Comparison of Displacement Encoding With Stimulated Echoes to Magnetic Resonance Feature Tracking for the Assessment of Myocardial Strain in Patients With Acute Myocardial Infarction

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The aim of this study was to compare myocardial strain by cardiovascular magnetic resonance feature tracking (CMR-FT) to those derived from displacement encoding with stimulated echoes (DENSE) in patients with acute myocardial infarction (AMI). Twenty patients (65 pa13 years) with AMI underwent cine, DENSE, black-blood T2-weighted and late gadolinium enhancement CMR at 1.5 T. Global and segmental strain was determined by CMR-FT analysis and DENSE on matched 3 short-axis planes. Global circumferential strain by CMR-FT showed a good agreement with that by DENSE ($r = 0.85$, $p < 0.001$; bias 0.02, limits of agreement −0.03 to 0.06). For segmental circumferential strain, r coefficient between CMR-FT and DENSE was 0.61 ($p < 0.001$) with bias of 0.02, limits of agreement of −0.07 to 0.11. Regional circumferential strain determined by CMR-FT in infarct segments (−0.08 ± 0.05) was significantly altered compared with that in remote normal segments (−0.15 ± 0.05, $p < 0.001$). CMR-FT measurement of regional and global circumferential strain showed good agreement with DENSE in patients with AMI. **(Am J Cardiol 2017;119:1542−1547)**

Two-dimensional CMR feature tracking (CMR-FT) has emerged as a postprocessing method to quantify in-plane regional myocardial strain on steady-state free precession cine CMR images in an analogous fashion to echocardiography speckle tracking.[1,2] CMR-FT has been validated for global and segmental strain analysis in healthy volunteers against tissue tagging.[3] However, accuracy of global and regional myocardial strain measured by CMR-FT in patients expected to have regional myocardial wall motion abnormalities has not been well established. The purposes of this study were to (1) validate global and segmental peak systolic circumferential strain measured by CMR-FT against displacement encoding with stimulated echoes (DENSE) in patients with reperfused acute myocardial infarction (AMI); (2) determine intraobserver and interobserver reproducibility of CMR-FT in patients with reperfused AMI; and (3) assess whether CMR-FT can detect the difference in myocardial strain between infarct myocardium and remote normal myocardium.

Methods

Sixty-eight (63 ± 14 years, 50 men) consecutive patients who were referred to routine CMR examinations including cine CMR, black-blood T2-weighted (T2W) CMR, and late gadolinium enhancement (LGE) CMR, and agreed to participate in this study were prospectively enrolled. The Mie University Hospital research ethics committee approved the study, and written informed consent was obtained for all participants before CMR. Inclusion criteria is first-time reperfused AMI who performed CMR within 14 days after AMI onset. Exclusion criteria are (1) patients with cardiomyopathies (n = 21), (2) myocarditis (n = 2), (3) cardiac arrhythmias (n = 0), (4) known or suspected coronary artery disease with previous MI (n = 15) and without MI (n = 10), and (5) previous coronary artery bypass graft surgery (n = 0). Consequently, 20 patients with AMI who were examined CMR study including DENSE were studied. Table 1 summarizes baseline patients' characteristics.

CMR studies were performed on a 1.5-T MR scanner (Achieva, Philips Medical System, Best, the Netherlands) with 32 channel coils. CMR study protocol included cine, black-blood T2W, DENSE, and LGE CMR. Cine MR images were acquired with a retrospective electrocardiographic gating, steady-state free precession technique.[4] Black-blood T2W MR images were acquired in 3 short-axis imaging planes (basal, midventricular, and apical) of the left ventricle (LV) with double inversion recovery pulses for blood suppression.[5] DENSE was acquired on the same 3 short-axis imaging planes used for black-blood T2W MR imaging.[6] Single-slice, multiphase acquisition mode was used in this study with 5 phases, trigger delay 250 ms, and

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Table 1
Patient characteristics

Variable	Patients (n = 20)
Age (years)	65 ±13
Men	15 (75%)
Body mass index (kg/m^2)	24 ± 4
Hypertension	15 (75%)
Dyslipidemia	14 (70%)
Diabetic mellitus	9 (45%)
Current smoker	10 (50%)
Family history of CAD	5 (25%)
eGFR (mL/min/1.73m^2)	67 ± 15
Peak CPK (U/L)	2245 (range 671 - 8800)
Interval AMI onset to MRI exam (days)	6.5 ± 3.7
AMI culprit coronary vessel (LAD/LC/Right)	6/2/12
Heart rate (bpm)	70 ± 12.
Left ventricular ejection fraction (%)	48.9 ± 9.9
Left ventricular end-diastolic mass (g/m^2 *)	67 (range 52 - 103)
Left ventricular end-diastolic volume (ml/m^2 *)	86 (range 51 - 134)
Left ventricular end-systolic volume (ml/m^2 *)	45 (range 18 - 89)

AMI = acute myocardial infarction; CAD = coronary artery disease; CPK = creatine phosphokinase; eGFR = estimated glomerular filtration rate; LAD = left anterior descending; LC = left circumflex; MRI = magnetic resonance imaging.
* Indexed for body surface area.

phase interval 50 ms. DENSE parameters were encoding strength 0.25 Hz/pixel; complementary spatial modulation of magnetization; 6 spiral interleaves of 8 ms over 2 cardiac cycles; echo time 1.26 ms; repetition time 11 ms; in-plane resolution 2.5 mm; slice thickness 6 mm, during a 12-heartbeat breath hold per slice. Flip angle was optimized for constant maximum signal-to-noise ratio during the systolic phases.[7] LGE images were acquired in the short-axis planes of LV covering entire LV.[4]

Two-dimensional CMR-FT strain analyses were performed using CMR analysis software, cvi42 (Circle Cardiovascular Imaging Inc., Calgary, Canada). The 3 short-axis cine MR images corresponding to DENSE slice locations were analyzed. Two observers independently traced the endocardial and epicardial border of LV myocardium in end-diastole. The software automatically propagated the endocardial and epicardial contours and tracked the motion of the in-plane tissue voxels through the entire cardiac cycle. Then, the LV myocardium was divided into 6 equal segments in each slice. Consequently, circumferential normal strain values were recorded at segmental and global (basal, mid, and apical slices) levels. DENSE images were analyzed using custom software written in MATLAB (The Math Works Inc., Natick, Massachusetts). In this study, circumferential strain was calculated as Lagrangian principal strain (E2) because E2 approximately represents circumferential normal strain. E2 maps were generated from DENSE images without any manual interaction.[4,6] After reconstruction of strain maps, LV myocardium was divided into 6 equal radial sectors in each slice. Two observers independently placed regions of interest manually excluding LV papillary muscle/trabeculation in the 6 equal radial sectors in each slice on the magnitude image that was automatically propagated to strain map. Segmental and global strain values for E2 were recorded in the same manner as for CMR-FT strain analysis. Peak strain value was selected from 5 phases of DENSE MR images. The CMR-FT strain values obtained with trigger delay nearest to that giving the peak strain value of DENSE was selected for the further analysis.

Myocardial strain values were compared between infarct and remote normal segments with CMR-FT and DENSE (Figure 1). The 3 short-axis LGE images corresponding to the DENSE images were selected. On T2W images and LGE images, infarct-related edema and infarct myocardium were determined as described previously.[8,9] An infarct segment was defined as the segment with infarct myocardium visible in at least 50% of the arc of the endocardial border of the segment regardless of transmural extent.[10] Remote normal segments were defined as the segments without infarct-related edema or infarct myocardium.

The statistical analyses were performed using MedCalc Statistical Software, version 13.2.0 (MedCalc Software bvba; Ostend, Belgium). Distribution of the continuous variables was assessed by the Shapiro-Wilk test. As the strain values were skewed variables Wilcoxon signed rank test, and Mann-Whitney signed rank test was used to compare differences within group and between groups, respectively. Correlation analysis was performed using linear regression by Pearson correlation coefficient, whereas agreement between CMR-FT and DENSE was assessed using Bland-Altman plots[11] and coefficients of variation (CVs). Intraobserver and interobserver reproducibility were assessed using Bland-Altman plots, CV, and intraclass correlation coefficients (ICCs) for absolute agreement. The CV was defined as the standard deviation of the differences divided by the mean × 100 (%).[12] A p value of <0.05 was considered statistically significant.

Results

DENSE was obtained on 60 slices in the 20 patients. Of 60 slices (360 segments), 5 slices (30 segments) of 5 patients were excluded from analysis because of suboptimal image quality of DENSE, and these segments had no infarction. In addition, another 6 segments on 3 slices in 1 patient with thinned myocardium because of myocardial infarction were also excluded due to difficulty of strain measurement in DENSE. Therefore, 6 of 36 excluded segments had infarction. Circumferential strain by CMR-FT in the excluded segments due to suboptimal image quality of DENSE and thinned myocardium due to infarction were −0.233 (range −0.273 to −0.194) and −0.022 (range −0.075 to 0), respectively. All the slices and segments of cine, T2W, and LGE images were analyzable. Consequently, 324 segments on 55 slices were analyzed in this study. All infarct lesions recognized on LGE images accompanied myocardial edema determined by T2W images.

A linear regression analysis demonstrated significant correlation between global circumferential strain determined by CMR-FT and circumferential strain calculated as E2 by DENSE (Figure 2). Bland-Altman analysis yielded a good agreement between CMR-FT and DENSE for the measurement of global circumferential strain (Figure 2). Corresponding CV and ICC was 16% and 0.679, respectively.