memorial Sloan-Kettering Cancer Center, New York, New York (J.E.L.); Santa Marie University Hospital, Lisbon, Portugal (A.M.); Menzies Research Institute Tasmania, Hobart, Australia (T.M.); CNR Institute of Clinical Physiology, Pisa, Italy (R.S.); and the Mayo Clinic, Rochester, Minnesota (H.R.V.).

The following authors reported no actual or potential conflicts of interest in relation to this document: Juan Carlos Plana, MD, FASE, Maurizio Galderisi, MD, FESC, Marielle Scherrer-Crosbie, MD, PhD, FASE, Javier Ganame, MD, PhD, FASE, Deborah A. Agler, RCT, RDCS, FASE, Luigi P. Badano, MD, PhD, FESC, Jose Banchs, MD, FASE, Daniela Cardinale, MD, Joseph Carver, MD, Thor Edvardsen, MD, PhD, FESC, Brian Griffin, MD, Guy Jerusalem, MD, PhD, Jennifer E. Liu, MD, FASE, Andreia Magalhães, MD, Liza Y. Sanchez, RCS, FASE, Rosa Sicari, MD, PhD, FESC, Hector R. Villarraga, MD, FASE, and Patrizio Lancellotti, MD, PhD, FESC. The following authors reported relationships with one or more commercial interests: Ana Barac, MD, received research funding and lectures honoraria from Genentech and consultancy fees from Cell Therapeutics. Manuel Cerqueira, MD, heim. Scott D. Flamm, MD, MBA, serves on advisory boards for Philips Healthcare, Bayer Healthcare, and TeraRecon and received institutional research support from Siemens Healthcare. Thomas Force, MD consults for GlaxoSmithKline. Bonnie Ky, MD, FASE, received an investigator-initiated award from Pfizer, Inc. Thomas Marwick, MBBS, PhD, MPH, received research funding from the National Health and Medical Research Council in Australia and the Royal Hobart Hospital Foundation, an equipment grant from Philips Medical Systems and Siemens, and a project grant from GE Medical Systems. Igal A. Sebag, MD, FASE, serves on the speakers bureau for Lantheus.

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0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2014.07.012

J Am Soc Echocardiogr 2014;27:911-39

Definition of Cancer Therapeutics–Related Cardiac Dysfunction (CTRCD)

>10% absolute reduction in LVEF, to a value <53% (2D Echo normal reference), confirmed by repeated cardiac imaging in 2 to 3 weeks. May be symptomatic or asymptomatic.

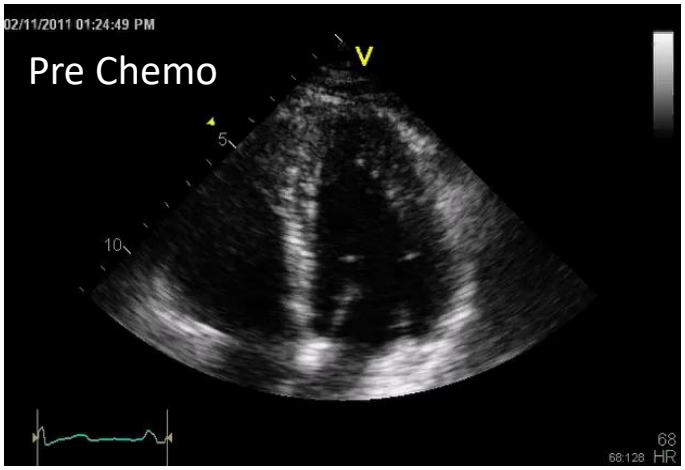
- **Reversible:** to within 5 percentage points of baseline
- **Partially reversible:** improved by >10% from the nadir but remaining >5% below baseline
- **Irreversible:** improved by <10% from the nadir and remaining >5% below baseline
- **Indeterminate:** patient not available for re-evaluation

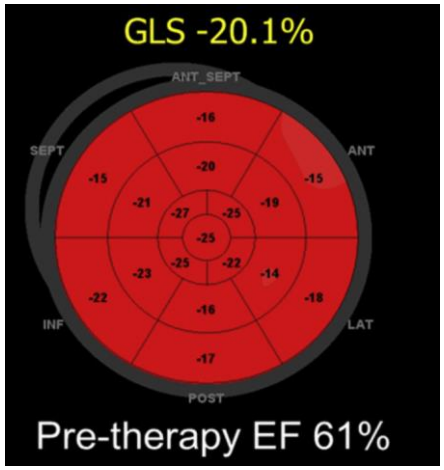
J Am Soc Echocardiogr 2014;27:911-39

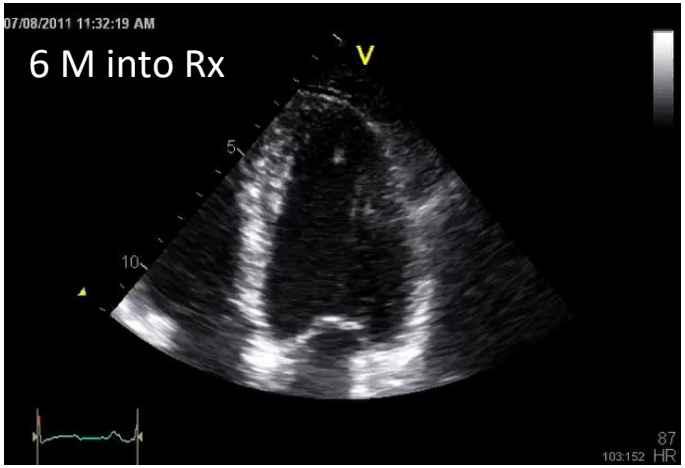

LVEF

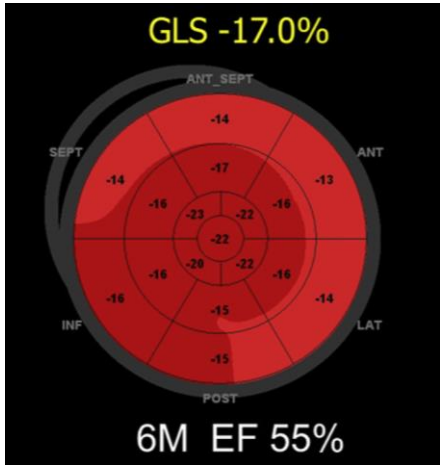
Echo derived LVEF: Important Considerations

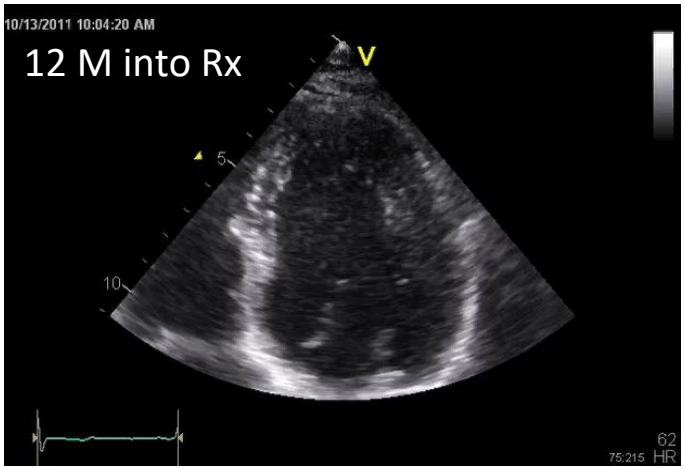
- **2D techniques have low sensitivity for detection of small changes in LV *function* or subclinical cardiotoxicity**
  - Minimal detectable change is of the same order of magnitude used to adjudicate CTRCD
- **Susceptibility of 2-Dimensional techniques to:**
  - LV geometric assumptions
  - Inadequate visualization of the true LV apex (aka. foreshortening)
  - Suboptimal windows
  - Lack of consideration of subtle regional wall motion abnormalities
  - Inherent variability of the measurement
- **Load dependent nature of LVEF [(EDV-ESV)/EDV]**
  - Intravascular volume expansion due to IV infusions
  - Intravascular volume contraction due to vomiting or diarrhea

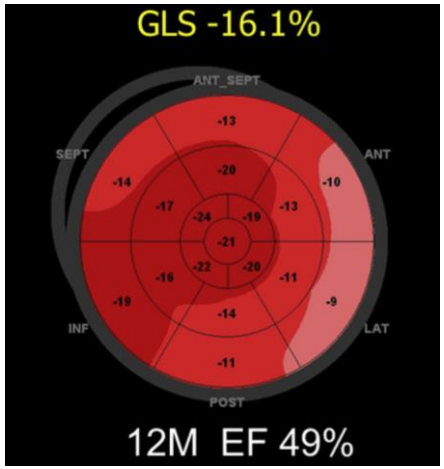






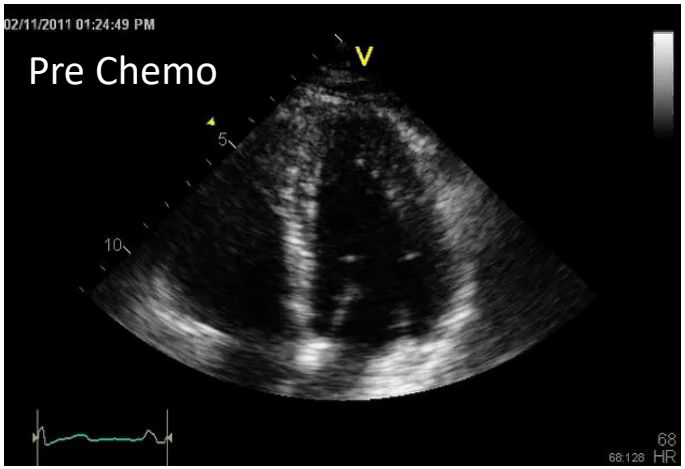


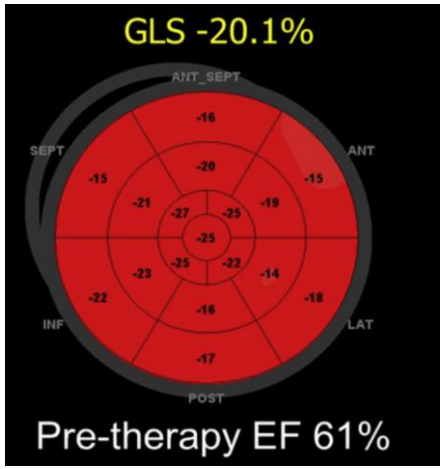


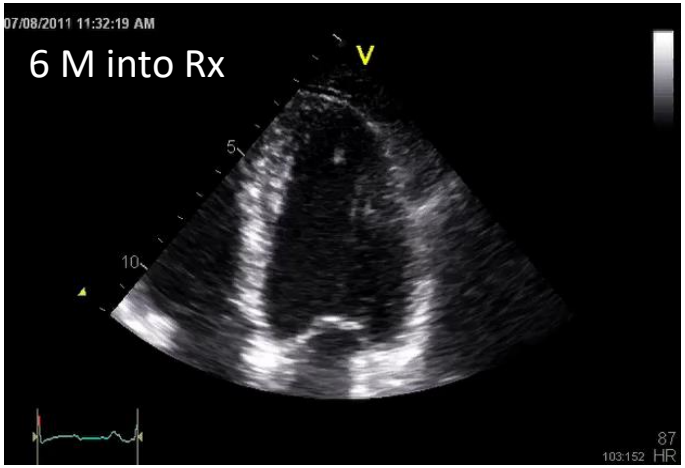


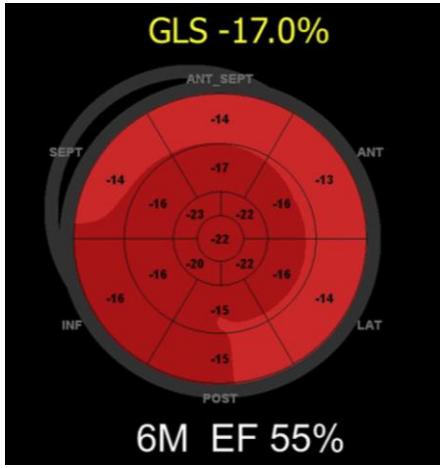
15.4% reduction in peak GLS

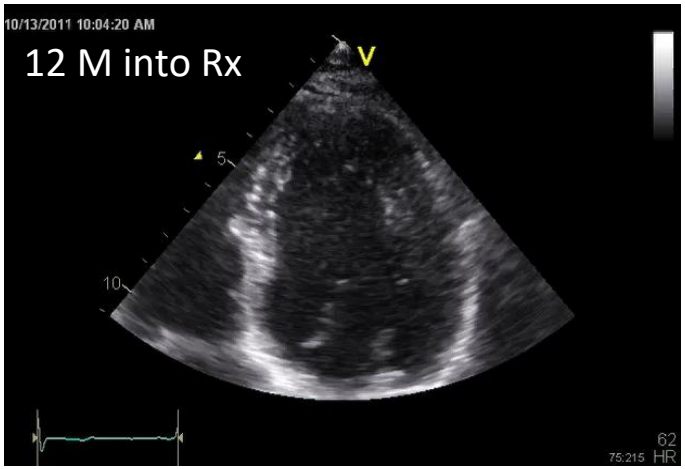
J Am Coll Cardiol 2014;63:2751–68

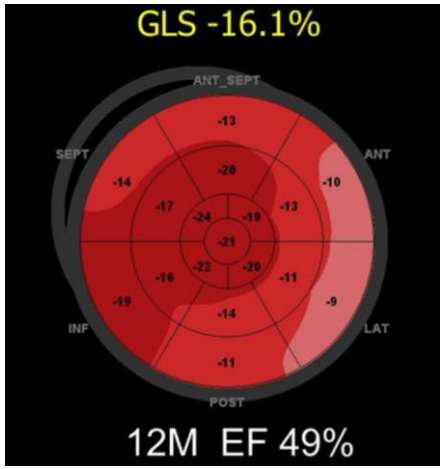












Potential role of myocardial strain imaging for:

1. Detection of early myocardial changes
2. Prediction of subsequent cardiotoxicity
3. Detection of late consequences of therapy (>1 year posttreatment)

J Am Coll Cardiol 2014;63:2751–68

Journal of the American College of Cardiology
© 2014 by the American College of Cardiology Foundation
Published by Elsevier Inc.

Vol. 63, No. 25, 2014
ISSN 0735-1097/$36.00
http://dx.doi.org/10.1016/j.jacc.2014.01.073

STATE-OF-THE-ART PAPERS

Use of Myocardial Strain Imaging by Echocardiography for the Early Detection of Cardiotoxicity in Patients During and After Cancer Chemotherapy

A Systematic Review

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Juan Carlos Plana, MD,‡ Anna Woo, MD,* Thomas H. Marwick, MD§

Toronto, Ontario, Canada; Cleveland, Ohio; and Hobart, Australia

The mortality rate among patients with cancer has decreased over the past 20 to 30 years (1,2). However, cardiac toxicity (cardiotoxicity) from cancer therapy has become a leading cause of morbidity and mortality in survivors (3,4). In patients who develop heart failure (HF) from cancer therapy, the mortality rate is as high as 60% by 2 years (5). Therefore, contemporary management of patients with cancer should include careful consideration of potential cardiotoxicity during therapy, with a focus on early detection and intervention (6).

Historically, several definitions of cardiotoxicity have been proposed (7). The most commonly used definition is a ≥5% reduction in symptomatic patients (or ≥10% reduction in asymptomatic patients) in the left ventricular ejection fraction (LVEF) from baseline to an LVEF <55% (8). Early detection of cardiotoxicity has predominantly relied upon serial cardiac imaging to identify a reduction in left ventricular (LV) function without signs or symptoms of heart failure (stage B HF) (9). The use of LVEF has important limitations. First, the measurement of LVEF is subject to technique-related variability, which can be higher than the thresholds used to define cardiotoxicity (8,10). Second, the reduction in LVEF is often a late phenomenon, with failure to recover systolic function in up to 58% of patients despite intervention (11–15). Hence, there has been a growing interest in markers of early myocardial changes (i.e.,

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Manuscript received December 19, 2013; revised manuscript received January 24, 2014, accepted January 28, 2014.

Detection of early myocardial changes during cancer chemotherapy

- All studies uniformly demonstrate changes in myocardial deformation ***prior*** to the occurrence of a significant change in LVEF and at anthracycline doses ***lower*** than what was historically thought to be cardiotoxic (e.g., 200 mg/m2 of epirubicin).

- In the absence of a reduction in LVEF, a ***9-19% relative decline*** in peak ***GLS*** from baseline by 2D STE seems to be common either during or immediately after anthracycline therapy

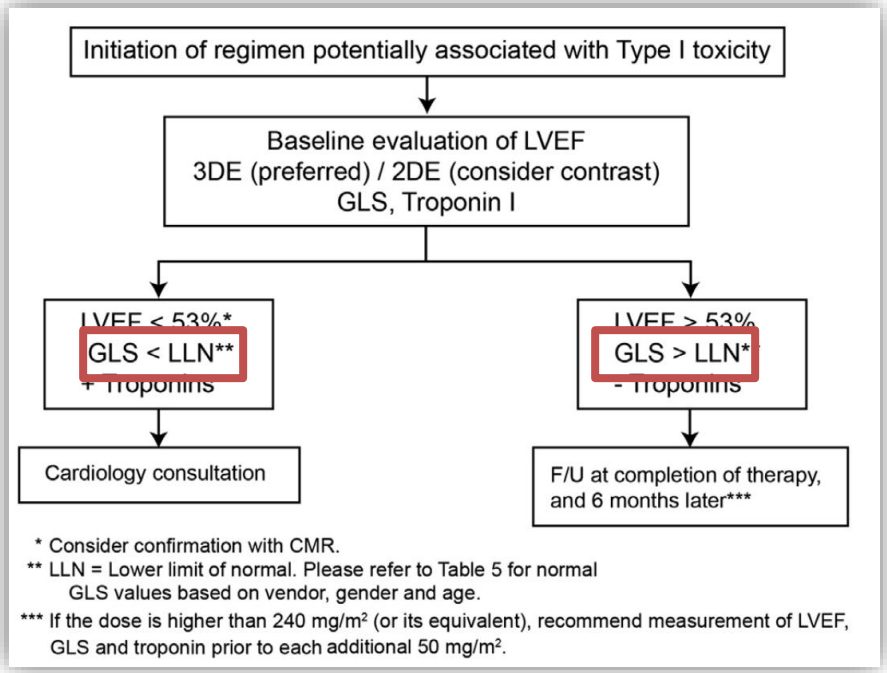
- Reductions in peak GRS or peak systolic GCS may also indicate early myocardial changes, however these changes, along with 2D STE derived SR have all been *less consistent and not well reproducible.*

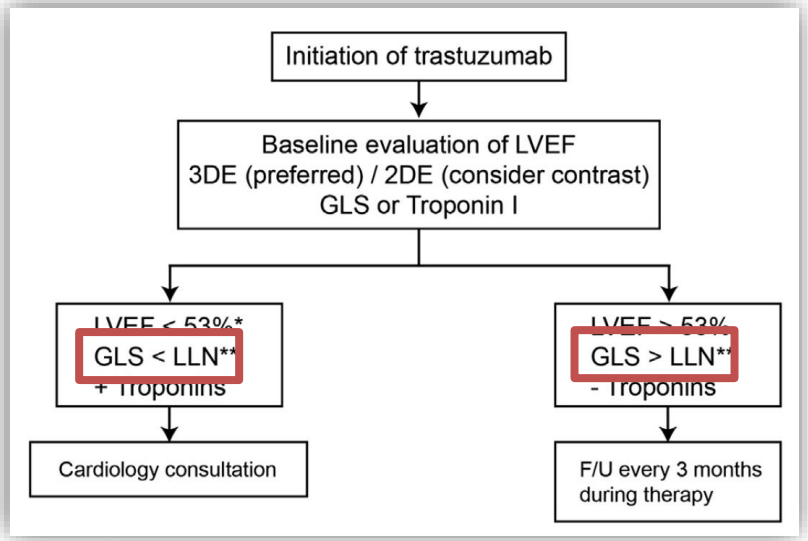
- Other deformation parameters are currently neither sufficiently feasible or reliable for clinical application

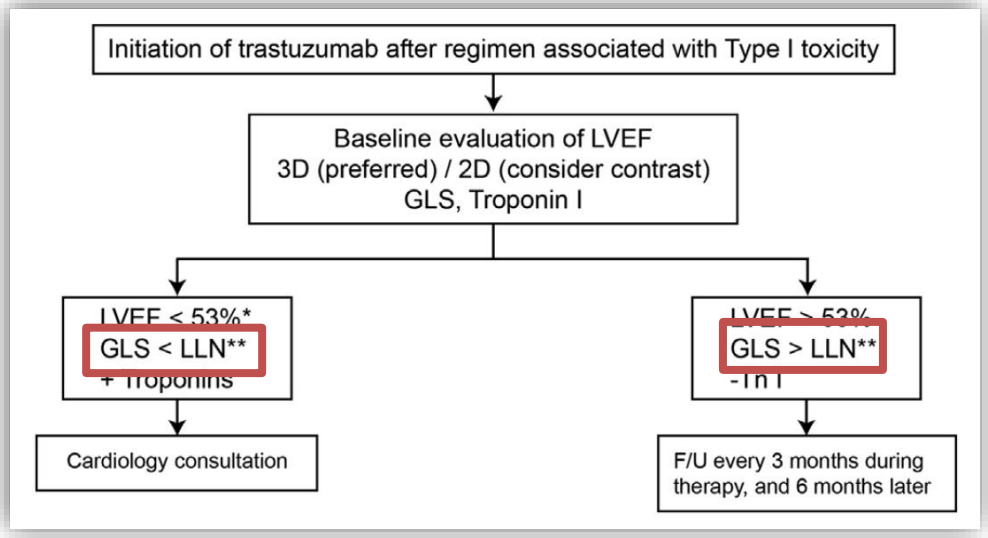
Prognostic value of myocardial deformation parameters to detect cardiotoxicity

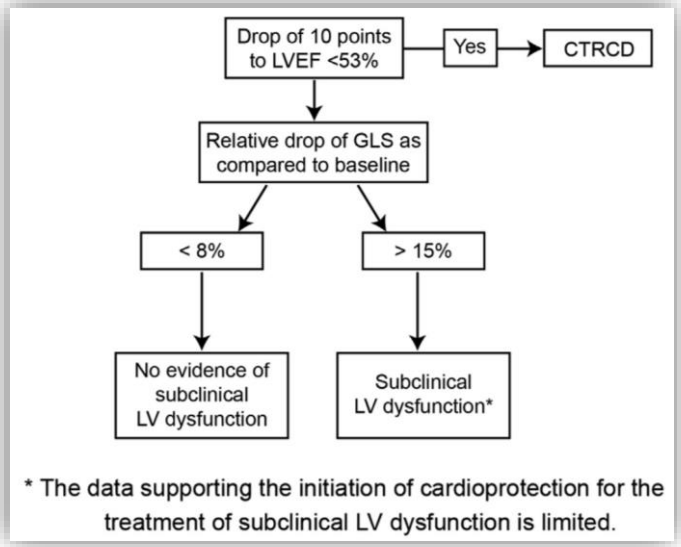
- An early ***10-15% decline in GLS by STE*** predicts subsequent cardiotoxicity (both asymptomatic & symptomatic LV dysfunction)
- In two studies where the relative change in GLS was unavailable, ***absolute abnormal levels*** of GLS >-19% and >-20.5% early during therapy have been associated with cardiotoxicity
- GLS thresholds generally have ***better negative than positive predictive value***, probably reflecting the low prevalence of cardiotoxicity in the patients studied.
- GRS was not predictive of cardiotoxicity in the 2 larger studies, and GCS was not predictive in any studies.
- A combined parameter of (***GLS x LV twist***) promising to be superior even to GLS as a predictor of subsequent cardiotoxicity – further studies needed.

Expert consensus for screening & diagnosis of CTRCD







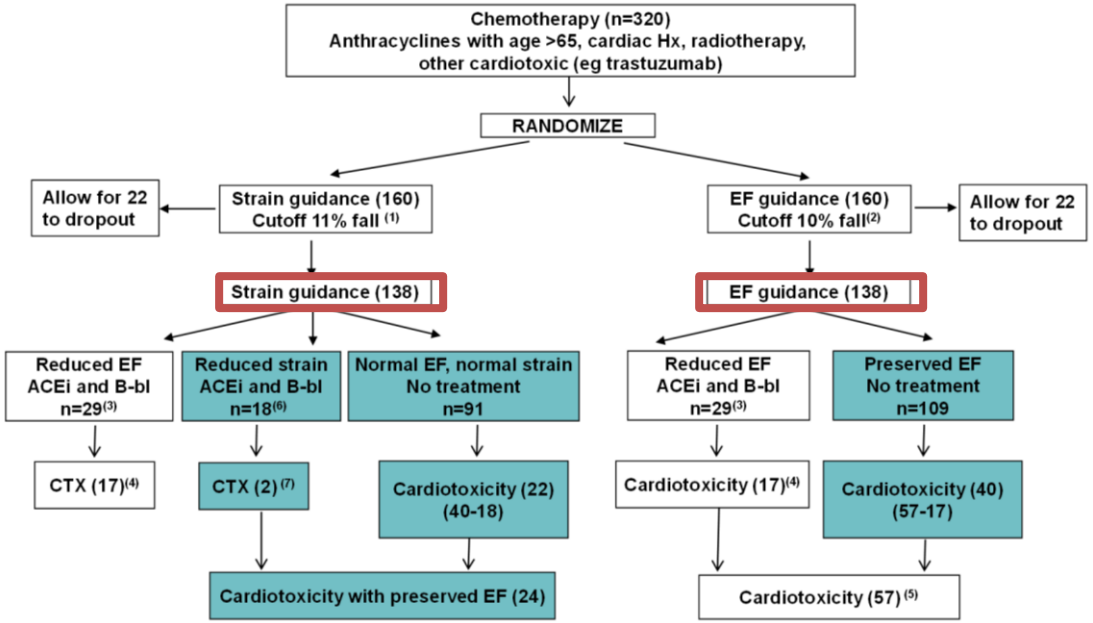


J Am Soc Echocardiogr 2014;27:911-39

ANZCTR
Australian New Zealand Clinical Trials Registry

Strain sUrveillance during Chemotherapy for improving Cardiovascular Outcomes (SUCCOUR)

International, multicenter, prospective, RCT



Trial ID	ACTRN12614000341628
Ethics application status	Approved
Date submitted	21/03/2014
Date registered	31/03/2014
Type of registration	Retrospectively registered

Titles & IDs

Public title	Strain sUrveillance during Chemotherapy for improving Cardiovascular OUtcomes
Scientific title	Randomised controlled trial (RCT) of chemotherapy patients at risk of cardiotoxicity undergoing cardioprotection guided by measurement of LV strain compared with cardioprotection guided by measurement of left ventricular (LV) ejection fraction for avoidance of cardiotoxicity
Secondary ID [1]	none
Universal Trial Number (UTN)	
Trial acronym	SUCCOUR Study
Linked study record	

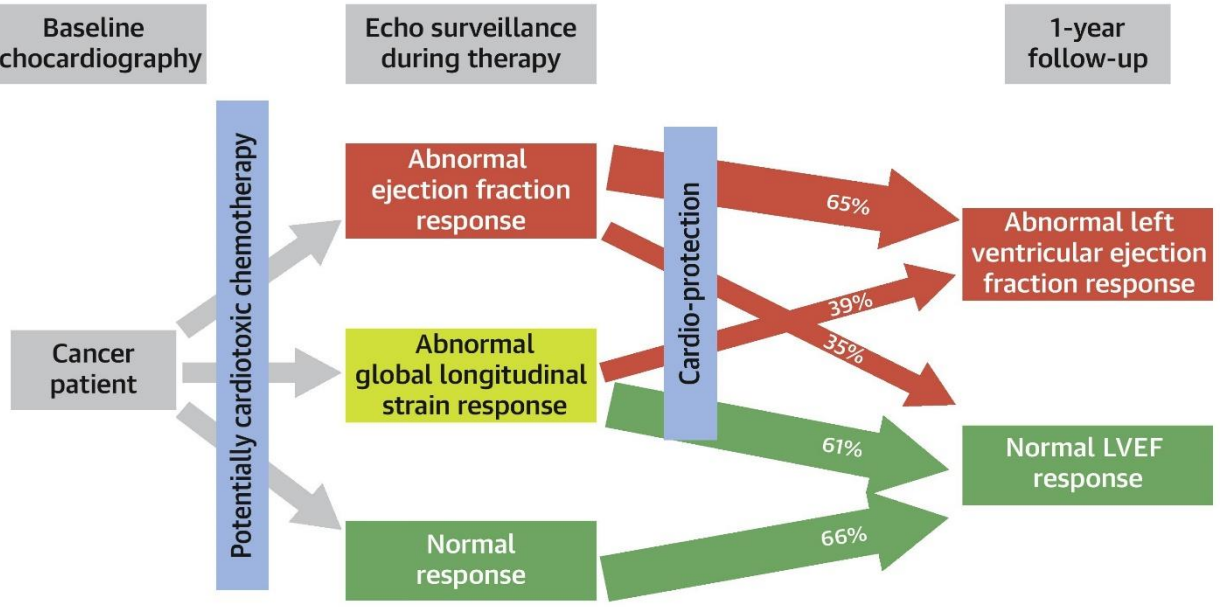
https://www.anzctr.org.au/Trial/Registration/TrialReview.aspx?id=366020

Strain-Guided Management of Potentially Cardiotoxic Cancer Therapy

Paaladinesh Thavendiranathan, MD, SM,[a,*] Tomoko Negishi, MD,[b,c,*] Emily Somerset, MS,[d] Kazuaki Negishi, MD, PhD,[b,c] Martin Penicka, MD, PhD,[e] Julie Lemieux, MD, MSc,[f] Svend Aakhus, MD, PhD,[g] Sakiko Miyazaki, MD,[h] Mitra Shirazi, MD,[i] Maurizio Galderisi, MD, PhD,[j,†] Thomas H. Marwick, MBBS, PhD, MPH,[b,k] on behalf of the SUCCOUR Investigators[‡]

Patients were followed for EF and development of CTRCD (symptomatic EF reduction of >5% or >10% asymptomatic to <55%) over 1 year

CENTRAL ILLUSTRATION: Various Surveillance Strategies, Initiation of Cardioprotective Therapy, and the Subsequent Response at the 1-Year Follow-Up



Thavendiranathan, P. et al. J Am Coll Cardiol. 2021;77(4):392–401.

Strain-Guided Management of Potentially Cardiotoxic Cancer Therapy

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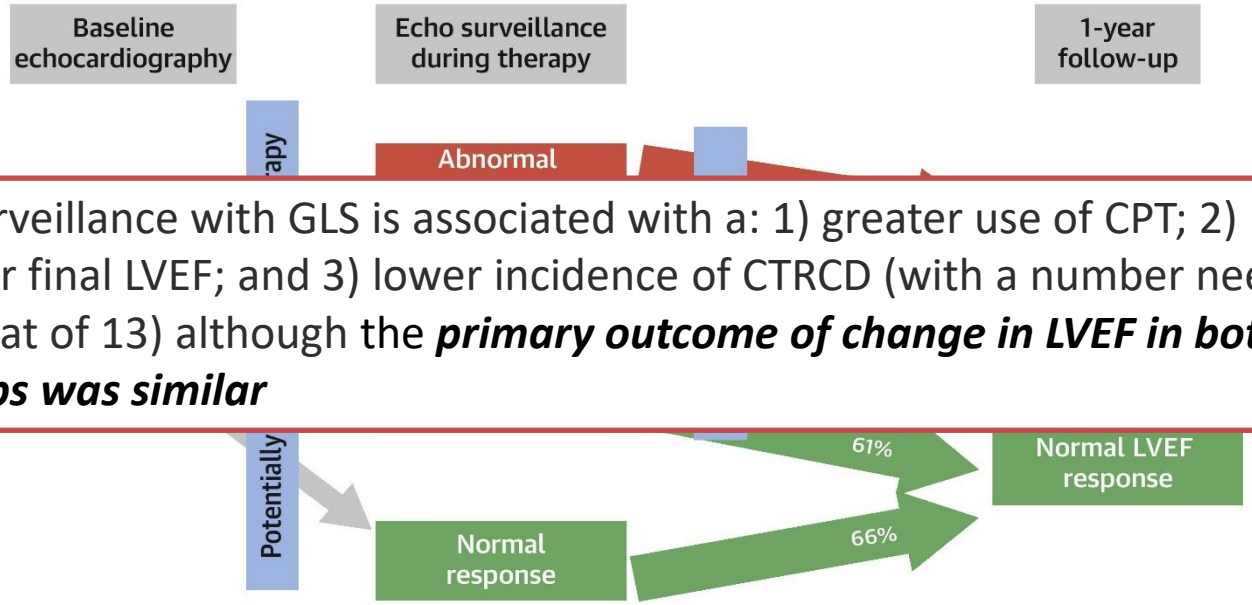
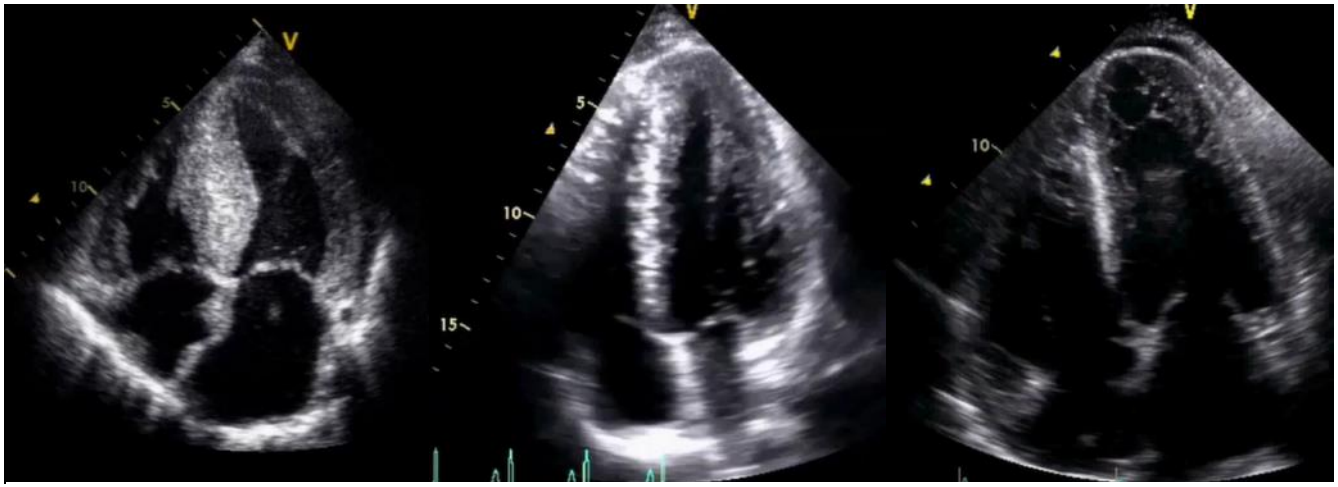


LV surveillance with GLS is associated with a: 1) greater use of CPT; 2) higher final LVEF; and 3) lower incidence of CTRCD (with a number needed to treat of 13) although the ***primary outcome of change in LVEF in both groups was similar***

Thavendiranathan, P. et al. J Am Coll Cardiol. 2021;77(4):392–401.

Identification of the cause of LVH



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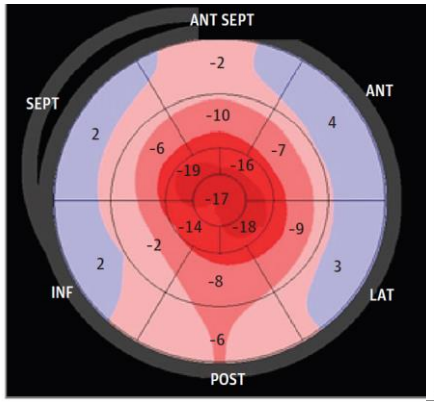
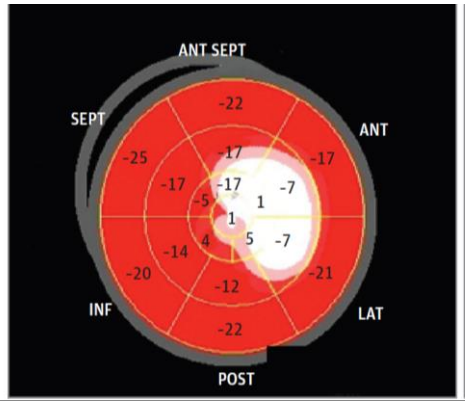
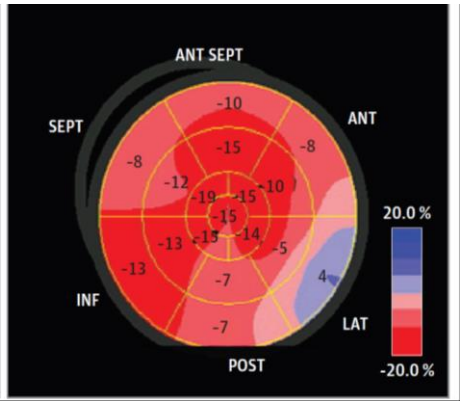


Apical sparing



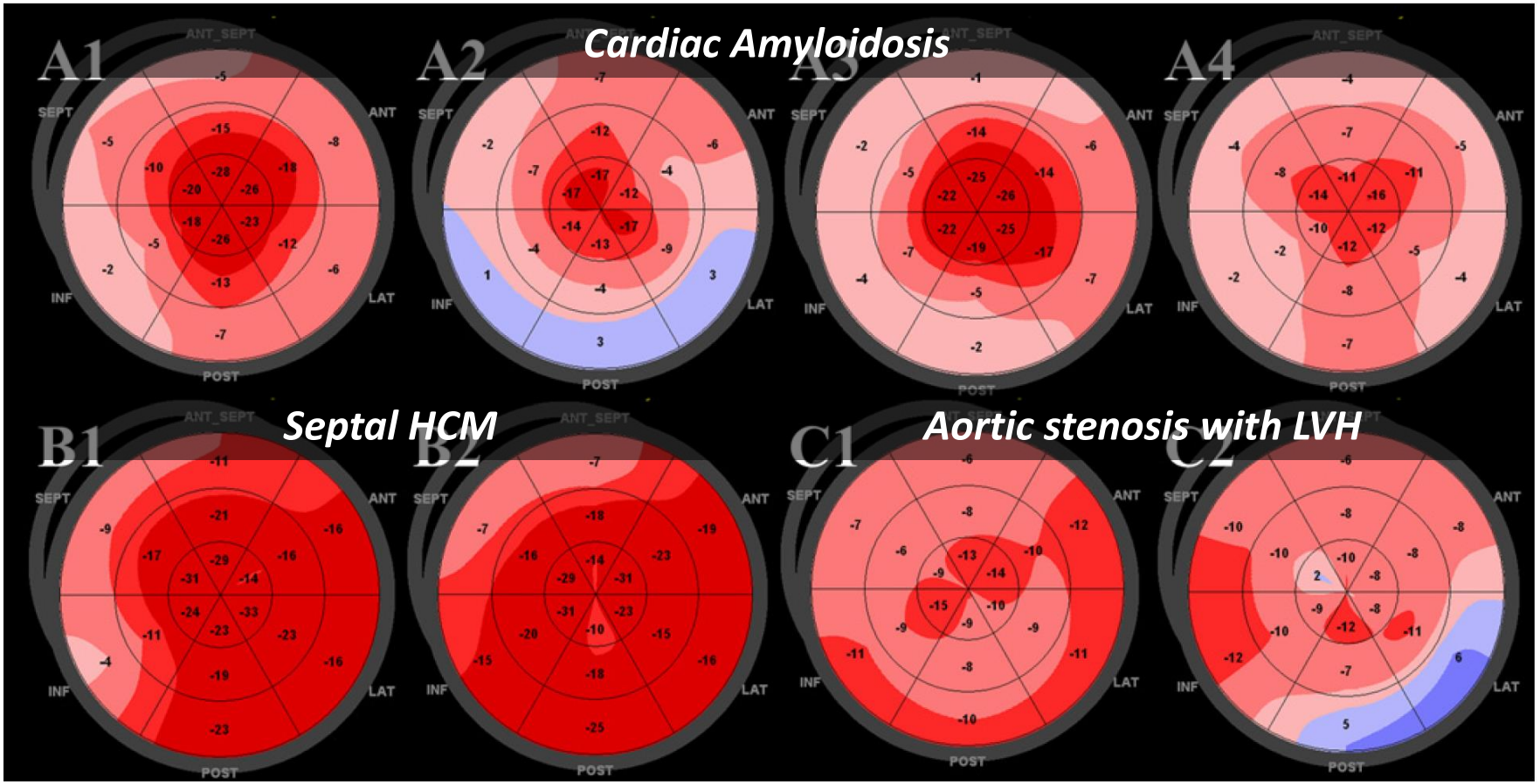
Apical involvement

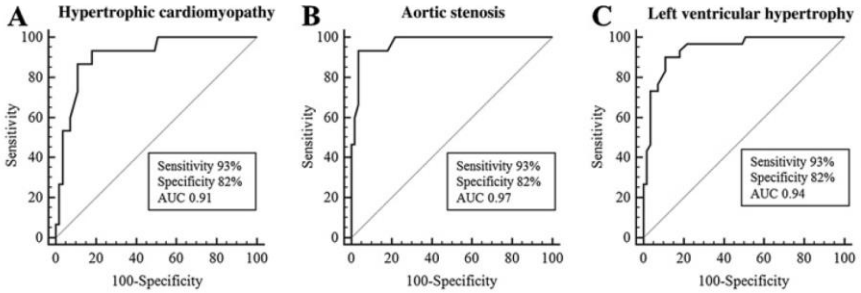


Lat. wall involvement

JAMA Cardiol. 2019;4(3):287-294

Relative apical sparing of GLS in Diagnosis of Cardiac Amyloidosis

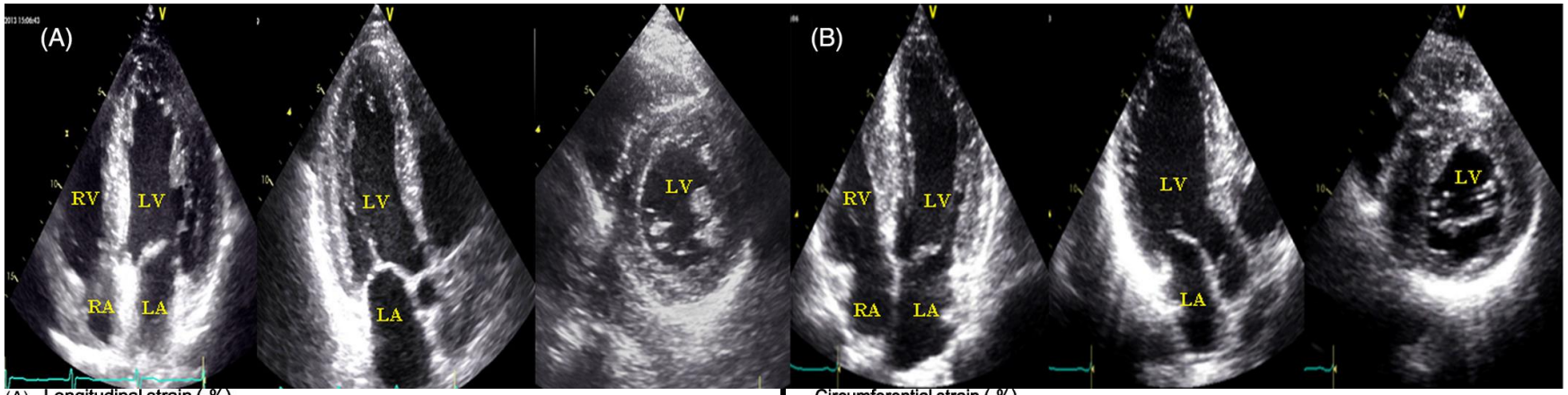


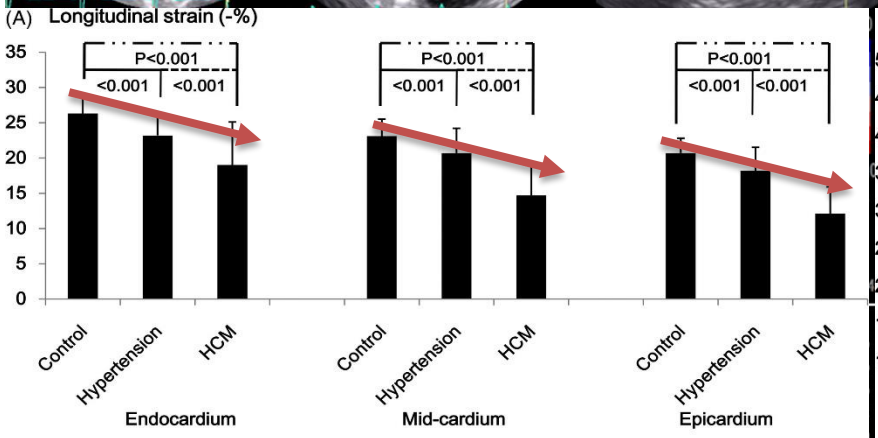


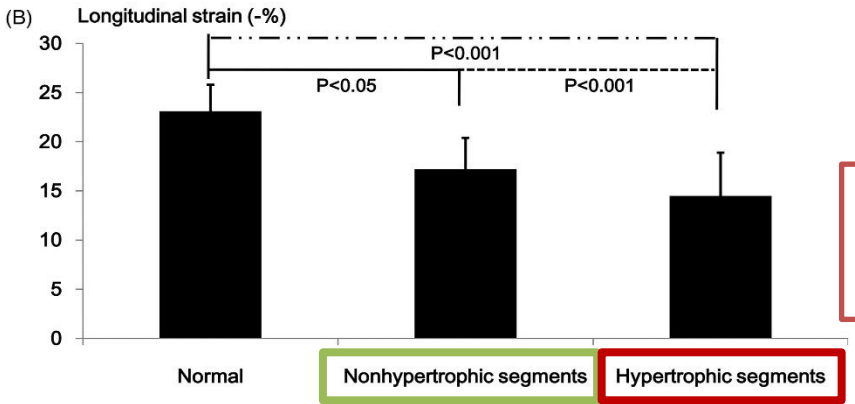
$$\text{Relative apical LS} = \frac{\text{Average apical LS}}{\text{Average basal LS} + \text{Average mid LS}}$$

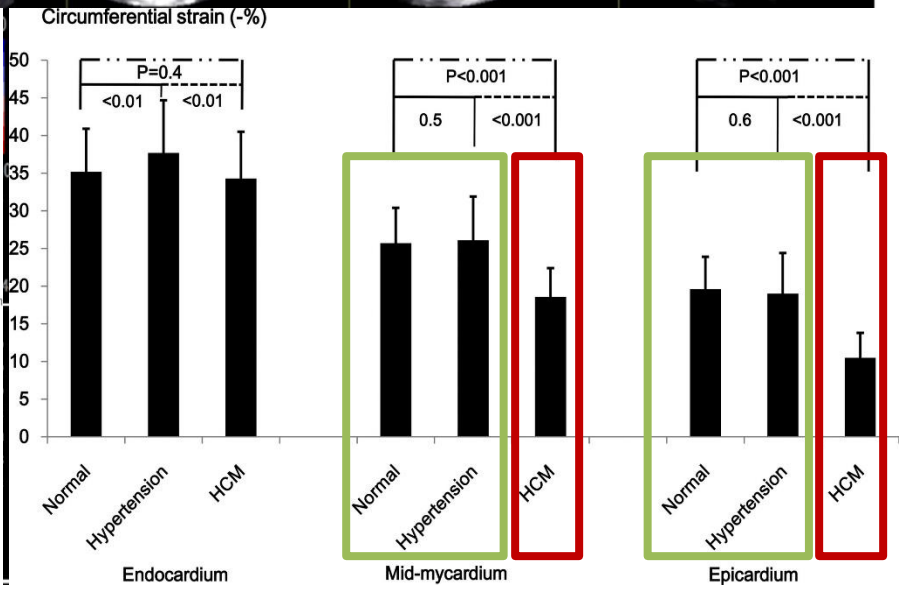
Heart 2012;98:1442e1448.

HCM vs Hypertensive LVH





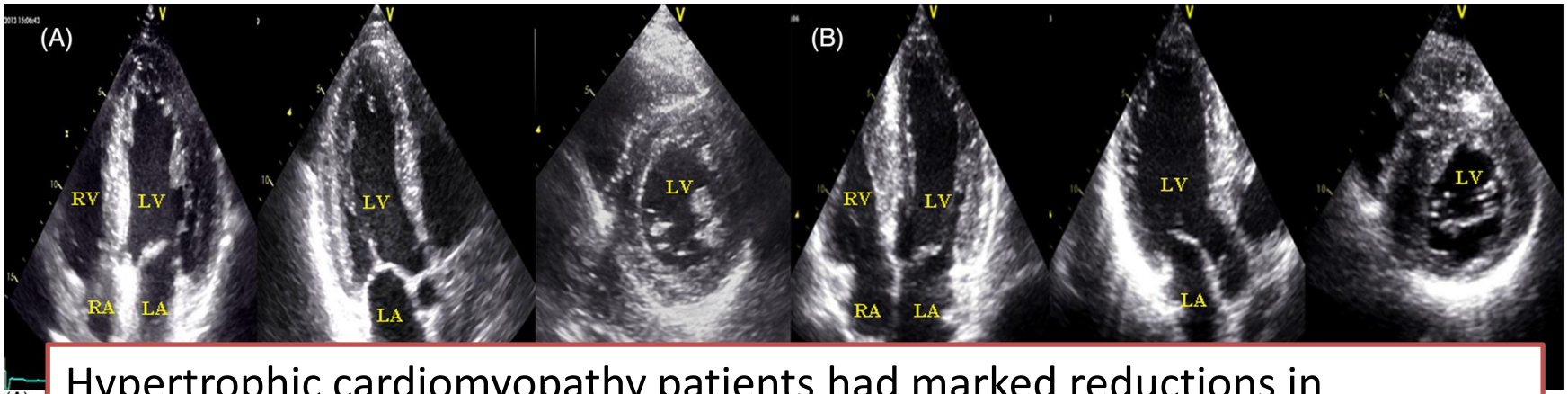




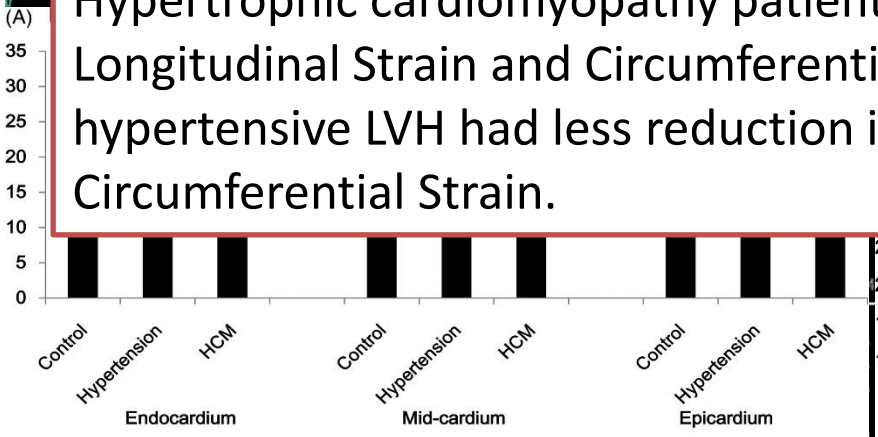
Increased endo-/epi-myocardial ratios of LS and CS may be useful in differentiating HCM from hypertensive LVH

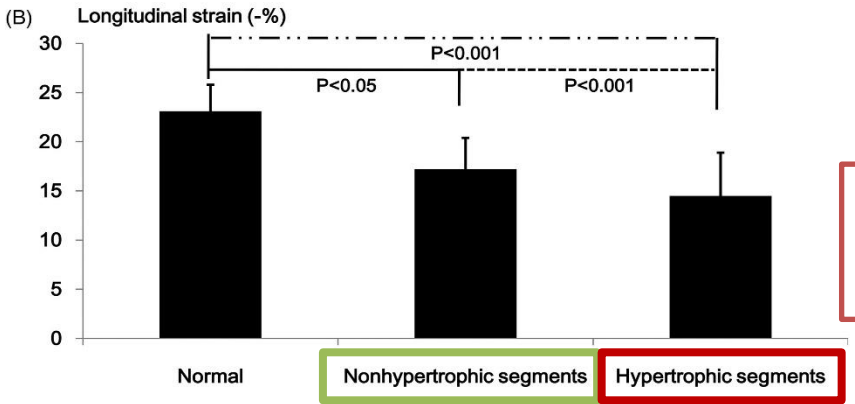
Echocardiography. 2019;36:257–265.

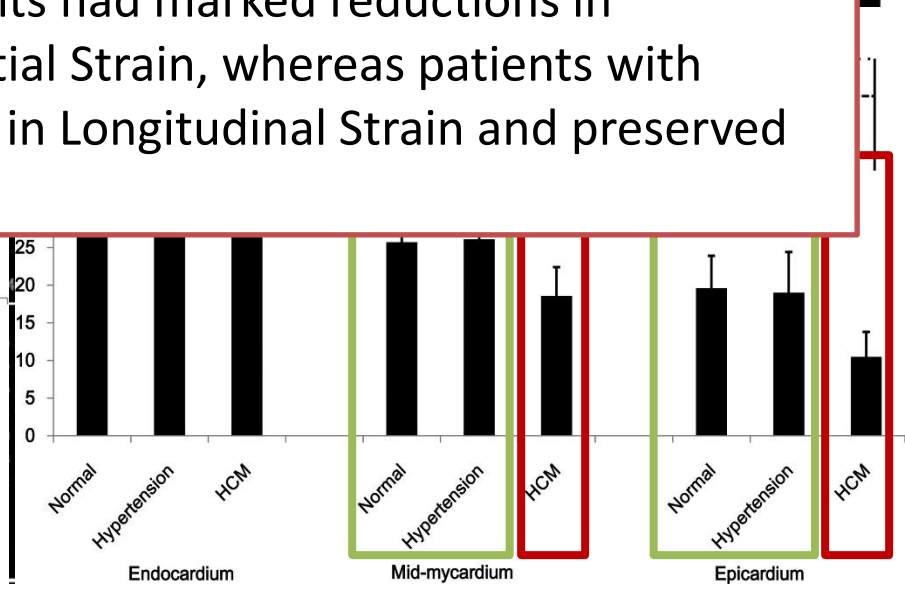
HCM vs Hypertensive LVH



Hypertrophic cardiomyopathy patients had marked reductions in Longitudinal Strain and Circumferential Strain, whereas patients with hypertensive LVH had less reduction in Longitudinal Strain and preserved Circumferential Strain.







Increased endo-/epi-myocardial ratios of LS and CS may be useful in differentiating HCM from hypertensive LVH

Echocardiography. 2019;36:257–265.

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*

Background: The distinction of hypertrophic cardiomyopathy (HCM) or cardiac amyloidosis (CA) from hypertensive heart disease may be difficult. The aim of this study was to determine the impact of parametric (polar) maps of regional longitudinal strain on identification of the etiology of mild to moderate left ventricular hypertrophy (LVH).

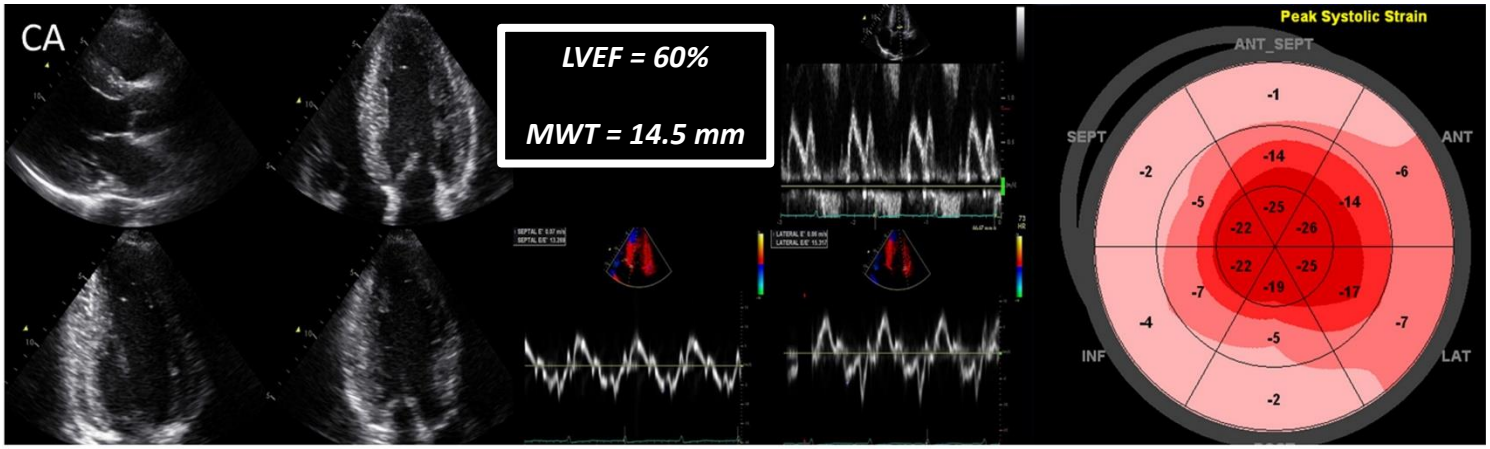
Methods: Twenty-four consecutive echocardiographic studies with mild to moderate LVH (eight with CA, eight with HCM, and eight with hypertensive heart disease) were selected on the basis of the availability of adequate images to assess longitudinal strain and absence of electrocardiographic criteria for low voltage or LVH or a pseudoinfarct pattern. Twenty level 3–trained readers provided the most likely of three diagnoses (CA, HCM, or hypertensive heart disease) and scored their confidence in making the diagnosis from two-dimensional images and diastolic parameters. A teaching exercise was provided on the interpretation of longitudinal strain in these cohorts, and interpretation was repeated with the addition of the strain polar map.

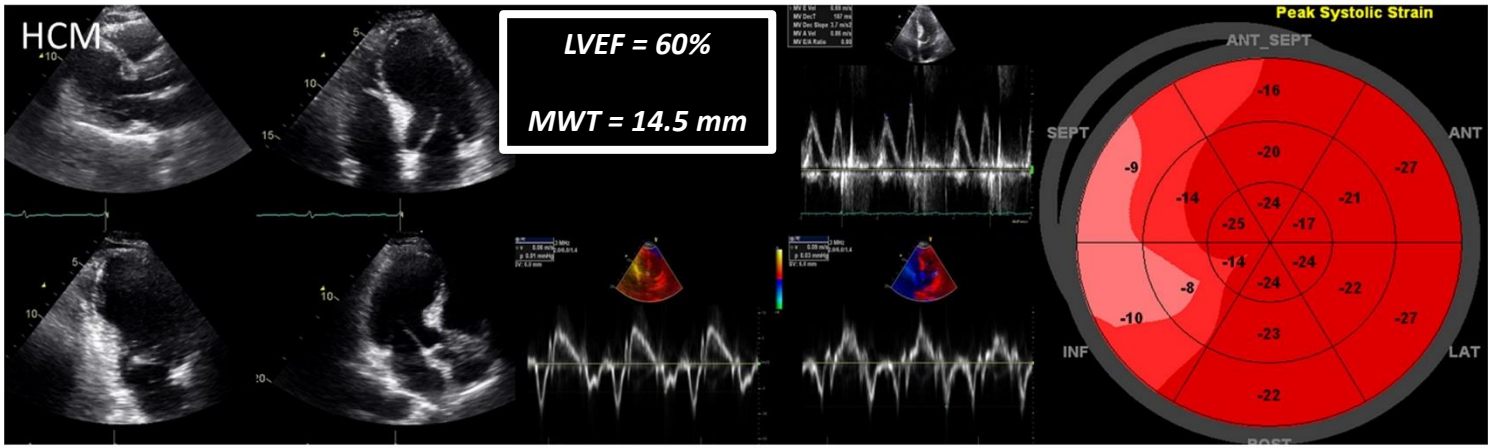
Results: Baseline concordance among the readers was poor ($\kappa = 0.28$) and improved with the addition of strain data ($\kappa = 0.57$). Accuracy was improved with the addition of polar maps for the entire study cohort ($P < .001$).

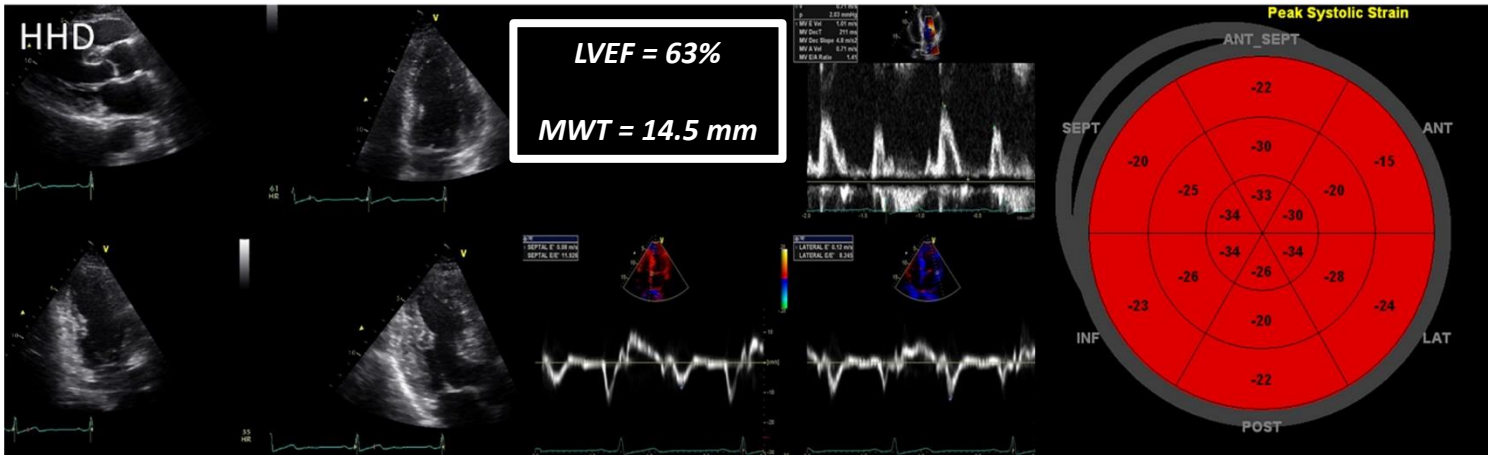
Conclusions: Regional variations in strain are easily recognizable, accurate, and reproducible means of differentiating causes of LVH. The detection of LVH etiology may be a useful clinical application for strain.

Echocardiogr 2014;27:888-95.)

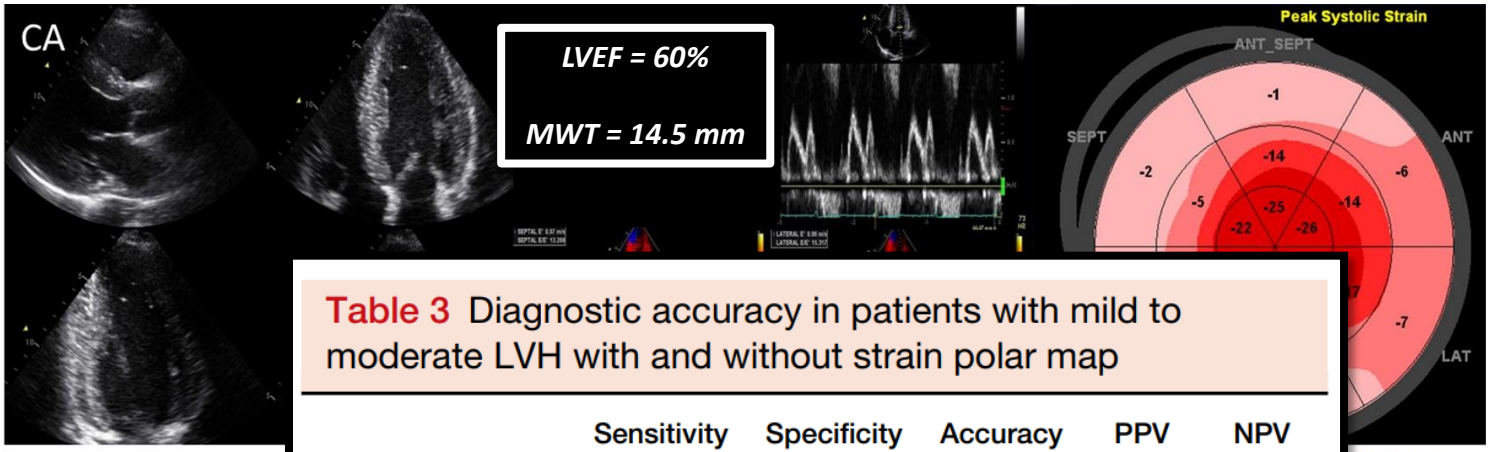
Keywords: LV hypertrophy, Hypertension, Hypertrophic cardiomyopathy, Amyloidosis, Strain

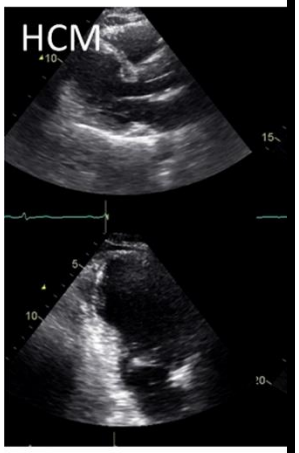


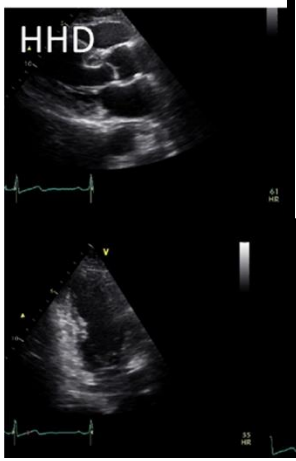




J Am Soc Echocardiogr 2014;27:888-95







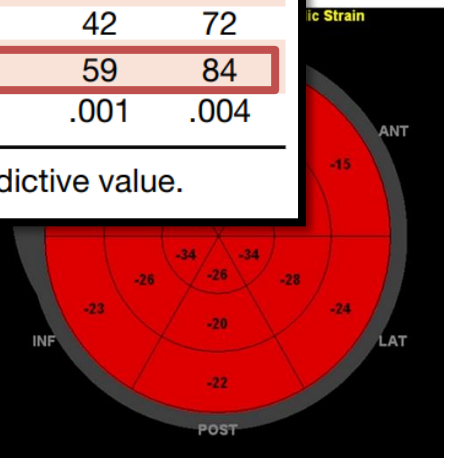


Table 3 Diagnostic accuracy in patients with mild to moderate LVH with and without strain polar map

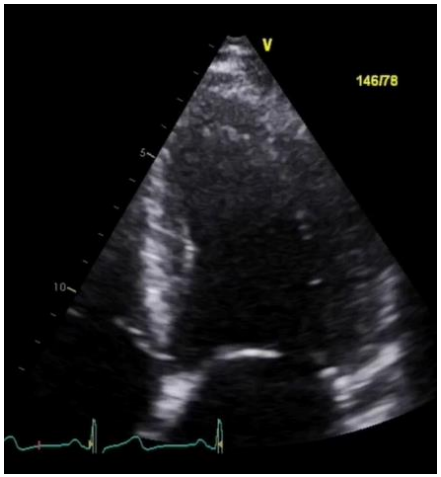
Diagnosis	Sensitivity (%)	Specificity (%)	Accuracy (%)	PPV (%)	NPV (%)
CA					
Baseline read	40	84	70	55	75
Strain read	86	95	92	92	94
P	<.001	.002	<.001	<.001	<.001
HCM					
Baseline read	44	75	65	45	73
Strain read	52	84	73	63	78
P	.054	.01	.001	<.001	.005
HHD					
Baseline read	60	59	60	42	72
Strain read	70	74	73	59	84
P	.061	.002	.001	.001	.004

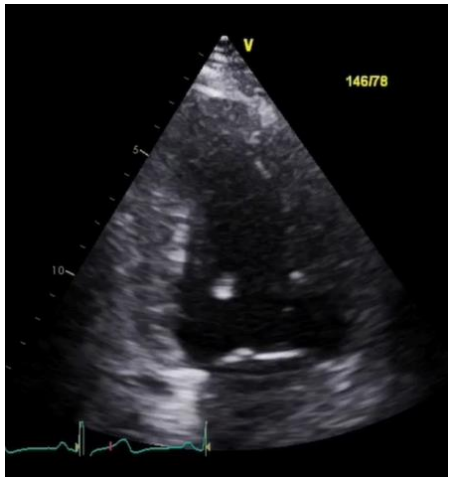
NPV, negative predictive value; *PPV*, positive predictive value.

J Am Soc Echocardiogr 2014;27:888-95

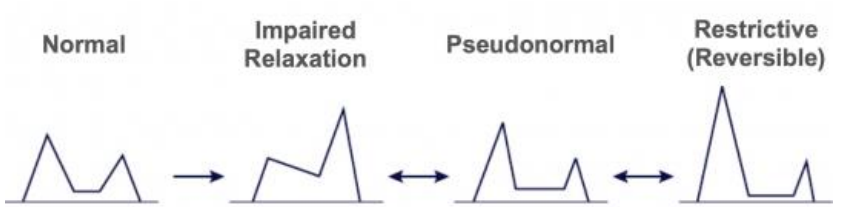
Assessment of LV filling in decompensated HFpEF

Dyspnea and LE edema in patient with alcoholic cirrhosis & HTN

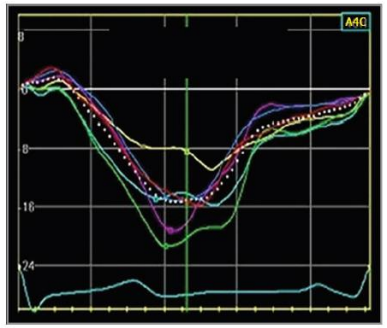




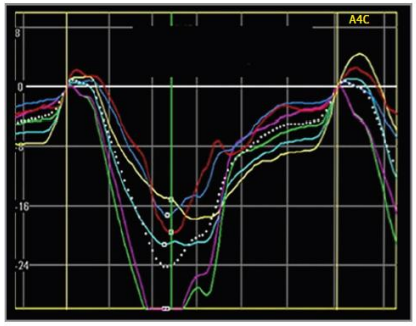
The process of pseudonormalization does not apply to GLS, ➔ strain may be used to aid in recognition and follow up of HFpEF



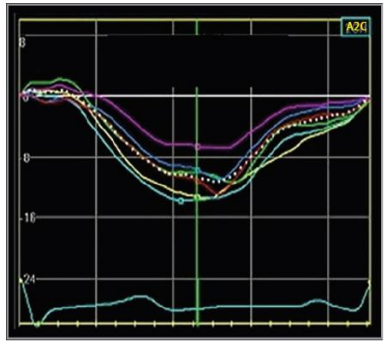
G A4C view at baseline



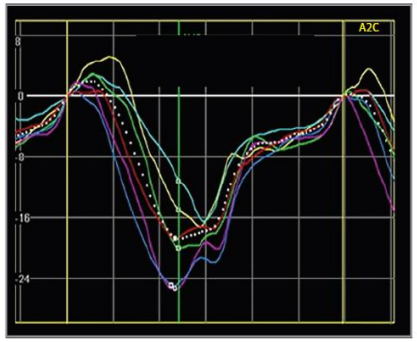
H A4C view 6 mo later



I A2C view at baseline

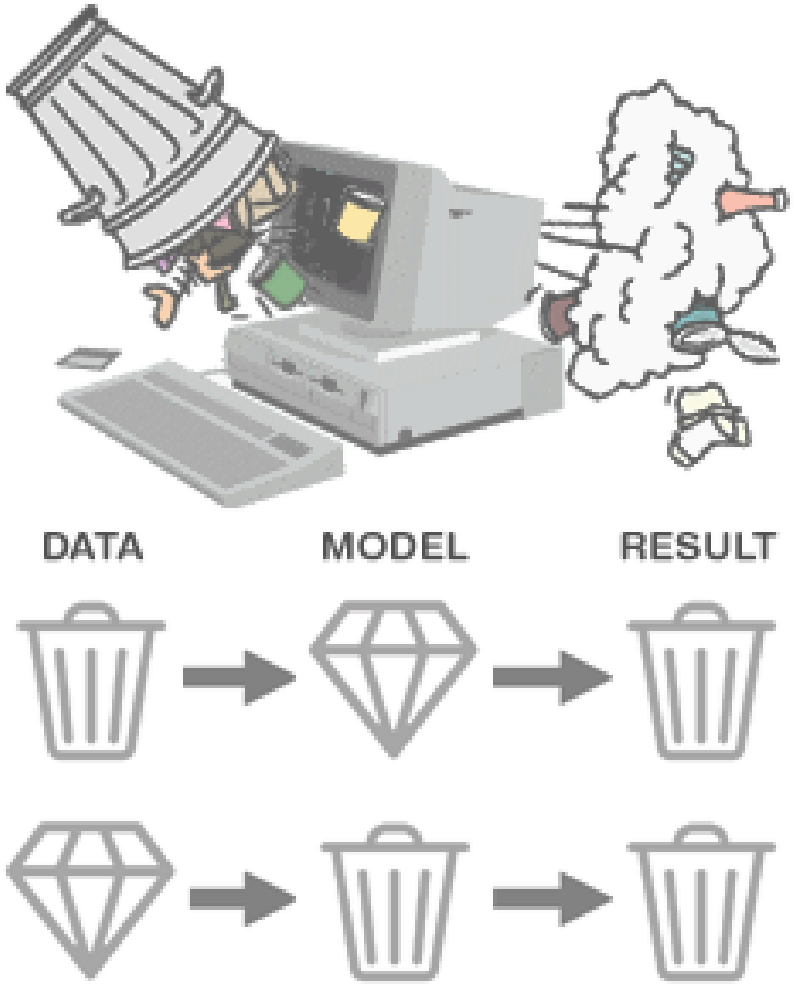


J A2C view 6 mo later

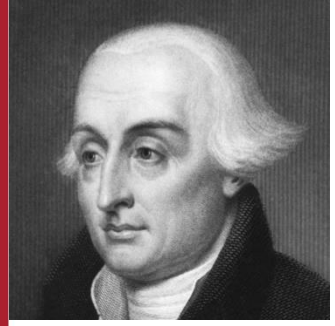


JAMA Cardiol. 2019;4(3):287-294

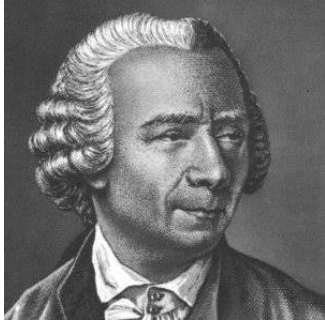
Technical Challenges and Barriers to Adoption



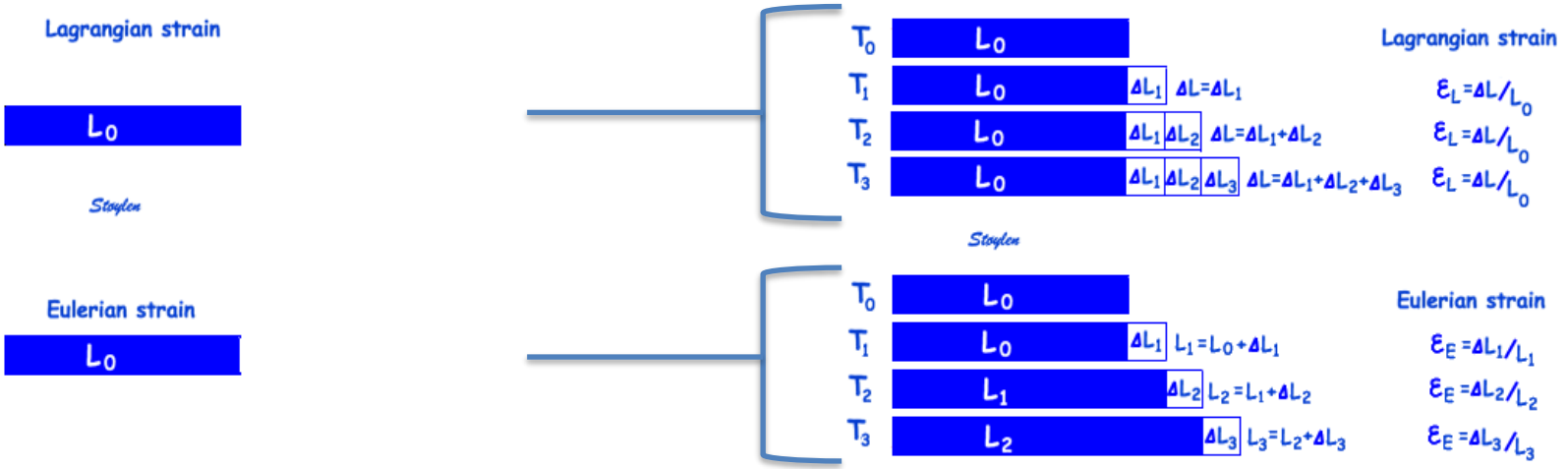
Lagrangian vs. Eulerian Strain



Joseph-Louis Lagrange



Leonhard Euler

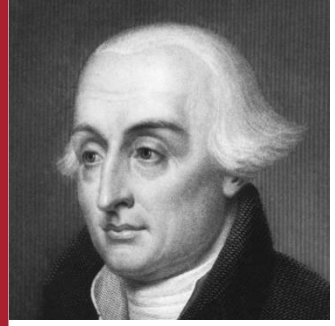


Lagrangian strain is the cumulated deformation, divided by the initial length:

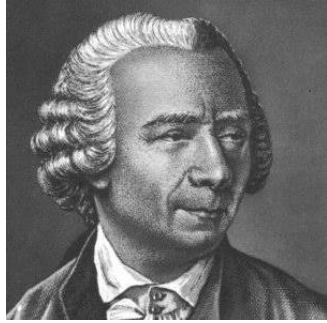
$$\varepsilon_L = \frac{\sum \Delta L}{L_o}$$

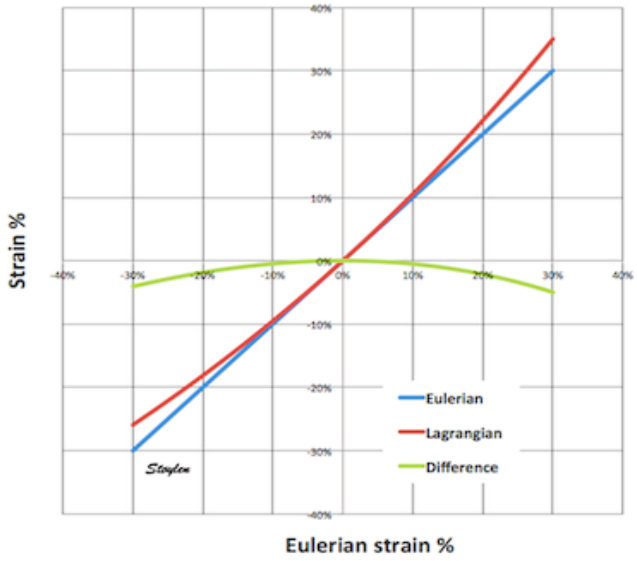
Eulerian strain is the cumulated *ratios* between the instantaneous deformation and the instantaneous length:

$$\varepsilon_E = \sum \frac{\Delta L_n}{L_n}$$

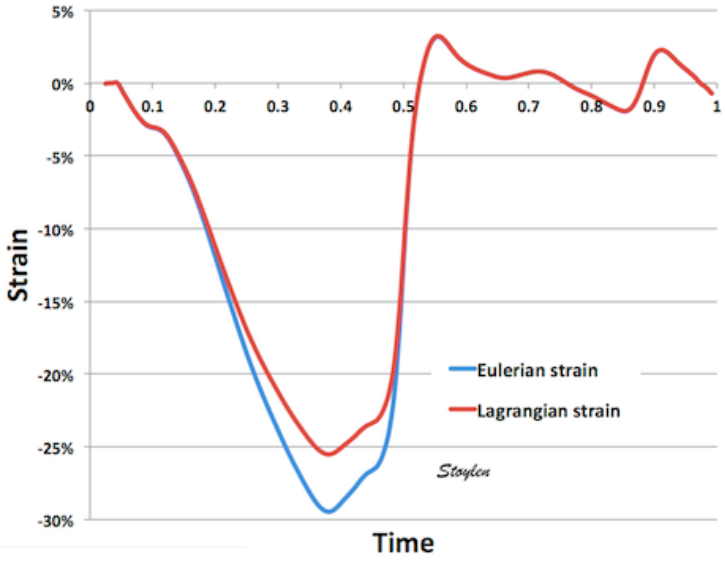


Need to know and report which of the two methods is used by the analysis software package for each of Strain & Strain rate



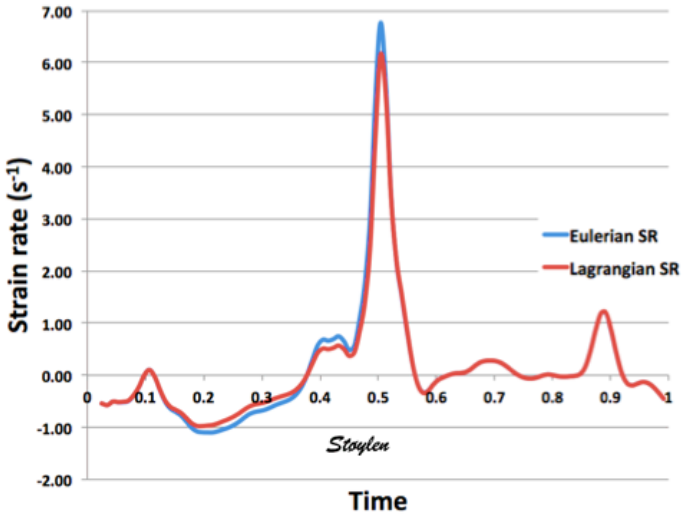


The two formulas will yield different results for Strain & Strain rate



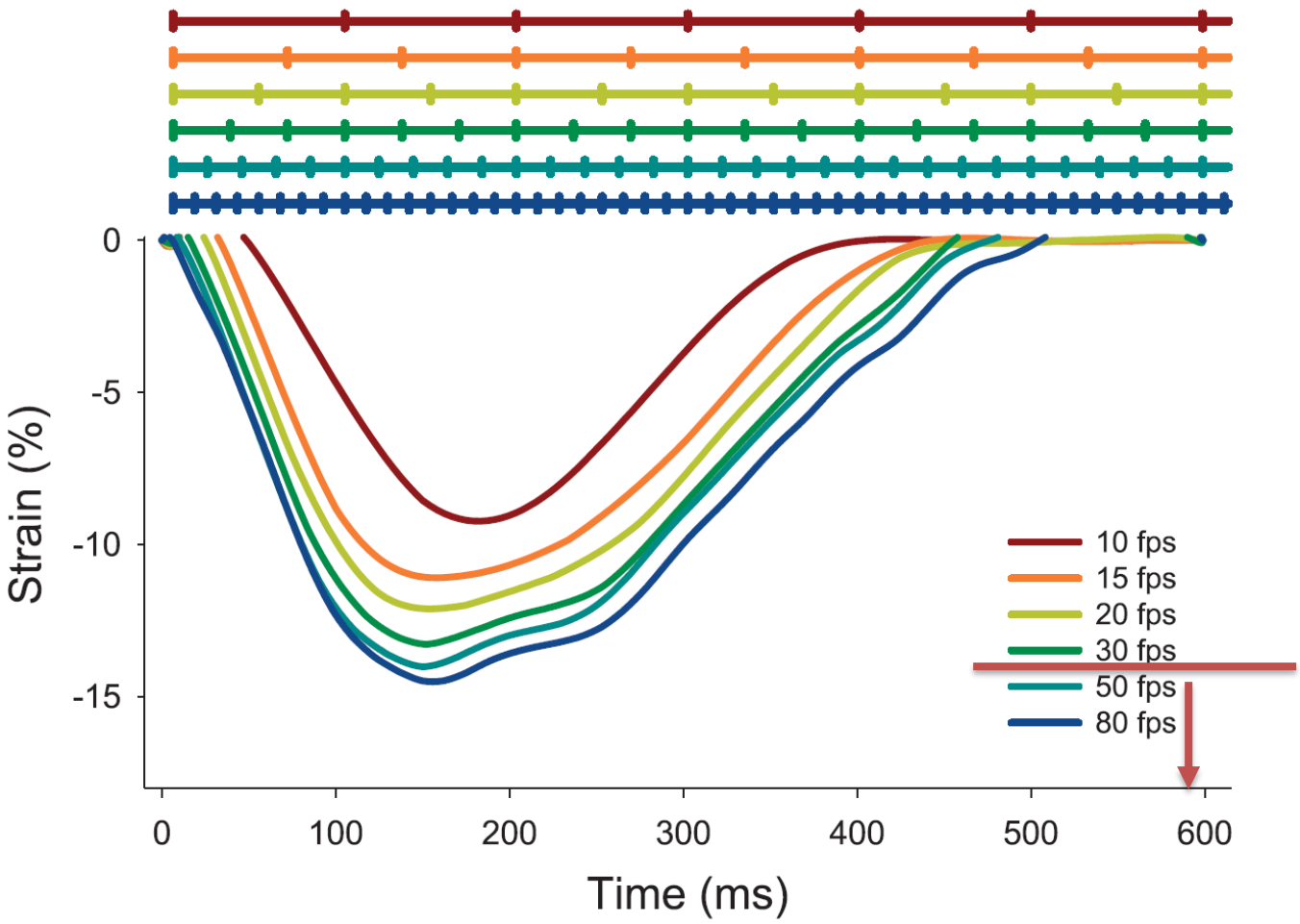
Customary to use **<u>Eulerian strain rate</u>** since first strain rate measurements by TDI correspond to Eulerian SR

Note that integrating TDI strain rate to strain, gives Eulerian strain which needs to be ***mathematically converted*** into Lagrangian strain



Customary to use **<u>Lagrangian strain</u>** since it was original method used to describe myocardial strain

Influence of temporal resolution on strain measurement



Data extrapolated from a high temporal resolution STE image under-sampled at lower frame rates

European Heart Journal - Cardiovascular Imaging (2019) 20, 605–619

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*

Background: Multiple vendor-specific two-dimensional speckle-tracking echocardiographic algorithms with which to characterize myocardial mechanics are commercially available. The purpose of this study was to compare global longitudinal strain (GLS) results between two independent software vendors using a neutral image platform.

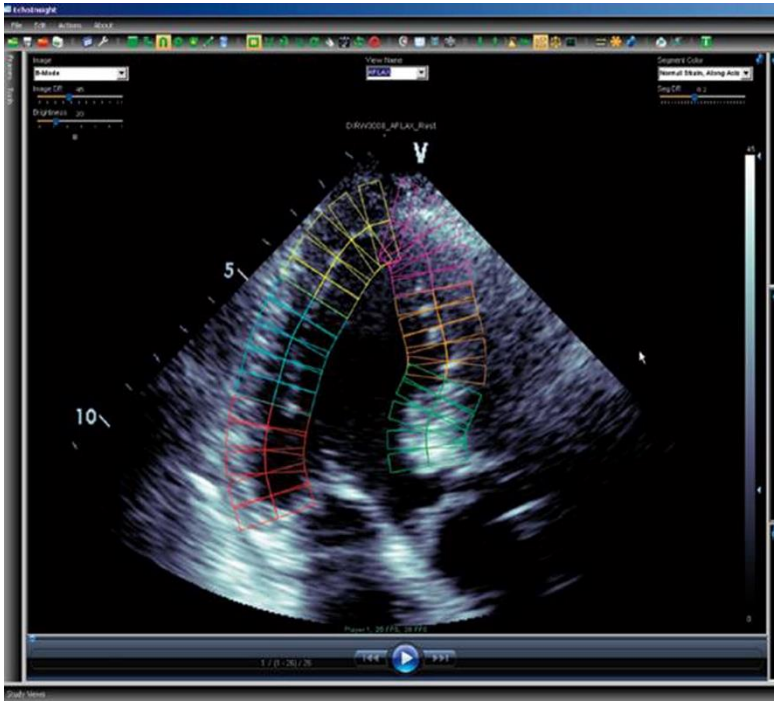
Methods: A convenience sample of 100 prospectively collected patients was evaluated. Subjects with more than two left ventricular endocardial segments poorly delineated were excluded. GLS was obtained from the apical four-chamber, three-chamber, and two-chamber views using two independent speckle-tracking 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 consistently different (more negative) than EchoInsight measures out of the box but became similar when information used to derive GLS was uniform. The evolution of measures 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.)

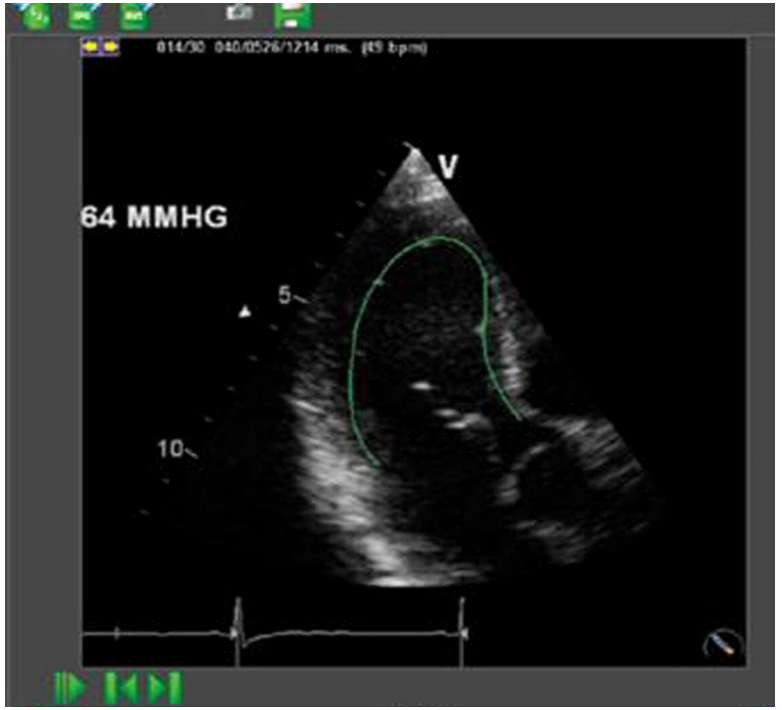
Keywords: Speckle-tracking, Strain, Echocardiography

Vendor 1



VS.

Vendor 2



Using **Out-Of-The Box Settings** to derive GLS

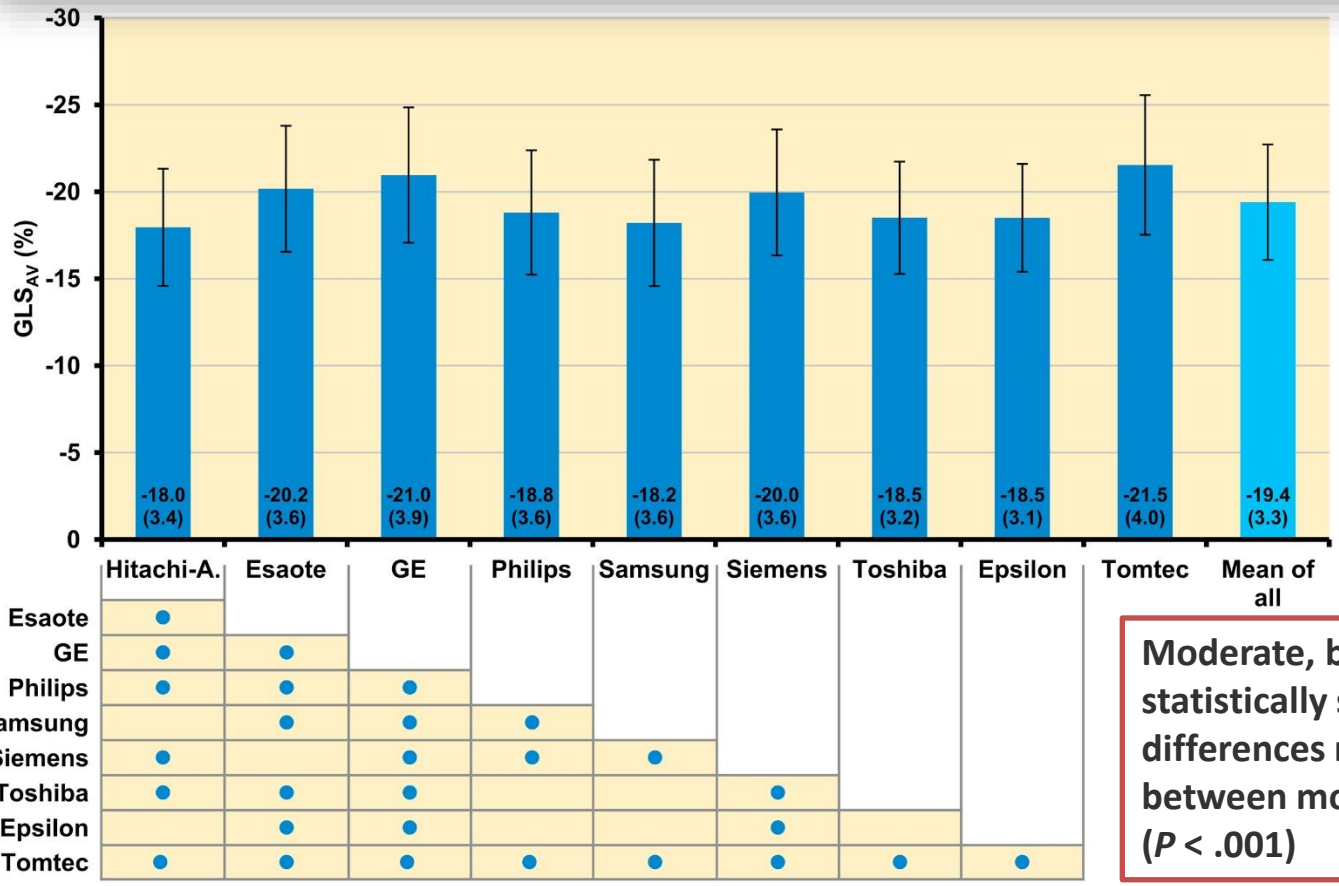
Mean GLS = -12.99 +/- 2.38% (P = .0001) **Mean GLS = -16.87 +/- 2.84%**

J Am Soc Echocardiogr 2012;25:1189-94

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*

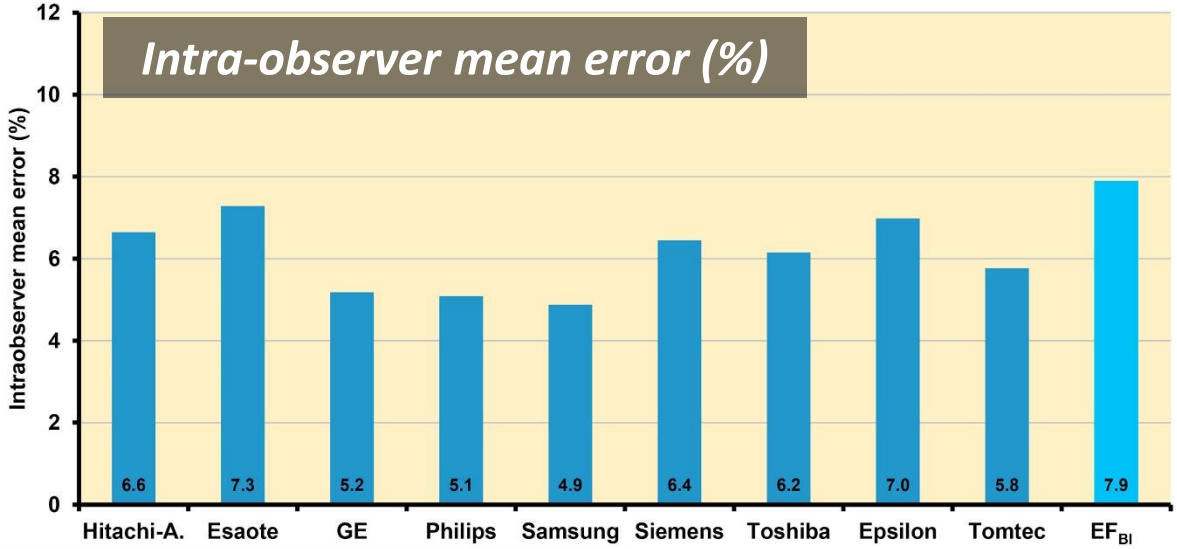


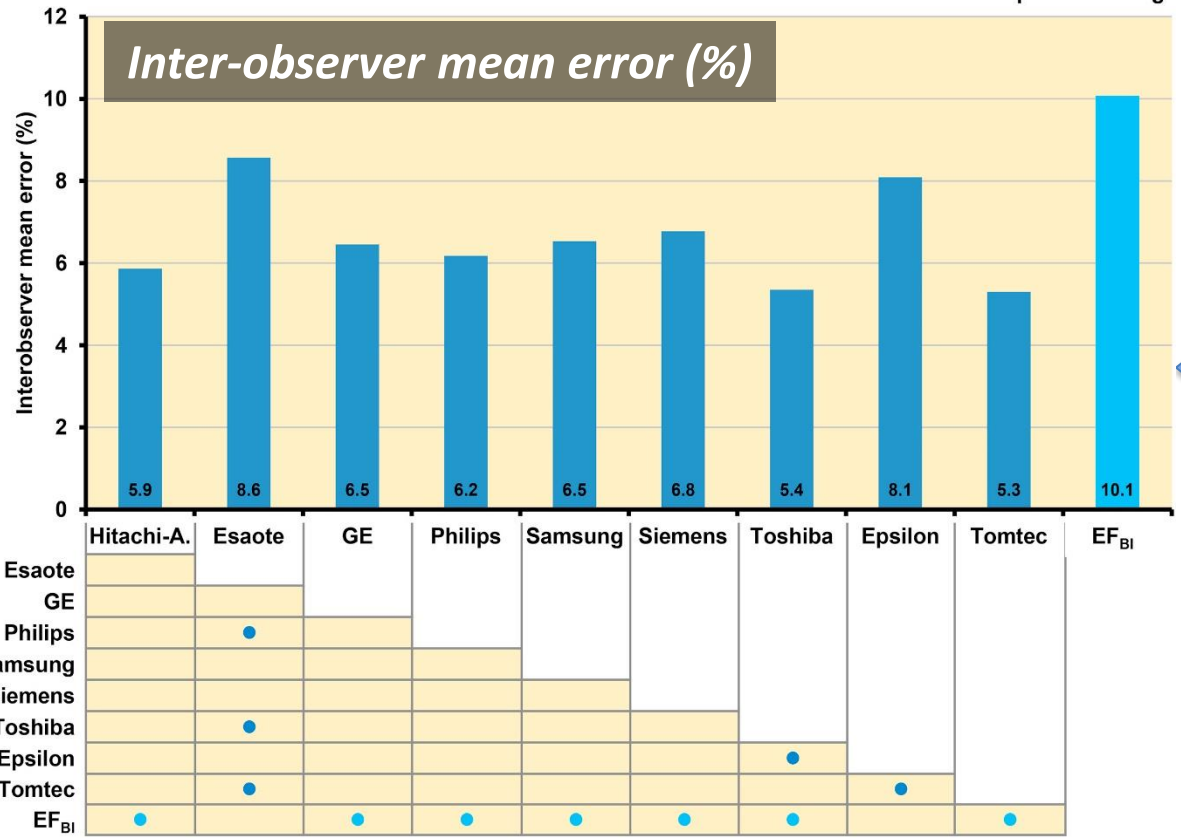
Moderate, but statistically significant differences noted between most vendors ($P < .001$)

A blue dot indicates significant variance between vendors (ANOVA P <0.05)

J Am Soc Echocardiogr 2015;28:1171-81

No significant differences were observed (P = .062)



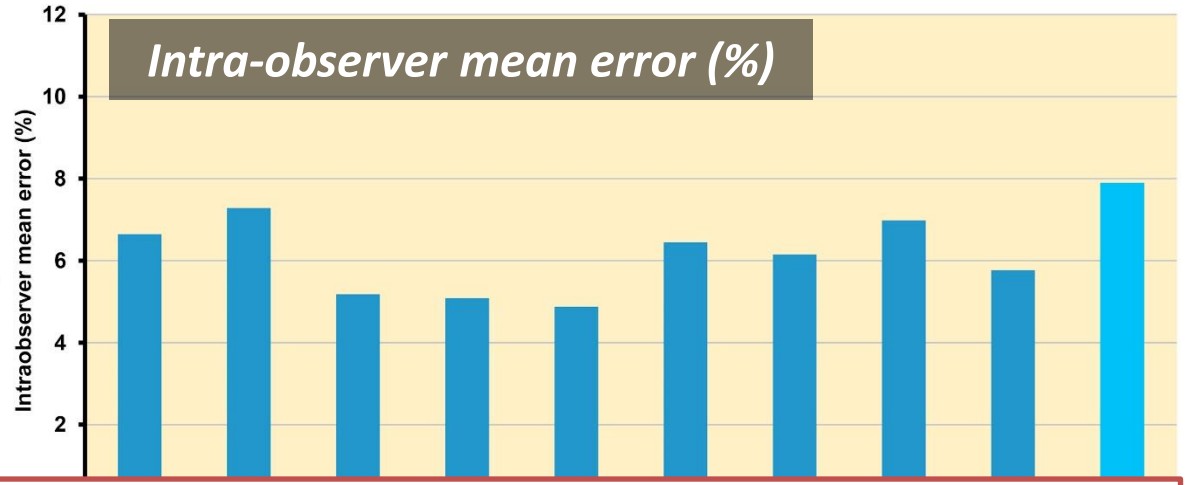


Significant differences noted between GLS & EF measurements as well as between some of the vendors (P < .001)

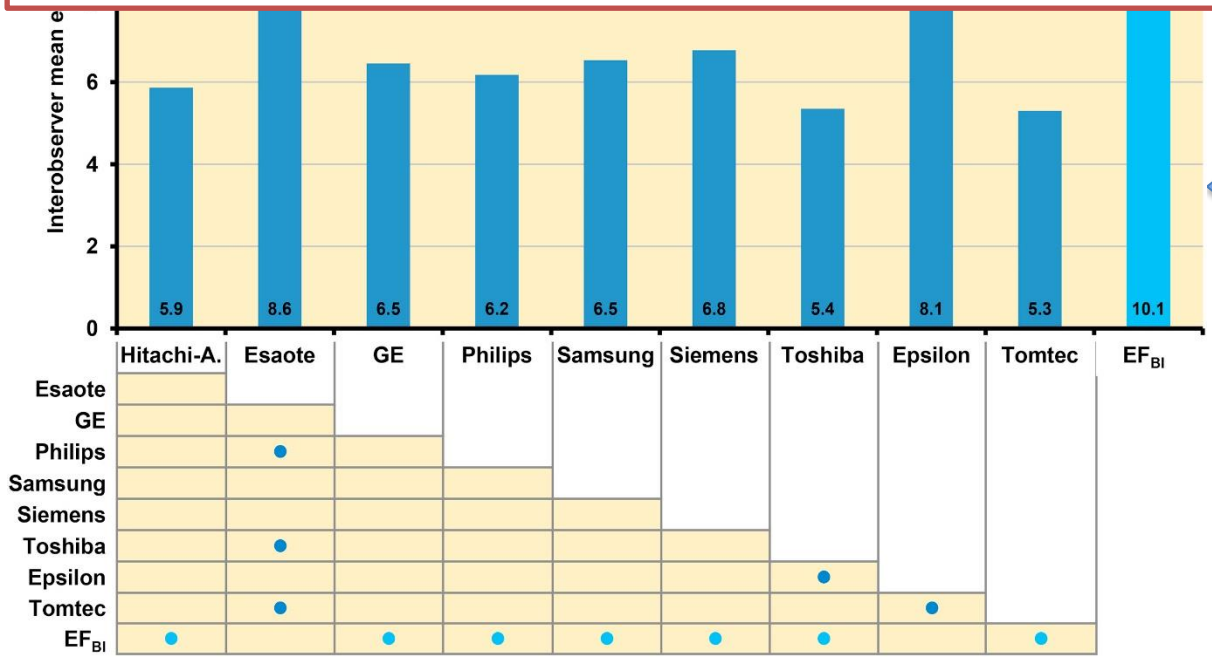
A blue dot indicates significant variance between vendors (ANOVA P <0.05)

J Am Soc Echocardiogr 2015;28:1171-81

No significant differences were observed (P = .062)



Inter-vendor variability in measurement of Peak Systolic Global Longitudinal Strain may now be even less than variability involved in measurement of LVEF



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J Am Soc Echocardiogr 2015;28:1171-81

Head-to-Head Comparison of Global Longitudinal Strain Measurements among Nine Different Vendors

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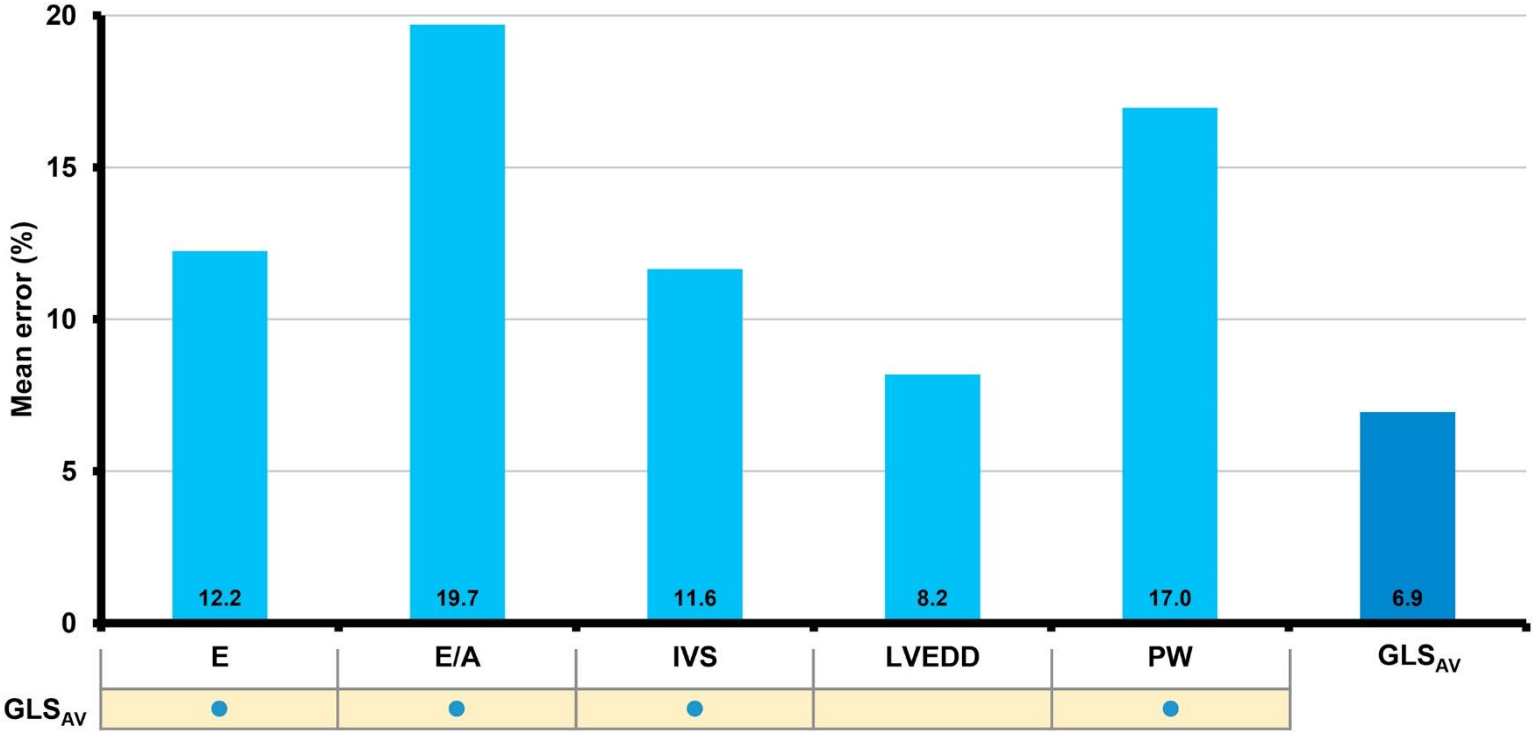
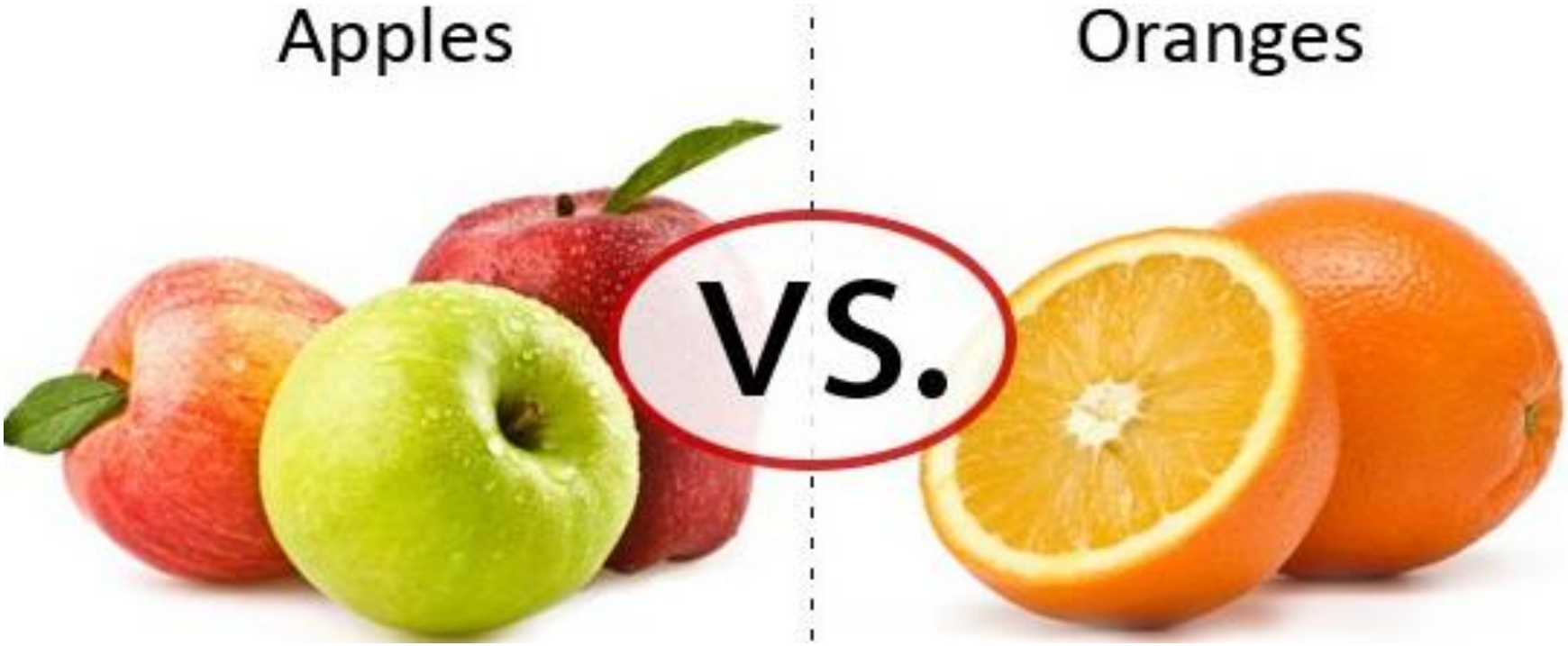
Most conventional echocardiographic parameters have a significantly higher measurement variability than GLS_{AV} ($P < .001$).



A blue dot indicates significant variance between vendors (ANOVA P <0.05)

J Am Soc Echocardiogr 2015;28:1171-81

Vendor 1	*Vendor 2*



Using **Out-Of-The Box Settings** to derive GLS

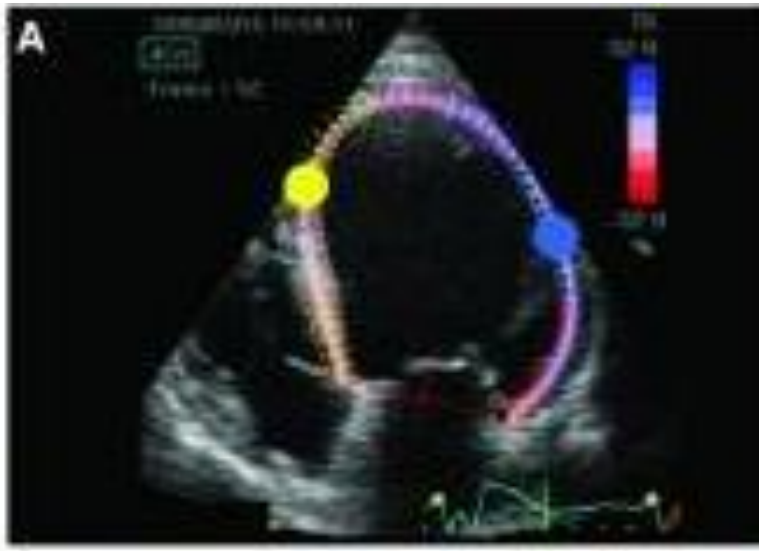
Mean GLS = -12.99 +/- 2.38% (P = .0001) **Mean GLS = -16.87 +/- 2.84%**

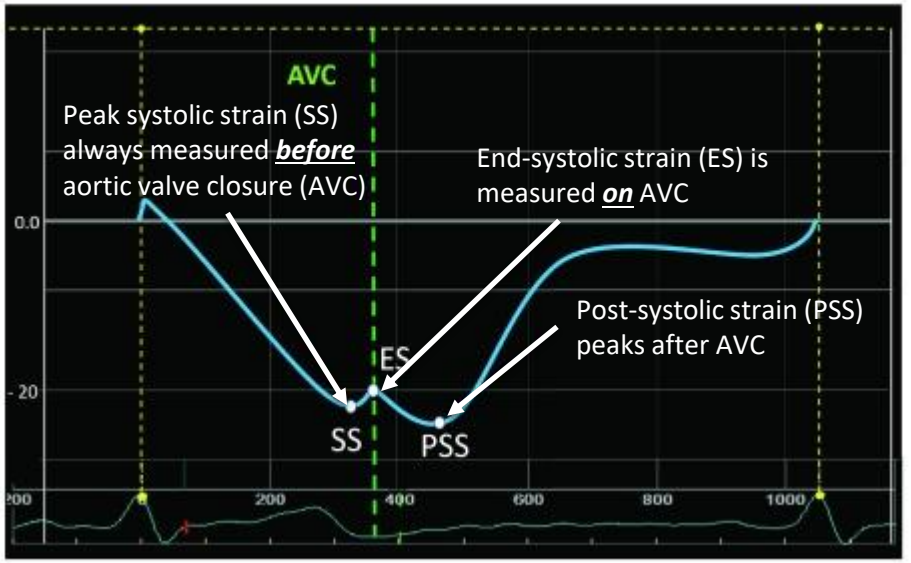
Using **uniform variables** to derive GLS

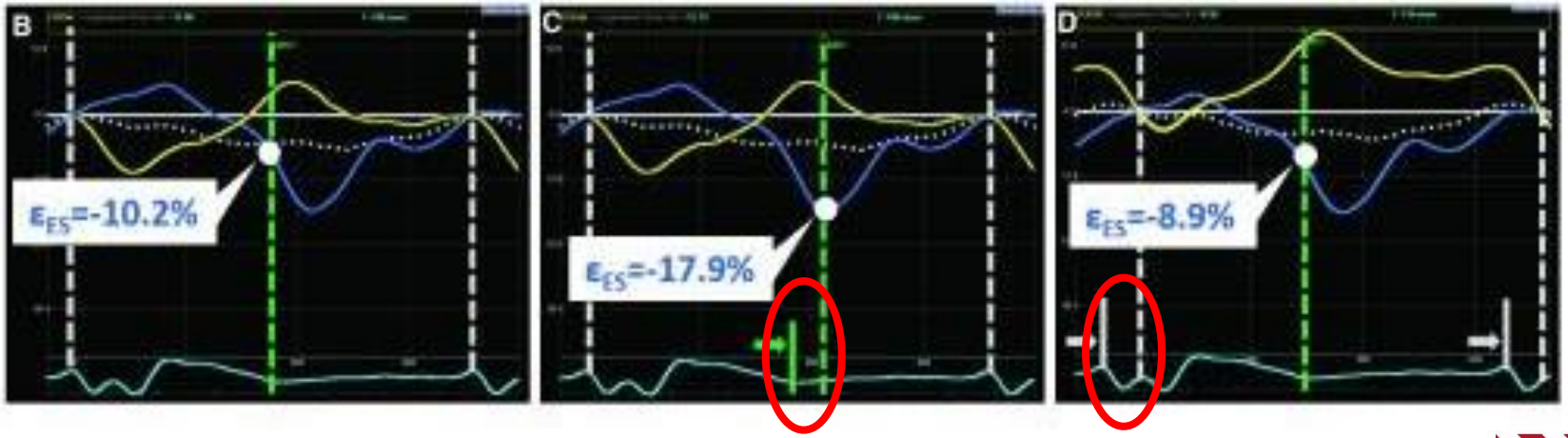
Mean GLS = -16.17 +/- 2.90% (P = .02) **Mean GLS = -16.87 +/- 2.84%**

J Am Soc Echocardiogr 2012;25:1189-94

Impact of commonly used strain measurements & timing definitions







Correct def. of ED & ES **ES shifted by 4 frames** **ED shifted by 4 frames**

F1000Research 2016, 5(F1000 Faculty Rev):787

SPECIAL ARTICLE

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

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

Recognizing the critical need for standardization in strain imaging, in 2010, the European Association of Echocardiography (now the European Association of Cardiovascular Imaging, EACVI) and the American Society of Echocardiography (ASE) invited technical representatives from all interested vendors to participate in a concerted effort to reduce intervendor variability of strain measurement. As an initial product of the work of the EACVI/ASE/Industry initiative to standardize deformation imaging, we prepared this technical document which is intended to provide definitions, names, abbreviations, formulas, and procedures for calculation of physical quantities derived from speckle tracking echocardiography and thus create a common standard.
(J Am Soc Echocardiogr 2015;28:183-93.)

Keywords: Echocardiography, Two-dimensional, Deformation imaging, Strain, Strain rate, Speckle tracking, Left ventricle, Myocardial, Standard, Definitions

Table 1 Recommended names, abbreviations, and units for 2D speckle tracking-derived parameters

Parameter	Definition	View for data acquisition	Abbreviation	Unit
Longitudinal velocity	Respective motion or deformation component parallel to the reference contour, viewed in from base to the apex	All three apical views (recommended) and parasternal long-axis view (not recommended in routine clinical practice)	V_l	cm/s
Longitudinal displacement			D_l	mm
Longitudinal strain rate			SR_l	1/s
Longitudinal strain			S_l	%
Radial velocity	Respective motion or deformation component perpendicular to the reference contour, viewed from the contour towards the LV cavity	All three apical views and parasternal short-axis view (recommend) and parasternal long-axis view (not recommended)	V_r	cm/s
Radial displacement			D_r	mm
Radial strain rate			SR_r	1/s
Radial strain			S_r	%
Circumferential velocity	Respective motion or deformation component tangential to the reference contour, perpendicular to the LV long axis, with counterclockwise orientation when viewed from the apex. Angular components refer to the centre of gravity of the LV within the image plane	Short-axis views only	V_c	cm/s
Rotation rate			RotR	8/s
Circumferential displacement			D_c	mm
Rotation			Rot	8
Circumferential strain rate			SR_c	1/s
Circumferential strain			S_c	%

J Am Soc Echocardiogr 2015;28:183-93

Task Force Recommendations

- The reported ***type of strain or strain rate*** (i.e. Lagrangian vs. natural) must be indicated by any software package
- Software should explicitly state what ***strain layer*** is being measured: endocardial, midline, epicardial, or full wall strain.
- Segment definitions refer to the anatomy at the ***end-diastolic frame*** with option for manual correction.
- Analysis software commonly uses the ***peak of the QRS complex to define end-diastole***, however user must be informed about the time reference which is used with option for manual adjustment.
- User must be informed about the time reference, which is used to ***define end-systole*** and be offered the opportunity to over-rule this definition if deemed necessary according to the pathophysiological situation
- ***End-systolic strain*** (ESS) should be reported as a default parameter for the description of myocardial deformation

Task Force Recommendations

- The ***global strain*** or strain rate should be calculated by using the ***entire myocardial line length*** & location (endocardium, midline, or averaged over the entire cardiac wall) must be explicitly reported by the software
- Analysis software should offer an automated ***measure of tracking quality*** with visual display for quality control
- Myocardial velocities should be reported ***perpendicular*** or ***tangential*** to the defined border
- ***Twist*** and ***torsion*** parameters are poorly defined in 2D echocardiography and ***caution*** is urged in their use.
- Since intensive drift correction may mask poor tracking, applied ***drift compensation*** should be indicated to the user and options for turning it off or on should be available
- Analysis software should inform the user about measures, which are applied for ***regularization*** (normal modeling, smoothing, etc..)
- *A*ll references to strain changes should consider the ***absolute value*** of the number (increased GLS ➔ more negative) always including the sign

Improvement in Strain Concordance between Two Major Vendors after the Strain Standardization Initiative

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

Supplemental Table 2 **Coefficient of Variation (CV)**

Variable	CV ± SD
LVEDV (GE/Philips)	0.10 ± 0.07
LVESV (GE/Philips)	0.13 ± 0.09
LVEF (GE/Philips)	0.05 ± 0.05
GLS (E12_Q8)	0.12 ± 0.08
GLS (E13_Q8)	0.14 ± 0.08
GLS (E12_Q9)	0.06 ± 0.05
GLS (E13_Q9)	0.06 ± 0.04
GLS (E12_Q10)	0.07 ± 0.04
GLS (E13_Q10)	0.07 ± 0.04

Before Standardization

After Standardization

J Am Soc Echocardiogr 2015;28:642-8

GUIDELINES AND STANDARDS

Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging

Roberto M. Lang, MD, FASE, FESC, Luigi P. Badano, MD, PhD, FESC, Victor Mor-Avi, PhD, FASE, Jonathan Afilalo, MD, MSc, Anderson Armstrong, MD, MSc, Laura Ernande, MD, PhD, Frank A. Flachskampf, MD, FESC, Elyse Foster, MD, FASE, Steven A. Goldstein, MD, Tatiana Kuznetsova, MD, PhD, Patrizio Lancellotti, MD, PhD, FESC, Denisa Muraru, MD, PhD, Michael H. Picard, MD, FASE, Ernst R. Rietzschel, MD, PhD, Lawrence Rudski, MD, FASE, Kirk T. Spencer, MD, FASE, Wendy Tsang, MD, and Jens-Uwe Voigt, MD, PhD, FESC, *Chicago, Illinois; Padua, Italy; Montreal, Quebec and Toronto, Ontario, Canada; Baltimore, Maryland; Créteil, France; Uppsala, Sweden; San Francisco, California; Washington, District of Columbia; Leuven, Liège, and Ghent, Belgium; Boston, Massachusetts*

The rapid technological developments of the past decade and the changes in echocardiographic practice brought about by these developments have resulted in the need for updated recommendations to the previously published guidelines for cardiac chamber quantification, which was the goal of the joint writing group assembled by the American Society of Echocardiography and the European Association of Cardiovascular Imaging. This document provides updated normal values for all four cardiac chambers, including three-dimensional echocardiography and myocardial deformation, when possible, on the basis of considerably larger numbers of normal subjects, compiled from multiple databases. In addition, this document attempts to eliminate several minor discrepancies that existed between previously published guidelines. (J Am Soc Echocardiogr 2015;28:1-39.)

Keywords: Adult echocardiography, Transthoracic echocardiography, Ventricular function, Normal values

Recommendations for LV Strain

1. Optimize image quality, maximize frame rate, and minimize foreshortening.
2. Perform GLS measurements in the three standard apical views and average results
3. Begin with the apical long-axis view to visualize aortic valve closure
4. Avoid calculating GLS when regional tracking is suboptimal in more than two myocardial segments in a single view
5. Committee refrains from recommendations regarding basis for GLS calculation using endocardial, midwall, or average deformation and refers to the ongoing joint standardization initiative of the ASE, EACVI, and the ultrasound imaging industry
6. Serial assessment of GLS in individual patients should be performed using the same vendor's equipment and the same software
7. Use strain data as compliment to EF

Quantification of RWM Using Doppler and STE

1. Speckle tracking is preferred over DTI due to its angle dependency and susceptibility to underestimation
2. Use of deformation parameters, such as strain and strain rate, is

Despite promising data, quantitative assessment of the magnitude of ***regional*** LV deformation ***cannot be recommended*** at this stage because of lack of reference values, suboptimal reproducibility, and considerable inter-vendor measurement variability

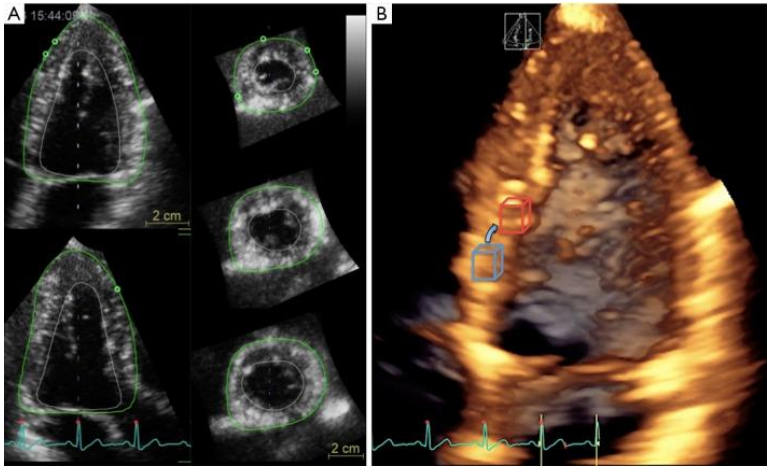
4. No specific normal ranges are provided for regional strain
5. The value of regional deformation parameters and temporal patterns of strain such as post systolic shortening or thickening (aka tardokinesis) is the subject of ongoing research and remains to be determined
6. The 16-segment model is recommended for wall motion aseessment

Recommendations for RV Strain

1. ***RV longitudinal strain*** is less confounded by overall heart motion but depends on RV loading conditions as well as RV size & shape
2. RVLS should be measured by ***STE*** in the ***A4CH RV-focused view***
3. RV STE strain is influenced by image quality, reverberation, attenuation, other artifacts, placement of basal reference points
4. The ***width*** of the region of interest should be limited to the ***myocardium***, excluding the pericardium, which may be difficult given the usually thin RV free wall
5. ***Peak RV Free Wall GLS*** (excluding IVS) has been reported by largely single center studies to have prognostic value in various disease states, such as heart failure, acute myocardial infarction, pulmonary hypertension, and amyloidosis, and to predict RV failure after LV assist device implantation
6. Pooled data suggest that global longitudinal ***RV free wall strain > -20%*** (i.e., <20% in absolute value) is likely abnormal

Journey from 2D to 3D strain

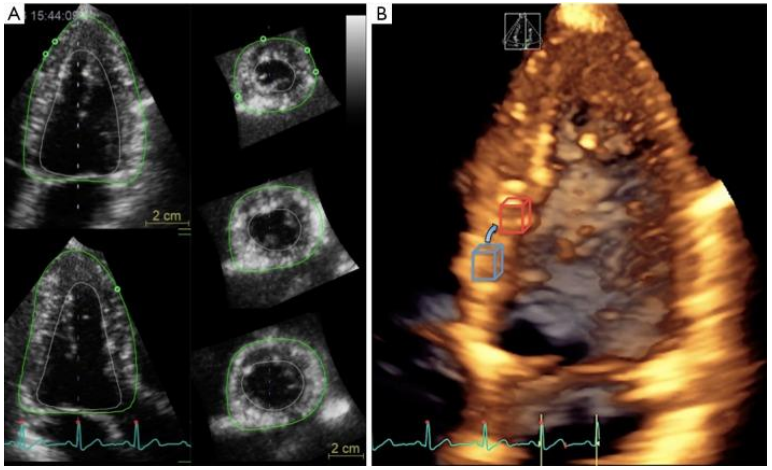
- Speckles can be followed in any direction
- Allows calculation of all 3D strain parameters from single volumetric data set (workflow + time saving)
- Avoids errors caused by heart rate variability between different 2D acquisitions



Characteristics	3D strain	2D strain
Acquisition	One apical 3D full volume	Three parasternal and three apical 2D views
Heart rate	Regular (6-beat LV full volume)	Regular (consecutive 2D LV planes)
Feasibility in sinus rhythm	Good	Very good
Reliance on good image quality	Yes (++)	Yes (+)
Temporal resolution*	34–50 volumes/s	40–80 frames/s
Parameters	All strains (longitudinal, radial, circumferential)	All strains (longitudinal, radial, circumferential)
Two-directional (area) strain†	Yes	No
Bull's-eye map‡	Dynamic	Static
Calculation of global strain	Simultaneous segmental values§	Non simultaneous segmental peaks§
Radial strain	Calculated from area strain (by the law of volume conservation)	Measured
Out-of-plane motion of speckles	No	Yes
Positive peak rule‖	No	Yes
Drift compensation¶	No	Yes
Definition of end-systole	Time of LV minimal volume	Time of aortic valve closure

Cardiovasc Diagn Ther 2018;8(1):101-117

Journey from 2D to 3D strain



- Speckles can be followed in any direction
- Allows calculation of all 3D strain parameters from single volumetric data set (workflow + time saving)
- Avoids errors caused by heart rate variability between different 2D acquisitions

Reproducibility

- Intraobserver variability: 1% to 13%; Interobserver variability: 2% to 14%
- ***Temporal variability*** depends on acquisition, post processing, and hemodynamics
- Most important aspect is probably to achieve the optimal ***trade-off between temporal and spatial resolution***
- The biggest concern regarding the reproducibility of 3DSTE is related to ***vendor dependency*** ➔ should obtain the baseline and follow-up acquisitions and analyses from the same hardware and software equipment

Feasibility

- ***Much lower feasibility*** (63%-83%) vs. (80–97%) compared to 2DSTE *after* excluding patients with irregular rhythm and unable to perform adequate breath-hold
- Further limited by stringent technical requirements to maintain accuracy

Cardiovasc Diagn Ther 2018;8(1):101-117

The International Journal of Cardiovascular Imaging (2021) 37:1189–1201
https://doi.org/10.1007/s10554-020-02100-3

ORIGINAL PAPER

Left ventricular strain values using 3D speckle-tracking echocardiography in healthy adults aged 20 to 72 years

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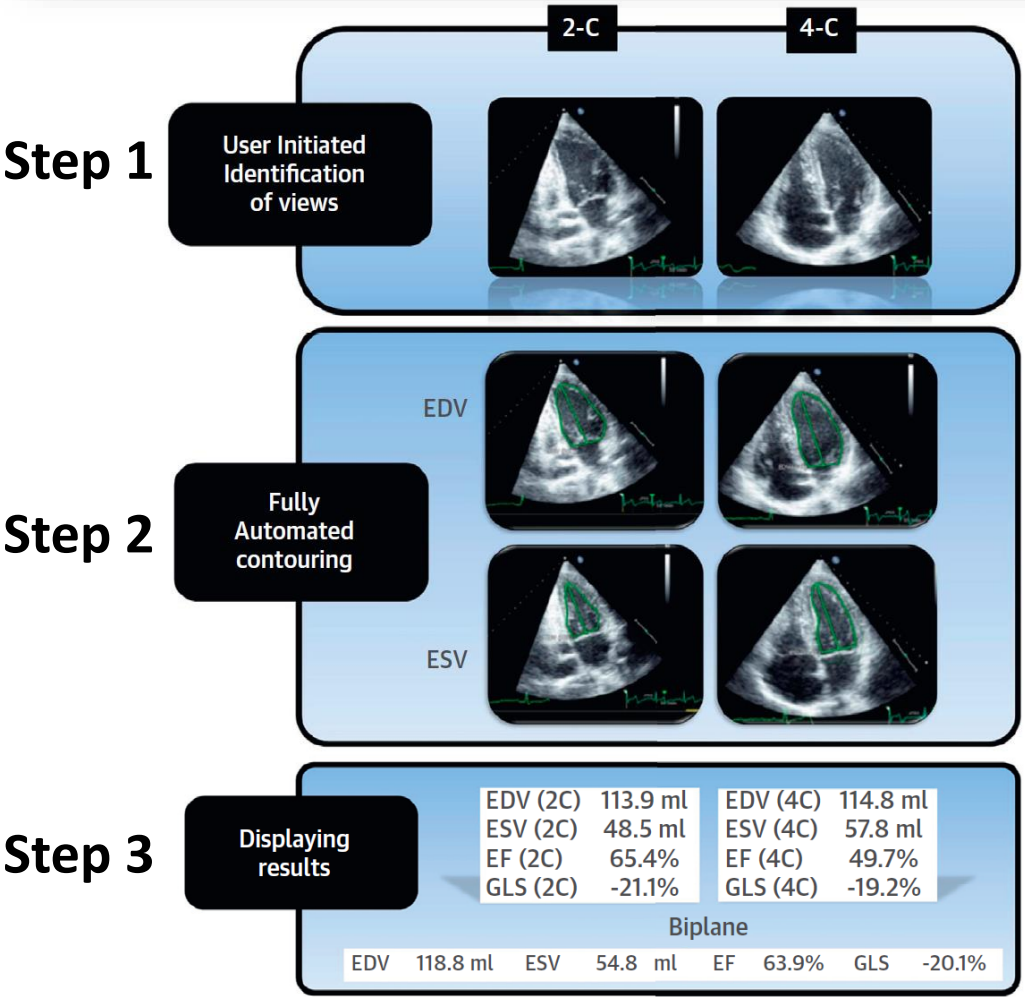
Received: 7 September 2020 / Accepted: 7 November 2020 / Published online: 23 November 2020

Feasibility of 3D-STE = 71% **???Applicability to higher (real-world) BMI???**

Characteristic	All patients	Patients in whom 3D and 2D-STE are both feasible		P
	(n = 147)	Yes (n = 105)	No (n = 42)	
Sex, female	74 (50.3%)	56 (50.9%)	18 (48.6%)	0.277
Age (years)	45 ± 14	44 ± 14	47 ± 14	0.140
Current smoker	13 (8.8%)	8 (7.6%)	5 (11.9%)	0.520
Physical examination				
Body mass index (kg/m^2)	24.4 ± 3.3	**23.9 ± 2.9**	**25.5 ± 3.9**	**0.008**
Body surface area (m^2)	1.89 ± 0.19	1.88 ± 0.19	1.93 ± 0.20	0.104

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

The FAST-EFs Multicenter Study



- Auto LV measurements were **feasible in 98% of studies**
- Average analysis time was **8 +/- 1 s/patient**
- Automated and manual LS measurements obtained at the reference center showed ***good agreement***
- Automated EF and LS had **no variability.**

J Am Coll Cardiol 2015;66:1456–66

Circulation

ORIGINAL RESEARCH ARTICLE

Fully Automated Echocardiogram Interpretation in Clinical Practice

Feasibility and Diagnostic Accuracy

Editorials, see p 1636 and p 1639

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BACKGROUND: Automated cardiac image interpretation has the potential to transform clinical practice in multiple ways, including enabling serial assessment of cardiac function by nonexperts in primary care and rural settings. We hypothesized that advances in computer vision could enable building a fully automated, scalable analysis pipeline for echocardiogram interpretation, including (1) view identification, (2) image segmentation, (3) quantification of structure and function, and (4) disease detection.

METHODS: Using 14 035 echocardiograms spanning a 10-year period, we trained and evaluated convolutional neural network models for multiple tasks, including automated identification of 23 viewpoints and segmentation of cardiac chambers across 5 common views. The segmentation output was used to quantify chamber volumes and left ventricular mass, determine ejection fraction, and facilitate automated determination of longitudinal strain through speckle tracking. Results were evaluated through comparison to manual segmentation and measurements from 8666 echocardiograms obtained during the routine clinical workflow. Finally, we developed models to detect 3 diseases: hypertrophic cardiomyopathy, cardiac amyloid, and pulmonary arterial hypertension.

RESULTS: Convolutional neural networks accurately identified views (eg, 96% for parasternal long axis), including flagging partially obscured cardiac chambers, and enabled the segmentation of individual cardiac chambers. The resulting cardiac structure measurements agreed with study report values (eg, median absolute deviations of 15% to 17% of observed values for left ventricular mass, left ventricular diastolic volume, and left atrial volume). In terms of function, we computed automated ejection fraction and longitudinal strain measurements (within 2 cohorts), which agreed with commercial software-derived values (for ejection fraction, median absolute deviation=9.7% of observed, N=6407 studies; for strain, median absolute deviation=7.5%, n=419, and 9.0%, n=110) and demonstrated applicability to serial monitoring of patients with breast cancer for trastuzumab cardiotoxicity. Overall, we found automated measurements to be comparable or superior to manual measurements across 11 internal consistency metrics (eg, the correlation of left atrial and ventricular volumes). Finally, we trained convolutional neural networks to detect hypertrophic cardiomyopathy, cardiac amyloidosis, and pulmonary arterial hypertension with C statistics of 0.93, 0.87, and 0.85, respectively.

CONCLUSIONS: Our pipeline lays the groundwork for using automated interpretation to support serial patient tracking and scalable analysis of millions of echocardiograms archived within healthcare systems.

Key Words: diagnosis ■ echocardiography ■ machine learning

Sources of Funding, see page 1635

https://www.ahajournals.org/journal/circ

Q1: What signal processing steps are required to transform a regular PW Doppler to a high-fidelity tissue Doppler signal?

A. Turn off high pass filter > decrease receiver gain > decrease scale > Turn on low pass filter

B. Turn on high pass filter > decrease receiver gain > decrease scale > Turn off low pass filter

C. Turn off high pass filter > increase receiver gain > increase scale > Turn on low pass filter

D. Turn on high pass filter > increase receiver gain > increase scale > Turn off low pass filter

Q2: Which of the following statements is most accurate regarding Tissue Doppler Imaging (TDI) and Speckle Tracking Echocardiography (STE)

A. Unlike pulsed wave TDI, 2D-color TDI measurements are not angle dependent and as such may yield higher velocities

B. Both STE and TDI methods allow for evaluation of longitudinal, circumferential, radial, and twist/torsional strain

C. It is conventional to report Eulerian strain but LaGrangian Strain rate

D. Both STE and TDI methods allow calculation of Strain, Strain Rate, Velocity, and Displacement

Q3: Regarding strain measurements by Speckle tracking echocardiography:

A. Lagrangian and Eulerian strain calculations start to diverge when values drop below 15%

B. Strain is first calculated as the spatial derivative of displacement, then strain rate is obtained as the temporal derivative of strain

C. Strain rate is first calculated by as the spatial derivative of velocity, then strain is obtained by temporal integration of strain rate

D. When making strain measurements, most processing software utilize the peak of the QRS complex as a marker of end diastole and the midpoint of the T wave as a marker of end systole

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