Strain by CMR, where do we stand?

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Introduction:

- Global measures, e.g. ejection fraction (EF), stroke volume, and myocardial thickness, represent the current standard for evaluating the heart condition.
- However, regional myocardial functions, e.g. as strain, strain rate, and torsion, allow for early identification of dysfunction, and therefore are becoming extremely important for clinical risk assessment, patient treatment, and therapeutic efficiency.
- More importantly, many cardiac disorders do not affect the heart wall uniformly, e.g. most ischemic heart diseases.
- This makes global measures insensitive to alterations in regional performance.
- A normal EF may conceal a significant underlying regional dysfunction.

Introduction: (continued)

- Understanding the intrinsic myocardial kinematics improves the interpretation and prediction of changes in different heart conditions.
- Cardiac function can be evaluated using echocardiography by techniques like speckle tracking.
- However, it makes simplifying geometric assumptions, which are not applicable in distorted heart anatomy.
- Computerized tomography (CT) is limited by relatively high radiation dose that restricts repeated studies or studies on healthy volunteers.

Introduction: (continued)

- Cardiovascular magnetic resonance (CMR) is excelling in terms of tissue contrast, spatial resolution, and signal-to-noise ratio (SNR).
- Different techniques are available for assessment of strain using CMR.

Measurement of Deformation:

- Strain: fractional or the percent change of length in a specific direction.
- Strain rate: strain changes per unit time.
- Torsion: basal clockwise rotation and apical counterclockwise rotation around the ventricular long axis

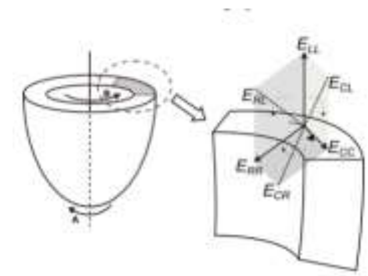


Figure 3
Schematic diagram demonstrating the three dimensional circumferential - radial - longitudinal (RCL) coordinate system used for strain calculation. Normal strains (dark solid arrows) are described with respect to the short axis plane: E_{CC} represents circumferential shortening tangential to epicardial surface, E_{RR} represents myocardial thickening radially towards the center of the ventricle and E_{LL} represents basal to apical shortening along the ventricular long axis. E_{RC}, E_{RL} and E_{CL} (dotted and curved arrows) represent change in angle caused by shear. Torsion represents the wringing motion caused by an apical counterclockwise rotation (curved arrow A) and a basal clockwise rotation (curved arrow B) around the ventricular long axis at end systole. Torsional deformation compensates for the opposing vectors in the subepicardium and subendocardium created by opposing myofiber arrangement in both layers.

Cardiovascular MR imaging offers different techniques for regional wall motion analysis:

- Myocardial tagging
- Phase velocity (Phase-velocity–based methods allow direct observation of the velocity of the tissue)
- Phase displacement phase contrast (PC) (velocity encoding of the myocardial spins)
- Optical flow methods (feature tracking)

Myocardial tagging

- Magnetization saturation bands in a grid format are placed onto the myocardium at the start of the cardiac cycle.
- Tagging approaches deliberately obliterate lines or grids of signal and watch-grid deformation, as these regions move during the cardiac cycle.

Myocardial tagging application

- Regional LV function
- Heart rotation and torsion motion (rate of recoil of myocardial torsion provides an assessment of LV relaxation.)
- Coronary artery disease (smoking & hypertension decreasing ECC in the LAD and RCA territory/increased calcium burden decreases circumferential strain)
- Ischemic heart disease (combining tagging with dobutamine stress for detecting chronic hibernating myocardium yielded a sensitivity of 89% and a specificity of 93% for recovery of segmental function 4-8 weeks after revascularization in 10 patients/tagging could detect more angiographically confirmed new wall motion abnormalities (68 patients) than dobutamine CMR without tagging(58patients).)

Myocardial tagging application: (continued)

- RV contractility pattern
- Hypertrophic cardiomyopathy (HCM
- Inter-ventricular synchrony
- Valvular diseases
- Congenital heart disease

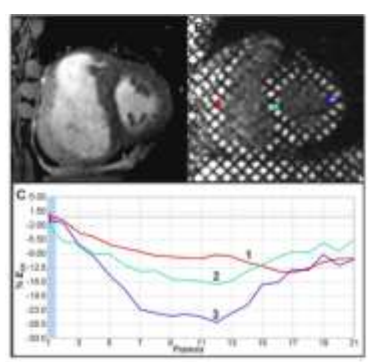


Figure 5
Pulmonary Arterial Hypertension (A-C). Cine gradient echo short axis image (A) showing right ventricular hypertrophy and systolic flattening of the inter-ventricular septum in a 64 year old patient with pulmonary arterial hypertension. Corresponding tagged image (B) and graph (C) show reduced magnitude and delayed RV free wall peak shortening (red curve 1) compared to the septum (green curve 2) and LV lateral wall (blue curve 3).

Limitations of tagging:

- Limited temporal resolution and the
- Need for sophisticated and time-consuming methods for image processing.
- Tags gradually fade during the cardiac cycle at 1.5T (less at 3T) due to tissue T1 relaxation and the imaging radiofrequency (RF) pulses.
- Limited evaluation of diastolic function.

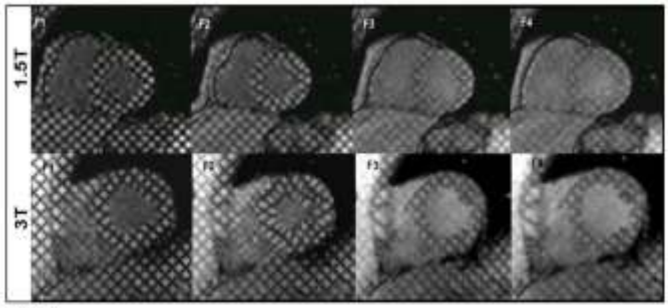
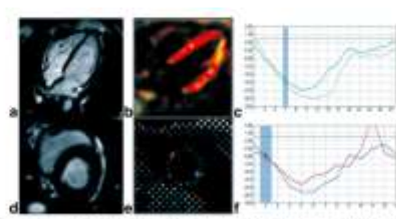


Figure 2
1.5 and 3T mid ventricular short axis tagging covering the cardiac cycle (F1-F4). Note better tag-tissue contrast and longer tag persistence (F4) on 3T MRI system.

Strain-Encoded MRI (SENC)

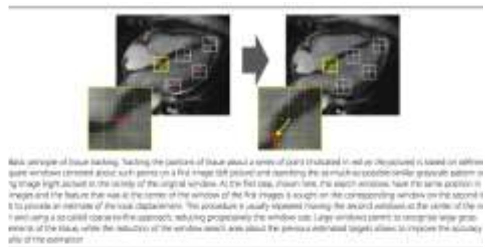
- In contrast to conventional tagging, SENC uses tag surfaces parallel—not orthogonal as in MR tagging—to the image plane combined with out-of- plane phase-encoding gradients along the slice-selected direction .
- Thus, long-axis views have to be generated to calculate circumferential strain and short-axis views to measure longitudinal strain. SENC pro-vides a higher temporal resolution of strain measure-ments throughout the whole cardiac cycle.



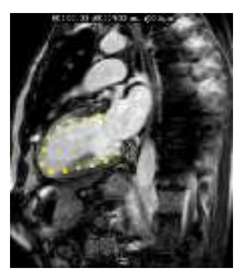
- SENC was validated against MR tagging as the reference method for noninvasive standard for evaluation of systolic deformation .
- There was a narrow limits of agreement between the two methods, which is at odds with previous published studies (10). The cor- relation coefficient was only sufficient (*r* 0.3), which is possibly due to the limited variance of strain values in this study cohort.
- However, using SENC, shorter breath-hold times are provided, which is important when investigating patients with severe heart failure or pulmonary diseases.
- Comparing our strain values obtained by SENC to strain values generated with other imaging modalities in previous published studies, such as echocardiographic speckle tracking and tissue Doppler we found similar strain values.
- However, the peak SENC values in our study were slightly higher than the peak MR tagging values in our and previous published studies (16,22,23).
- This phenomenon can be attributed to the higher temporal resolution of SENC resulting in a higher probability of acquisition of the peak systolic contraction.

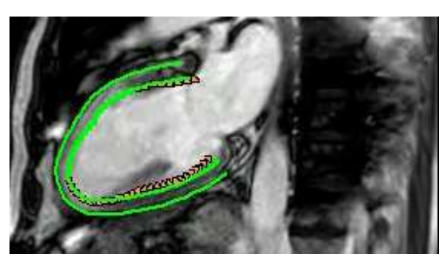
Optical flow methods: feature tracking

- Myocardial feature tracking (FT) is a technique similar to echocardiographic speckle tracking.
- CMR-FT allows the tracking of tissue voxel motion of cine-CMR images to derive wall mechanics and strain without acquisition of additional sequences .
- CMR-FT has been validated against myocardial tagging with good agreement between CMR-FT and harmonic phase imaging (HARP).

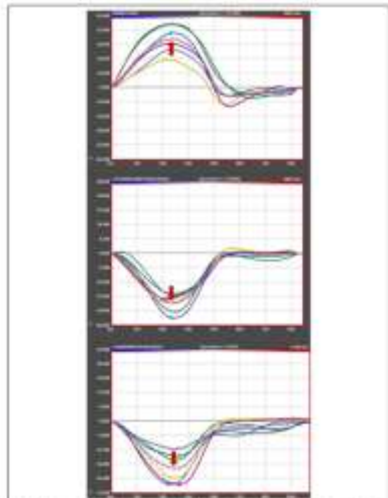


- Feature Tracking software delivers outputs of myocardial strain, segmental velocity and displacement parameters which are relatively quick in terms of image acquisition and post processing.
- The technique avoids the additional time needed for either tissue phase mapping or tagging and raises the possibility of retrospective analysis of existing CMR datasets.
- It also allows for the assessment of atrial strain.





- Reference values for feature tracking in healthy volunteers have been published by Andre et al..



Feature tacking vs. 2D/3D echo speckle tracking

- Although the LOA in GLS and GCS findings between CMRFT and 2D/3DEST cannot be ignored, there were excellent correlation be- tween CMRFT and 2D/3DEST for strain measurements. CMRFT can be a valid alternative to 2D/3DEST for the quantification of glo- bal LV strains, especially in patients with suboptimal echo image quality.

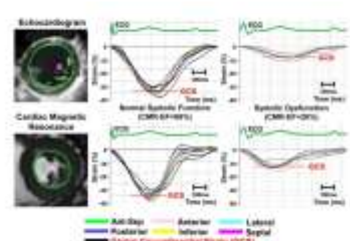


Figure 1 Examples of LV circumferential strain (mid-LV short-axis, papillary muscle level) in a subject with normal LV systolic function (left) and a subject with LV systolic dysfunction. Six segmental strain and GCS curves were generated after semiautomated endocardial border tracking at end-systole (inner green contours) in echocardiography (top) and in CMR (bottom). Paired top and bottom time-strain curves are from the same two subjects. CMR, Cardiac magnetic resonance; EF, ejection fraction; GCS, global circumferential strain; GLS, global longitudinal strain; LV, left ventricular.

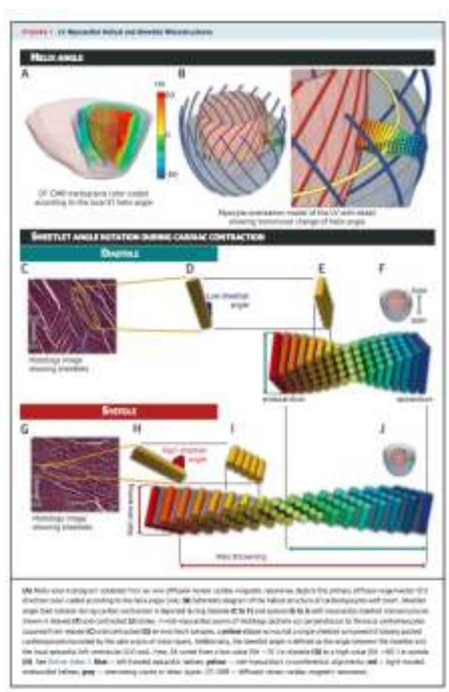
Feature tracking vs. Tagging

- In a study comparing FT and tagging in Duchenne muscle dystrophy (DMD) found FT-based assessment of circumferential strain correlates highly with circumferential strain derived from tagged images in a large DMD patient population with a wide range of cardiac dysfunction and can be performed without additional imaging.
- However, Tagging-based circumferential strain measurement discriminated between younger and older DMD patients, yet feature tracking– based circumferential strain could not detect this difference.

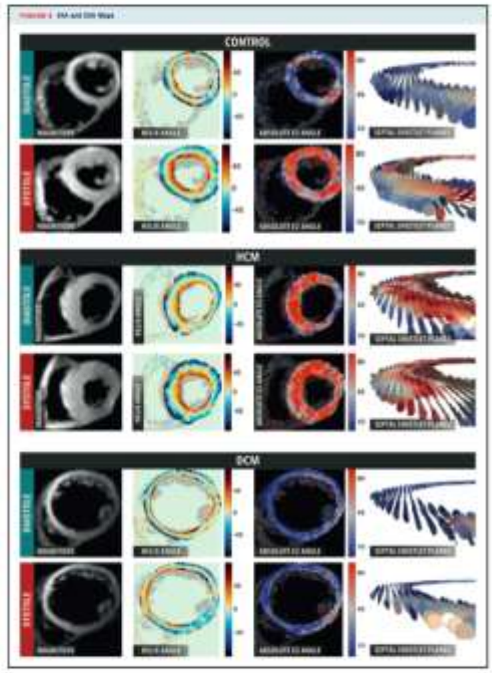
Is there more?

Diffusion Tensor Cardiac Magnetic Resonance

- Recently, a number of studies have indicated that diffusion-weighted magnetic resonance imaging (MRI) may be used to determine the muscle fiber orientation of tissues.
- In one approach, known as diffusion tensor magnetic resonance imaging (DT- MRI), this fact is used to estimate a voxel-averaged diffusion tensor specifying diffusivity in each of three principal coordinate directions at each voxel of the tissue image.
- It appears that water, being unrestricted by membrane, preferentially diffuses in the direction of the long axis of a cylindrical fiber. This observation has been used to map fiber orientation of the myocardium



- Myocardial microstructure dynamics can be characterized by in vivo DT-CMR.
- Sheetlet function was abnormal in DCM with altered systolic conformation and reduced mobility indicating a failure of systolic sheetlet rotation to a contracted conformation
- Contrasting with HCM, which showed reduced mobility with altered diastolic conformation indicating failure of rotation of sheetlets to a relaxed conformation in diastole in HCM.
- These novel insights significantly improve understanding of contractile dysfunction at a level of noninvasive interrogation not previously available in humans.



Conclusion:

- CMR for the assessment of strain is a rich and complex modality for the assessment of strain.
- It offers different techniques, some of which are time consuming and not suited for daily clinical practice, rendering them only for research purposes.

Conclusion: (continued)

- Ongoing developments in the technology, imaging techniques, and analytical tools used will facilitate its use in daily clinical practice.
- This will give us insights into the different disease patterns and ultimately allow better, more efficient patient outcomes.

References:

1. Obokata, M. et al. Direct comparison of cardiac magnetic resonance feature tracking and 2D/3D echocardiography speckle tracking for evaluation of global left ventricular strain. Eur Heart J Cardiovasc Imaging 17, 525–532 (2016).
2. Hor, K. N. et al. Comparison of Magnetic Resonance Feature Tracking for Strain Calculation With Harmonic Phase Imaging Analysis. JACC Cardiovasc Imaging 3, 144–151 (2010).
3. Petersen, S. E. et al. Myocardial Tissue Phase Mapping with Cine Phase-Contrast MR Imaging: Regional Wall Motion Analysis in Healthy Volunteers. Radiology 238, 816–826 (2006)
4. Neizel, M. et al. Strain-encoded (SENC) magnetic resonance imaging to evaluate regional heterogeneity of myocardial strain in healthy volunteers: Comparison with conventional tagging. J. Magn. Reson. Imaging 29, 99–105 (2009).Strain-Encoded (SENC) Magnetic Resonance Imaging to Evaluate Regional Heterogeneity of Myocardial Strain in Healthy Volunteers: Comparison With Conventional Tagging
5. Augustine, D. et al. Global and regional left ventricular myocardial deformation measures by magnetic resonance feature tracking in healthy volunteers: comparison with tagging and relevance of gender. JACC Cardiovasc Imaging 1–10 (2013). doi:10.1186/1532-429X-15-8
6. Andre, F. et al. Age- and gender-related normal left ventricular deformation assessed by cardiovascular magnetic resonance feature tracking. Journal of Cardiovascular Magnetic Resonance 1–14 (2017). doi:10.1186/s12968-015-0123-3
7. Shehata, M. L., Cheng, S., Osman, N. F., Bluemke, D. A. & Lima, J. A. Myocardial tissue tagging with cardiovascular magnetic resonance. J Cardiovasc Magn Reson 11, 55–12 (2009).
8. MD, G. A. M., PhD, J. D. P. & PhD, K. G. H. Diffusion Tensor Magnetic Resonance Imaging of the Heart. JAC 69, 677–678 (2017).

Thank you!