Myocardial Strain Imaging Using Feature Tracking Method of Cardiac MRI: Our Initial Experience of This Novel Parameter as an Additional Diagnostic Tool

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Abstract

Background Left ventricular ejection fraction (LVEF) is used as quantitative parameter to evaluate myocardial function. However, interobserver variation, limited reproducibility, and dependence on pre-load and after-load reduces its accuracy. The fall in LVEF occurs very late, when myocardial dysfunction is already advanced. Myocardial strain measurements (especially global longitudinal strain) is a new parameter to detect myocardial dysfunction before derangements in LVEF. The aim of this article is to share our experience of this novel diagnostic tool.

Methods Feature tracking method of strain assessment is performed using routine long and short axis cine images of cardiac MRI (CMR). Dedicated post-processing CMR software can perform off-line analysis and provide results in form of color-coded maps, percentage values as well as strain over time curve for each myocardial segments.

Results Global longitudinal strain (GLS) is more sensitive than LVEF and can identify subclinical left ventricular (LV) dysfunction in various cardiomyopathies. It is also an important prognostic marker in serial assessment of heart failure patients. Regional differences in strain parameters can provide clues in hypertrophic cardiomyopathy as well as amyloidosis. GLS is recommended as routine measurement in patients undergoing chemotherapy to detect LV dysfunction prior to fall in LVEF. Strain imaging can be applied to guide placement of the LV pacing lead in patients receiving cardiac resynchronization therapy. More clinical data is needed to evaluate its role in ischemic heart disease.

Conclusion Strain imaging can identify LV dysfunction earlier than conventional methods and this opens a new perspective in risk stratification and therapeutic decision-making of various cardiac pathologies.

Keywords
- myocardial strain
- feature tracking
- cardiac magnetic resonance imaging

Introduction

The left ventricular (LV) and right ventricular myocardial strain measurements with speckle tracking echocardiography have established its role as diagnostic and prognostic marker of myocardial dysfunction in noninvasive cardiac imaging. It is established tool in clinical practice in chemotherapy-related myocardial dysfunction.[1,2] We intended to

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Table 1 List of various cardiovascular pathologies along with patient demographic data where myocardial strain was used as an incremental diagnostic tool

No of patients	Primary clinical indication/diagnosis for cardiac MRI study	Age group	Males	Females
30	Cancer patients receiving various chemotherapy drugs	38–42 yr	3	27
74	Ischemic heart disease (viability studies/stress perfusion studies)	62–74 yr	54	20
68	Cardiomyopathy of various causes (HCM/amyloid/sarcoid, etc.)	62–74 yr	45	23
45	Heart failure due to various reasons (DCM and other causes)	65–78 yr	32	13
38	Abnormal rhythm evaluation/pericardial diseases/cardiac masses	55–67 yr	24	14

Abbreviations: DCM, dilated cardiomyopathy; HCM, hypertrophic cardiomyopathy; MRI, magnetic resonance imaging.

Table 2 Details of the scanner and processing software and normal range of different strain parameters in our study

Vendor	Software	Type of strain	Mean normal values
Siemens (3T)	suiteHEART, NeoSoft	Longitudinal strain	−20% (±1.0%)
		Circumferential strain	−20% (±1.0%)
		Radial strain	+40% (±2%)

use the same principle of detecting myocardial deformation as an additional diagnostic tool using feature tracking method myocardial strain assessment.

Feature tracking cardiac magnetic resonance imaging (MRI) strain measurements are obtained using offline analysis of cardiac MR (CMR) images (balanced steady-state free precession/b-SSFP) or spoiled fast gradient echo (GRE) sequences (spoiled GRE). It is based on identification of anatomic features in CMR image along with myocardial boundaries. There is no increase in acquisition time.[3] Though CMR may be performed for different clinical indications, strain post-processing can be performed with routinely acquired b-SSFP or spoiled GRE long- and short-axis images. This additional information of myocardial strain provides more insight into disease pathology and serves as diagnostic tool of incremental value.

Methods

MRI Examination Protocol

All cardiac MRI examinations were performed on Siemens Verio 3 Tesla Scanner System with 70 cm bore. All CMR examinations were conducted with electrocardiogram (ECG) gating and performed with adequate breath hold using both anterior and posterior array coils. Segmented acquisition of 25 phases of a cardiac cycle were obtained for each long- and short-axis view. Complete examination with cine images in three long-axis and six short-axis views, flow imaging of aorta and pulmonary artery with phase contrast sequences, and late gadolinium enhancement imaging using inversion recovery sequences were performed as per routine protocol.

Patients

We primarily evaluated role of this technique for the diagnosis of chemotherapy-induced cardiotoxicity. However, we extended its use in post-processing of all CMR investigations performed at our institute. Total 255 CMR studies were evaluated over period of 6 months. The aim of this study was to assess its usefulness as an additional diagnostic tool.

Study included CMR performed for various clinical indications, such as cardiomyopathy, ischemic heart disease, ventricular tachycardia, pericardial diseases, and others. MRI findings were assessed and then strain measurements were obtained to evaluate its utility as an additional diagnostic tool (►**Table 2**).

Image Interpretation

Post-processing was performed using commercially available dedicated CMR post-processing software (suiteHEART, NeoSoft LLC, Wisconsin, United States). Offline CMR strain analysis was conducted by manually delineating endocardium and epicardium of the left ventricle in long- and short-axis views in end diastole. The trabecular or spongy myocardium was included in the LV cavity volume. Automatic computation was triggered. Applied Software algorithm automatically outlines the border throughout the cardiac cycle. The quality of tracking was visually validated and manually corrected if needed.[4]

Results

The longitudinal strain data was derived from two-chamber, three-chamber, and four-chamber long-axis views and the radial and circumferential strain data was derived from short-axis views. Peak global longitudinal strain (GLS), global radial strain, and global circumferential strain values and strain over time curves were automatically generated by the software. Additionally, the segmental peak systolic strain values and strain over time curves for American Heart Association prescribed 17 segment model were automatically generated by the software.

The longitudinal strain is deformation (shortening) of the left ventricle from base to apex and the circumferential strain

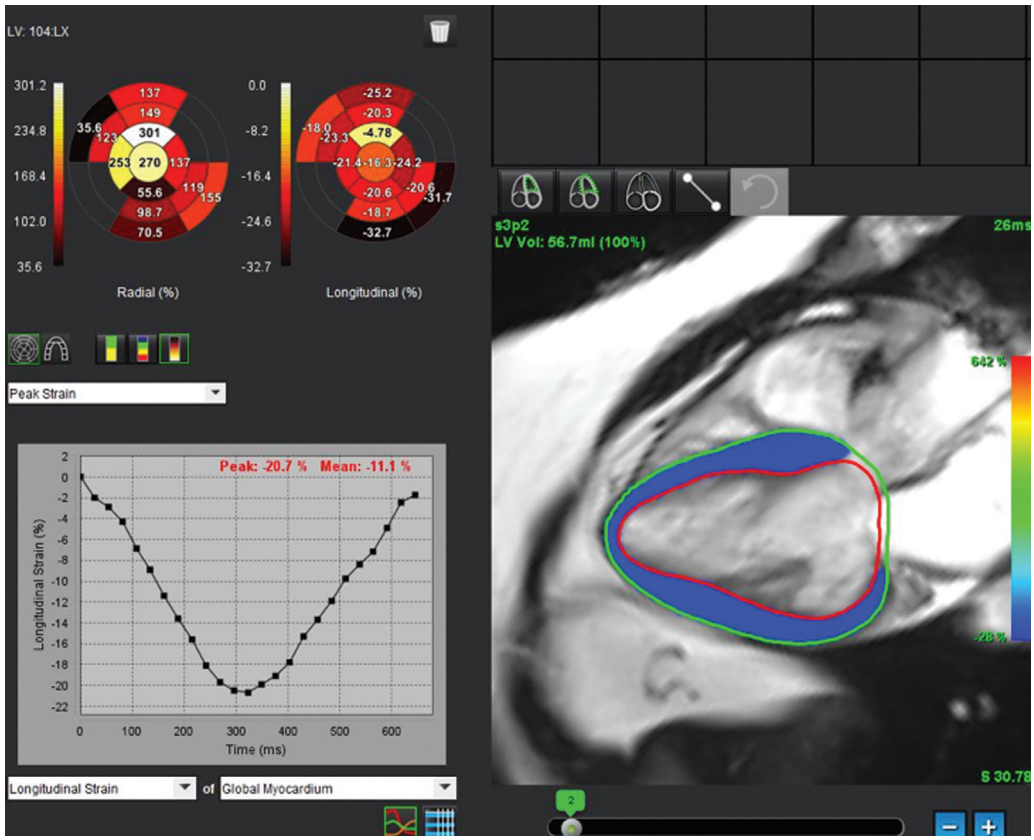

Fig. 1 Post-processing of radial and longitudinal strain measurements is performed on long axis images. Results can be obtained as bullseye map (left panel top) or graph (left panel bottom) along with color coding of cine images (right panel).

is deformation (shortening) of the left ventricle in circumferential direction. The longitudinal strain and the circumferential strain results are conventionally given negative strain values. Radial strain refers to radial deformation (thickening) of the LV wall. The radial strain results are conventionally given positive strain values[5] (►**Figs. 1** and **2**).

Due to intervendor and intersoftware variability, the normal values for GLS can vary from −17.3 to −21.5%. Hence, serial assessment of GLS in individual patients should be performed using the same vendor's equipment and the same software.

Also, strain is not uniform in all the three layers of the myocardium. There is a gradient from endocardium to epicardium as the endocardium undergoes more deformation as compared with the epicardium resulting in higher strain values in the endocardium. There is also a gradient from the base to the apex of the heart with apical strain being higher than the strain in the basal segments. It is recommended that every center creates its normal values after scanning healthy patients of different age groups (►**Table 2**).

Discussion

Left ventricle has three-dimensional helical myocardial fibers, orientation that changes continuously from a right-handed helix in the subendocardial region to a left-handed helix in the subepicardial region. This complex fiber arrangement in myocardium results in torsional movement during myocardial contraction.[6]

The LV deformation can be described in three dimensions by three normal strains (longitudinal, circumferential, and radial) and three shear strains (circumferential–longitudinal, circumferential–radial, and longitudinal–radial).[5]

For clinical use, only three Lagrangian strains (longitudinal, circumferential, and radial) are measured and are expressed in percentage values. Positive strain values describe thickening or lengthening and negative strain values describe shortening or thinning of a given myocardial segment related to its original length (Lagrangian strain). During myocardial contraction assessment of radial thickening (positive strain), circumferential shortening (negative strain) and longitudinal shortening (negative strain) are useful for the objective evaluation of contractile function.

Longitudinal strain occurs from base to apex as mitral annulus displaces toward the relatively stationary LV apex predominantly due to contraction of subendocardial helical fibers. Since most of the cardiac pathologies (ischemia, infarction, infiltration, hypertension, diabetes) affect subendocardial fibers first, the LV longitudinal strain is affected earlier than other strain components and left ventricular ejection fraction (LVEF). The early reduction in longitudinal function is compensated by increase in the torqueing (twisting) function described below.

The contraction of subepicardial helical fibers results in counter-clockwise LV rotation near the apex and clockwise rotation near the LV base during ejection.[6] This torque causes

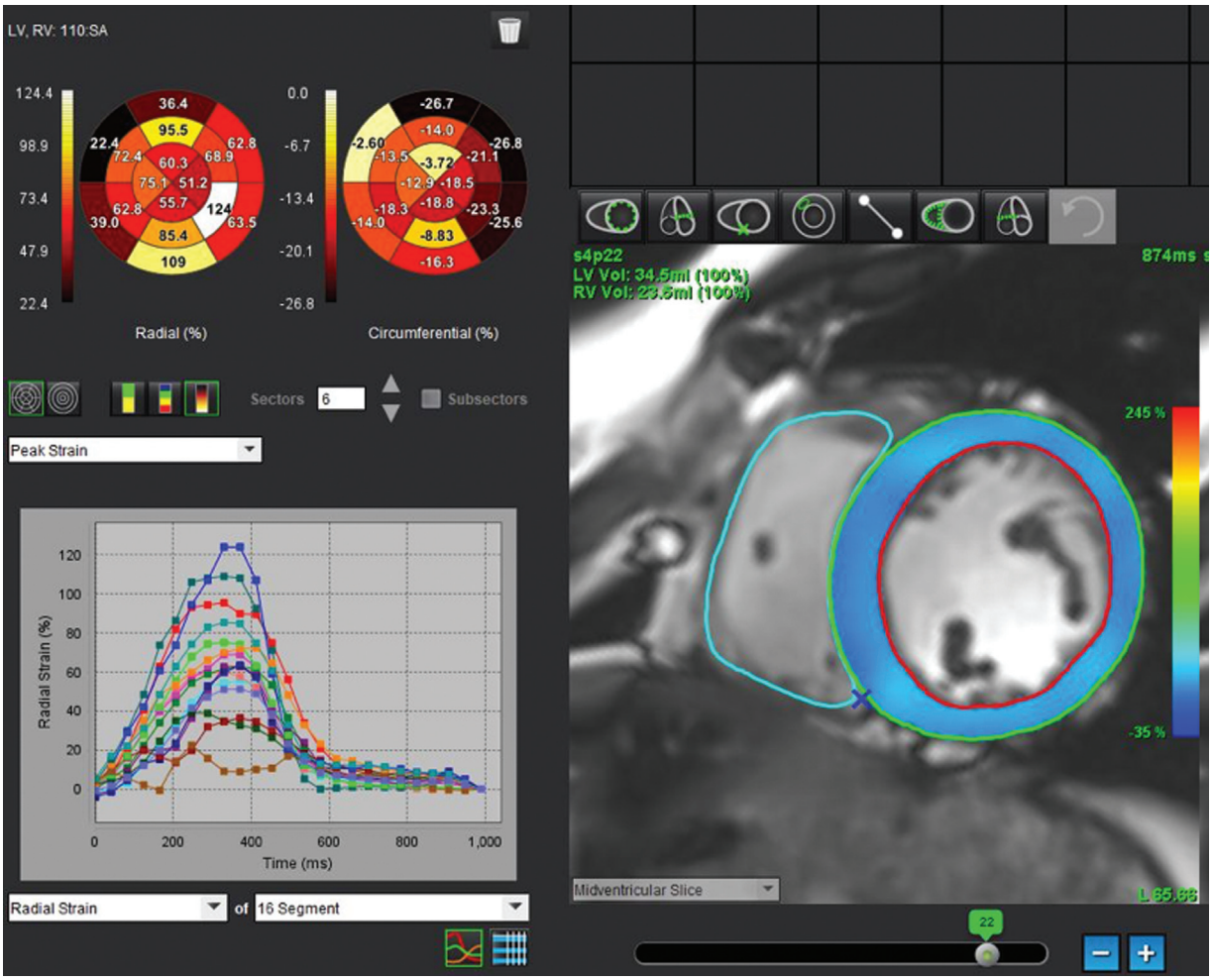

Fig. 2 Post processing of radial and circumferential strain is performed on short axis images. This can be plotted as Bulls eye map (left panel top), Graphic representation for 16 segments (Left panel bottom), and color coded image (Right panel).

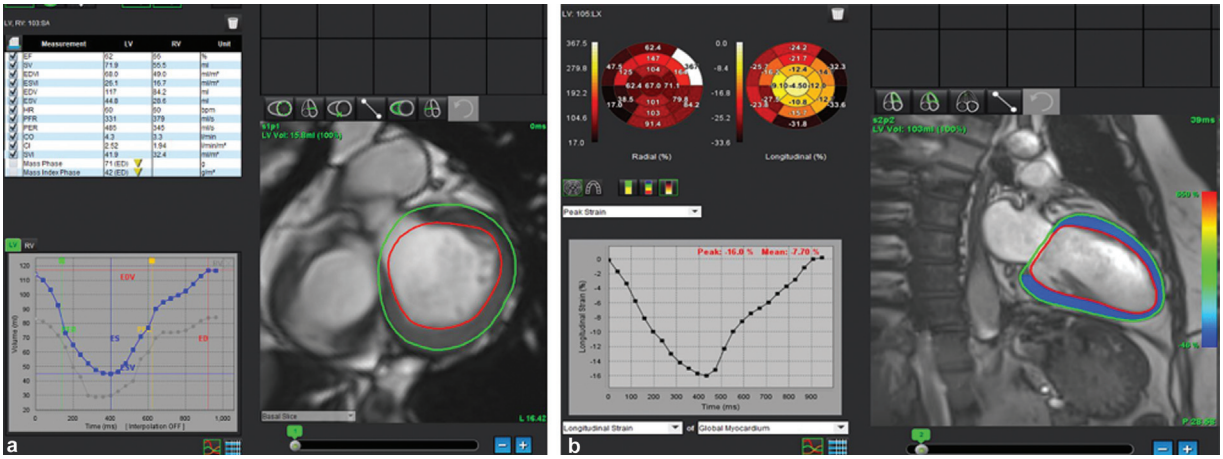

Fig. 3 Cardiotoxicity of chemotherapy drugs can be monitored using routine parameters. Ejection fraction can be calculated on short axis images (left image). Global longitudinal strain measurements are obtained using long axis images. This serves as additional adjunct to diagnose subclinical LV dysfunction. Strain is often reduced before derangements in LVEF.

shortening in the circumferential direction in the midwall. The circumferential strain is affected by transmural involvement of fibers (e.g., transmural infarct, advanced cardiomyopathies) or by epicardial fiber involvement (e.g., myopericarditis). The torque described above also causes fiber rearrangement, so that the noncompressible mid- and subendocardial fibers are sheared (pushed) toward the center of the LV cavity causing LV wall thickening in the radial direction.[6] The radial strain is affected late in the disease process when the pathological process is transmural.

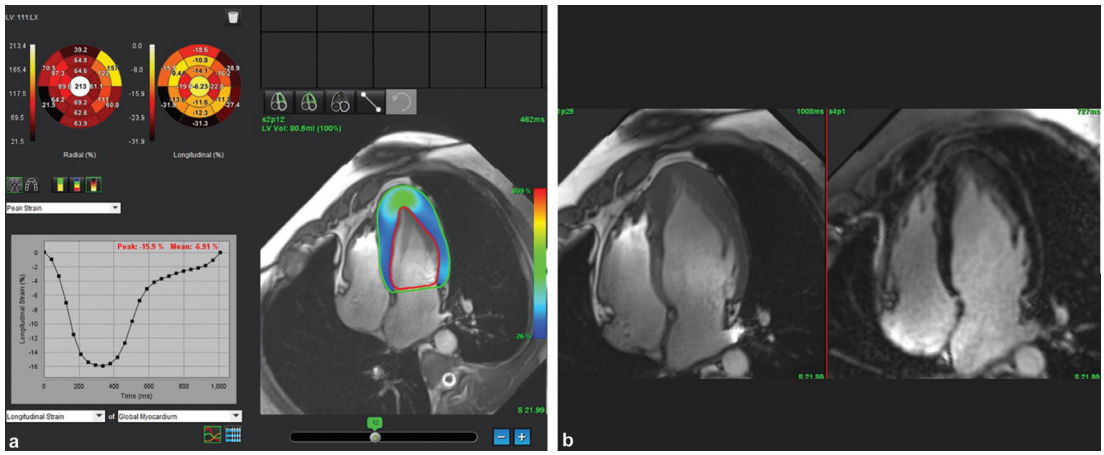

Fig. 4 Apical hypertrophic cardiomyopathy showing thickening of apical myocardium with obliteration of LV apex and late gadolinium enhancement (right image). Reduced strain values are seen in thickened apical myocardium due to fibrosis.

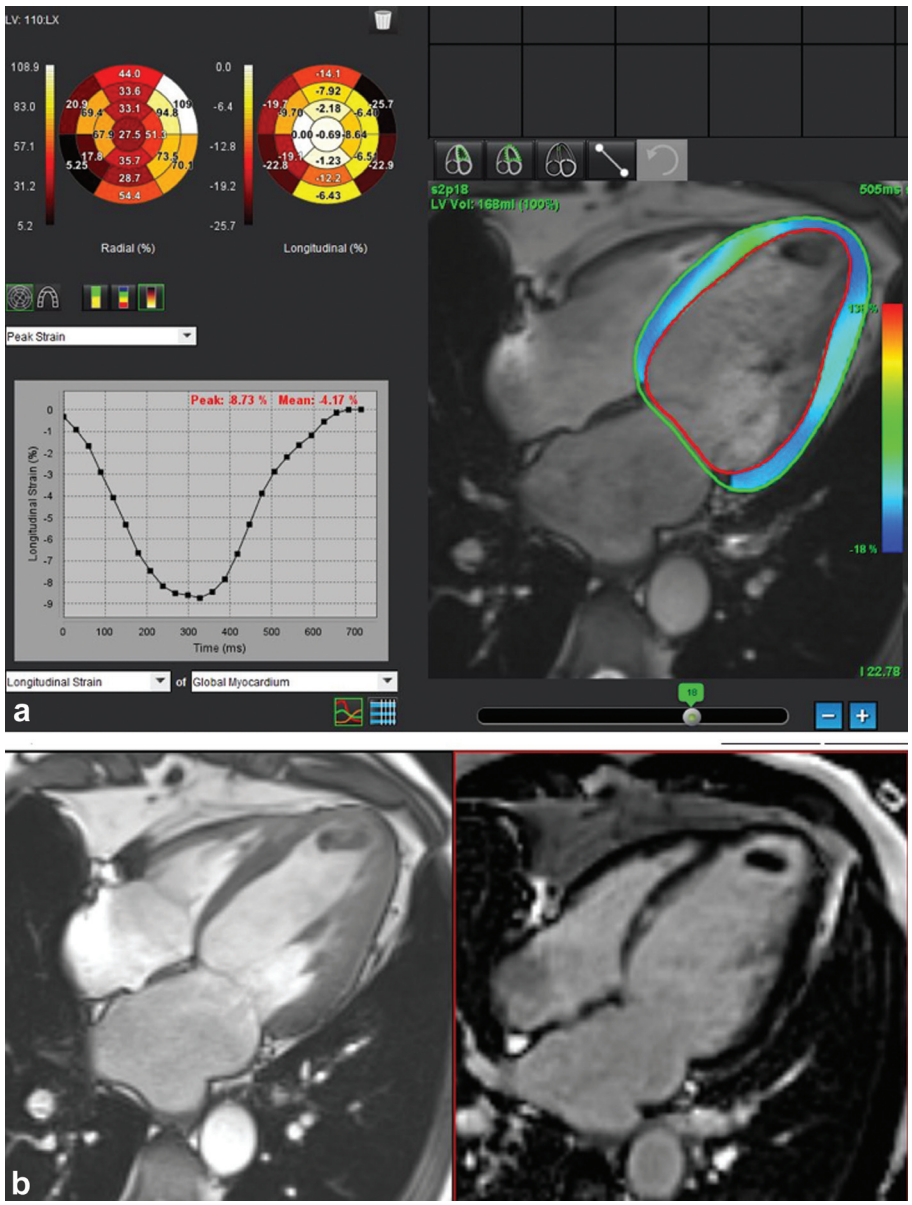

Fig. 5 Diagnosed case of ischemic heart disease with subendocardial late gadolinium enhancement involving interventricular septum and thrombus near apex of left ventricle (bottom image). Reduced strain values are seen in myocardial segments with infarction.

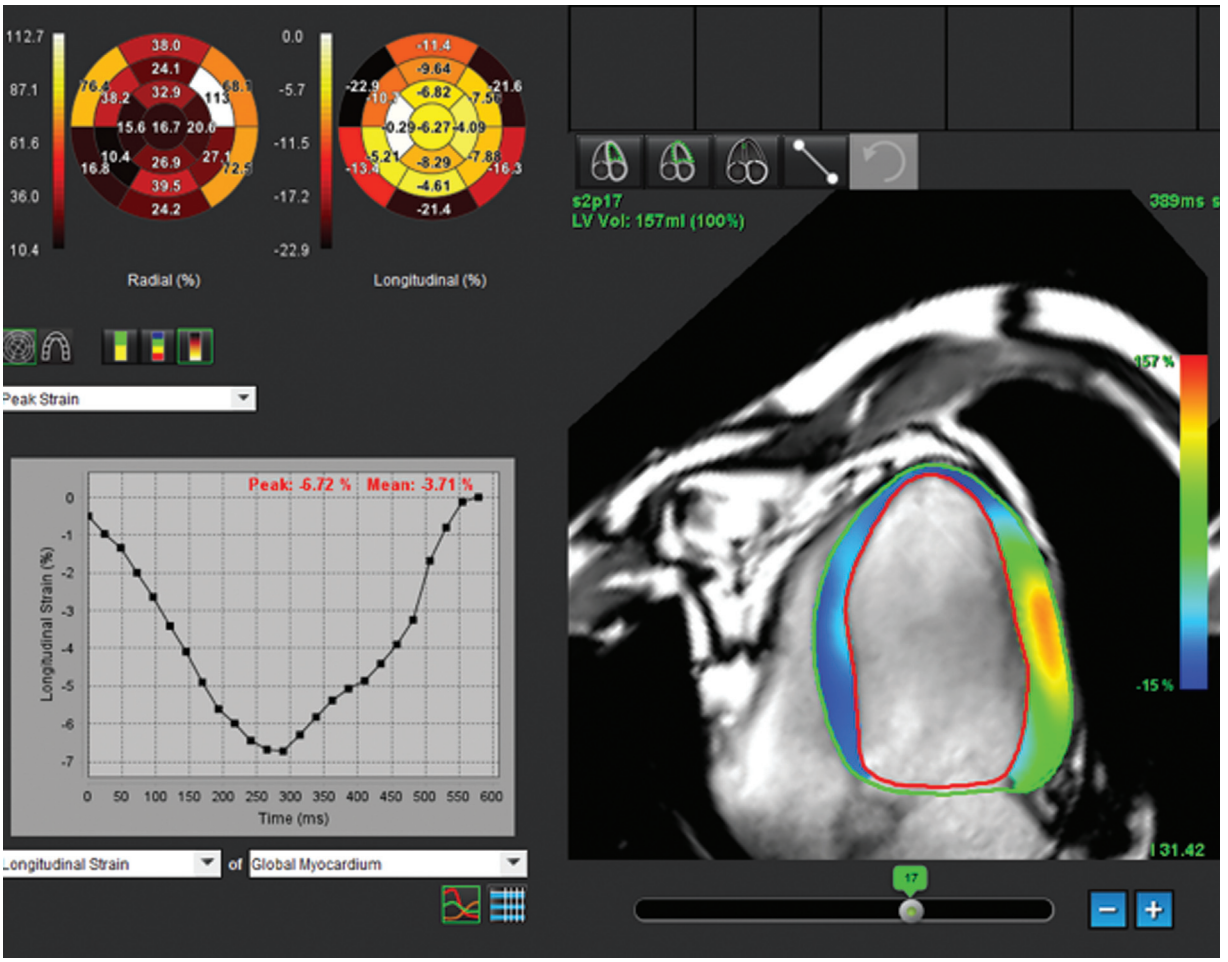

Fig. 6 Case of dilated cardiomyopathy with significantly reduced global longitudinal strain (left panel). There is marked reduction in lateral wall, which may suggest underlying fibrosis. This segment-wise assessment is helpful for planning of resynchronization therapy.

Various cardiac pathologies evaluated with strain measurements are as follows:

Cardiotoxicity of chemotherapy drugs is leading cause of morbidity and mortality in cancer patients. Regular monitoring of cardiac function needs to be performed in cost-effective manner during chemotherapy. The appropriate antiheart failure medical therapy can be administered at an appropriate time before irreversible LV dysfunction or overt clinical heart failure sets in. The reduction in LV longitudinal strain occurs many months prior to reduction in LVEF during anthracycline chemotherapy.[2,7] The current expert consensus document advises periodic assessment of LV GLS in patients undergoing chemotherapy to detect early subclinical cardiotoxicity induced myocardial dysfunction. Abnormal strain values should result in implementation of antiheart failure medications, modification of chemotherapy, and close monitoring of cardiac function (►**Fig. 3**). Relative decline in GLS of > 15% is indicative of subclinical LV dysfunction and should prompt cardiology consultation and potential initiation of cardioprotective drugs as well as chemotherapy dosing modifications.

Hypertrophic cardiomyopathy (HCM) is an inherited disease characterized by myocardial disarray and interstitial fibrosis that can result in reduction in longitudinal strain prior to reduction in EF. This may be useful in monitoring first-degree relatives of HCM patient who may not have yet manifested phenotypical disease. The reduction in regional longitudinal strain is quite variable depending upon the asymmetric nature of the disease (asymmetric septal or focal or apical hypertrophy) with strain being markedly affected at the area of late gadolinium enhancement. The finding of variably reduced longitudinal strain helps in differentiating HCM from athlete's heart-related physiological hypertrophy (►**Fig. 4**)

Ischemic heart disease will result in reduction in regional peak systolic strain. Further demonstration of systolic lengthening (in transmurally infarcted myocardial segments) and post systolic shortening (resting ischemic/hibernating myocardial segments) are also characteristic features of ischemic heart disease. Different myocardial segments with different levels of ischemia and transmurality of scarring will show different strain maps. Myocardial infarction confined to subendocardium reduces regional longitudinal strain profoundly while minimally affecting or preserving circumferential and radial strains (►**Fig. 5**).

Heart failure is a key application for strain assessment as these patients will have reduced strain values before reduction of ejection fraction. Strain imaging identifies patients

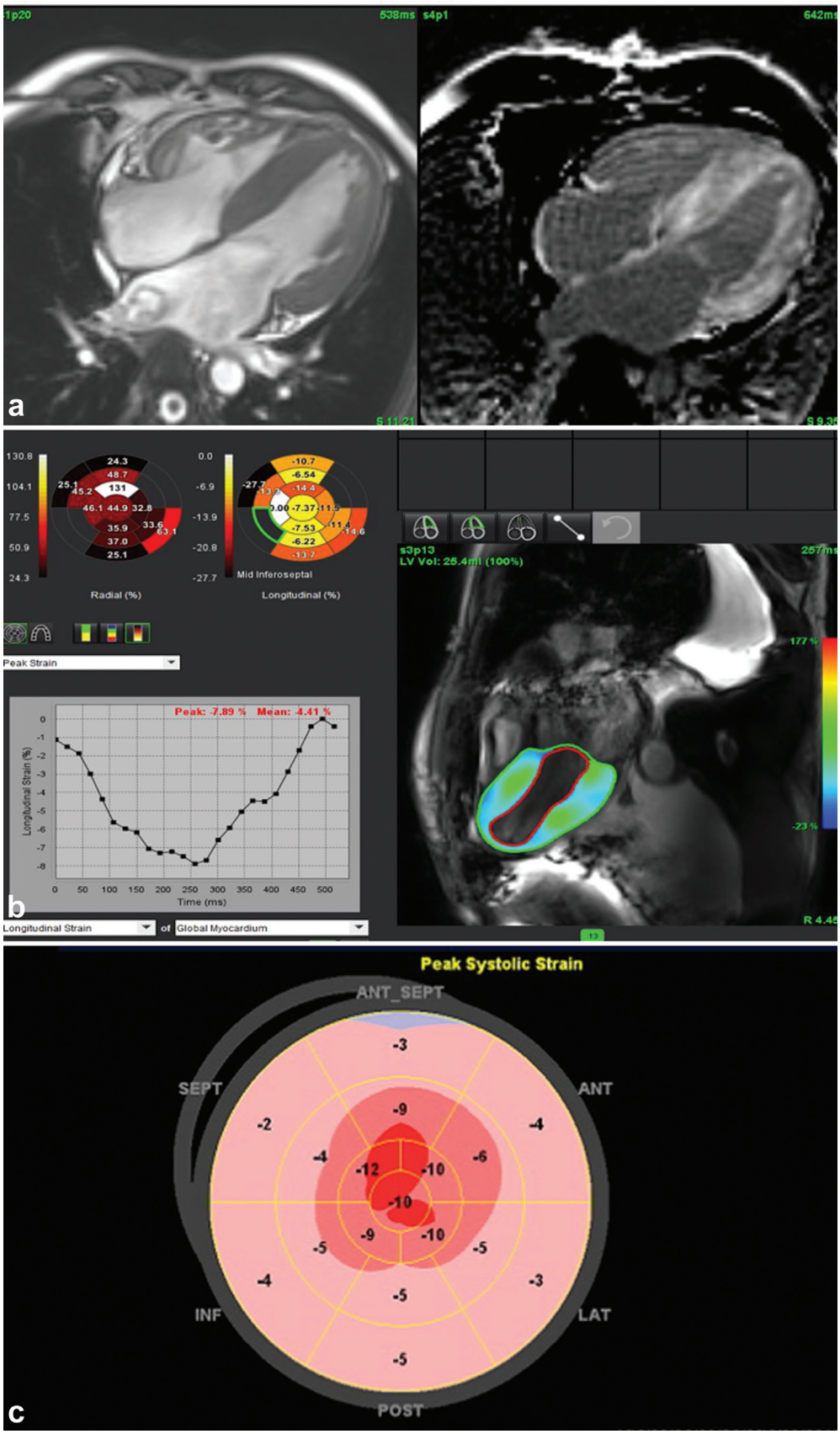

Fig. 7 Cardiac amyloidosis with hypertrophy of left ventricular myocardium and diffuse subendocardial hyperenhancement (top image). There is reduction of global longitudinal strain is values with relative apical sparing. This finding is described as 'cherry on top' appearance in speckle tracking echocardiography (bottom image).

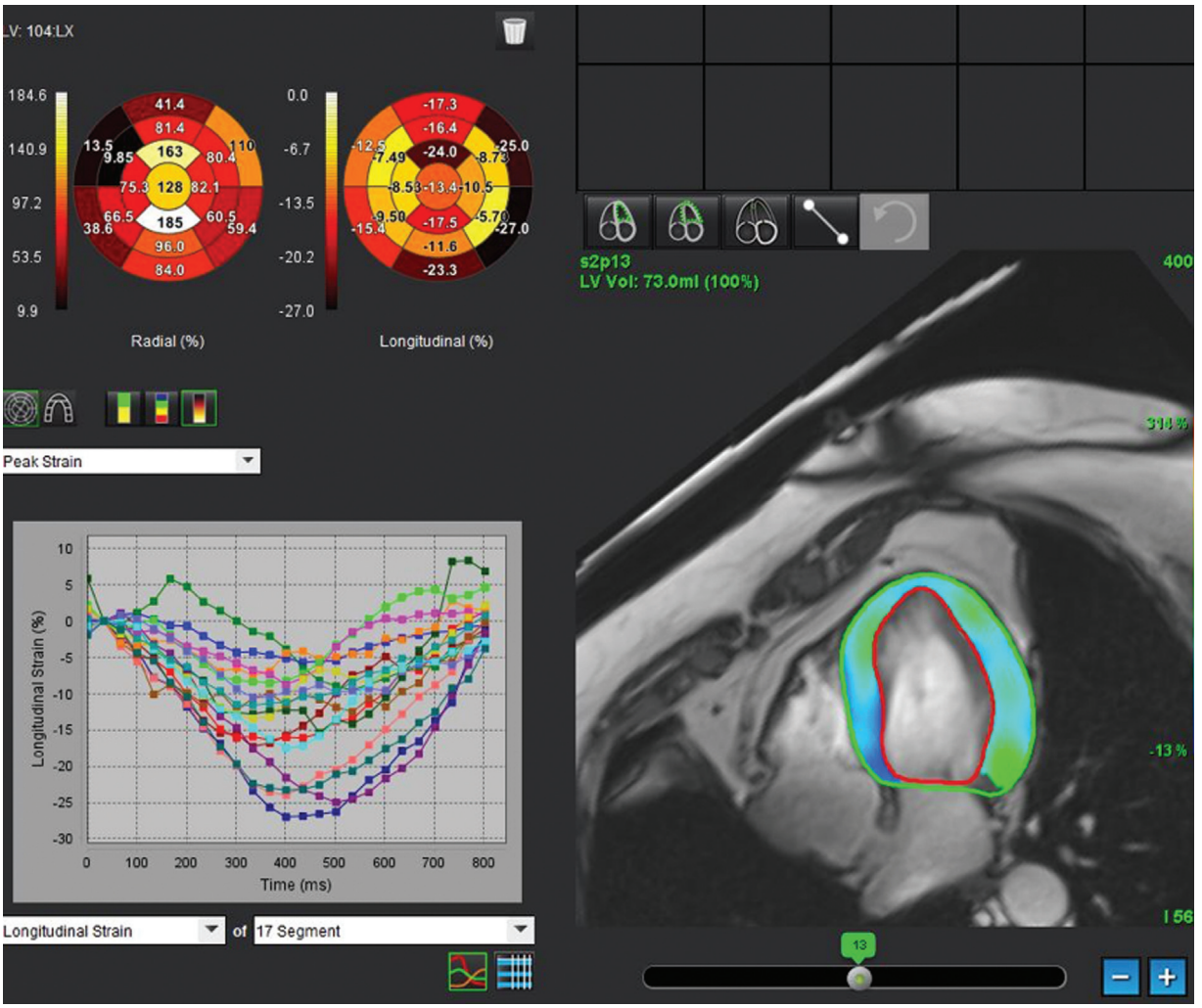

Fig. 8 Patient with left bundle branch block showing highly discordant graph curves of different myocardial segments (left panel bottom image). This occurs as due to variability in time to peak strain due to impulse reaching at different times.

with mild systolic dysfunction early in the natural history of the disease course. In patients of heart failure with preserved ejection fraction, longitudinal strain is reduced in a majority of patients, while in patients of heart failure with reduced ejection fraction, all the three components of the strain are reduced (►**Fig. 6**).

Apical sparing pattern of GLS is a classical sign of amyloid cardiomyopathy with characteristic pattern of reduced strain at the base with sparing of apex due to progressive base to apex deposition of amyloid[8,9] (►**Fig. 7**).

The other cardiovascular risk factors such as diabetes, hypertension, obesity, and renal insufficiency are associated with reduced LV longitudinal strain that is strong predictor of major adverse cardiac events. The LV GLS impairment may be a better parameter for timing of surgery in aortic stenosis and mitral regurgitation than the current parameters of linear LV dimensions and LVEF.

A subgroup of patients with LV ischemic and nonischemic cardiomyopathy and broad complex ECG shows significant regional mechanical dyssynchrony on regional strain over time curves. This may help in guiding cardiac resynchronization therapy[5] (►**Fig. 8**).

In case of constrictive pericarditis, subendocardium is normal and hypercontractile, while epicardium may be affected due to adjacent pericardial tethering. Hence, LV GLS may be well preserved in constrictive pericarditis, while circumferential strain may be reduced.[10]

As compared with speckle tracking echocardiography, cardiac MRI has less temporal resolution that may limit appreciation of strain events during isovolumic contraction and relaxation, measurement of strain rate and apical twist rate. However, higher spatial resolution of cardiac MRI provides better signal-to-noise ratio. Comparative analysis shows good correlation between the two modalities.[3]

Other limitations are claustrophobic patient, inadequate breath hold, and implanted metal devices. Compared with speckle tracking echocardiography algorithms, the CMR post-processing software algorithm is comparatively less available for clinical use and is less validated and standardized across vendors. The clinical outcome literature of CMR strain is sparse compared with two-dimensional Echo strain.

CMR offers advantage due to superior myocardial volumetric and functional assessment and at the same time

enabling evaluation of myocardial perfusion and tissue composition. No additional time was required for myocardial strain assessment as same dataset of the CMR study can be used. Strain measurements were feasible in almost all cases irrespective of underlying cardiovascular disease.

Conclusion

CMR feature tracking strain imaging is undergoing rapid development and more clinical outcome data are needed to define its diagnostic and prognostic utility in various clinical conditions. Taking parallels from echocardiographic strain literature, the CMR strain will surely give incremental diagnostic and prognostic information in various cardiac diseases. The CMR feature tracking strain imaging does not need additional acquisition time or sequences and can further enrich the already established value of CMR as one-stop shop for cardiac evaluation.

Conflict of Interest
None.

Acknowledgments
All CMR data post-processing has been done using suite-HEART, NeoSoft LLC, Wisconsin, United States.

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