Systolic Function: It's Not Just EF Anymore

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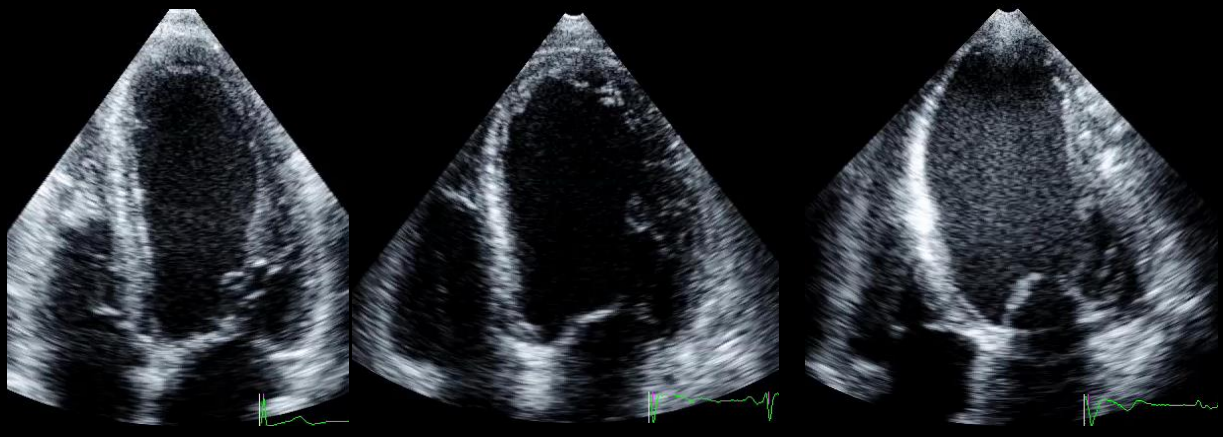
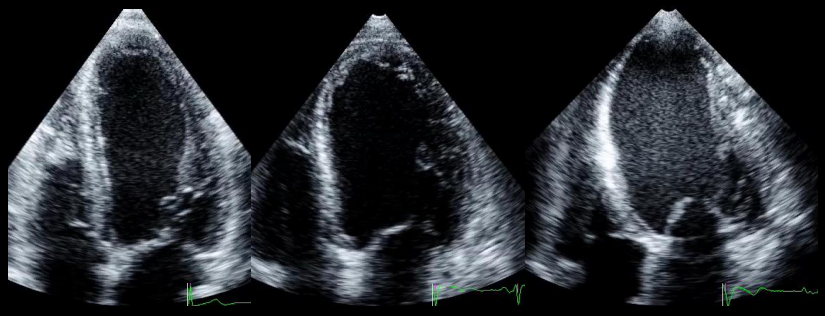
Which has the worse LV systolic function?

A **B** **C**



How Do We Assess LV Function?



Qualitative

- Wall Thickening
- Wall Shortening
- Symmetry of motion
- Excursion

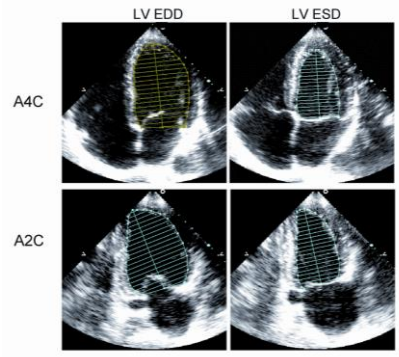
Limitations

- Subjective
- Experience dependent
- Lack of standardization
- Large inter- and intra-observer variability

ASE American Society of Echocardiography

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

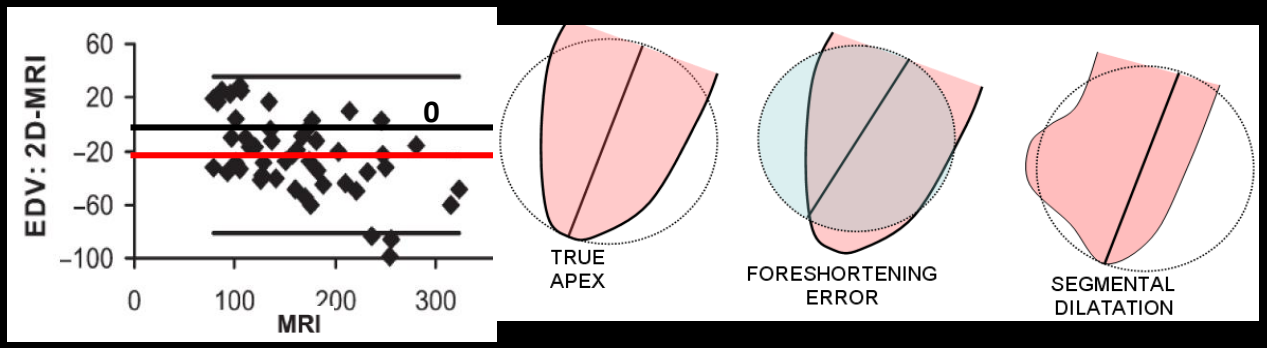
Roberto M. Lang, MD, FASE, FESC, Luigi P. Badano, MD, PhD, FESC, Victor Mor-Avi, PhD, FASE, Jonathan Afilalo, MD, MSc, Anderson Armstrong, MD, MSc, Laura Ernande, MD, PhD, Frank A. Flachskampf, MD, FESC, Elyse Foster, MD, FASE, Steven A. Goldstein, MD, Tatiana Kuznetsova, MD, PhD, Patrizio Lancellotti, 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*



J Am Soc Echocardiogr 2015;28:1-39

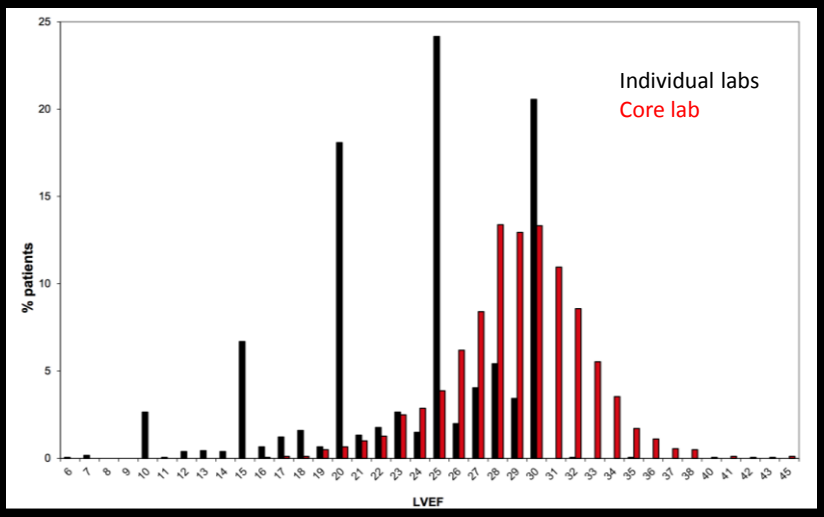
2D Echo LVEF Underestimates Compared to CMR

Left Ventricular Volume



Mor-Avi V et al. JACC: Cardiovascular Imaging 2012:8:769

2D LVEF has Poor Reproducibility



Kutyifa V. et al. JACC 2013:61:936-44

3DE LV Assessment is Recommended

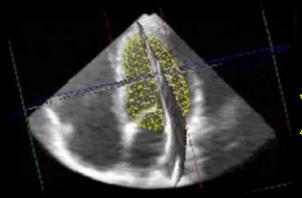
Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging

Recommendation. LV size should be routinely assessed on 2DE by calculating volumes using the biplane method of disks summation technique. In laboratories with experience in 3DE, 3D measurement and reporting of LV volumes is recommended when feasible depending on image quality. When reporting LV

J Am Soc Echocardiogr 2015;28:1-39

3DE LV Measurements Are More Accurate

3DE



MRI

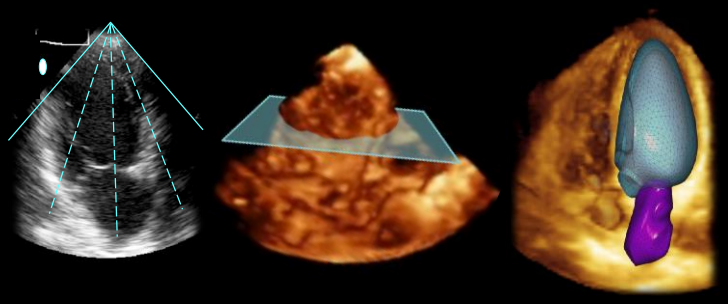
LV EDV
LV ESV

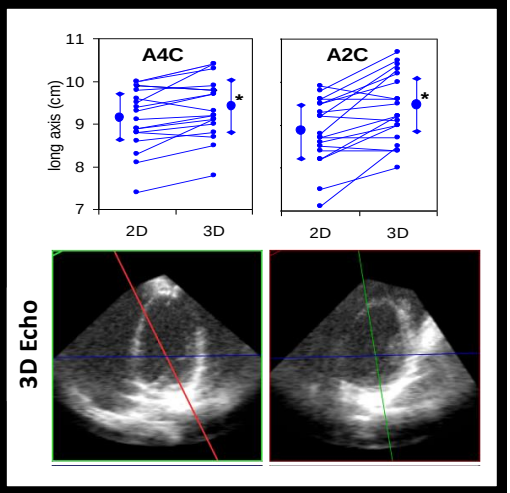
- Excellent correlation (r^2>0.85)
- Small biases
- Narrow limits of agreement

Ahmad M, et al. *JACC 2001; 37:1303-9*
Qin JX, et al. *JACC 2000; 36:900-7*
Arai K, et al. *AJC 2004; 94:552-8*
Jenkins C, et al. *JACC 2004; 44:878-86*
Kuhl HP, et al. *JACC 2004; 43:2083-90.*
Gutierrez-Chico JL, et al. *AJC 2005; 95:809-13*
Mor-Avi V, et al. JACC: CV Img 2012;5:769

Why is 3D more accurate?

Volumetric

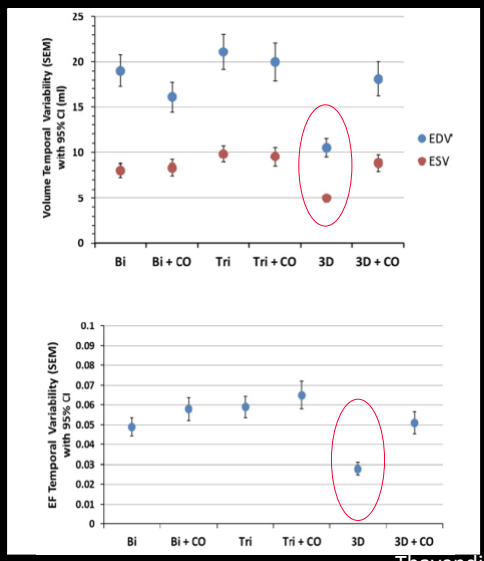




- No geometric assumptions
- No image foreshortening

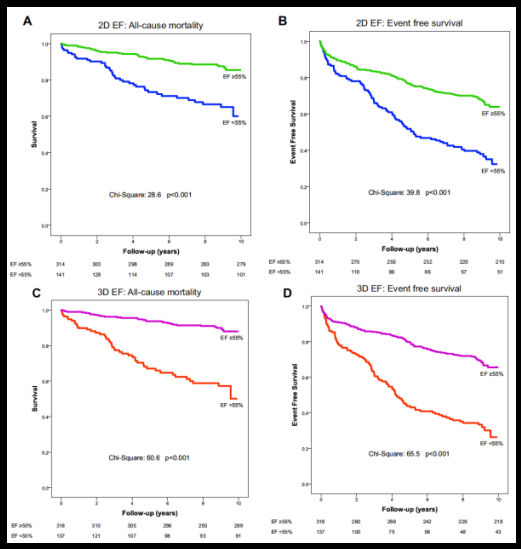
Mor-Avi V, et al. Circulation 2004. 110: 1814-1818.

3DE LV Variability



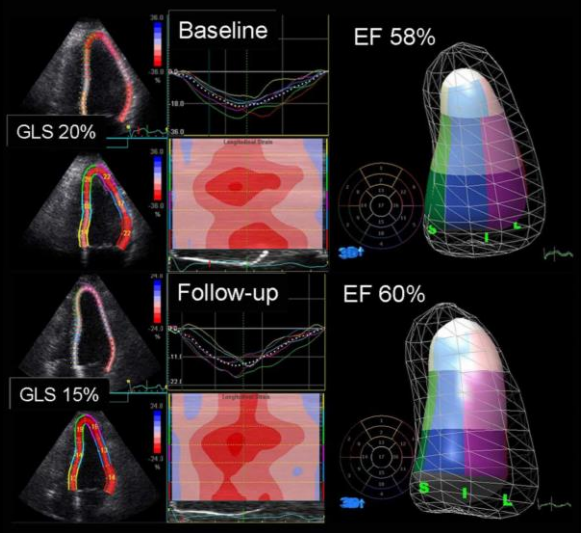
Thavendiranathan P. JACC. 2013

2DE vs 3DE and Outcomes



Stanton et al. JASE 2014;27:65-73

Why do we need something else?

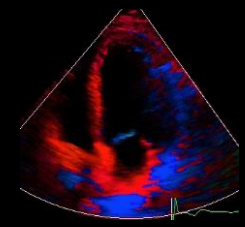


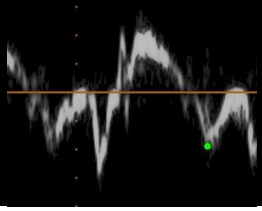
Marwick TH. *Heart* 2013;**99**:15 1078-1086

Deformation Imaging

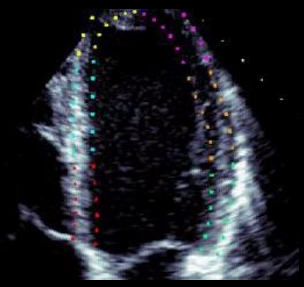
TISSUE DOPPLER

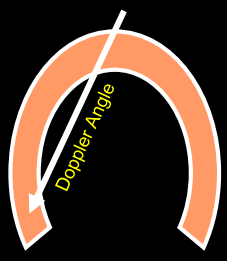
SPECKLE TRACKING

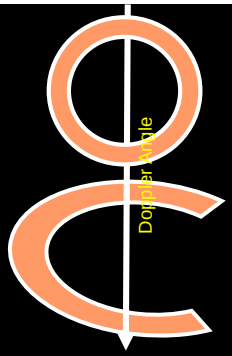


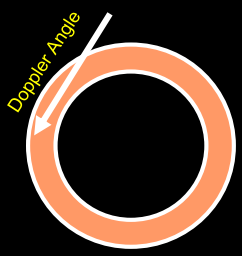


STRAIN





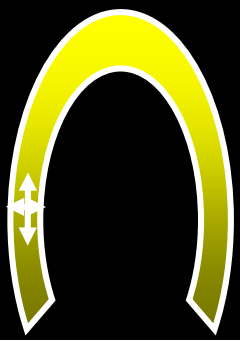




Longitudinal

Radial

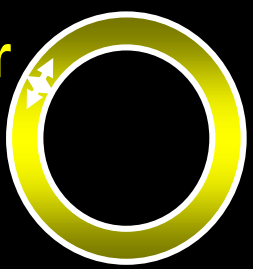
Circumferential

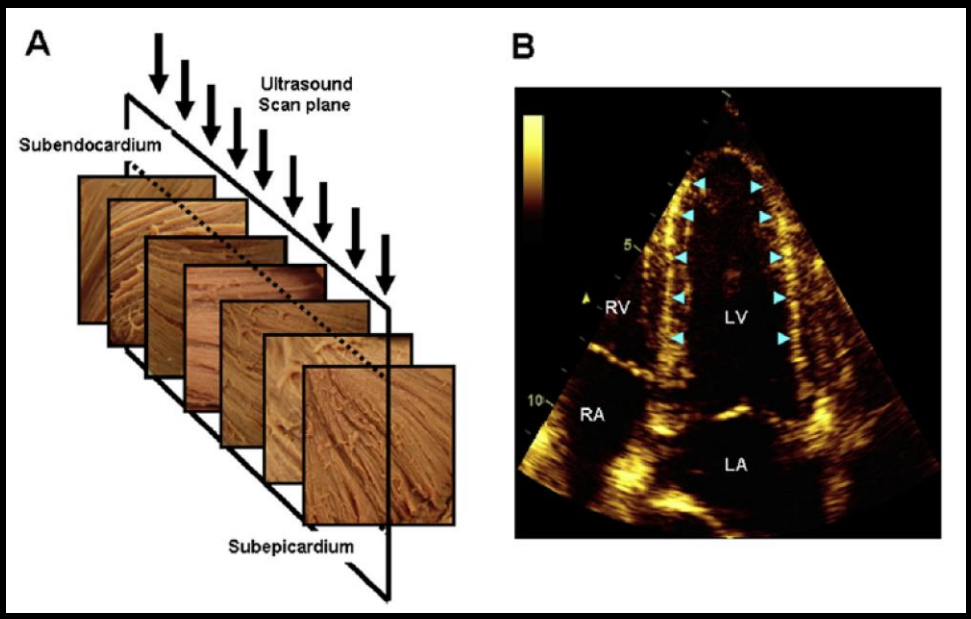


Tissue Doppler

Myocardial Speckle Displacement

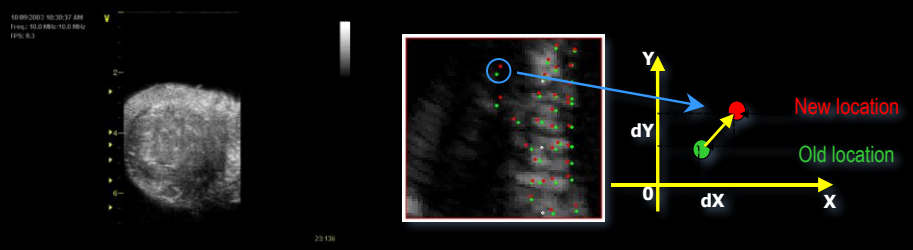
No Doppler Angle limitation !!



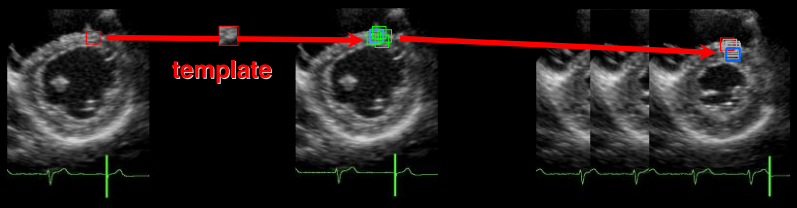


J Am Soc Echocardiogr 2011;24:277-313.

Speckle tracking strain



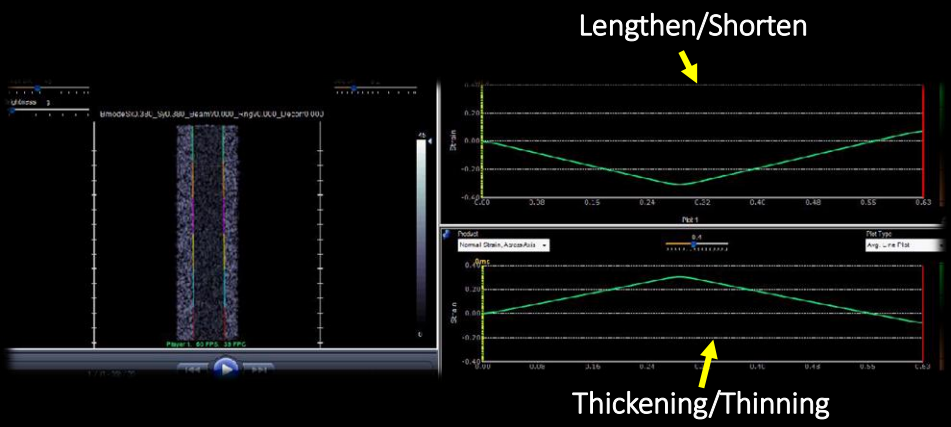
Sengupta PP, et al. JACC 2006;48:1988-2001



Courtesy of Toshiba Medical Systems

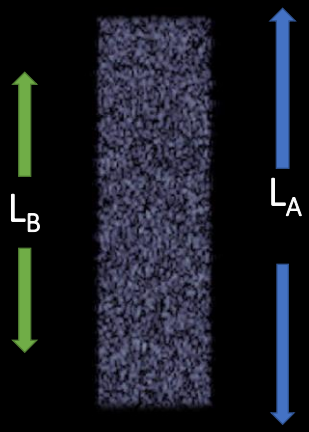
Speckle tracking strain

Strain imaging measures tissue deformation.



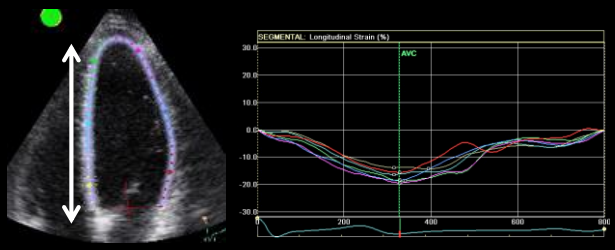
Speckle tracking strain

Strain is fractional change in length, area or volume.

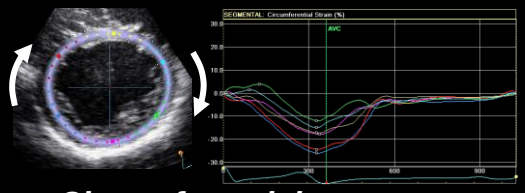


$$\text{Strain} = \frac{L_B - L_A}{L_A} = \frac{\Delta L}{L_A}$$

Principle Strains



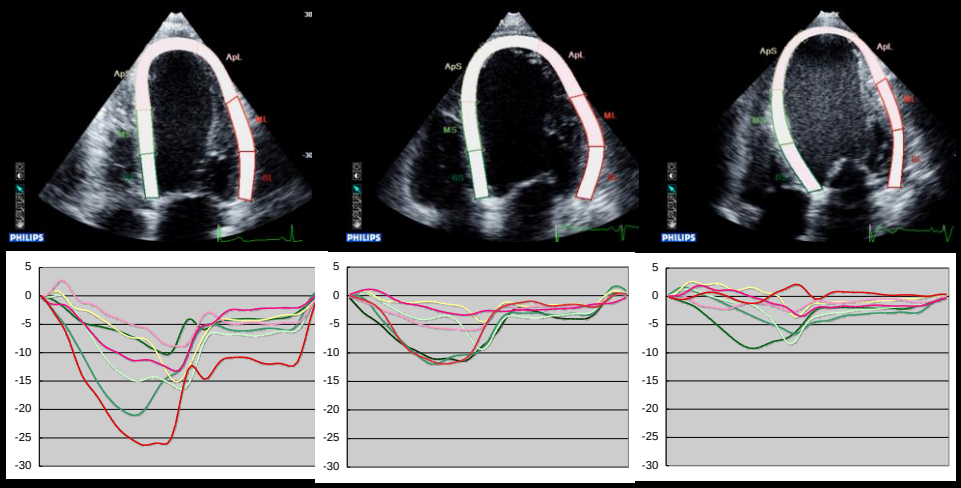
- ***Longitudinal – ε_L***
- Myocardial shortening from base to apex
- Negative value



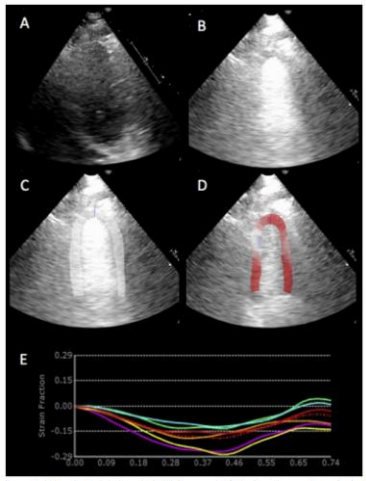
- ***Circumferential – ε_C***
- Intramural myocardial shortening
- Negative value

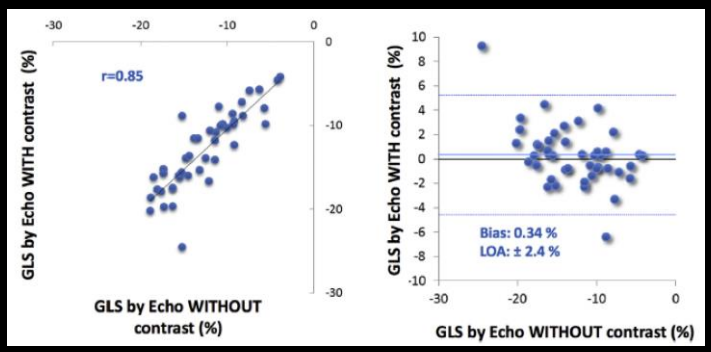
- ***Radial – ε_R***
- Myocardial wall thickening
- Positive value

2DSTE : Longitudinal Strain



Feasibility of Left Ventricular Global Longitudinal Strain Measurements from Contrast-Enhanced Echocardiographic Images





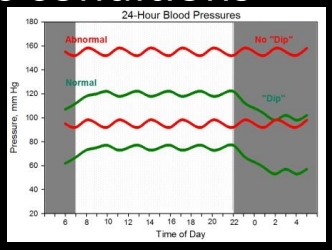
J Am Soc Echocardiogr 2017

Sources of Variation

1. Acquisition

- Frame rate (optimal ~60 frames/sec)
- Temporal vs spatial resolution with high frame rate

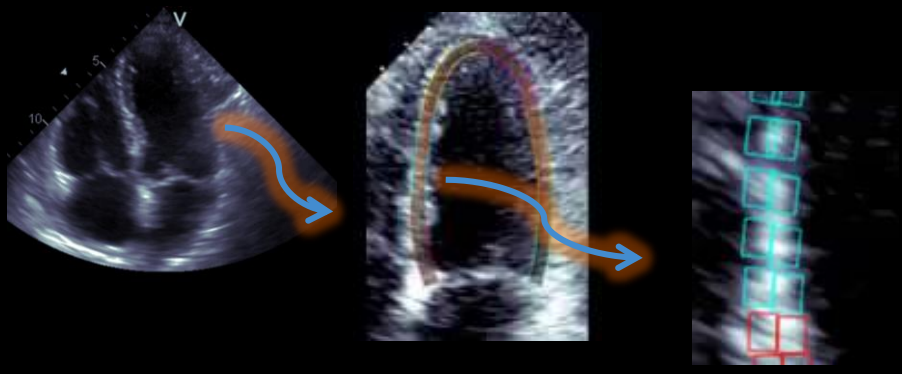
2. Physiologic conditions



- A 10 mmHg change in BP may have more effect than inter-vendor differences

J Am Soc Echocardiogr. 2013 Feb;26(2):185-91.
Image : http://blogs.scientificamerican.com

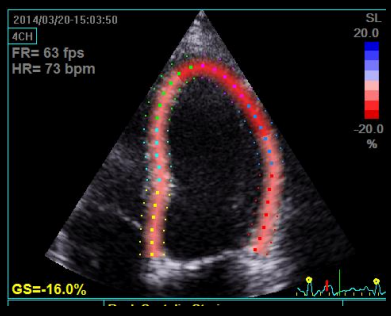
Sources of Variation
3. Post-processing



Algorithm
- Region of interest size
- Number of speckles tracked
- Endocardial, epicardial

Sources of Variation
3. Post-processing

GE- AFI

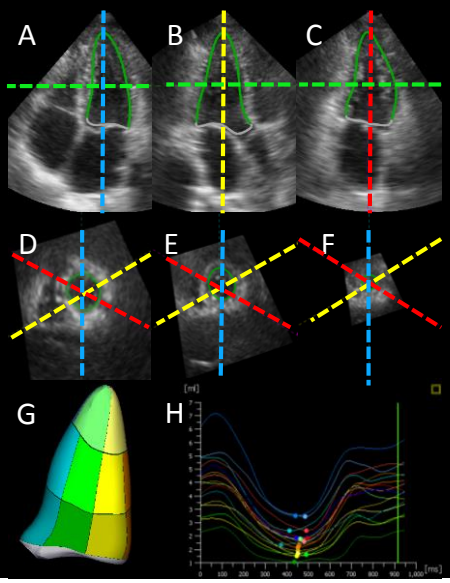


Siemens -VVI

Algorithm
- Contour assumptions
- Direction of contraction
- Smoothing

Sources of Variation
3. Post-processing

- Contour placement



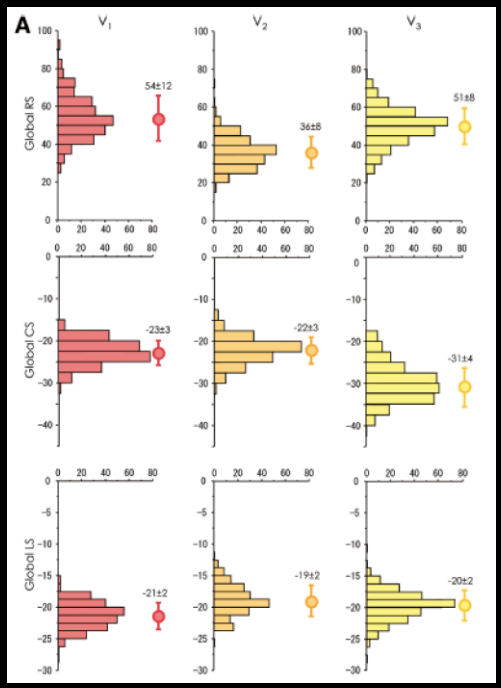
Tsang W, et al. JASE 2013;26:1253-7

Sources of Variation
3. Post-processing

- Lagrangian vs natural strain?
- What is peak global strain?
- Timing?
  - peak systolic, peak ES, peak cardiac cycle
- Measurement?
  - Average regional peak or average of all peaks

Sources of Variation

- Vendor Dependency



Takigiku, K. et al. Circ J 2012;76:2623

Call To Action: Speckle Validation

A Suggested Roadmap for Cardiovascular Ultrasound Research for the Future

within days. The development of standard characterization methods and specialized, well-characterized phantoms would provide an objective approach to estimate the limiting uncertainties of these echocardiographic image based measurements.

Courtesy: Scott Settlemeir

Kaul, S. et al. JASE 2011;24:455-64

LV Global Longitudinal Strain

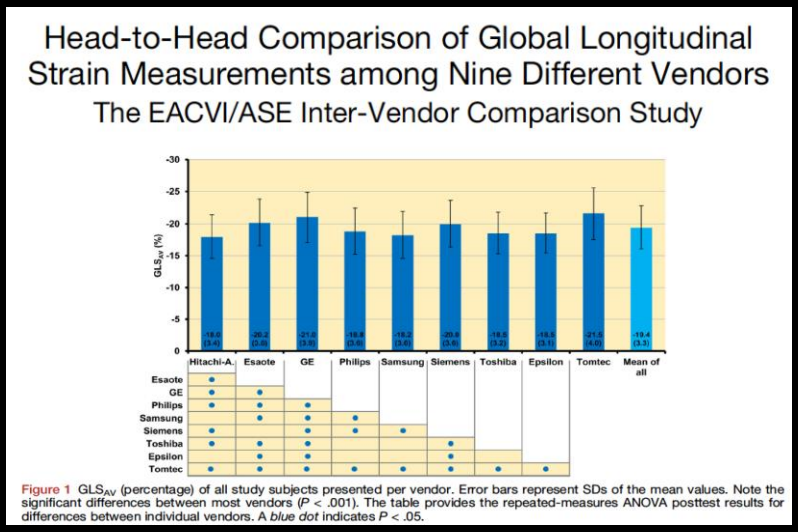
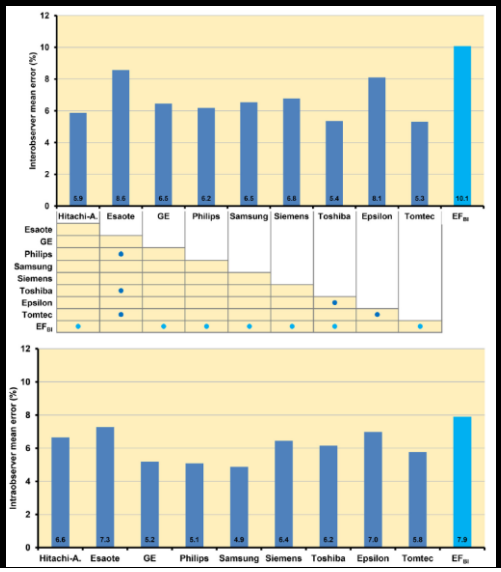


Figure 1 GLS_{AV} (percentage) of all study subjects presented per vendor. Error bars represent SDs of the mean values. Note the significant differences between most vendors ($P < .001$). The table provides the repeated-measures ANOVA posttest results for differences between individual vendors. A *blue dot* indicates $P < .05$.

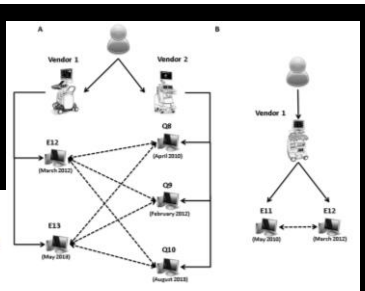
JASE 2015;28:1171-81

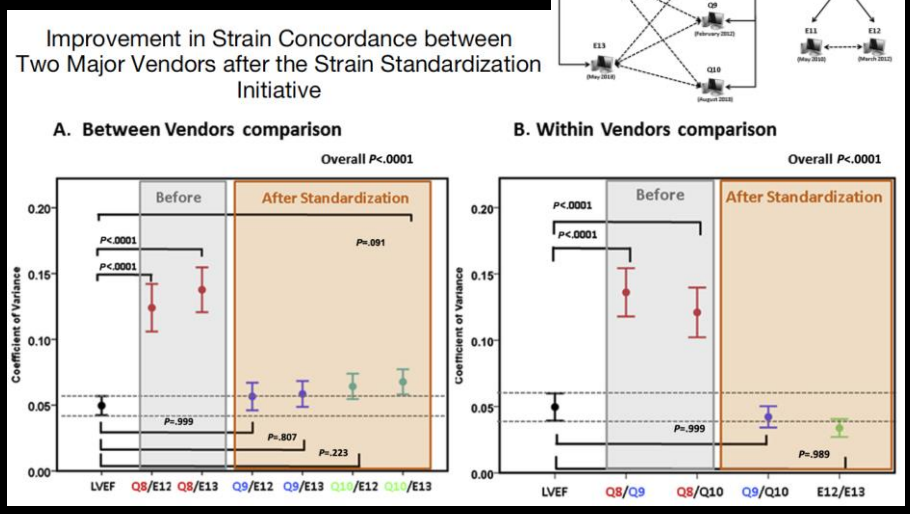
LV Global Longitudinal Strain



JASE 2015;28:1171-81

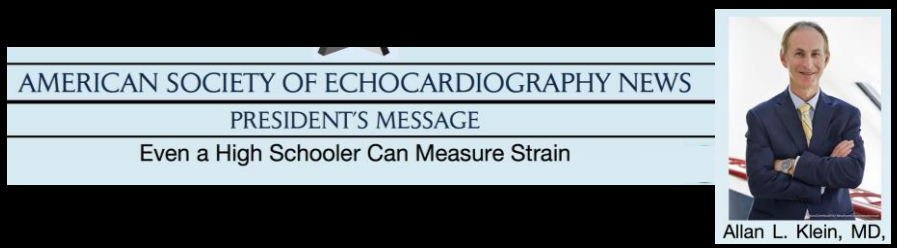
LV Global Longitudinal Strain





JASE 2015; 28:642-8

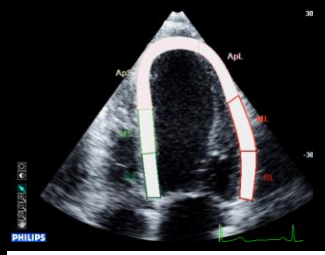
LV Global Longitudinal Strain

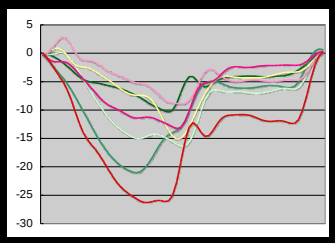


JASE 2016;21:A19-21

Regional Deformation

- Quantitative assessment of the magnitude of regional LV deformation is not recommended
  - lack of reference values
  - suboptimal reproducibility
  - considerable inter-vendor measurement variability





Reference Ranges and Regional Patterns of Left Ventricular Strain and Strain Rate Using Two-Dimensional Speckle-Tracking Echocardiography in a Healthy Middle-Aged Black and White Population: The CARDIA Study

	1. White women	2. African American women	3. White men	4. African American men	
	n = 243	*n* = 98	*n* = 142	*n* = 69	*P* < .05
Peak systolic strain (%)	Mean ± SD or median (interquartile range) [limits of normal]				
Longitudinal					
Four-chamber	−16.4 ± 2.2 [−20.8 to −12.0]	−15.9 ± 1.9 [−19.9 to −12.0]	−15.6 ± 2.0 [−19.7 to −11.5]	−14.7 ± 2.2 [−19.1 to −10.3]	1 vs 3, 1 vs 4, 2 vs 4, 3 vs 4
Two-chamber	−17.3 ± 2.3 [−22.0 to −12.6]	−16.7 ± 2.1 [−21.0 to −12.5]	−16.5 ± 2.2 [−21.0 to −11.9]	−14.9 ± 1.8 [−18.7 to −11.1]	1 vs 3, 1 vs 4, 2 vs 4, 3 vs 4
Combined	−17.0 ± 2.0 [−21.0 to −15.0]	−16.5 ± 1.8 [−20.1 to −12.9]	−16.1 ± 1.8 [−19.7 to −12.5]	−14.8 ± 1.9 [18.6 to 11.0]	1 vs 3, 1 vs 4, 2 vs 4, 3 vs 4
Circumferential	−16.2 ± 2.6 [−21.4 to −10.9]	−15.9 ± 2.7 [−21.4 to −10.4]	−15.4 ± 2.3 [−20.0 to −10.7]	−14.7 ± 2.6 [−20.0 to −9.5]	1 vs 3, 1 vs 4, 2 vs 4
Radial	35.5 ± 11.3 [12.8–58.2]	38.4 ± 10.5 [17.2–59.6]	37.6 ± 10.3 [16.8–58.3]	36.0 ± 10.4 [15.1–56.8]	—

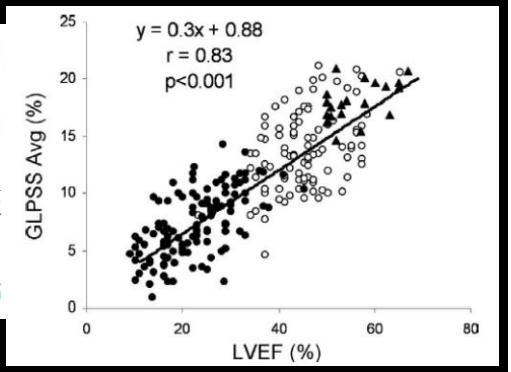
- Sex and race differences

J Am Soc Echocardiogr 2017;30:647-58

Relation Between Global Left Ventricular Longitudinal Strain Assessed with Novel Automated Function Imaging and Biplane Left Ventricular Ejection Fraction in Patients with Coronary Artery Disease

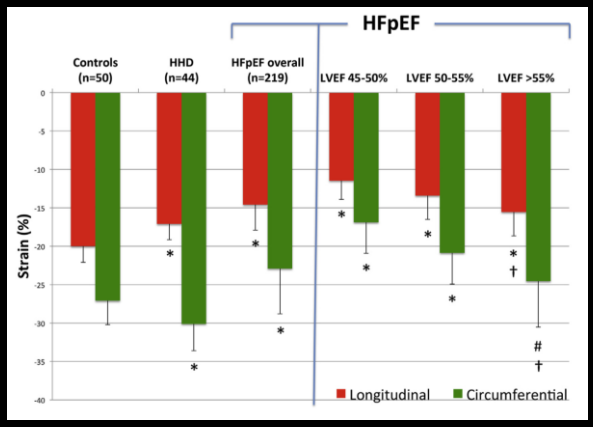
	Overall (n = 242)	Controls (n = 20)	STEMI (n = 99)	Heart failure (n = 123)	*P* value
Left ventricular end-systolic volume (mL)	118 ± 75	36 ± 12	68 ± 21	173 ± 68	<.0001
Left ventricular end-diastolic volume (mL)	175 ± 80	86 ± 22	128 ± 34	226 ± 78	<.0001
LVEF (%)	37 ± 14	58 ± 6	47 ± 7	24 ± 7	<.0001
GLPSS Avg (%)	11.1 ± 4.8	18.3 ± 1.7	14.0 ± 3.4	7.6 ± 3.0	<.0001

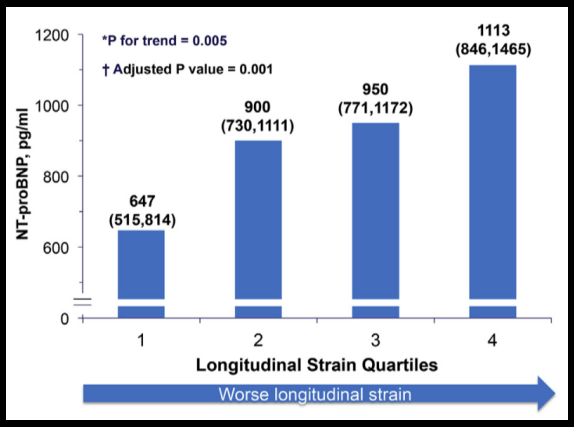
GLPSS Avg, Averaged global longitudinal peak systolic strain; *LVEF*, left ventricular ejection fraction; *STEMI*, ST-segment elevation myocardial infarction.



J Am Soc Echocardiogr 2008;21:1244-1250.

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





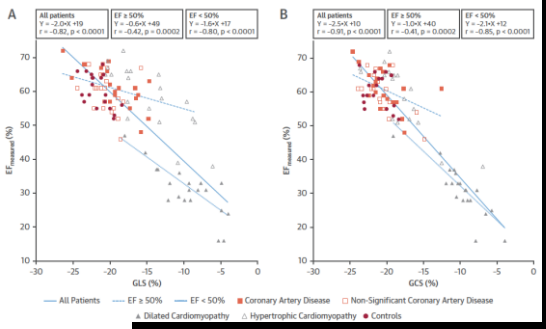
J Am Coll Cardiol 2014;63:447–56

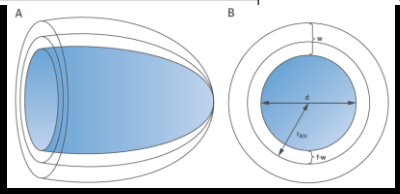
Geometry as a Confounder When Assessing Ventricular Systolic Function

Comparison Between Ejection Fraction and Strain

TABLE 1 Characteristics of the 5 Subject Groups

	CAD (n = 20)	nsCAD (n = 20)	DCM (n = 20)	HCM (n = 20)	Control (n = 20)	Total (N = 100)
Age, yrs	63 ± 7	59 ± 10	51 ± 20	40 ± 15	35 ± 11	50 ± 17
Male	13 (65)	10 (50)	13 (65)	16 (80)	15 (75)	67 (67)
BMI, kg/m^2	27 ± 3	26 ± 3	25 ± 4	25 ± 3	22 ± 2	25 ± 3
Heart rate, beats/min	64 ± 8	67 ± 12	69 ± 15	63 ± 12	62 ± 12	65 ± 12
SBP, mm Hg	146 ± 18	132 ± 17	110 ± 24	125 ± 24	129 ± 16	129 ± 23
DBP, mm Hg	77 ± 12	77 ± 12	64 ± 12	76 ± 10	79 ± 9	74 ± 12

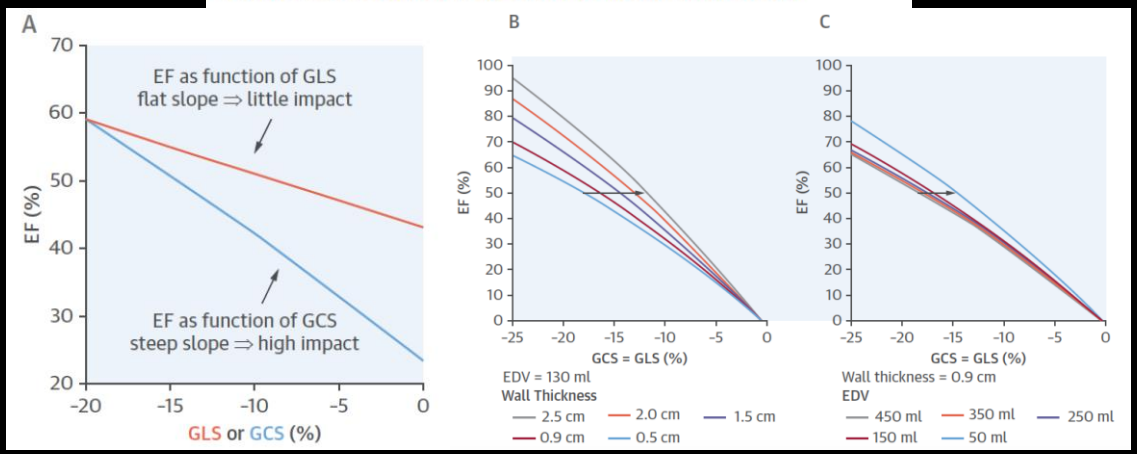




Stokke, T.M. et al. J Am Coll Cardiol. 2017;70(8):942–54.

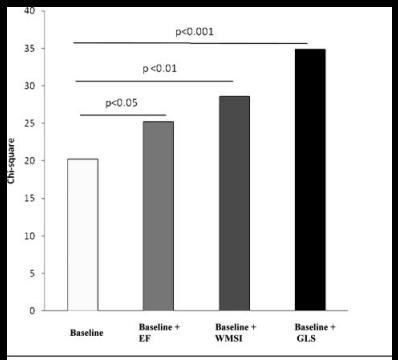
Geometry as a Confounder When Assessing Ventricular Systolic Function

Comparison Between Ejection Fraction and Strain



Stokke, T.M. et al. J Am Coll Cardiol. 2017;70(8):942–54.

GLS and Outcomes

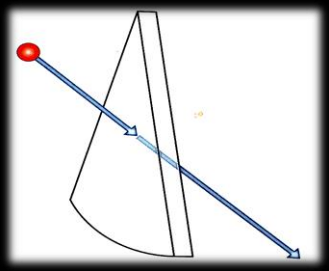


	HR	*p*	HR	*p*	HR	*p*	HR	*p*
Age	1.46	<0.001						
Diabetes	1.66	0.02						
Hypertension	1.39	0.14						
EF			1.23	<0.05				
WMSI					1.28	<0.01		
GLS							1.45	<0.001

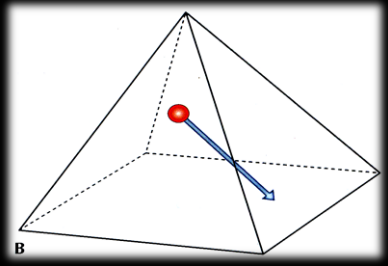
EF = ejection fraction, WMSI = wall motion score index, GLS = global longitudinal strain

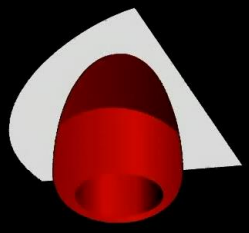
Circ Cardiovasc Imaging 2009;2;356-36

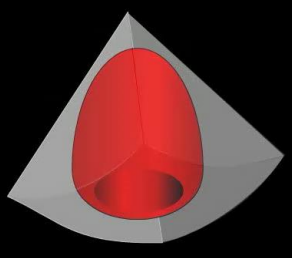
2D



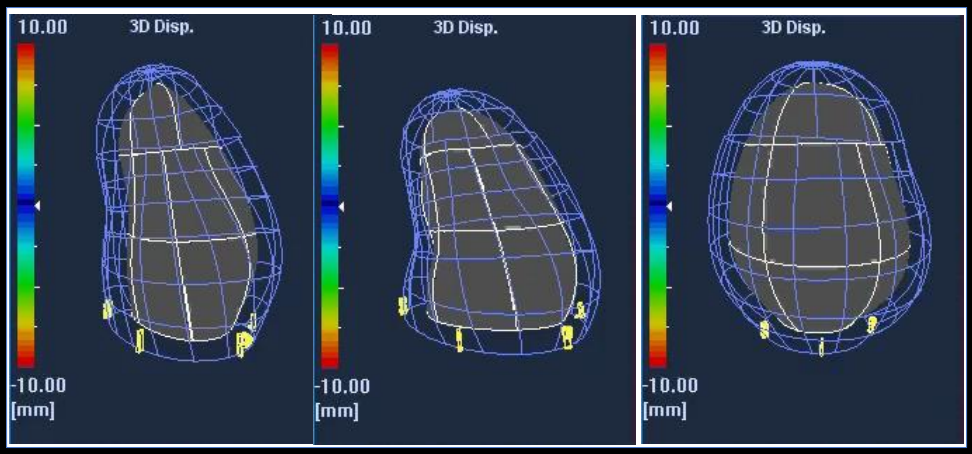
3D





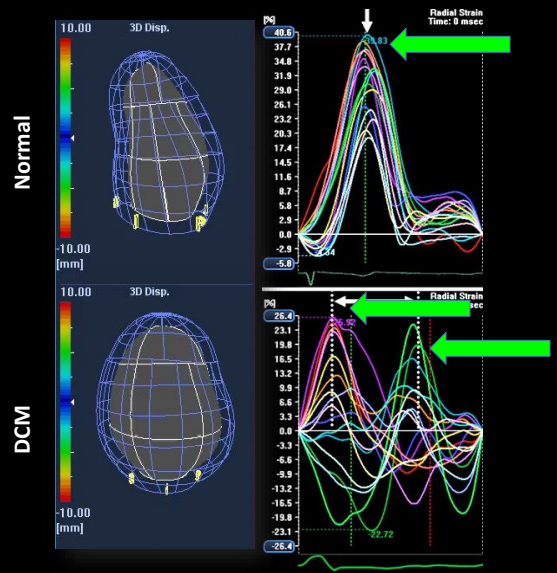


3D Speckle Tracking



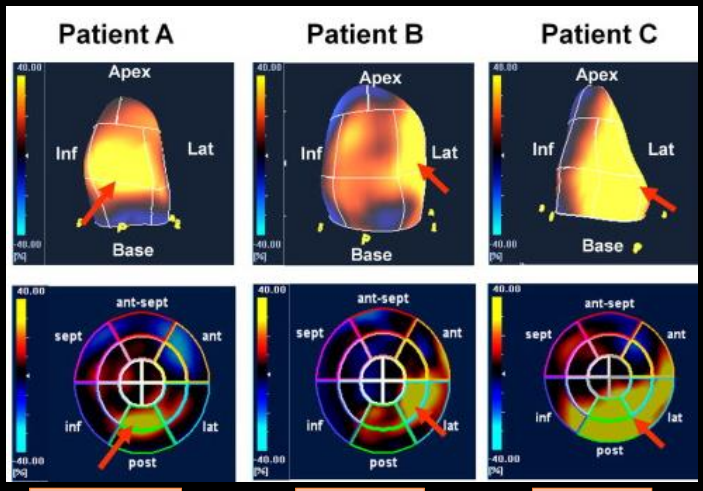
Normal **RWMA** **DCM**

3D Speckle Tracking



(Gorcsan J., *J Am Coll Cardiol* 2011;58:1401–13)

Color-Coded 3D Speckle Tracking Radial Strain Maps From 3 Different Heart Patients With LBBB

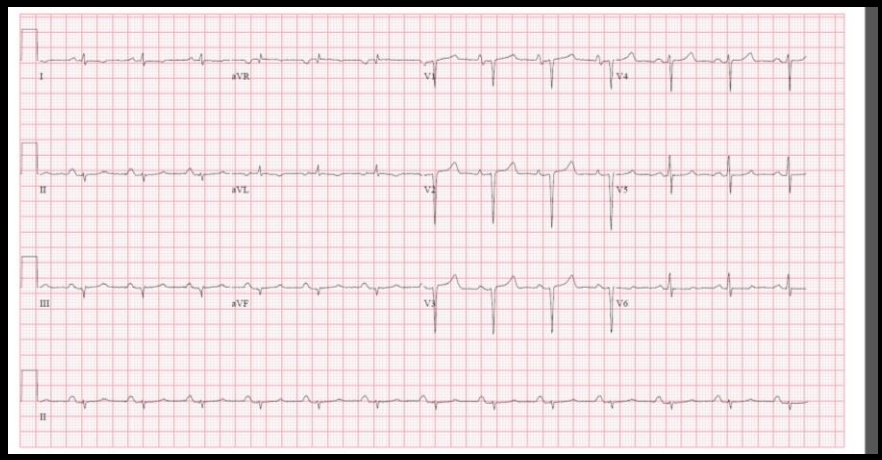


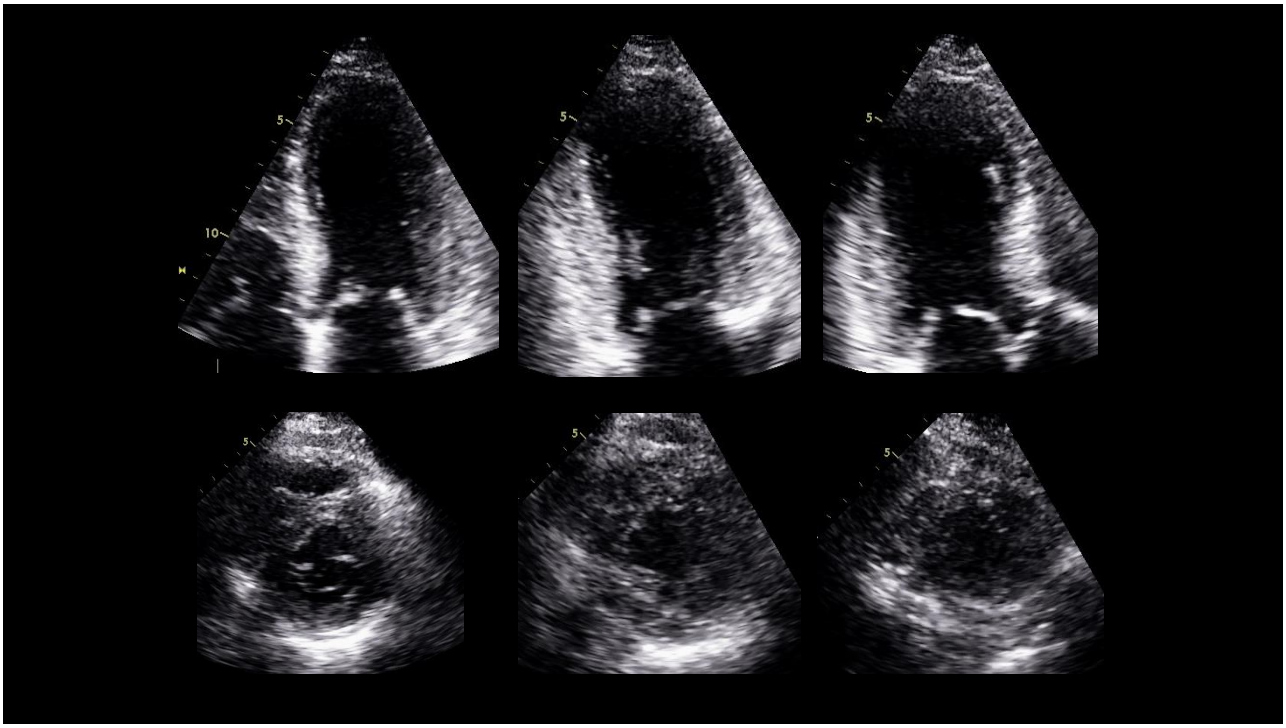
(J Am Coll Cardiol 2011;58:1401–13)

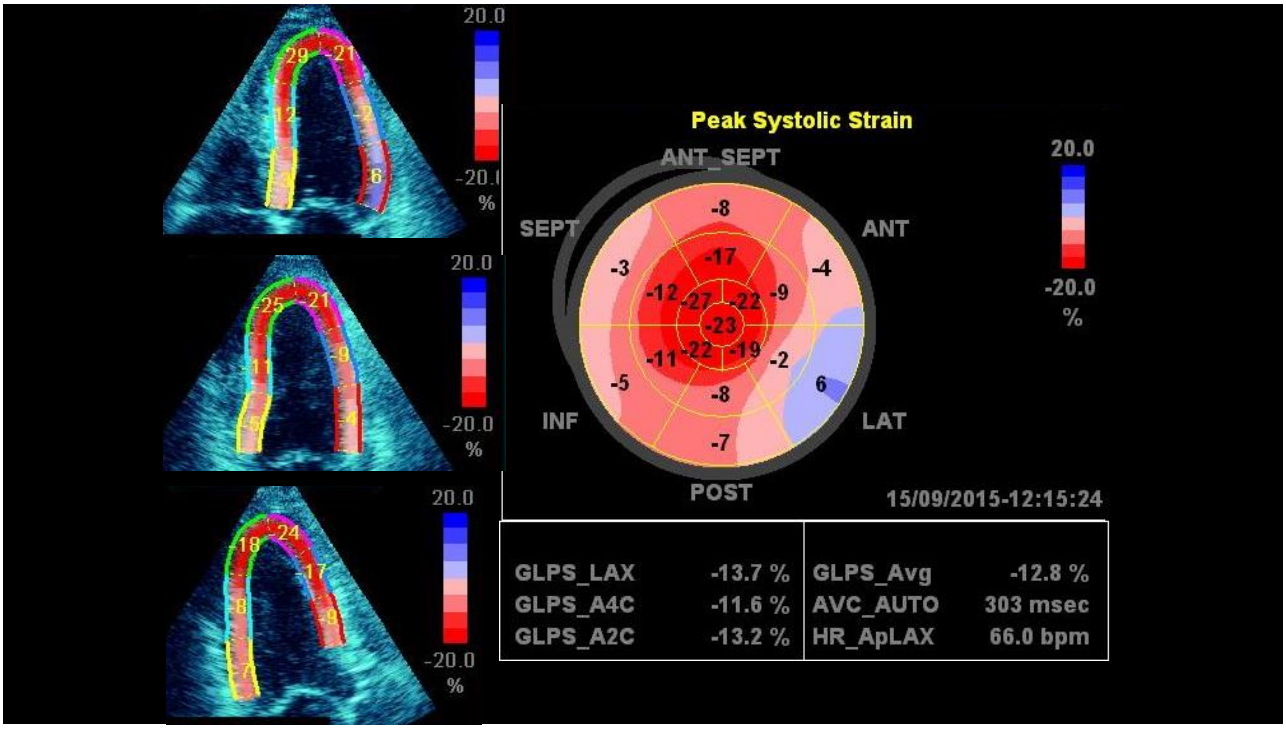
Case CA1

- Presented in 2012 to the heart failure clinic
- 58 y.o. M with progressive shortness of breath and exertional chest pain
- PMHx: HTN, atrial flutter
- Fam Hx: lymphoma in both parents and 1 sibling
- Cardiac catheterization: normal coronaries

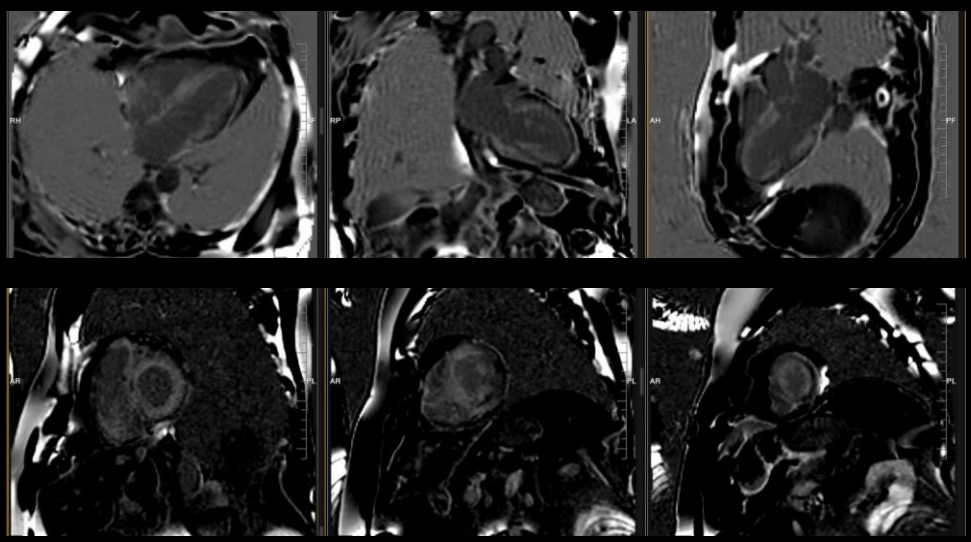
Case CA1






20.0
-20.0
%
Peak Systolic Strain
ANT_SEPT
SEPT
ANT
INF
LAT
POST
-8
-17
-3
-4
-12
-27
-22
-9
-23
-11
-22
-19
-2
-5
-8
6
-7
15/09/2015-12:15:24
GLPS_LAX -13.7 %
GLPS_A4C -11.6 %
GLPS_A2C -13.2 %
GLPS_Avg -12.8 %
AVC_AUTO 303 msec
HR_ApLAX 66.0 bpm

Case CA1



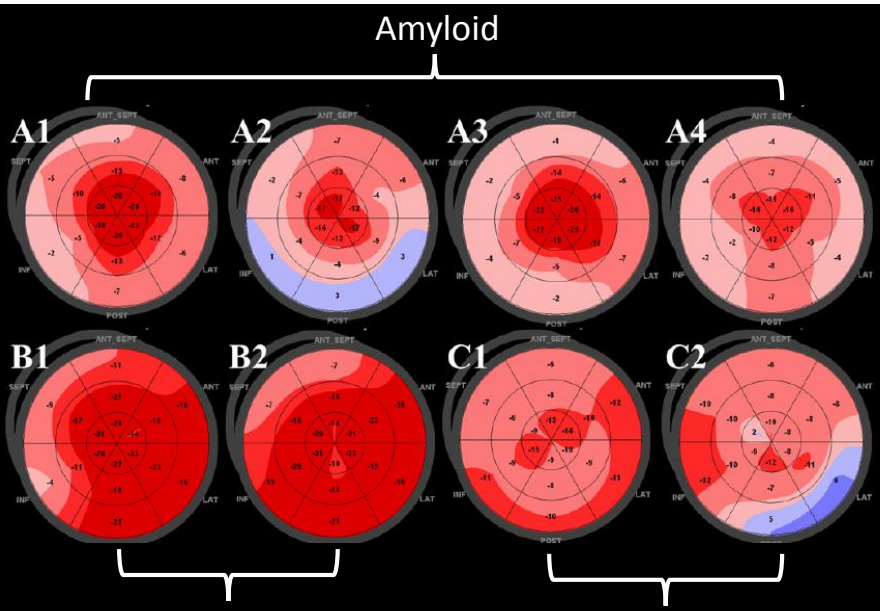
Case CA1

- Serum protein electrophoresis
  - IgG lamda paraprotein
- Bone marrow aspiration and biopsy
  - Plasma cell aggregate which stands for lamda chains
- Cardiac biopsy
  - Positive for amyloid

→ Amyloidosis with plasma cell dyscrasia.

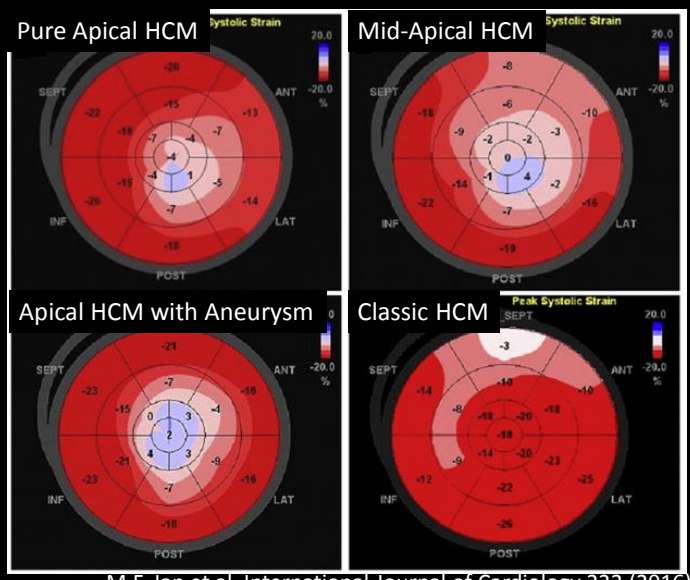
→ Cardiac and renal involvement.

- Started on chemotherapy



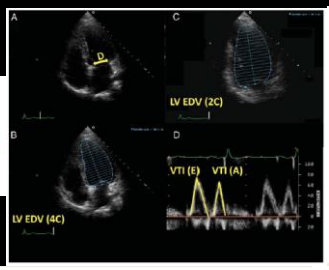
Phelan et al. Heart 2012;98:1442-1448.

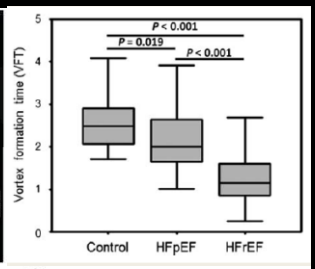
Strain

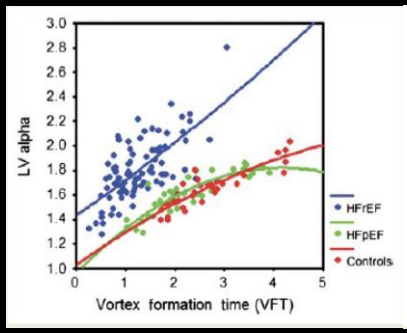


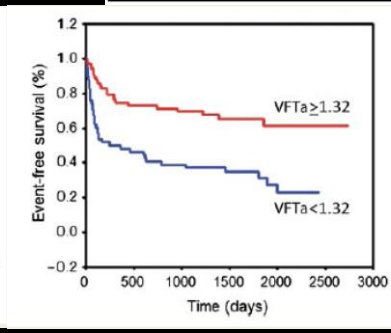
M.F. Jan et al. International Journal of Cardiology 222 (2016) 745–759

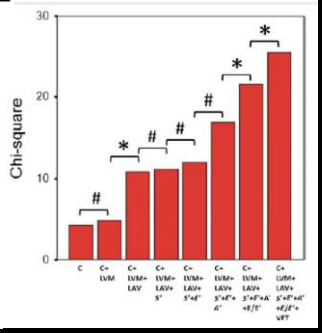
Left ventricular fluid dynamics in heart failure: echocardiographic measurement and utilities of vortex formation time







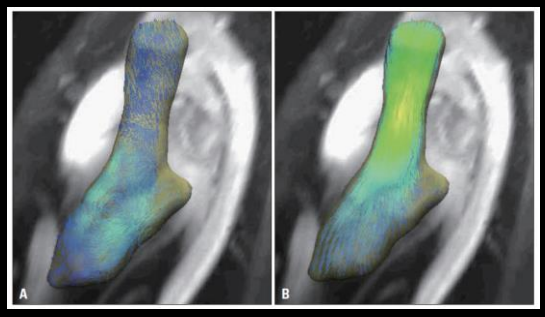




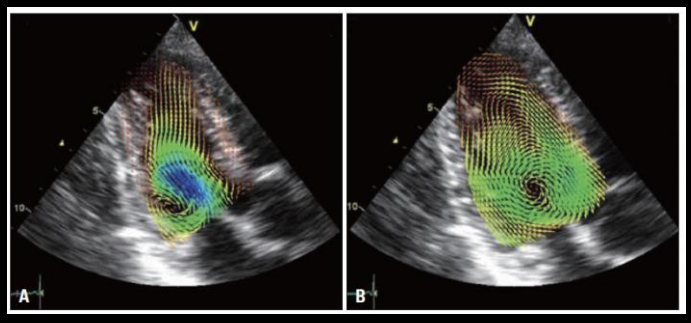
European Heart Journal – Cardiovascular Imaging (2012) 13, 385–393

Vortex Imaging

MRI

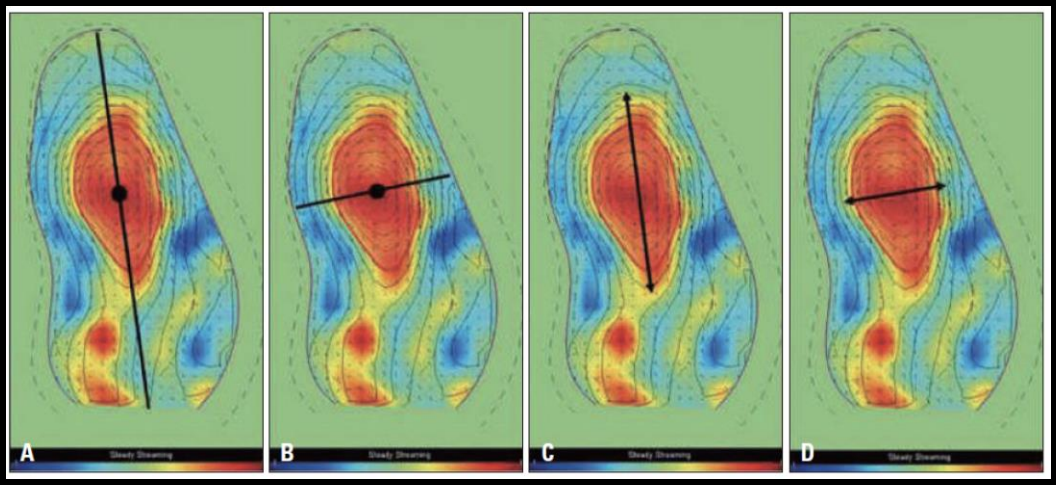


Echo

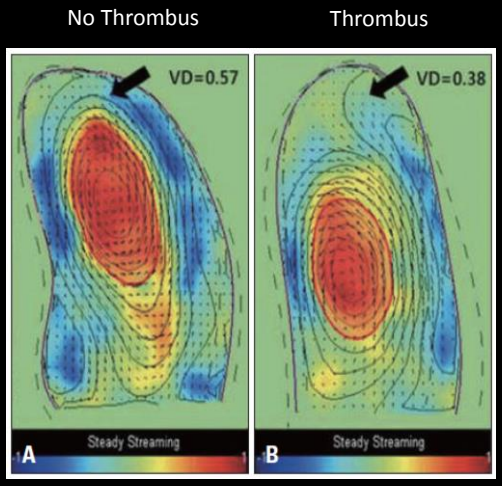


Vortex Imaging

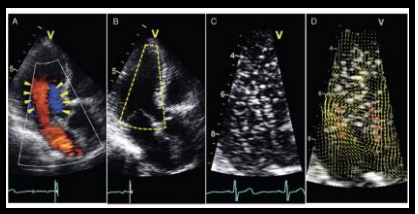
Vortex Depth | Vortex Transverse Position | Vortex Length | Vortex Width

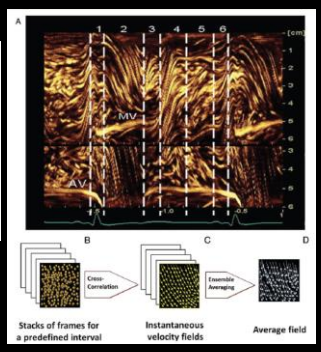


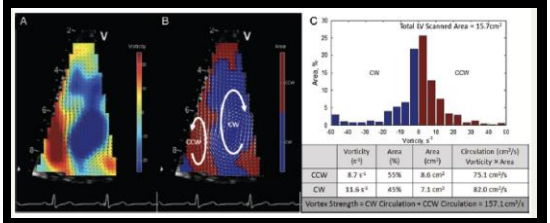
Vortex Imaging – steady streaming field



Contrast echocardiography for assessing left ventricular vortex strength in heart failure: a prospective cohort study

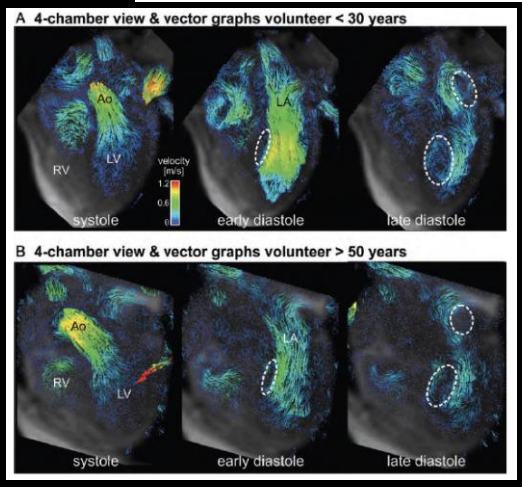


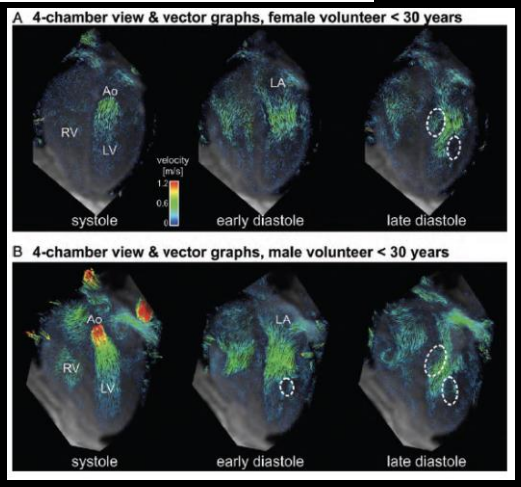




European Heart Journal – Cardiovascular Imaging (2013) 14, 1049–1060

Age, gender, blood pressure, and ventricular geometry influence normal 3D blood flow characteristics in the left heart

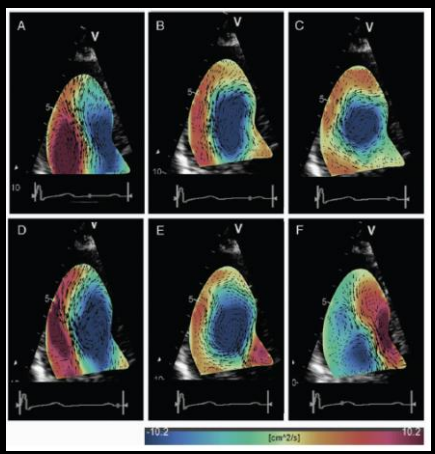




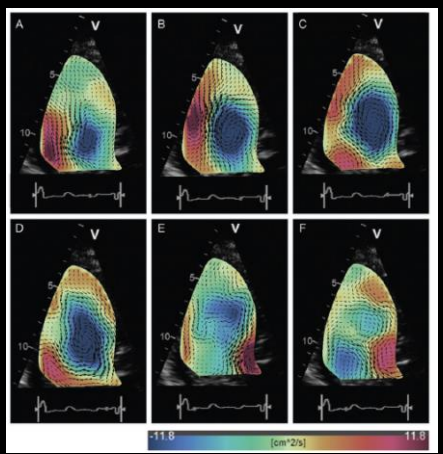
European Heart Journal – Cardiovascular Imaging (2013) 14, 366–373

Contrast echocardiography for assessing left ventricular vortex strength in heart failure: a prospective cohort study

Normal



HFrEF



European Heart Journal – Cardiovascular Imaging (2013) 14, 1049–1060

Summary

- 3D LVEF is more accurate and reproducible than 2D LVEF
- However, LVEF is relatively insensitive to myocardial changes
- Strain is used to identify myocardial changes
- Strain is related to LVEF
- However, LVEF and strain measure different components of systolic ventricular function
- Vortex imaging allows measurement of intraventricular flow and is a promising new technique for assessment of ventricular function

Thank you for listening