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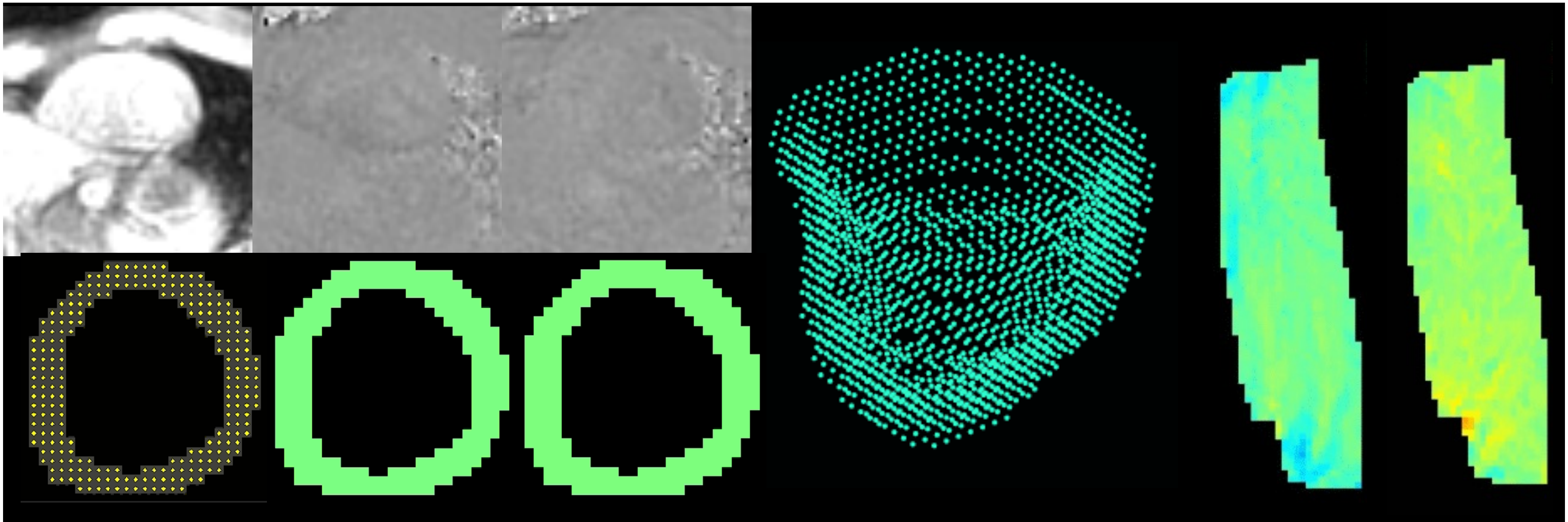
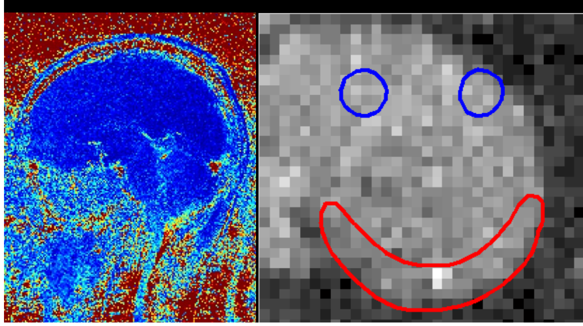




Basics of Strain Imaging

Xiaodong Zhong, PhD
Department of Radiological Sciences, UCLA

Outline

- Strain Imaging
- 2D MR Strain Imaging
- Example Applications
- One Step Further: Multi-Dimensional MR Strain imaging

*** Only a brief overview of strain imaging**

Outline

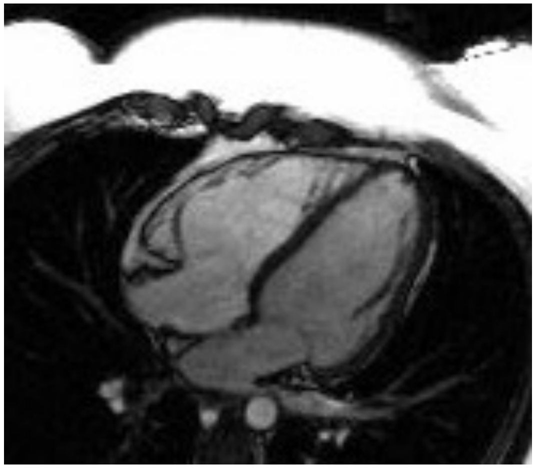
- Strain Imaging
- 2D MR Strain Imaging
- Example Applications
- One Step Further: Multi-Dimensional MR Strain imaging

Cine Imaging
For Cardiac Function and Myocardial Contractility Assessment

- Workhorse in cardiovascular MRI

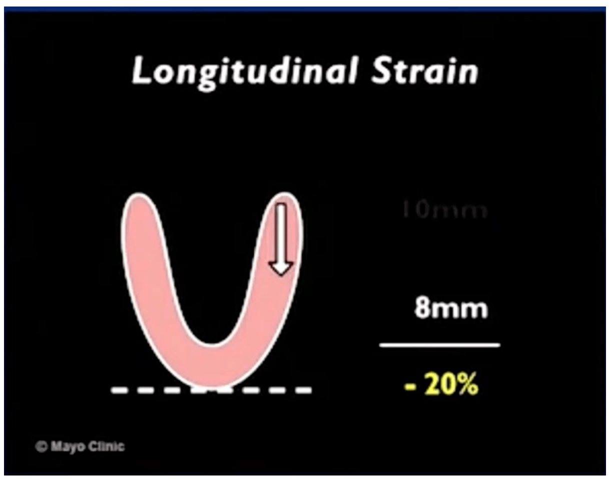
- Cardiac ejection fraction (EF):
  Global assessment of cardiac function
  - Inter-observer variability
  - No regional assessment

- Visual estimation of wall motion abnormalities:
  Regional assessment of myocardial contractility
  - Inter-observer variability
  - Imprecise, especially with isolated segments

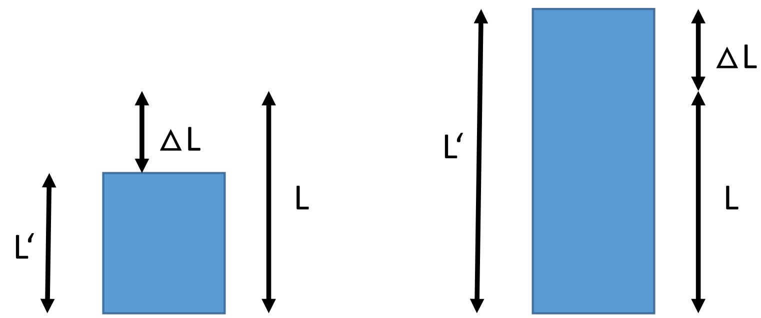


Strain Imaging
Tissue Deformation / Mechanics

- Strain is just tissue deformation (% or unitless decimal): $Strain\ (E) = \frac{\Delta L}{L}$



* Video courtesy of Jamil Aboulhosn, MD.



$\Delta L < 0$
$E < 0$
Tissue shortening

$\Delta L > 0$
$E > 0$
Tissue stretching

$\Delta L = L' - L$

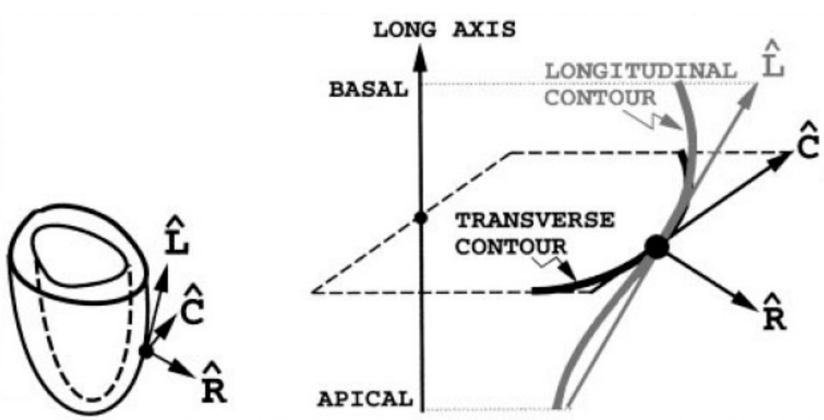
- More than just strain
  - Comprehensive tissue mechanics can be extracted in strain related data
  - Analogous to fluid mechanics measured by flow imaging[1-3]

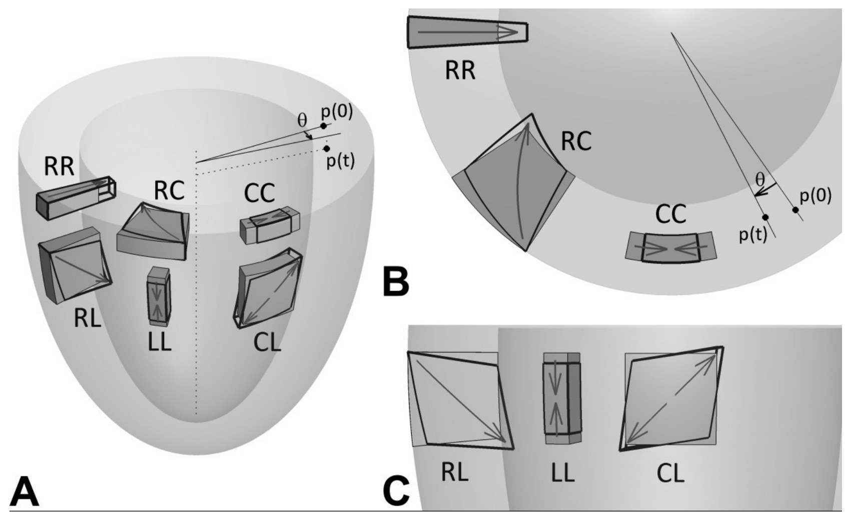
1. Oshinski et al. JMRI 1995;5:640-647.
2. Oyre et al. MRM 1998;40:645-655.
3. Petersson et al. JMRI 2012;36:128.-13.

Strain Imaging
Types of LV Strain

- Normal strains
  - Radial strain (Err)
  - Circumferential strain (Ecc)
  - Longitudinal strain (Ell)

- Shear strains
  - Radial-circumferential shear strain (Erc)
  - Radial-longitudinal shear strain (Erl)
  - Circumferential-longitudinal shear strain (Ecl)

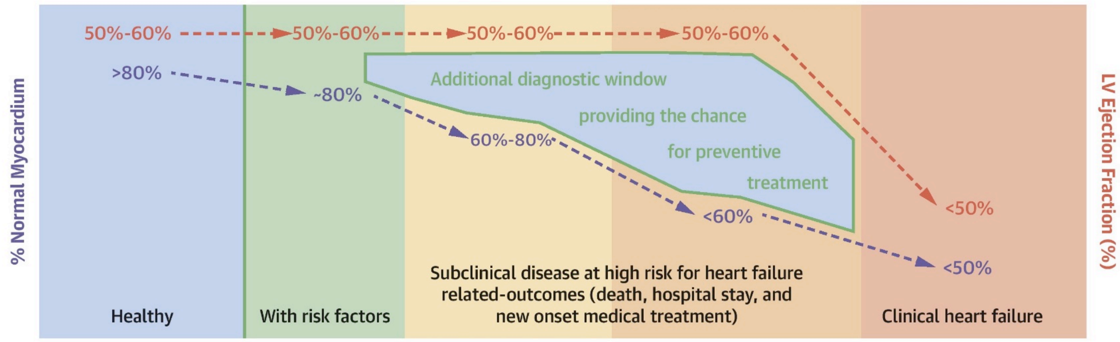




1. Moore et al. Radiology 2000;214:453-466. 2. Zhong et al. JCMR 2011;13:83.

Strain Imaging
Cardiac Function and Myocardial Contractility Assessment

- Cardiac strain imaging
  - Measure myocardial deformation through the cardiac cycle
  - Assess both global and regional myocardial contractility
  - More objective and quantitative than visual estimation of regional wall motion abnormality
  - Often more sensitive than EF, especially in early detection of disease states[4-12]



- **Strain identified patients with subclinical LV dysfunction compared to LVEF**
- **Strain imaging provided additional diagnostic window for prevention treatments**

Based on 1,169 heart failure patients and 61 healthy volunteers between September 2017 and February 2019 in Germany.
Korosoglou et al. JACC Cardiovasc Imaging 2021;14:1177-1188.

1. Oshinski et al. JMRI 1995;5:640-647.
2. Oyre et al. MRM 1998;40:645-655.
3. Petersson et al. JMRI 2012;36:128.-13.
4. Smiseth et al. Eur Heart J 2016;37:1196-207.
5. Lopez-Candales et al. CCR. 2017;13:118-29.
6. Scatteia et al. Heart Fail Rev. 2017;22(4):465-76.
7. Amzulescu et al. Eur Heart J 2019;20:605-619.
8. Voigt et al. Eur Heart J 2014;16:1-11.
9. Kalam et al. Heart 2014;100:1673-1680.
10. Sengelov et al. JACC 2015;8:1351-1359.
11. Korosoglou et al. JACC 2021;14:1177-1188.
12. Ansah et al. Children 2023;10:271.

Strain Imaging
Main Modalities and Techniques

- Ultrasound/echo strain imaging
  - Has been available as a commercial product
  - There are academia-industry standardization guidelines[1-3]
  - Techniques: Tissue Doppler imaging (TDI) and speckle-tracking echocardiography (STE)
  - Global longitudinal strain is the best evaluated parameter by ultrasound
- MR strain imaging
  - Commercial product is very limited
  - Techniques: Myocardial tagging, cine feature tracking, displacement-encoding with stimulated echoes (DENSE) and strain encoding (SENC)
  - More comprehensive and flexible strain evaluation
- CT could also be used for strain imaging, although not as preferable a choice as echo or MRI
- Reimbursement codes issued in 2020
  - Current Procedural Terminology (CPT) code 93356 for echocardiography myocardial strain imaging[4]
  - Healthcare Common Procedure Coding System (HCPCS) code for MR myocardial strain imaging[5]

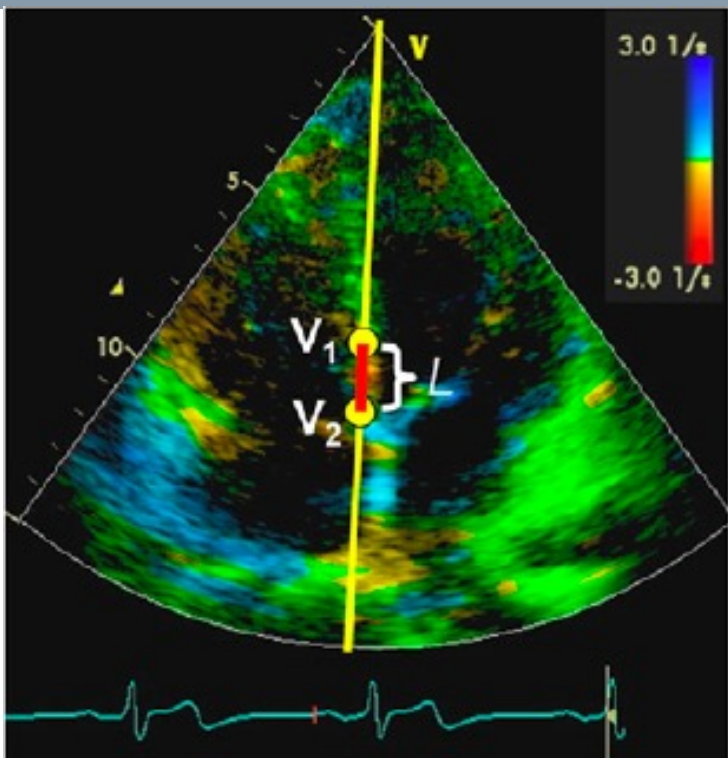
1. Voigt et al. Eur Heart J 2015;16:1-11.
2. Edvardsen et al. Eur Heart J 2022;23:e6-e33.
3. Heidenreich et al. Circulation. 2022;145:e895-e1032.
4. https://www.asecho.org/myocardial-strain-imaging-add-on-cpt-code-and-live-webinar/
5. https://www.auntminnie.com/index.aspx?sec=ser&sub=def&pag=dis&ItemID=129387

Non-MR Imaging Modalities
Echocardiography

- Features
  - Most commonly used noninvasive test to evaluate cardiac anatomy and function
  - Based on analysis of the ultrasonic wave reflection on the blood-tissue or tissue-tissue interfaces
  - Tissue Doppler to quantify blood flow and myocardial velocity[1]
  - Speckle tracking can be used to measure myocardial displacement[2]
- Advantages
  - Low cost, portability, real-time imaging capability
  - Abundance of experienced image interpreting physicians
- Disadvantages
  - Poor endocardial border delineation
  - Penetration of ultrasound through bone and lung is poor
  - Limited acoustic window
  - Image quality is relatively low compared to MRI and CT

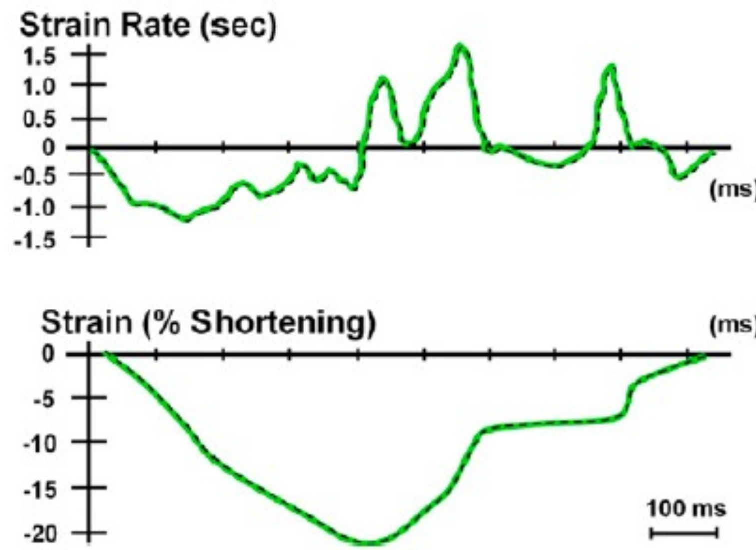
1. Sutherland et al. J Am Soc Echocardio 1994;7:441-458.
2. Li et al. Ultras Med Biol 2007;33(6):894-904.

Non-MR Imaging Modalities
Echocardiography Strain by Doppler imaging (TDI)



$$Strain\ Rate = \frac{V_1 - V_2}{L}$$

Myocardial ***velocity*** is measured at various points throughout the Doppler line at distance L apart (10mm)



1. Gorcsan et al. JACC 2011; 58(14): 1401-1413

Strain Imaging
Echocardiography Strain by Doppler imaging (TDI)

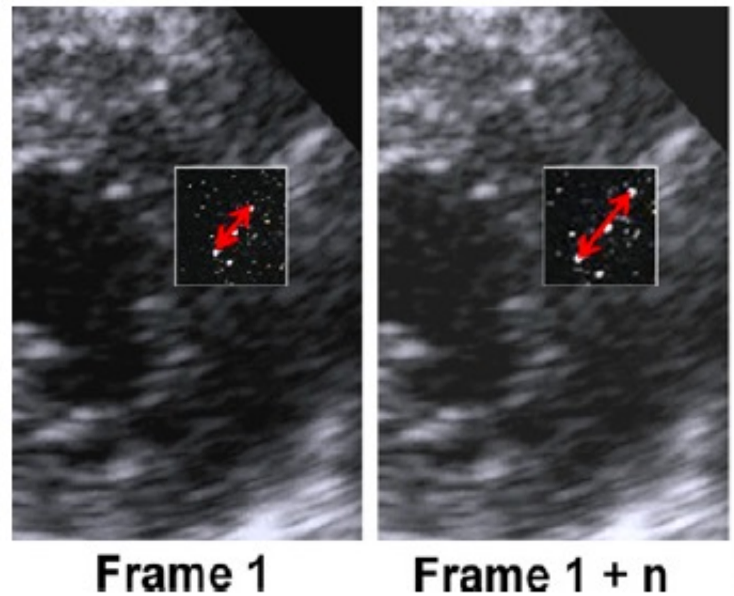
- Tethering effect
  - Akinetic segment may be pulled apically by adjacent normokinetic segment(s) and may have normal tissue velocity despite being non-contractile

- Angle dependency
  - If ultrasound beam is at a different angle to the actual movement of the myocardium, strain may be underestimated
  - Apical velocities cannot be accurately measured because the angle of incidence is too large due to apical curvature
  - Can only reliably measure longitudinal strain; other vectors are not possible

Non-MR Imaging Modalities
Echocardiography Strain by Speckle Tracking

- Speckle Tracking
  - Tracks the grayscale speckling pattern seen on echo images
  - Can track the movement of the speckles relative to each other over time (displacement, not velocity measurement)

- Angle independent
  - Longitudinal strain is still the most reliable measurement
  - But can image in any vector, including 3D

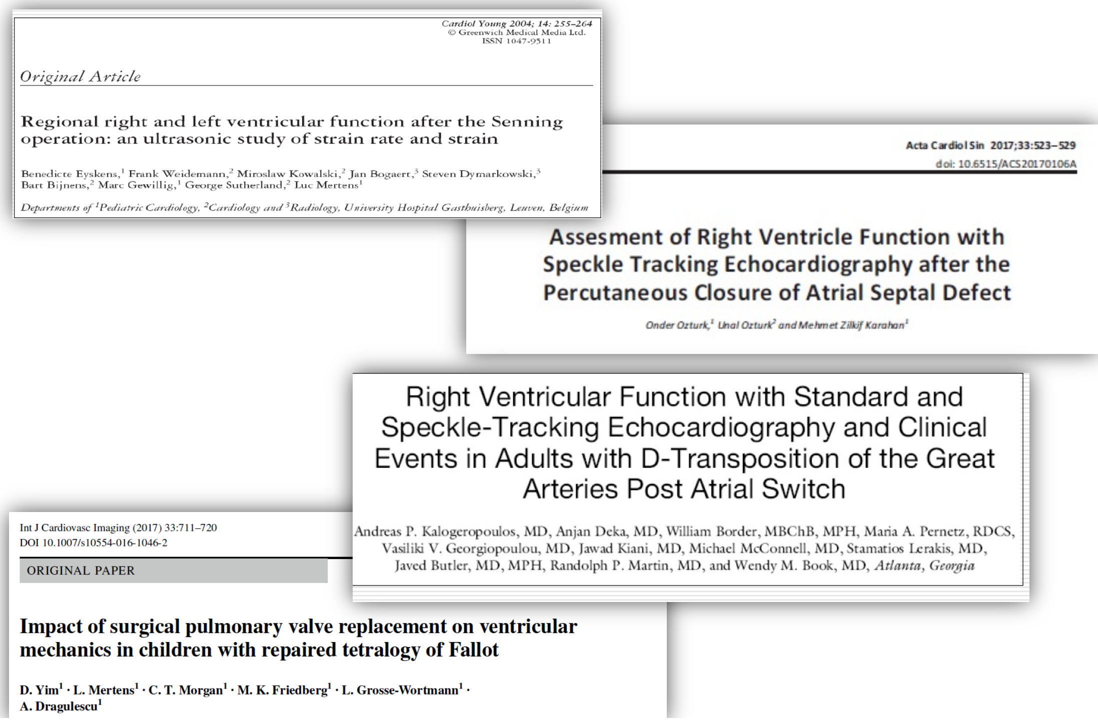


$$\text{Strain} = \frac{\Delta\,\text{Length}}{\text{Length}_0}$$

1. Gorcsan et al. JACC 2011; 58(14): 1401-1413.

Strain Imaging for Prognostic, Management and Treatment in Patients with Cardiovascular Diseases

- Echo strain imaging has been clinical guidelines for patients with various cardiovascular diseases including congenital heart diseases


Cardiol Young 2004; 14: 255–264
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ISSN 1047-9511

Original Article

Regional right and left ventricular function after the Senning operation: an ultrasonic study of strain rate and strain

Benedicte Eyskens,[1] Frank Weidemann,[2] Miroslaw Kowalski,[2] Jan Bogaert,[3] Steven Dymarkowski,[3] Bart Bijnens,[2] Marc Gewillig,[1] George Sutherland,[2] Luc Mertens[1]

Departments of [1]Pediatric Cardiology, [2]Cardiology and [3]Radiology, University Hospital Gasthuisberg, Leuven, Belgium

Acta Cardiol Sin 2017;33:523–529
doi: 10.6515/ACS20170106A

Assesment of Right Ventricle Function with Speckle Tracking Echocardiography after the Percutaneous Closure of Atrial Septal Defect

Onder Ozturk,[1] Unal Ozturk[2] and Mehmet Zülkif Karahan[1]

Right Ventricular Function with Standard and Speckle-Tracking Echocardiography and Clinical Events in Adults with D-Transposition of the Great Arteries Post Atrial Switch

Andreas P. Kalogeropoulos, MD, Anjan Deka, MD, William Border, MBChB, MPH, Maria A. Pernetz, RDCS, Vasiliki V. Georgiopoulou, MD, Jawad Kiani, MD, Michael McConnell, MD, Stamatios Lerakis, MD, Javed Butler, MD, MPH, Randolph P. Martin, MD, and Wendy M. Book, MD, *Atlanta, Georgia*

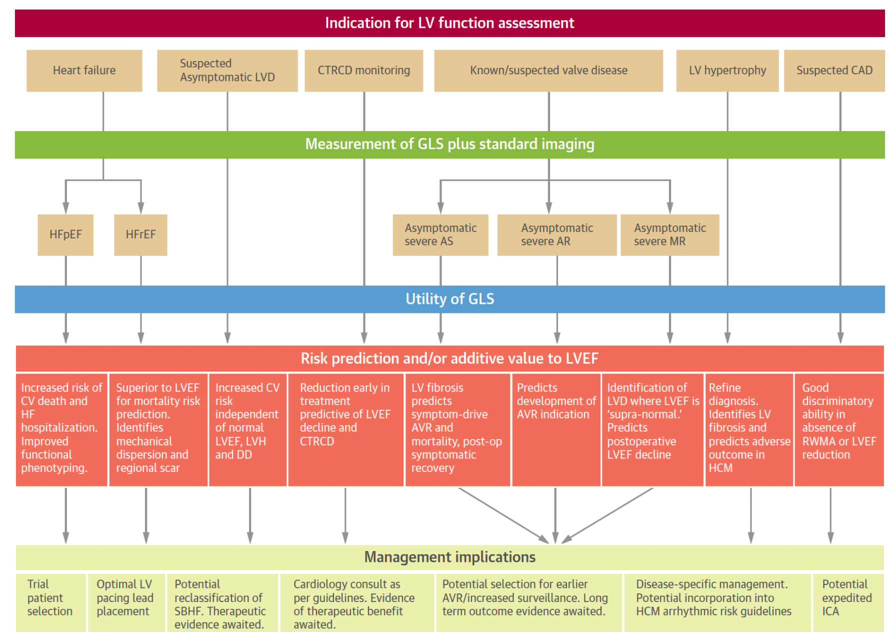
Int J Cardiovasc Imaging (2017) 33:711–720
DOI 10.1007/s10554-016-1046-2

ORIGINAL PAPER

Impact of surgical pulmonary valve replacement on ventricular mechanics in children with repaired tetralogy of Fallot

D. Yim[1] · L. Mertens[1] · C. T. Morgan[1] · M. K. Friedberg[1] · L. Grosse-Wortmann[1] · A. Dragulescu[1]

CENTRAL ILLUSTRATION Prognostic and Management Implications of Abnormal Strain Measurement in Common Clinical Scenarios



Potter, E. et al. J Am Coll Cardiol Img. 2018;11(2):260-74.

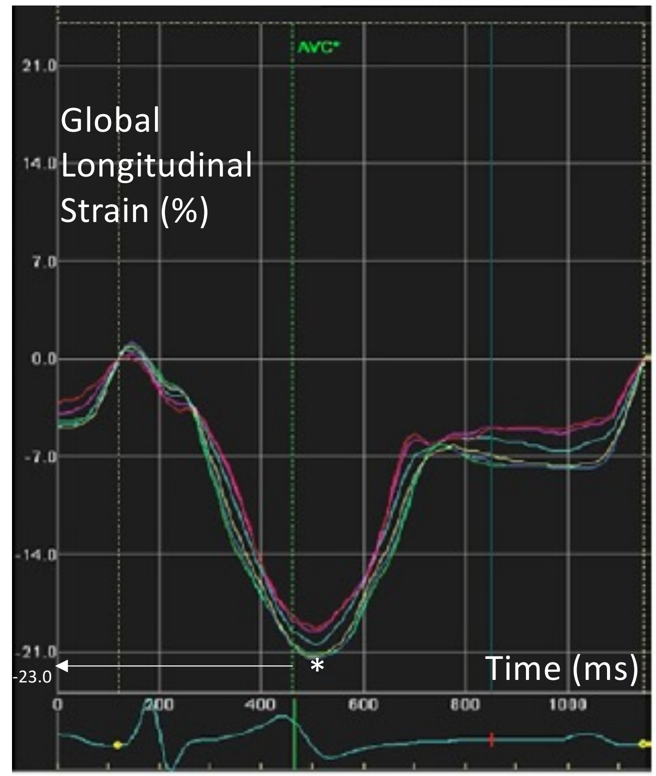
AR = aortic regurgitation; AS = aortic stenosis; AVR = aortic valve replacement; CAD = coronary artery disease; CTRCD = cancer therapeutics-related cardiac dysfunction; CV = cardiovascular; DD = diastolic dysfunction; GLS = global longitudinal strain; HF = heart failure; HFpEF = heart failure with preserved ejection fraction; HFrEF = heart failure with reduced ejection fraction; HCM = hypertrophic cardiomyopathy; ICA = invasive coronary angiography; LV = left ventricular; LVD = left ventricular dysfunction; LVEF = left ventricular ejection fraction; LVH = left ventricular hypertrophy; MR = mitral regurgitation; post-op = post-operative; RWMA = resting wall motion abnormality; SBHF = stage B heart failure.

JACC CV Imaging 2018; 11(2)

Strain Imaging
Most Representative: Global Longitudinal Strain (GLS) by Echo

- Integrate strain data from multiple segments over time to determine global myocardial strain

Degree of normalcy	Value of peak systolic GLS (%)
Normal	< -18 to -20 (more neg)
Borderline	- 16 to -18
Abnormal	> -16 (less neg)



* Slide courtesy of Jamil Aboulhosn, MD.

Strain Imaging
LV Strain Cutoffs - Age, Gender and Vendor Specific

- Data from echo strain imaging

Vendor	Age group (y)						*P*
	0–19	20–29	30–39	40–49	50–59	≥60	
V1							
Overall	−22.1 ± 2.4	−21.2 ± 1.9	−21.1 ± 2.1	−21.4 ± 2.0	−21.0 ± 2.2	−20.3 ± 1.9	.0218
Male	−21.7 ± 3.1	−20.9 ± 1.9	−20.6 ± 1.9	−20.9 ± 1.8	−21.0 ± 1.9	−19.7 ± 1.4	.1982
Female	−22.4 ± 1.6	−22.3 ± 1.6	−22.8 ± 1.8	−22.6 ± 2.1	−23.3 ± 1.9	−20.9 ± 2.1	.0348
P (male vs female)	.4292	.0316	<.0001	.0178	.0029	.1381	
V2							
Overall	−19.9 ± 2.5	−19.0 ± 2.1	−19.5 ± 2.2	−18.2 ± 2.5	−17.6 ± 2.5	−16.7 ± 2.1	<.0001
Male	−19.4 ± 2.7	−18.8 ± 2.0	−19.1 ± 2.3	−17.9 ± 2.8	−16.9 ± 2.3	−15.8 ± 1.4	.0019
Female	−20.5 ± 2.2	−20.6 ± 2.3	−20.2 ± 2.0	−19.3 ± 0.9	−20.4 ± 1.5	−17.3 ± 2.3	.0002
P (male vs female)	.1349	.0248	.1083	.4316	.0294	.0928	
V3							
Overall	−21.4 ± 1.7	−20.2 ± 2.1	−20.4 ± 2.3	−19.4 ± 2.2	−18.5 ± 2.6	−17.8 ± 2.8	<.0001
Male	−21.6 ± 2.0	−20.2 ± 2.0	−20.4 ± 2.2	−19.8 ± 2.3	−18.7 ± 2.6	−16.3 ± 3.1	<.0001
Female	−21.2 ± 1.5	−20.2 ± 2.4	−20.4 ± 2.8	−18.7 ± 1.8	−18.3 ± 2.8	−18.6 ± 2.3	.0141
P (male vs female)	.6076	.9787	.9201	.1415	.7374	.0668	

1. Plana et al. J Am Soc Echocardiogr 2014;27:911-39.

Non-MR Imaging Modalities
Computed Tomography (CT)

- Features
  - Non-enhanced CT allows visualization of cardiac and coronary artery calcification
  - With iodinated contrast, cardiac chambers and coronary artery lumen can be visualized
  - Strain measurement studies start to appear[1,2], using methods similar to Feature Tracking in MRI

- Advantages
  - High spatial resolution
  - Good temporal resolution

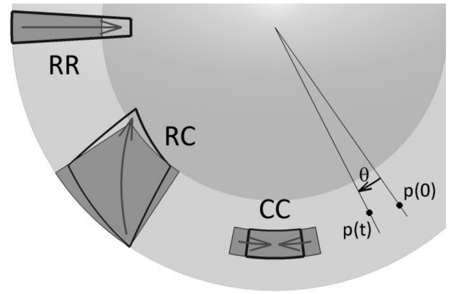
- Disadvantages
  - Radiation exposure
  - Necessity of contrast injection
  - Not suitable as a routine myocardial motion imaging method

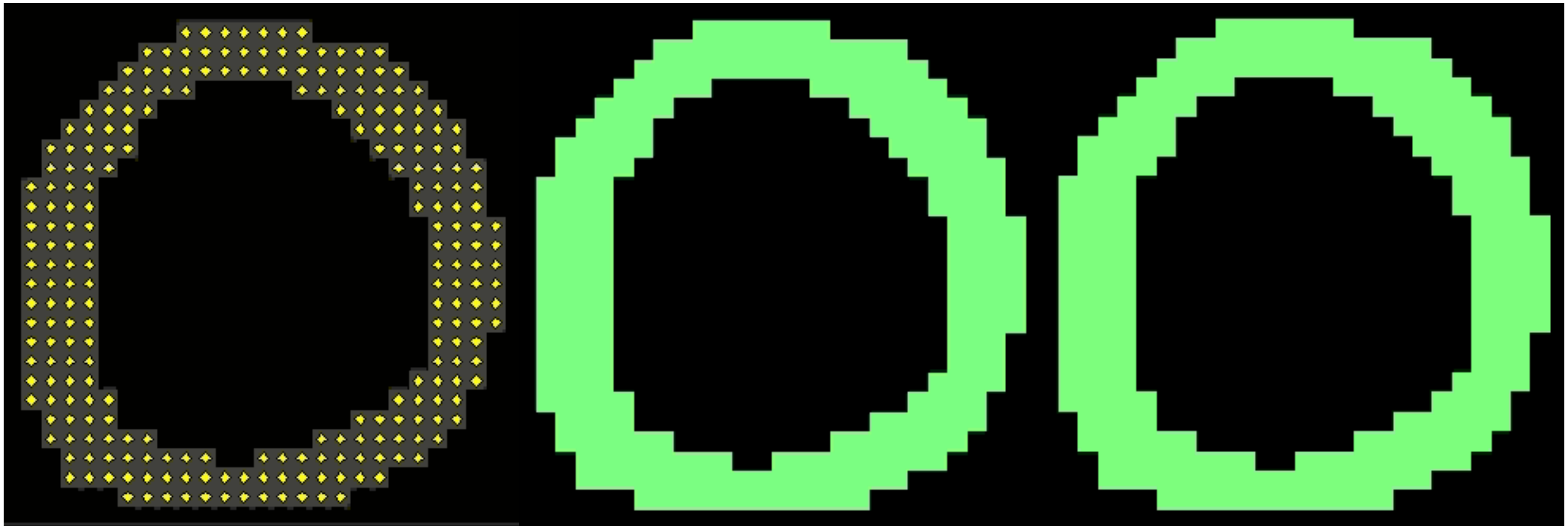
1. Vach et al. Sci Rep. 2021 Apr 22;11(1):8793.
2. Kinoshita et al. Heart Vessels. 2022 Jan;37(1):31-39.

Outline

- Strain Imaging
- 2D MR Strain Imaging
- Example Applications
- One Step Further: Multi-Dimensional MR Strain imaging

Strain Imaging
Goal of Strain Maps

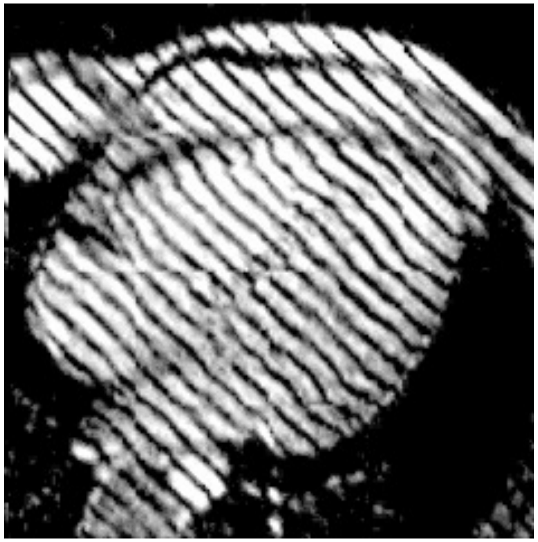




Displacement Ecc Err

Strain Imaging
MR Tagging

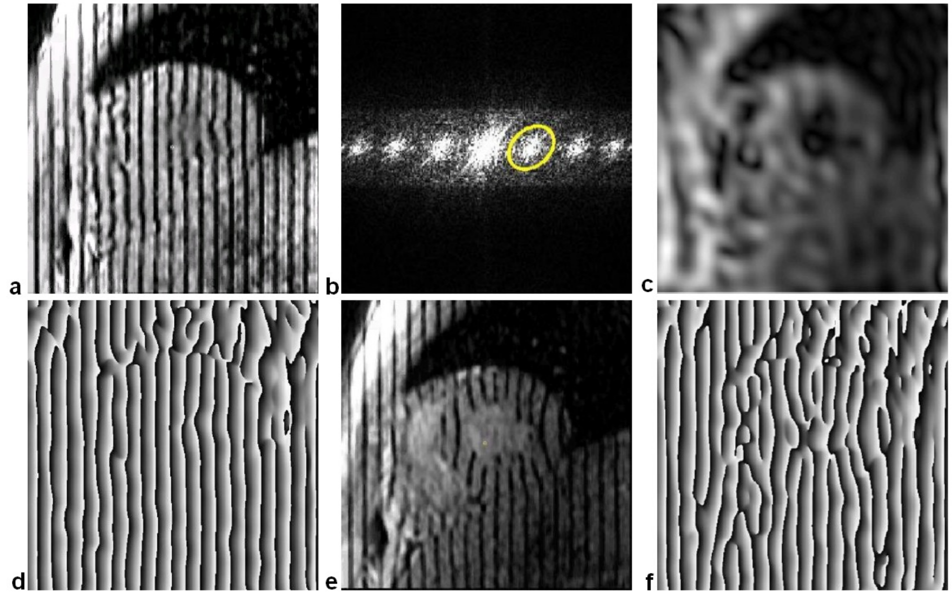
- Myocardial tagging[1,2]
  - Mark tag lines or grids using spatial modulation of magnetization
  - Labor and time consuming processing to track tags or grids
  - Low spatial resolution of motion and strain results



1. Zerhouni et al. Radiology 1988;169:59-63. 2. Young et al. IEEE Trans Med Imaging 1995;14:413-421.

Strain Imaging
Harmonic Phase Analysis (HARP) for MR Tagging

- Harmonic phase analysis (HARP)[1]
  - A way to utilize the phase image of tagging data to track motion
  - Low spatial resolution of motion and strain results (Need to filter the k-space peak, leading to reduced k-space extension and corresponding reduced resolution in image domain)

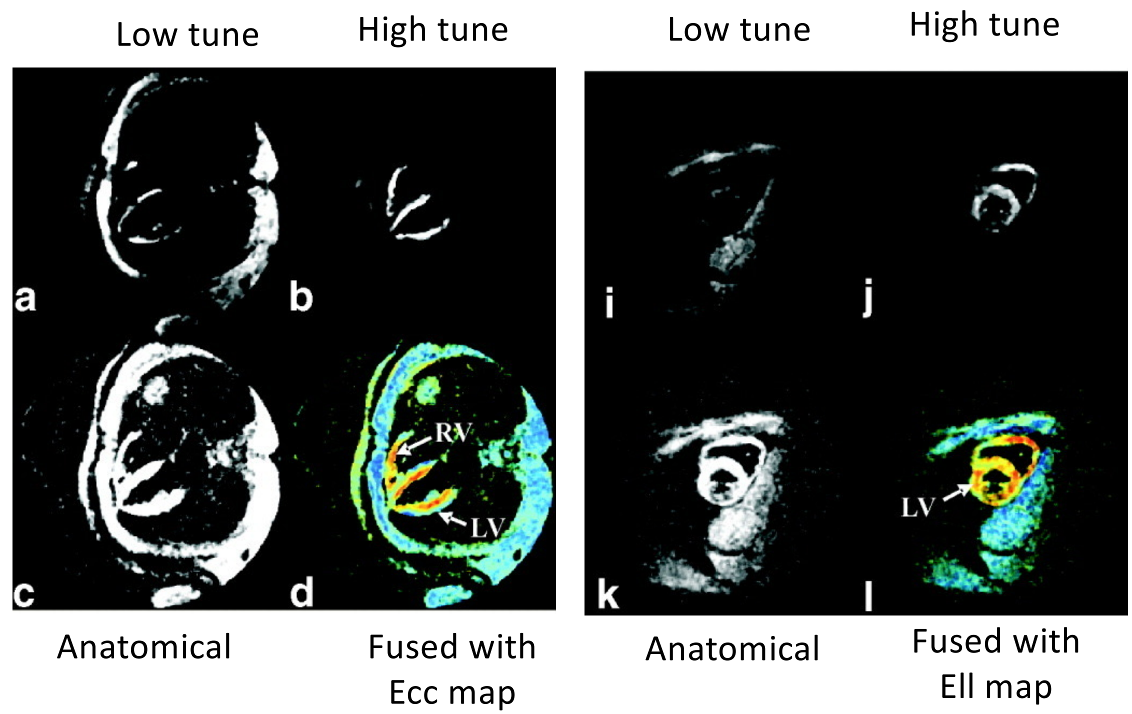


1. Osman et al. Magn Reson Med 1999;42:1048-1060.

Strain Imaging
Strain Encoding (SENC)

- Strain Encoding (SENC)[1,2]
  - Use a low tuning and a high tuning gradient encoding to calculate the strain directly from the magnitude images

- Limitations
  - Image SNR is generally low
  - Can only measure through-plane strain, not straightforward to observers
    - Discrepancy with the local coordinate system definition
  - No displacement information

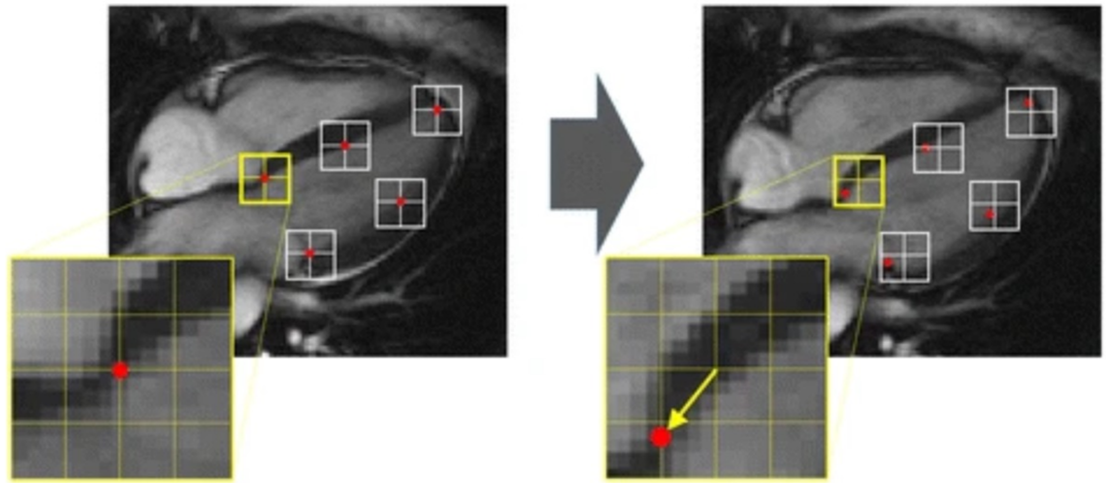


1. Osman et al. Magn Reson Med 2001; 46: 324–334.

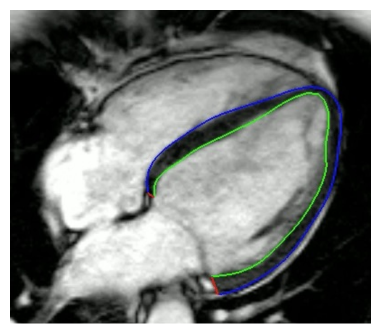
2. Pan et al. Magn Reson Med 2006; 55: 386–395.

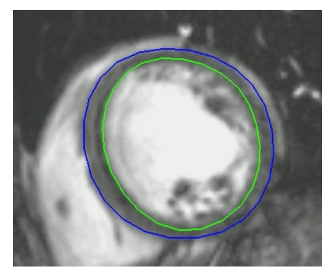
Strain Imaging
Feature Tracking

- Track the tissue feature (points on the boundary)[1,2]
  - Defining small square window centered on such features (points)
  - Search the similar-as-much-as-possible gray scale pattern on the following image near the original window[1]



- Limitations
  - Suboptimal repeatability[3,4]
  - Suboptimal accuracy[1,5]
    - Only track pixels on the boundary, not inside the myocardium
  - Tracking accuracy limited by the pixel size





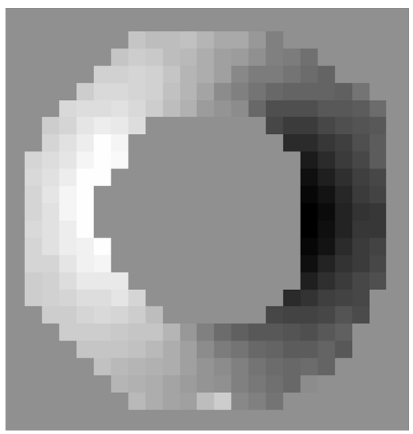
1. Pedrizzetti et al. J Cardiovasc Magn Reson. 2016 Aug 26;18(1):51.
2. Cao et al. JCMR 2018;20:26.
3. Morton et al. JCMR 2012;14:43.
4. Schuster et al. Eur J Radiol. 2013;82:296-301.
5. Wehner et al. JCMR 2018;20:63.

Strain Imaging
DENSE MRI

Displacement Encoding with Stimulated Echoes (DENSE)[1,2]:
Encode the tissue displacement into the phase of the MR images

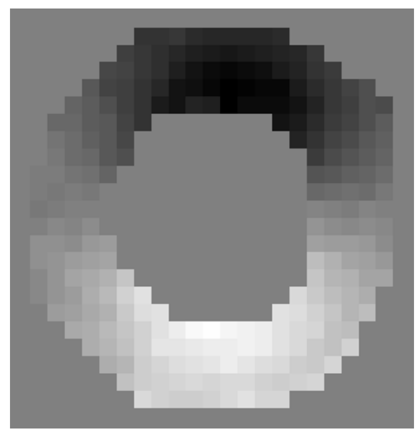
$$M_{xy}(x,t) = \frac{M_o}{2}\sin(\alpha)e^{-t/T1}e^{-jk_e\Delta x}$$

RO-encoded phase image



+

PE-encoded phase image



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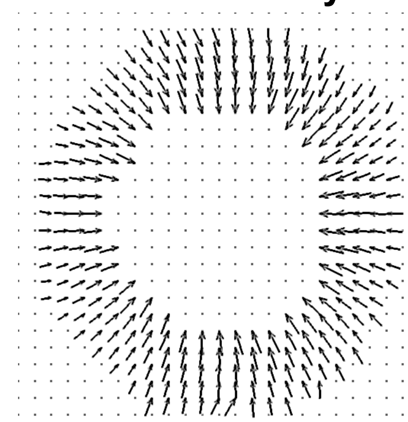
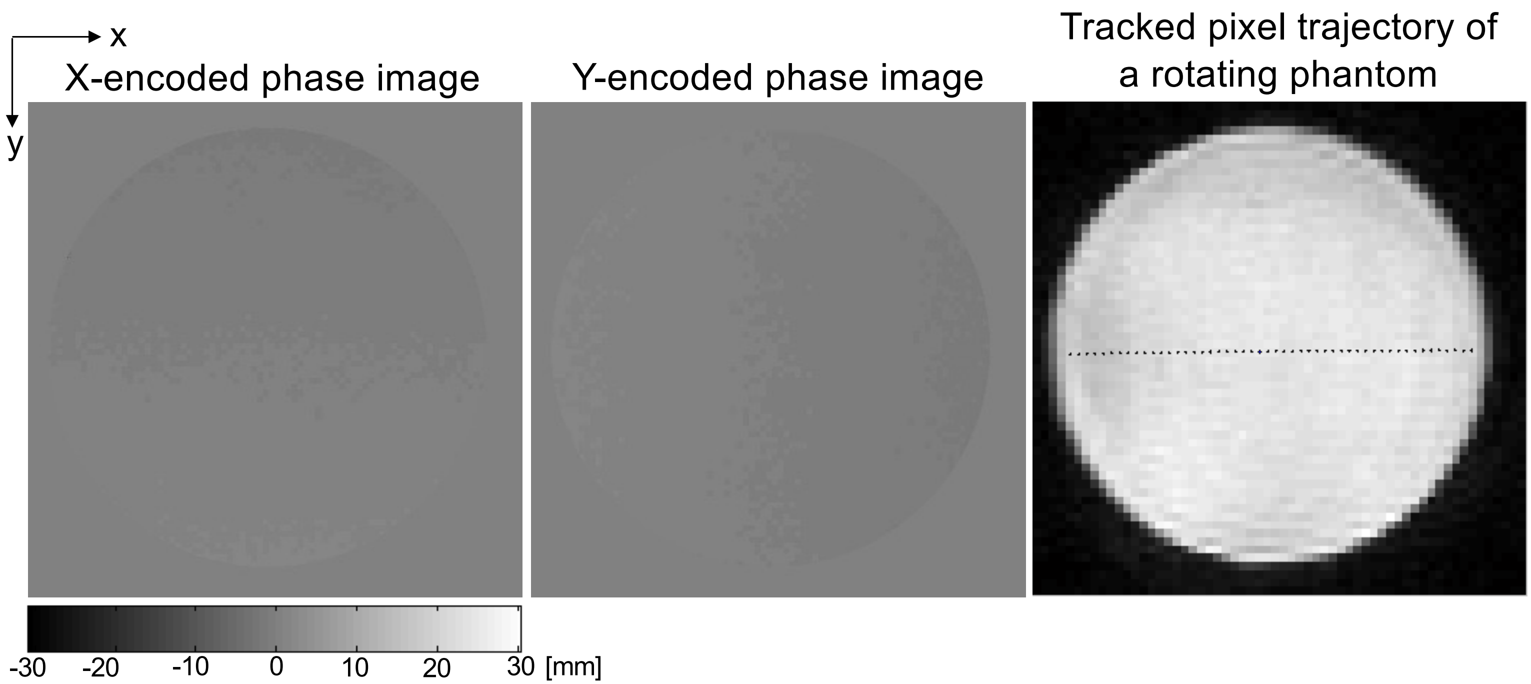
Displacement map of left ventricle at end systole



1. Aletras et al. JMR 1999; 137(1):247-252.

DENSE Imaging Validation
Measured Displacement on a Rotating Phantom

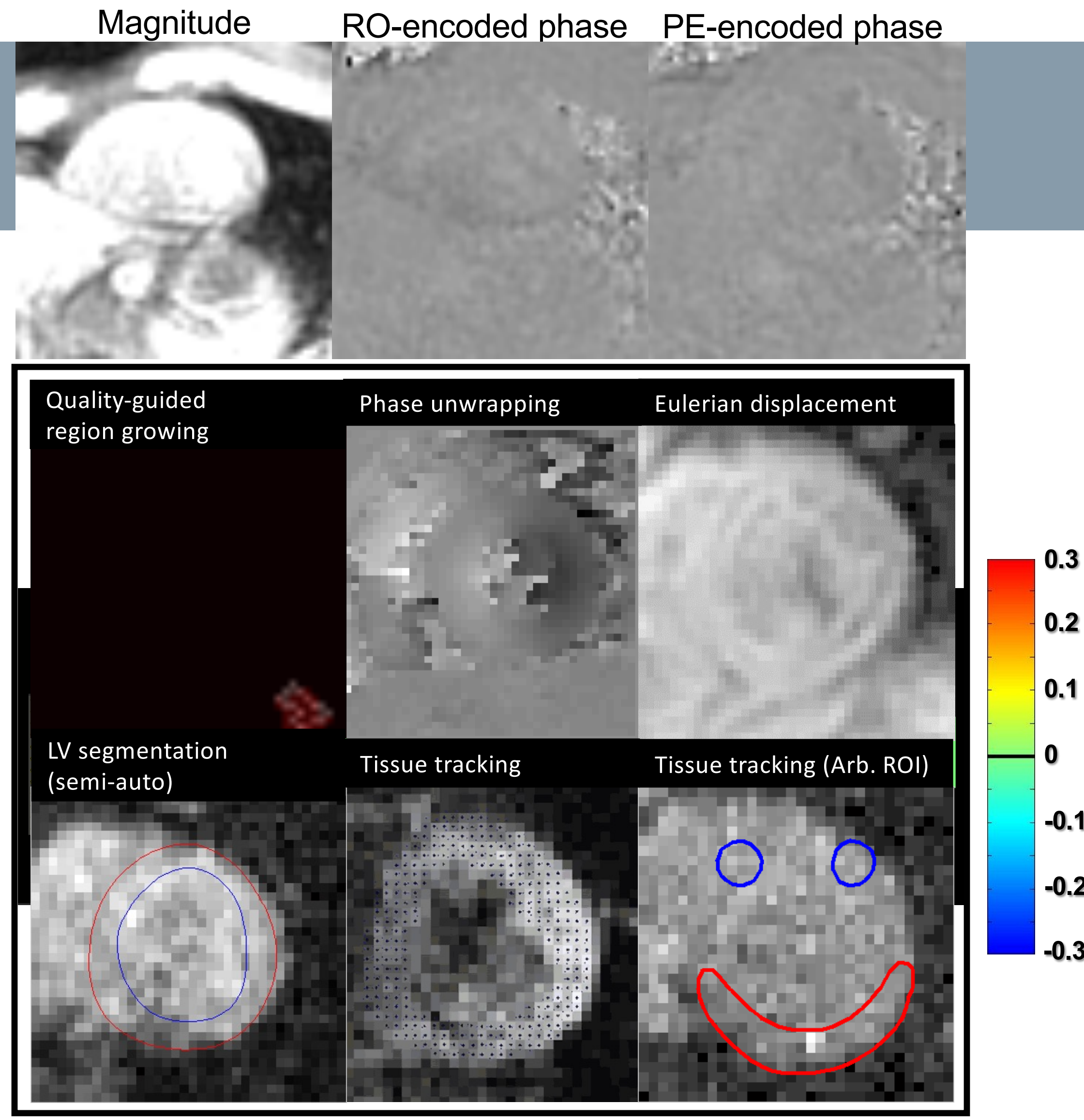
- Displacements *(Δx, Δy or Δz)* represented as a phase accrual
- Tracking accuracy: 0.24 ± 0.15 mm



1. Spottiswoode et al. IEEE-TMI 2007;15-30.

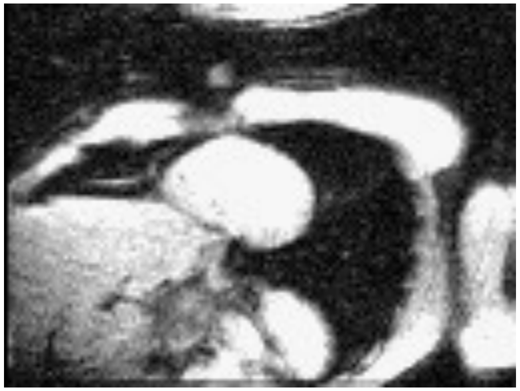
Cine DENSE: Post Processing

- Segmentation
- Phase unwrapping
- Displacement calculation (Eulerian displacement)
- Tracking (Lagrangian displacement)
- Strain calculation

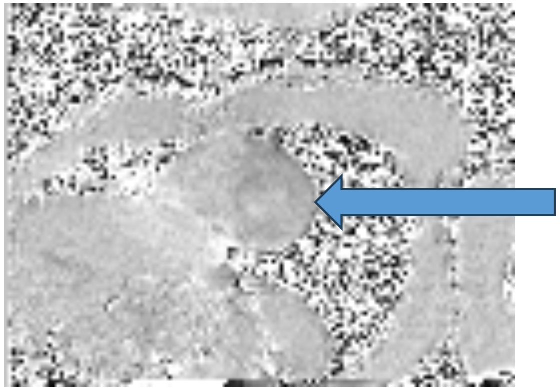


1. Spottiswoode et al. IEEE-TMI 2007;15-30.

Post-Processing of 2D DENSE Data
DENSE Magnitude and Phase Images to Process



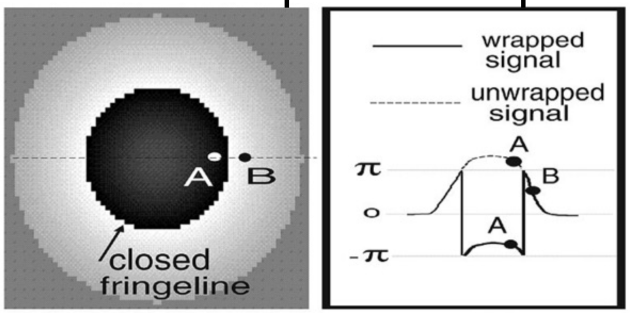
Magnitude image



Phase image

Phase wrapping

A simulated phase wrap example[1]

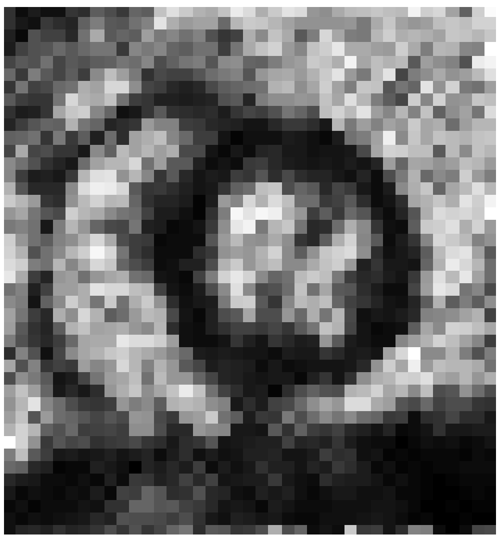


Phase angle θ (rad) = arctan(sin(θ), cos(θ))

There will be 2π value jump in the calculated θ by arctan()!

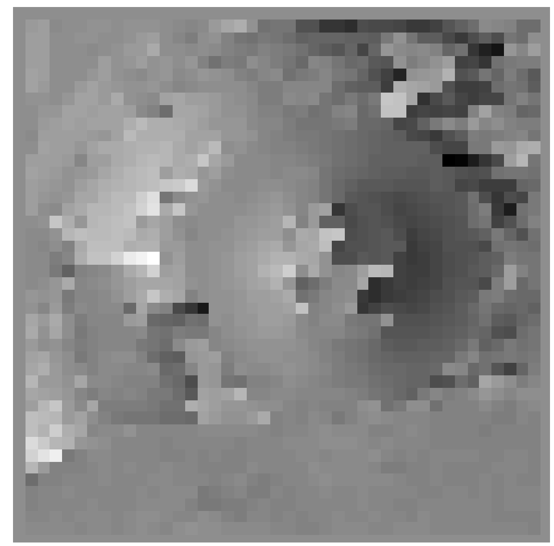
1. Chavez et al. IEEE Trans Med Imaging 2002;21:966-977.

Post-Processing of 2D DENSE Data
Quality-Guided Flood-Fill Phase Unwrapping



Quality map of phase image

Region growing path
for phase unwrapping



Unwrapped phase image

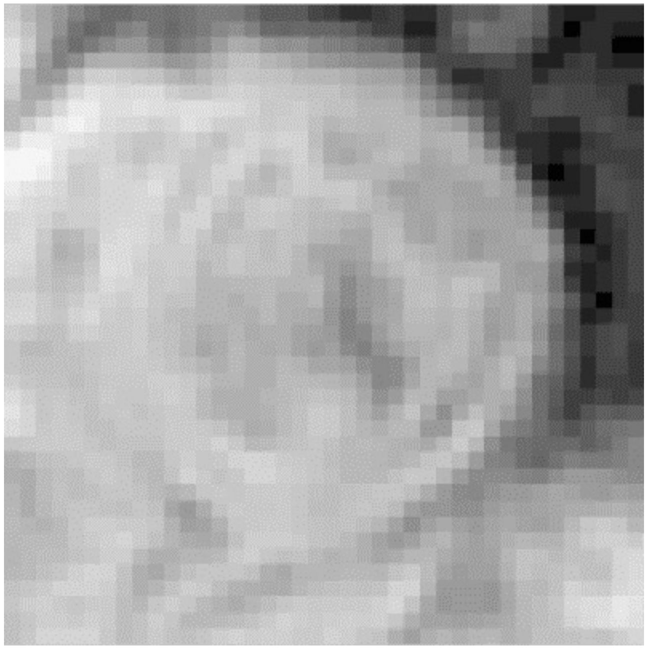
1. Spottiswoode et al. IEEE-TMI 2007;15-30.

Post-Processing of 2D DENSE Data
Eulerian Displacement Fields of Cine DENSE Data

- DENSE displacement vector heads lie on pixel centers
- Vector tails always refer to the position of these points at the initial time t_0, which is usually at end-diastole

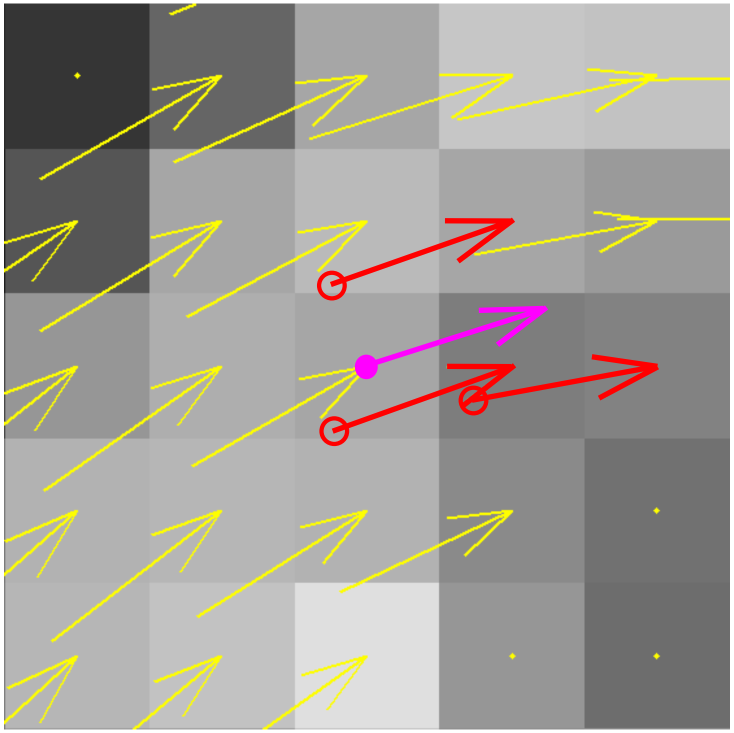
$$M_{xy}(x,t) =$$

$$\frac{M_o}{2}\sin(\alpha)e^{-t/T1}\boxed{e^{-jk_e\Delta x}}$$



Post-Processing of 2D DENSE Data
2D Frame-to-Frame Tissue Trajectory Tracking

- Designate a starting point at t_0 (pixel centre chosen here)
- For each frame:
  1. Find the 3 closest vector tails (red).
  2. Use 2D distance-weighted linear interpolation to estimate the position of the starting point at the current frame (purple).

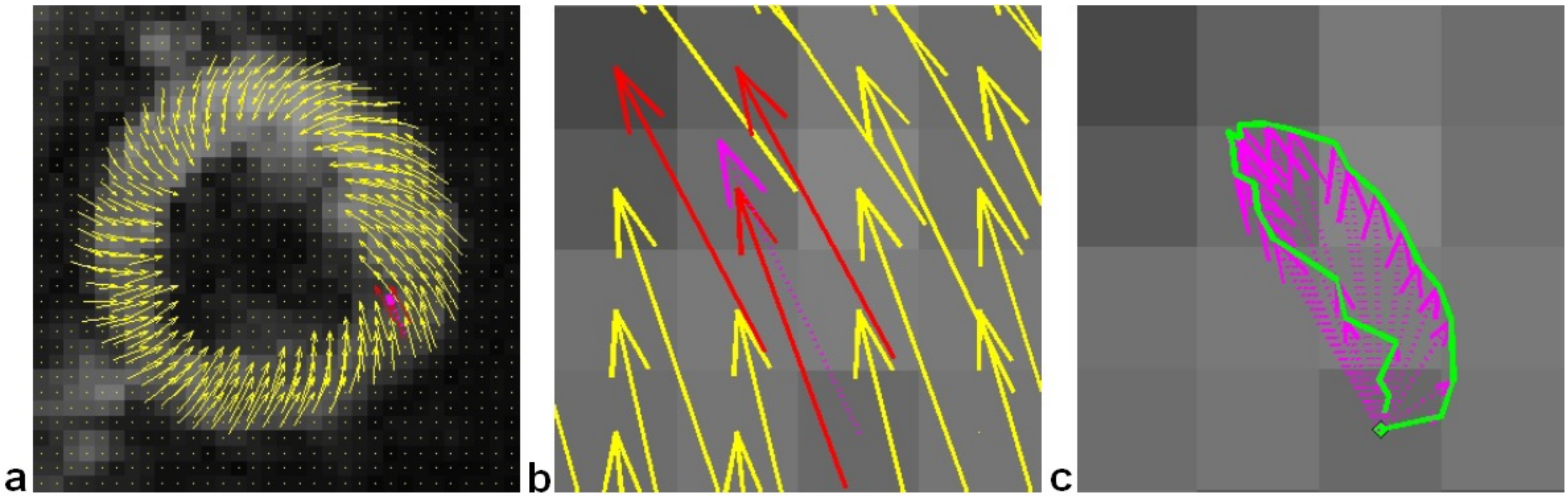


* Animation courtesy of Bruce Spottiswoode, PhD.

1. Spottiswoode et al. IEEE-TMI 2007;15-30.

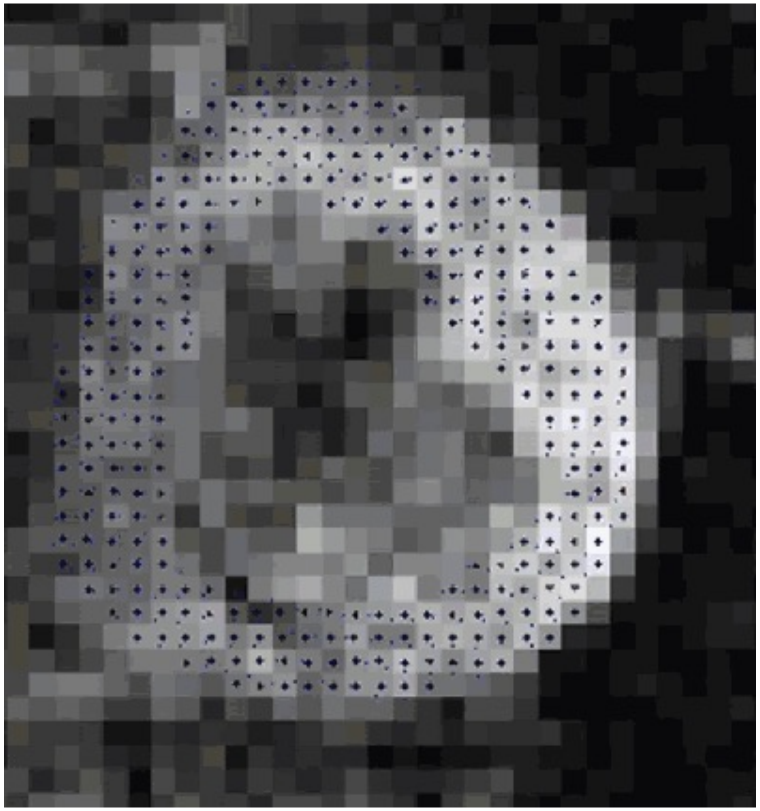
Post-Processing of 2D DENSE Data
Tissue Tracking

- Three-nearest-neighbor vector interpolation to convert Eulerian displacement to Lagrangian displacement for 2D DENSE data[1]



1. Zhong et al. JCMR 2011;13:83.

Post-Processing of 2D DENSE Data
2D Motion Trajectories

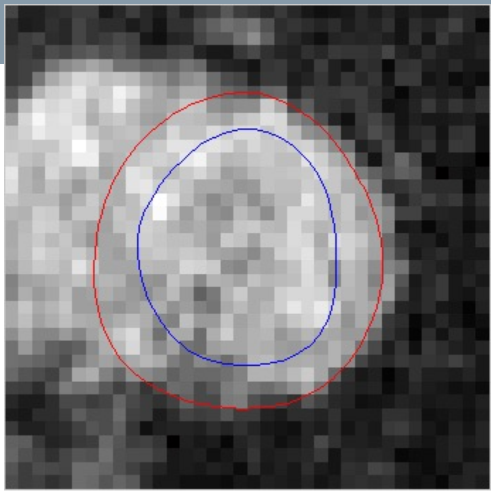


1. Spottiswoode et al. IEEE-TMI 2007;15-30. 2. Zhong et al. JCMR 2011;13:83.

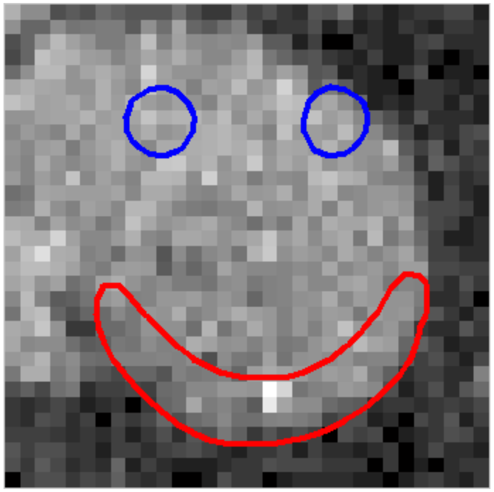
Post-Processing of 2D DENSE Data
Motion Guided Segmentation

- Perform spatiotemporal phase unwrapping without predefined contours
- Calculate the raw Eulerian displacement
- Manually segment the myocardium at any cardiac phase
- Tissue tracking algorithm can then be applied to estimate the position of this myocardium at all other cardiac phases

- Fit periodic Fourier basis functions (4th order) using least squares to get smooth contours



- Allow to track arbitrary regions of interest

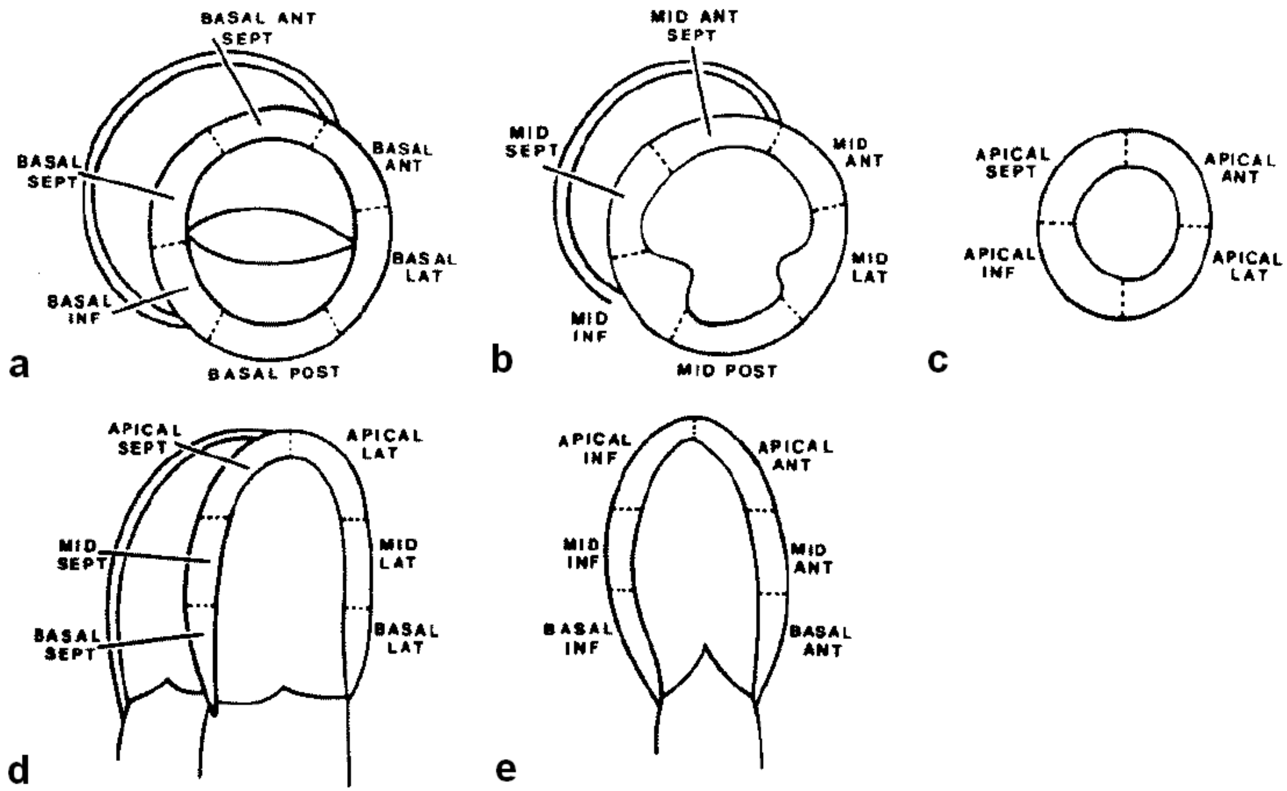


Post-Processing of DENSE Data
Strain Tensor Calculation

- The finite strain theory[1,2]
  - Position vector u in n-dimensional space R^n
  - Find N_n neighbors p_1-p_{N_n}, define: $q_i = p_i - u \quad (i = 1, \cdots, N_n)$
  - Record in matrix form: $A = [q_1 \quad \cdots \quad q_{N_n}]$
  - After deformation: $A' = [q_1' \quad \cdots \quad q_{N_n}']$
  - The relationship between A and A': $A' = FA$
  - Deformation gradient tensor: $F = A' A^T (AA^T)^{-1}$
  - SVD can be used to calculate F in ill conditions
  - Lagrangian strain tensor: $E = \frac{1}{2}(F^T F - I)$

1. Young et al. Radiology 1992;185:241-247.
2. Zhong et al. JCMR 2011;13:83.

Visualization of DENSE Data
LV Segments



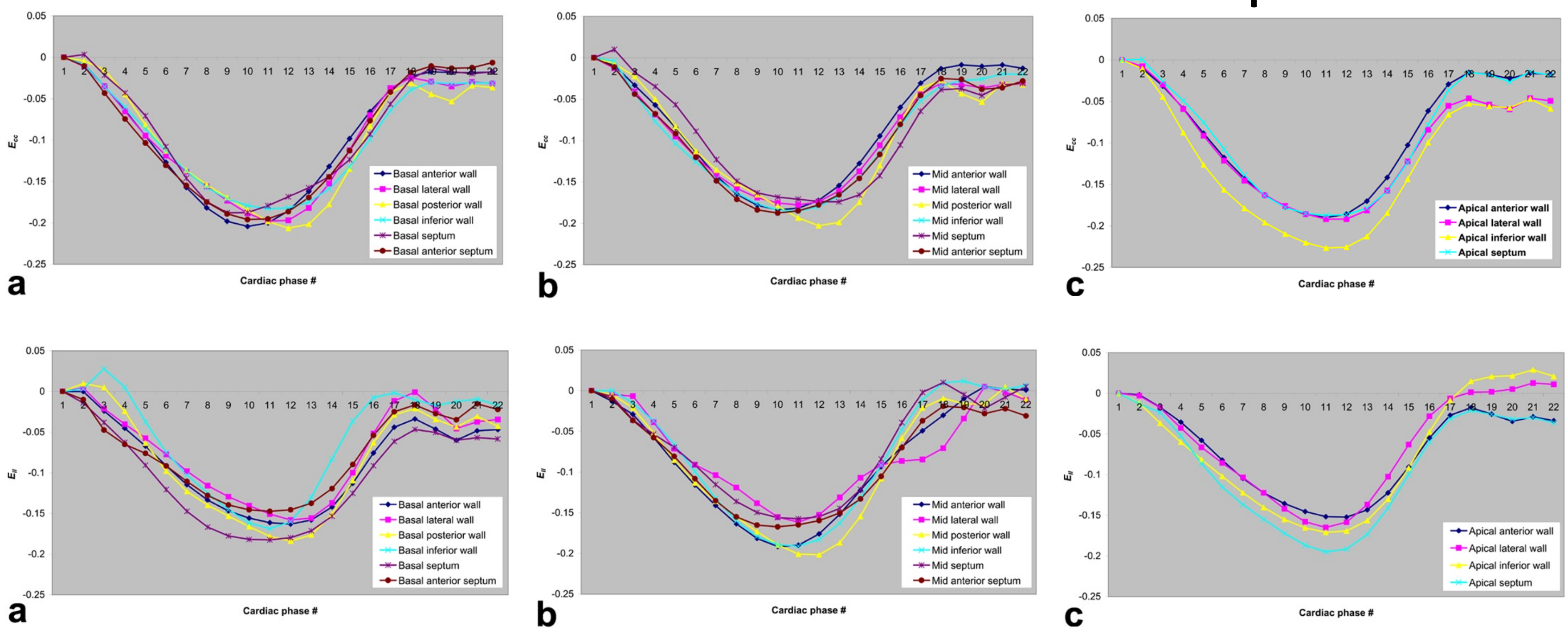
1. Cerqueira et al. Circulation 2002;105:539-542.

Post-Processing of DENSE Data
Strain-Time Curves of LV Segments for One Healthy Volunteer

Basal slice | Mid slice | Apex slice

Ecc

Ell

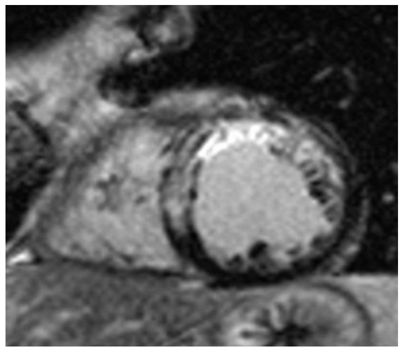


Outline

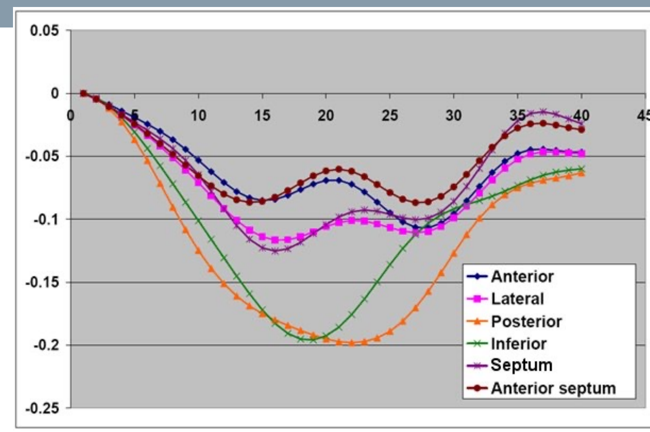
- Strain Imaging
- 2D MR Strain Imaging
- Example Applications
- One Step Further: Multi-Dimensional MR Strain imaging

Heart Failure Patient 1

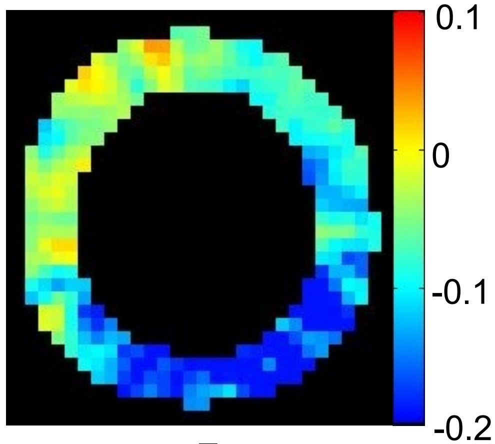
Heart failure due to ischemia (infarct)



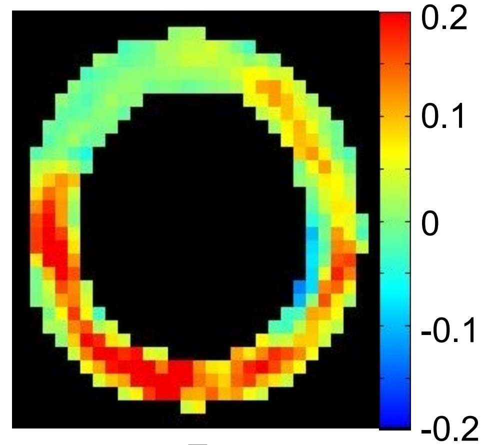
Gd-enhanced TrueFISP



Ecc curve



Ecc



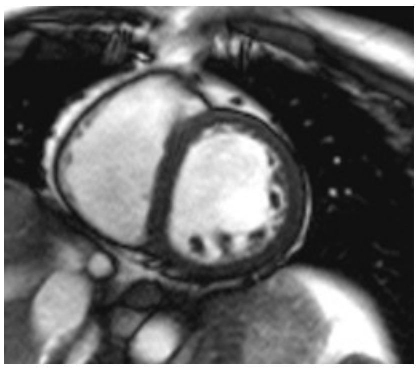
Err

* Courtesy of Christopher Kramer, MD and Frederick Epstein, PhD, University of Virginia.

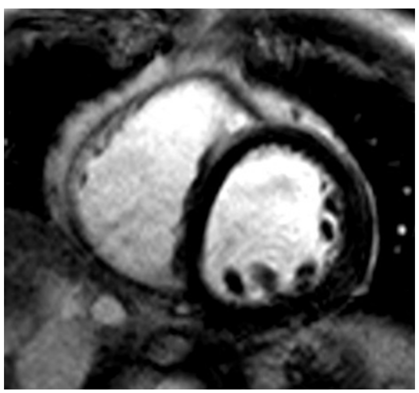
Heart Failure Patient 2

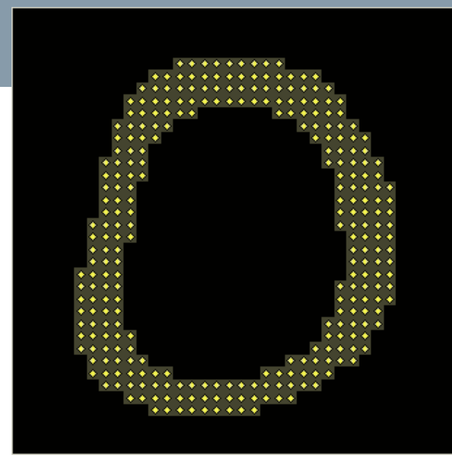
Heart failure due to non-ischemia disease (probably virus)

Cine

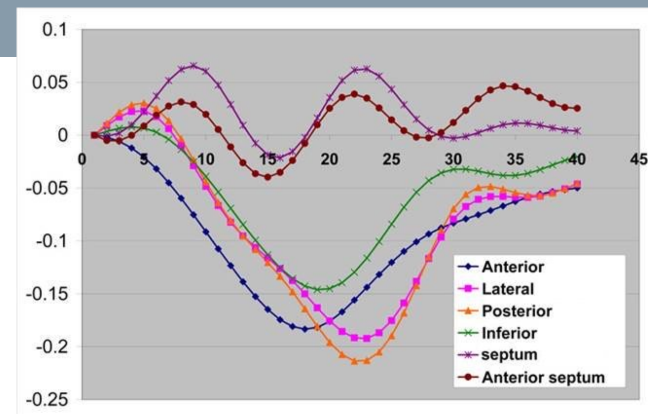


LGE

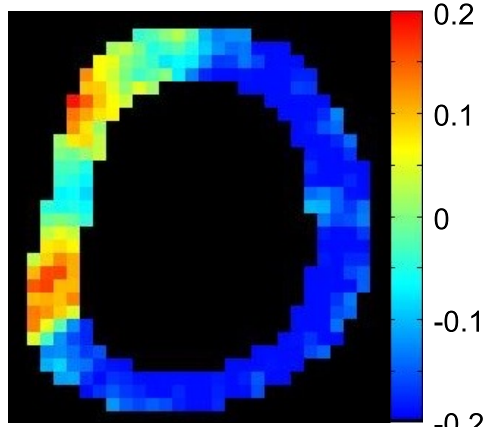




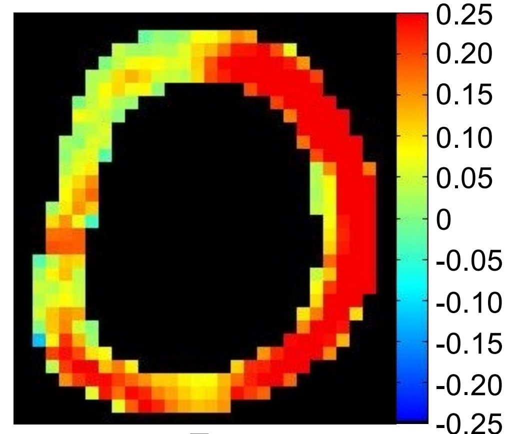
Displacement



Ecc curve



Ecc

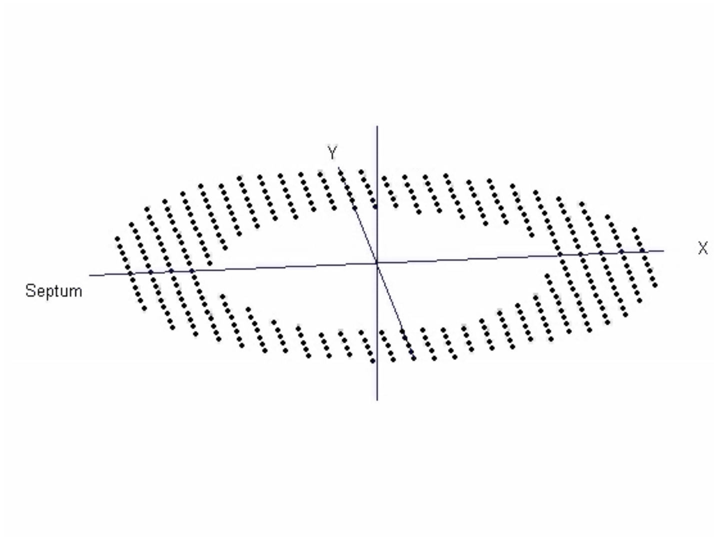


Err

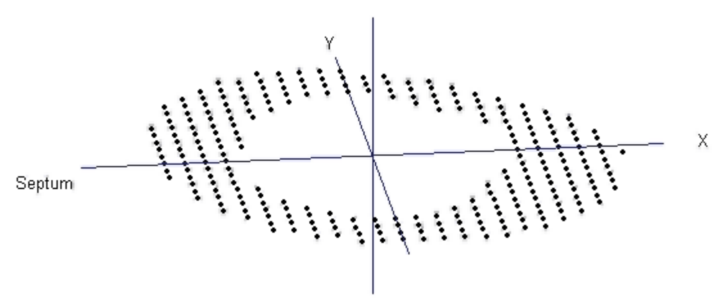
* Courtesy of Christopher Kramer, MD and Frederick Epstein, PhD, University of Virginia.

LV Dyssynchrony

- LV dyssynchrony occurs in
  - Approximately 25-50% of heart failure patients
  - Congenital heart disease (CHD) patients with Tetralogy of Fallot repair

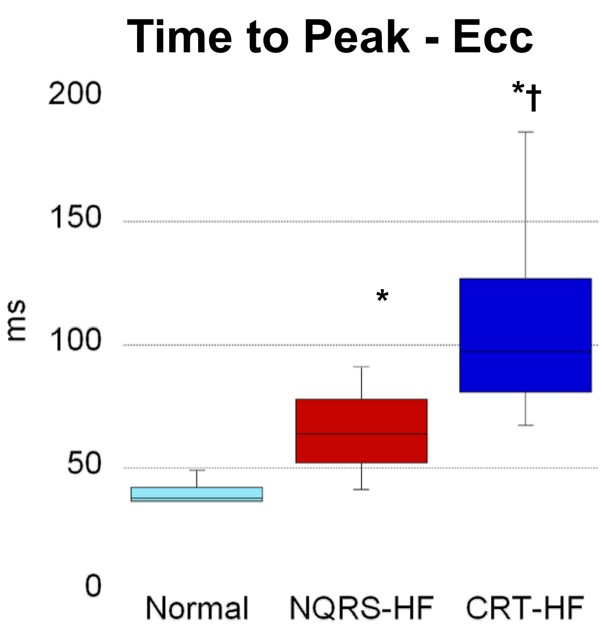


Healthy volunteer

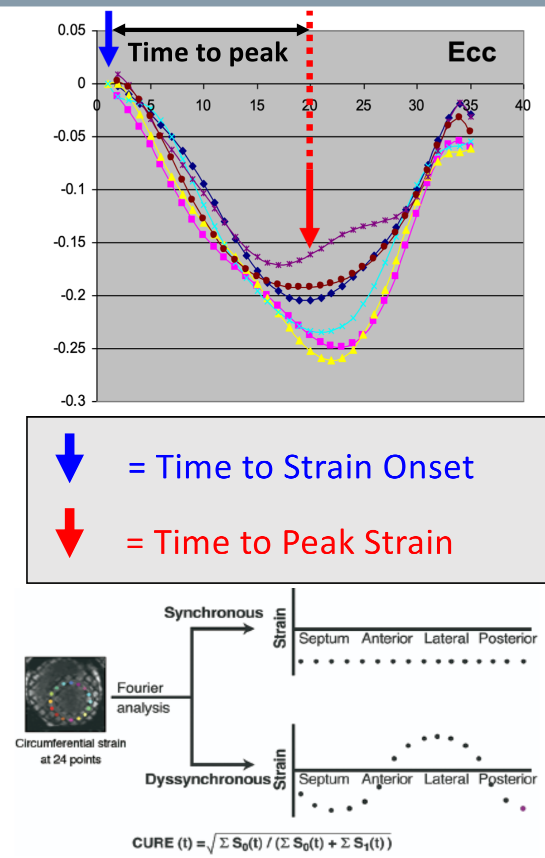


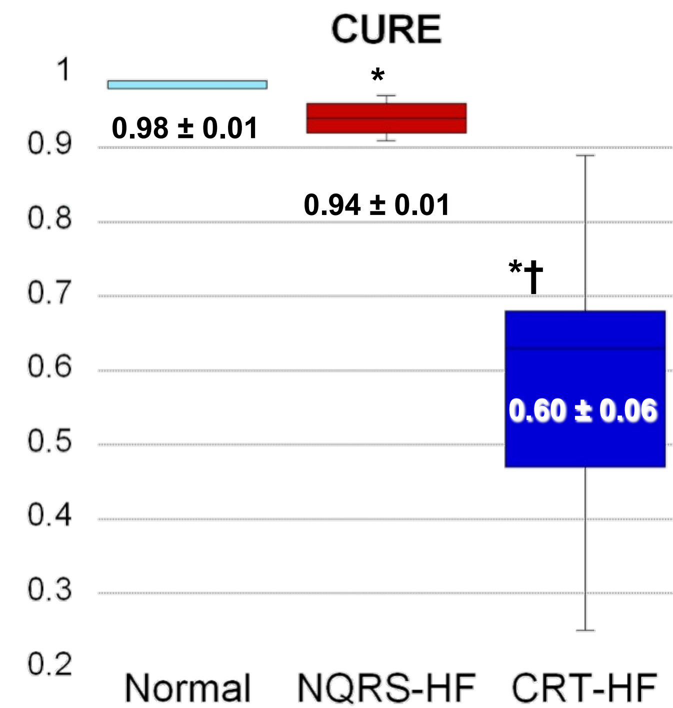
Dyssynchrony patient

Stratifying LV Dyssynchrony Patients with Strain Imaging
Patients with Normal QRS & Cardiac Resynchronization Therapy (CRT)



* *p*<0.05 vs. Normal
† p<0.01 vs. NQRS-HF





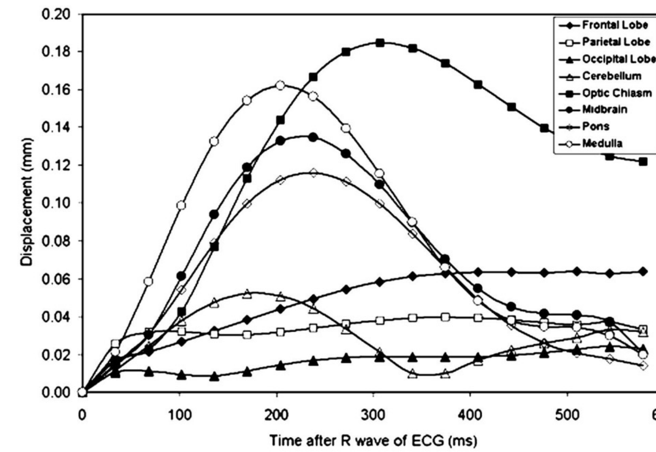
* *p*<0.01 vs. Normal
† p<0.04 vs. NQRS-HF

1. Leclercq et al. Circulation 2002;106:1760-1763.
2. Bilchick et al. JACC Imaging 2008;1:561-568.

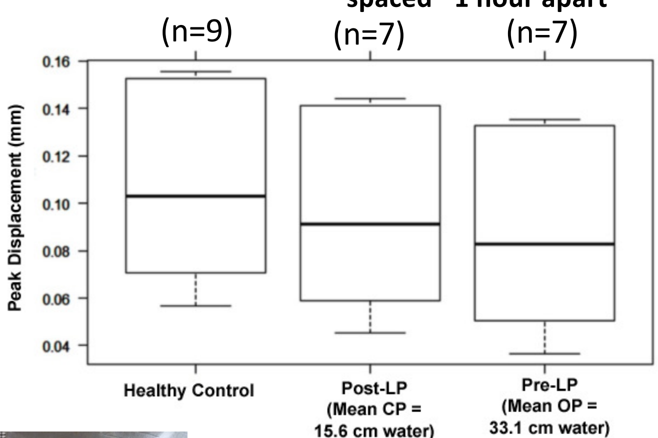
* Results courtesy of Kenneth C. Bilchick, MD, University of Virginia

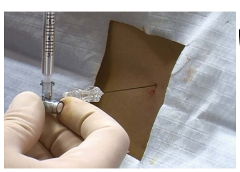
2D Cine DENSE MRI on Brain
Ability to Measure Subtle Displacement

- Pulsatile brain motion in the 0.01 mm level[1]
- Differentiated the intracranial pressure in idiopathic intracranial hypertension patients before and after CSF removal[2]

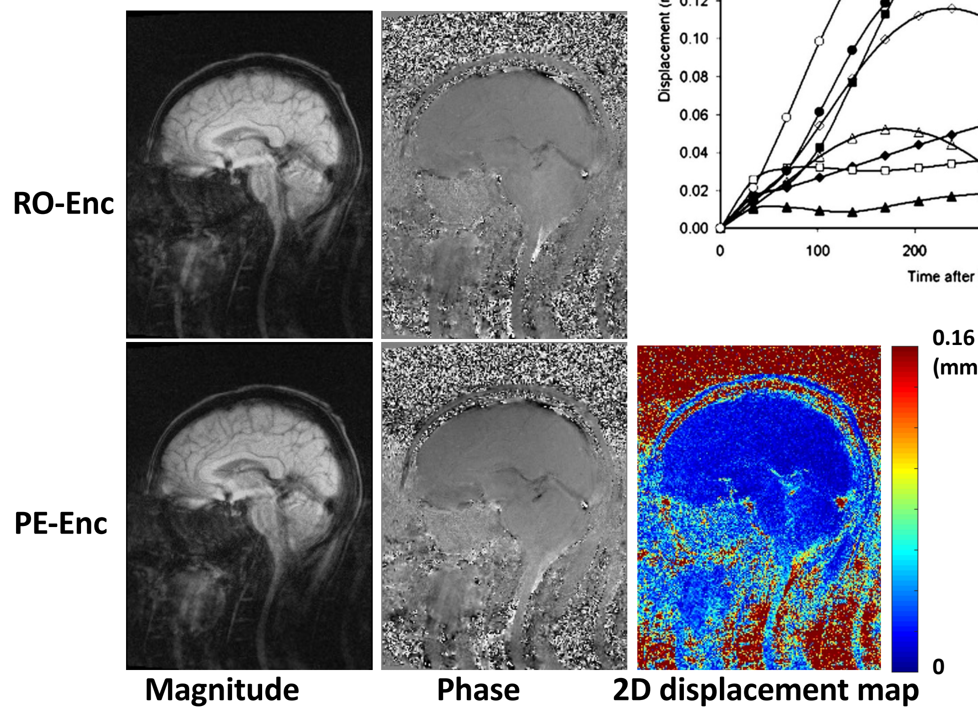


Pre- and post-surgery scans spaced ~1 hour apart



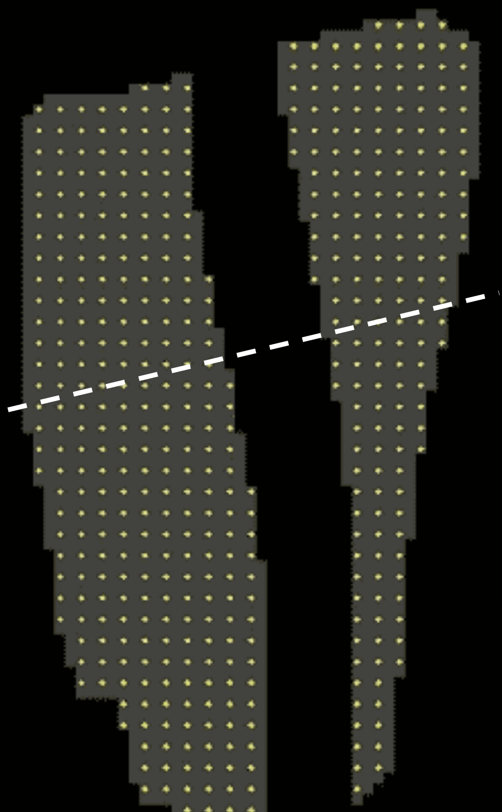


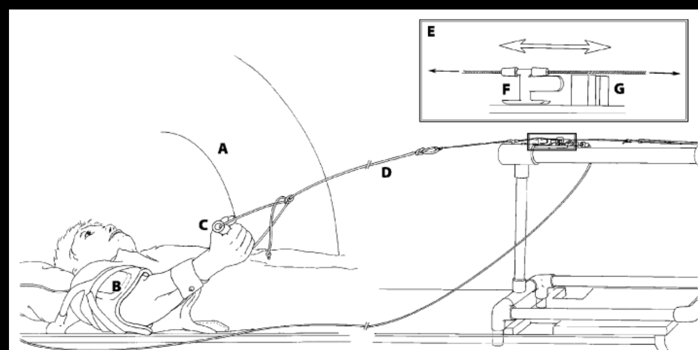
$p = 0.0021$

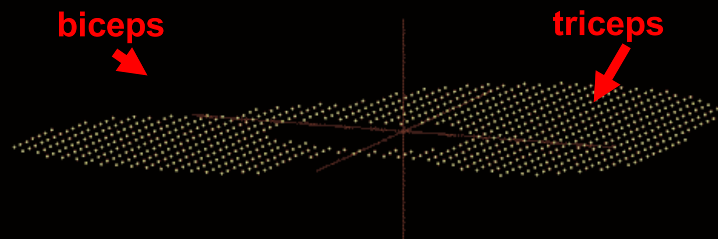


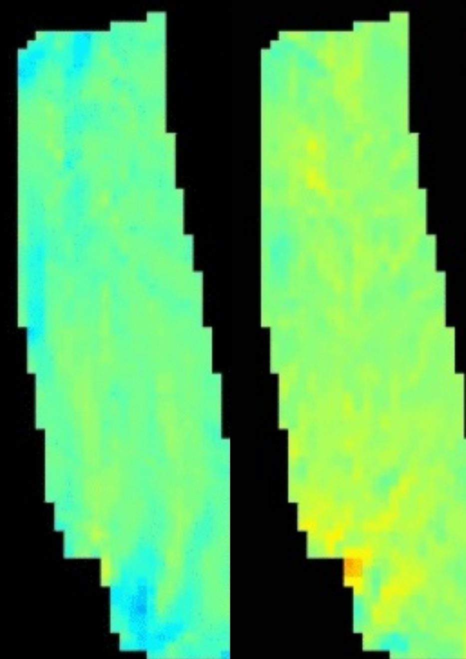
1. Zhong et al. Med Phys 2009;36:3413-3419.
2. Saindane et al. Am J Neuroradiol 2018;39:311-316.

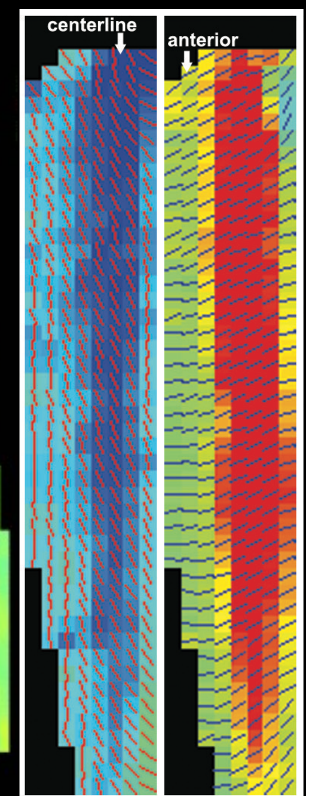
2D Cine DENSE MRI on Skeletal Muscle











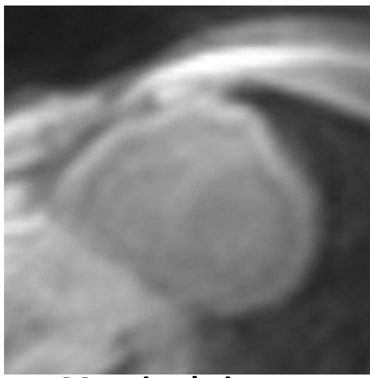
1. Zhong et al. J Biomech 2008; 41:532-540

Outline

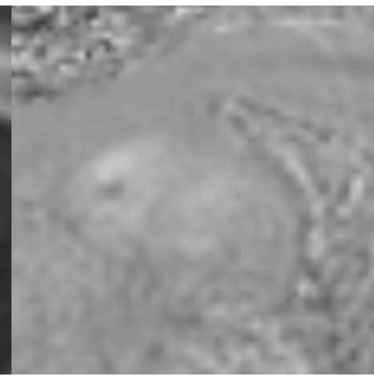
- Strain Imaging
- 2D MR Strain Imaging
- Example Applications
- One Step Further: Multi-Dimensional MR Strain imaging

4D DENSE Data (3D Spatial + Time)

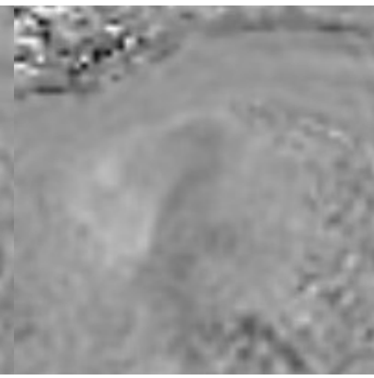
- Short-axis view obtained online directly



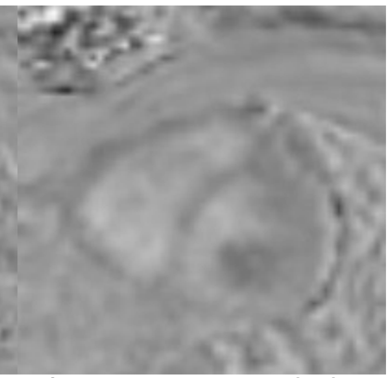
Magnitude image



Phase image encoded in horizontal direction

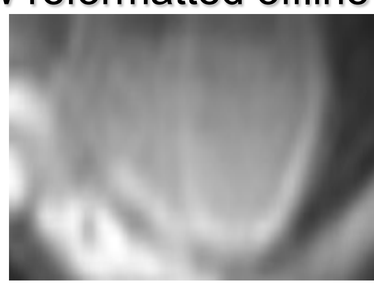


Phase image encoded in vertical direction



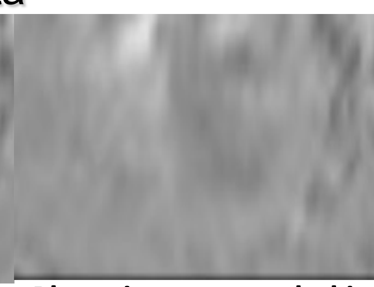
Phase image encoded in through-plane direction

- Long-axis view reformatted offline from short-axis data

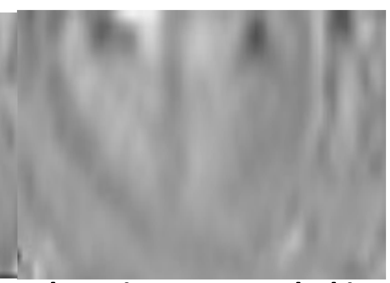


Magnitude image

Phase image encoded in horizontal direction



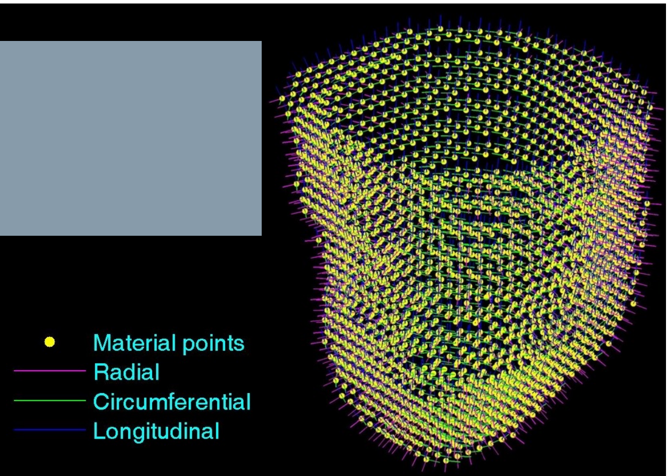
Phase image encoded in through-plane direction

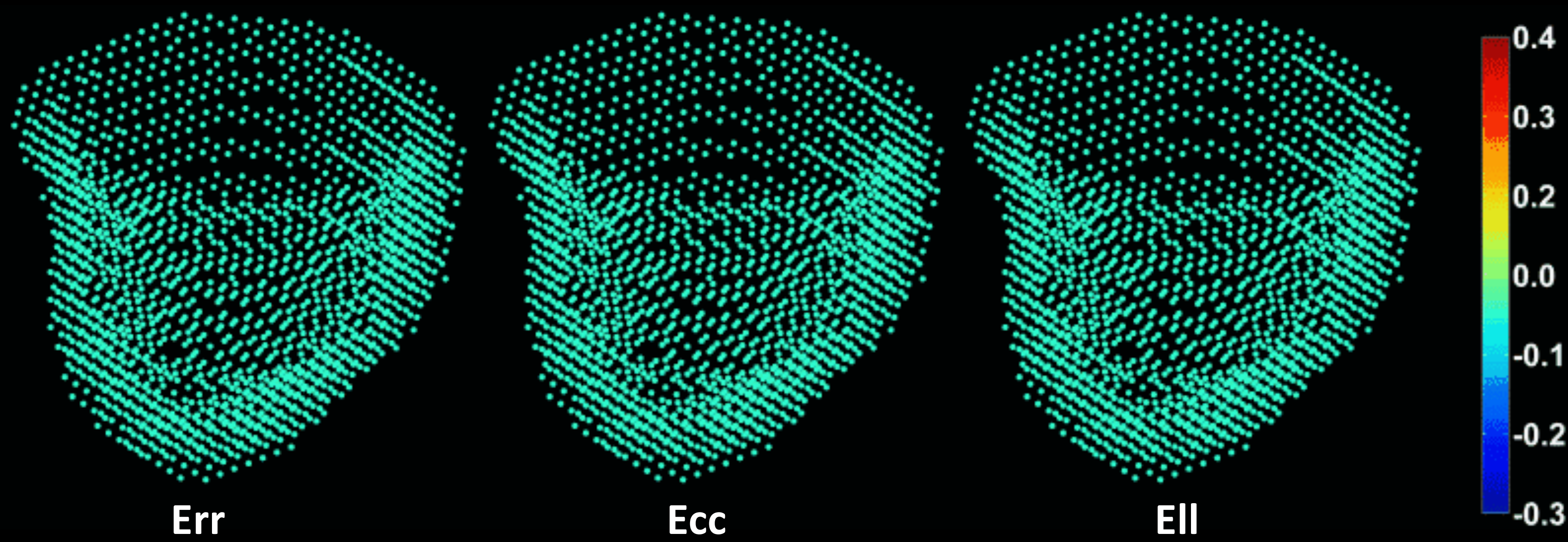


Phase image encoded in vertical direction

1. Zhong et al. MRM 2010; 64:1089-109.

Whole Heart Imaging (3D + Cine)
4D DENSE for LV Strain Imaging



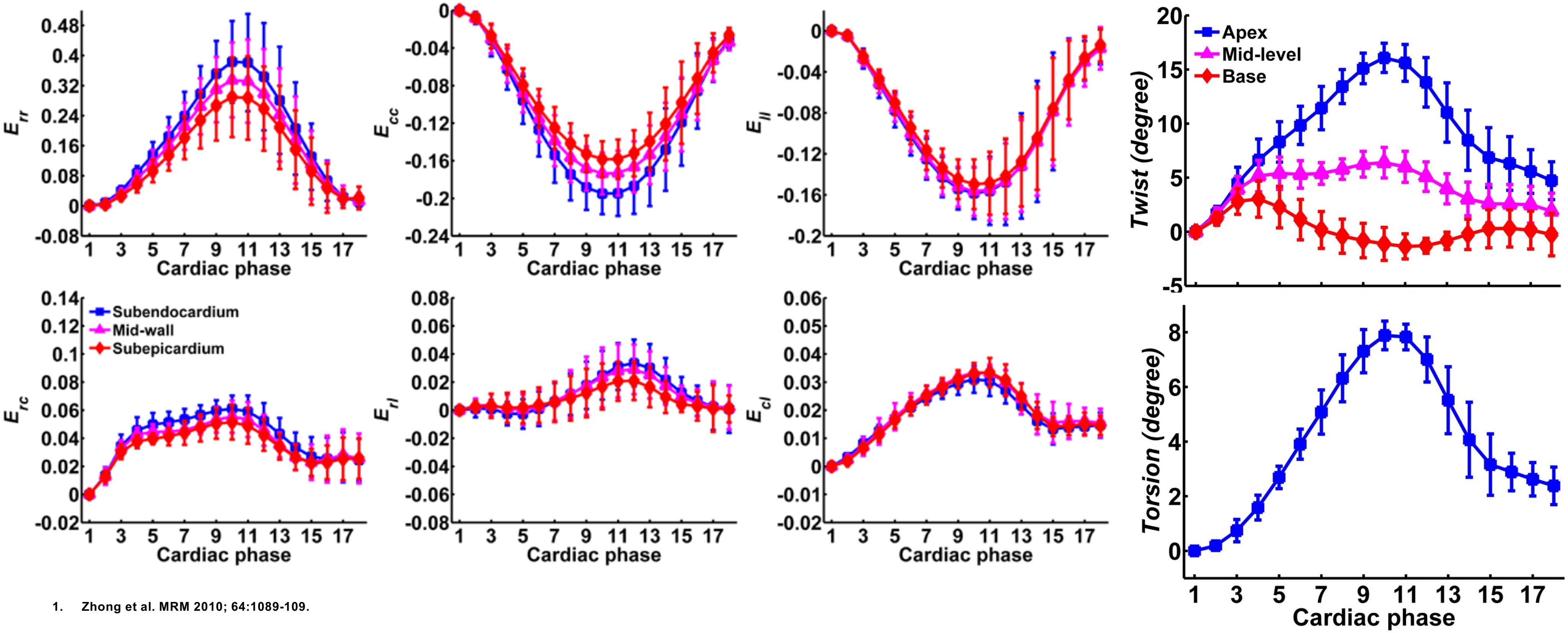


1. Zhong et al. MRM 2010; 64:1089-1097.

Example Ellipsoid Visualization of 3D End-Systolic LV Function

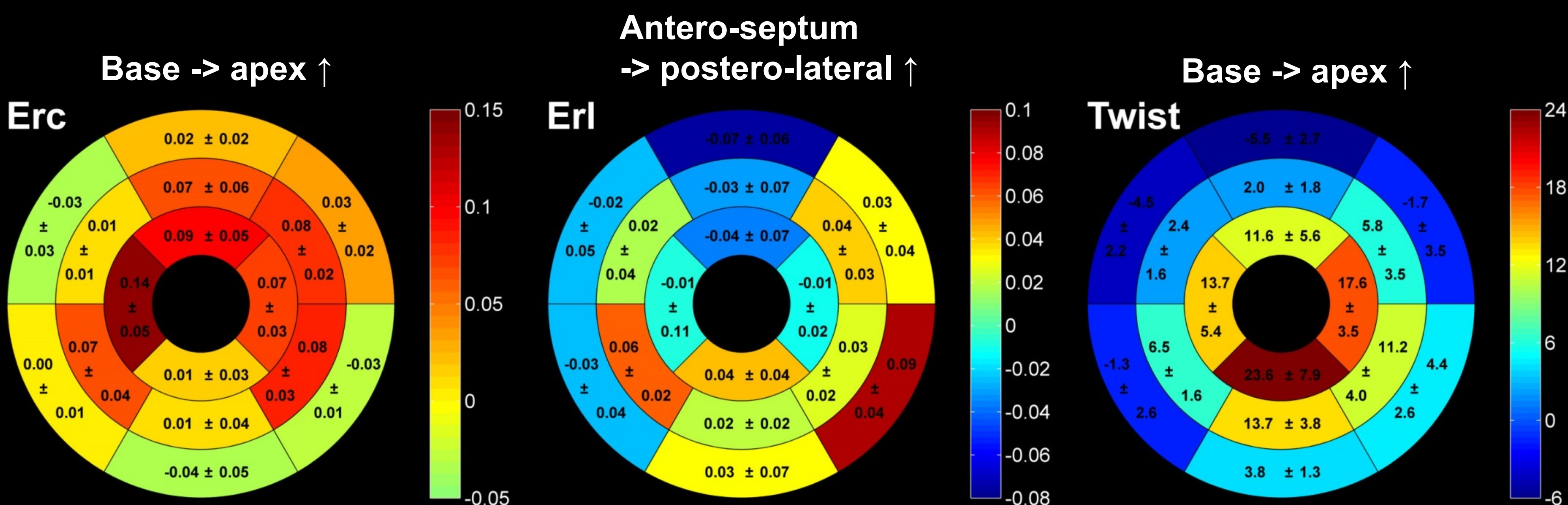
1. Zhong et al. MRM 2010; 64:1089-1097.

Strain, Twist/Torsion Curves as a Function of Time Averaged from 5 Healthy Volunteers



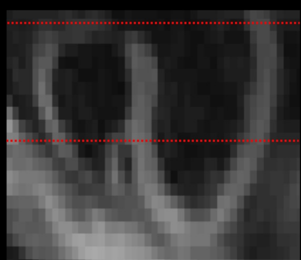
1. Zhong et al. MRM 2010; 64:1089-109.

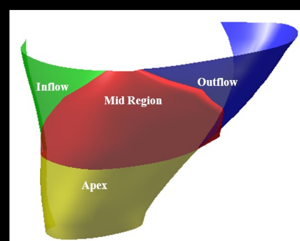
Bull's Eye Plots of Whole Heart Strain Biomarkers at End-Systole Averaged from 5 Healthy Volunteers

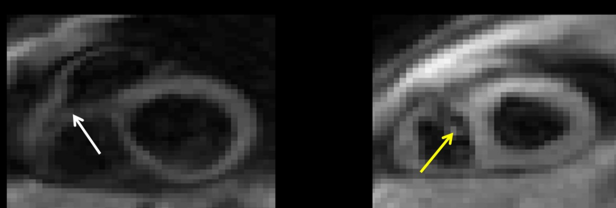


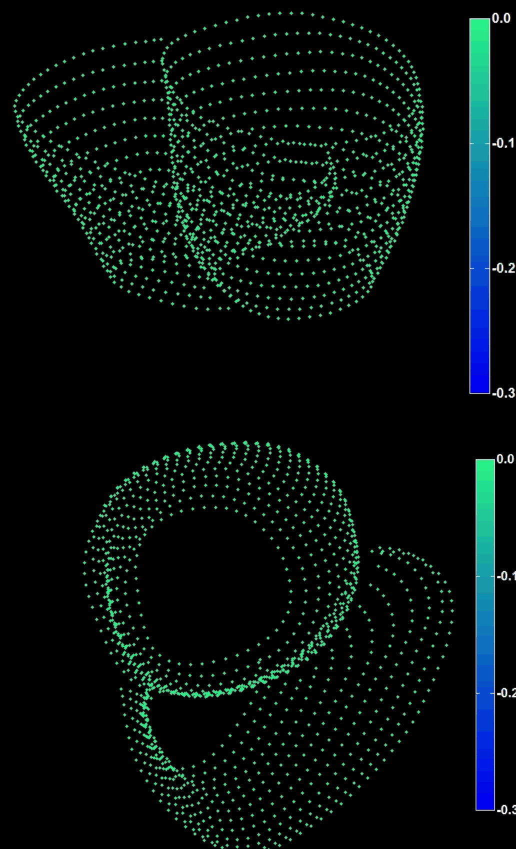
1. Zhong et al. MRM 2010; 64:1089-109.

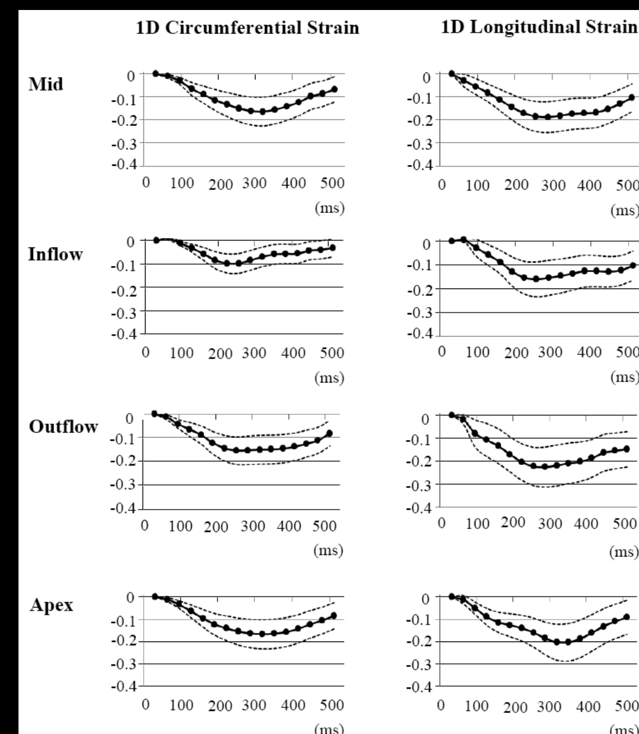
Whole Heart Imaging (3D + Cine)
4D DENSE for LV + RV











1. Auger et al. JCMR 2012;14:4.

Summary

Strain imaging is emerging as a clinical tool to improve the assessment of cardiac function and myocardial contractility

DENSE is advantageous for strain imaging
- Sensitive to subtle motion/strain (not limited by pixel size)
- Can measure various mechanical indices such as strain, strain rate, twist, torsion, strain-time curve

Multi-dimensional strain imaging offers highly comprehensive information

Many potential applications
- CV
- Neuro
- MSK
- etc

Zhong Lab @ MRRL

Advanced MRI Techniques

Novel AI Networks/Models

MR Pulse Sequence Design and Development

MR Data Reconstruction

MR Image Analysis

Clinical Applications

Collaboration with Research Partners

Collaboration with Physician Researchers

- Graduate student (PhD, MD/PhD, MS, rotating students)
- Postdoc scholar
- Project scientist
- Visiting scholar

https://mrrl.ucla.edu/zhonglab/

David Geffen School of Medicine

UCLA Health | Radiology

UCLA MAGNETIC RESONANCE Research Labs

David Geffen School of Medicine

UCLA Health | Radiology

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Acknowledgement

UCLA

- Paul Finn, MD
- Jamil Aboulhosn, MD
- Kim-Lien Nguyen, MD
- Holden Wu, PhD

Siemens

- Xiaoming Bi, PhD
- Fei Han, PhD
- Dominik Nickel, PhD
- Stephan Kannengiesser, PhD
- Vibhas Deshpande, PhD

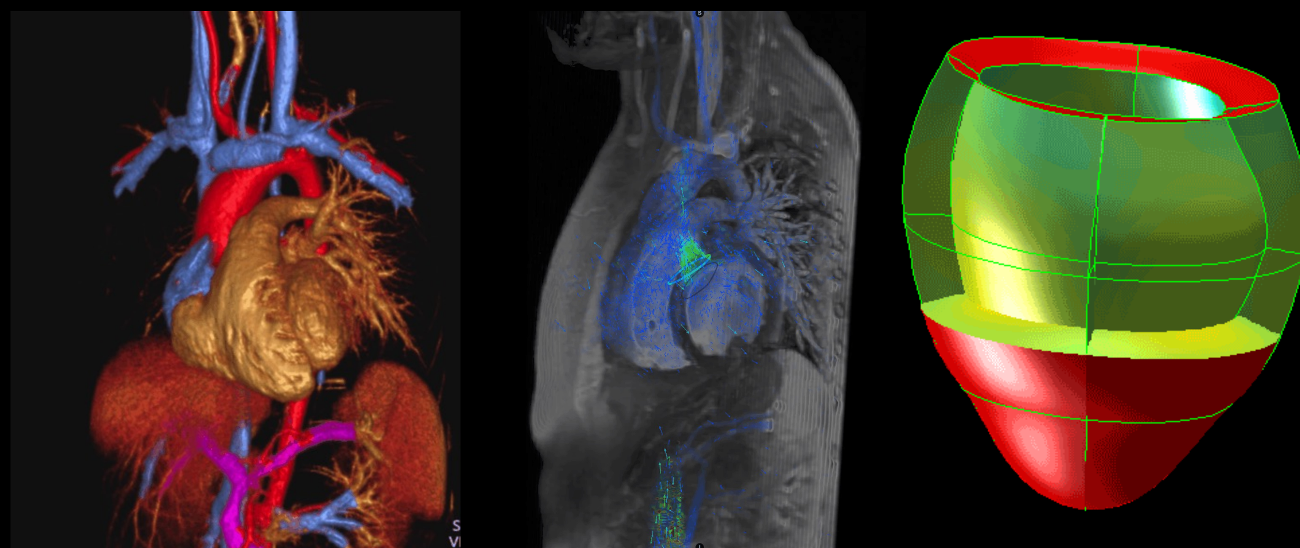
UVA

- Frederick Epstein, PhD
- Christopher Kramer, MD
- Patrick Helm, PhD

Emory

- John Oshinski, PhD
- Amit Saindane, MD, MBA

Thank You for Your Attention



* Conceptual images courtesy of Paul Finn, MD and Patrick Helm, PhD.