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Clinical Note

Long Axis Strain by MRI and Echocardiography in a Postmyocardial Infarct Population

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Purpose: To compare long axis strain (LAS) by magnetic resonance imaging (MRI) and echocardiography in a post-infarct patient population. Long axis left ventricle (LV) function is a sensitive index of incipient heart failure by echocardiography, but is less well established in MRI. LAS is an index of global LV function, which is easily assessed in cine loops provided by most cardiac MRI protocols.

Materials and Methods: In all, 116 patients (57 ± 9 years) were studied the same day using echocardiography and MRI 7.4 ± 4.1 months after a first myocardial infarction. LV length was measured in end diastole and end systole in conventional cine images with a temporal resolution of 50 msec or less, and LAS (%) was calculated as the change in LV length, relative to end diastole. Infarct mass was assessed by contrast-enhanced MRI.

Results: LAS was progressively reduced in patients with larger infarcts, and demonstrated good correlations with infarct mass ($r = 0.55$, $P < 0.01$). There was a good agreement between LAS assessed by echocardiography and MRI ($r = 0.77$, $P < 0.01$), and between LAS by MRI and speckle tracking strain by echocardiography ($r = 0.74$, $P < 0.01$).

Conclusion: LAS is an index that allows measurement of LV long axis function by conventional cine MRI.

Key Words: heart; strain; long axis; echocardiography; validation
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ASSESSMENT OF LEFT VENTRICULAR (LV) systolic function provides important prognostic and diagnostic information in patients with symptoms of heart failure or following acute myocardial infarction (1).

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The deformation of the LV during the normal cardiac systole is complex and three-dimensional, and is characterized by longitudinal and circumferential shortening, radial thickening, as well as torsion (2). Novel methods like speckle tracking echocardiography and tagged magnetic resonance imaging (MRI) can assess and characterize deformation (3,4).

Indices of myocardial deformation (strain) have demonstrated good correlations with disease severity as well as the ability to predict prognosis (5,6), and adds information compared to established indices like LV ejection fraction (LVEF) (1). Although these methods are reliable and reproducible, specific competencies and time-consuming protocols are often needed, as well as dedicated software. Moreover, poor acoustic window may in some patients obscure the visibility of LV walls by echocardiography, and thus prevent a reliable evaluation. In clinical practice, there is a need for fast and robust methods with high feasibility for accurate assessment of LV global function across different imaging modalities.

During systole, the LV apex is relatively stationary and long axis shortening has therefore been assessed by measurements of the systolic mitral annulus displacement (7), an index which has been validated and found to predict events in patient populations (8–11). The normal LV size is dependent on anthropometry and since relative deformation is conserved, there is reason to believe that LV long axis shortening would be higher in a healthy and large heart as compared to the smaller heart (1). To correct for this normal variation, long axis shortening normalized to end diastolic LV length (long axis strain [LAS]) was introduced and found to correlate well with infarct mass and with global longitudinal strain by echocardiography (12). LAS thus represents an alternative to tagged MRI to estimate global long axis LV function.

The present study aims to test the correlation between LAS measured by echocardiography and MRI in a postinfarct population.

PATIENTS AND METHODS

In all, 116 patients (age 57 ± 9 years; 19 women) previously treated with percutaneous coronary intervention (PCI) due to first-time ST-elevation myocardial

Table 1
Patient Characteristics

Patients	(n = 116)
Age (years)	57.2 ± 9.4
Gender (male:female)	97:19
Height (cm)	177 ± 7
Weight (kg)	81 ± 11
Heart rate (min^{-1})	58 ± 9
Systolic blood pressure (mmHg)	126 ± 21
Diastolic blood pressure (mmHg)	75 ± 11
Medication:	
β-blockers (n)	116 (100%)
ACE-inhibitor or ARB (n)	107 (92%)
LV mass (g)	160 ± 40
LV mass/ BSA (g/m^2)	85.3 ± 20.2
Infarct mass (g)	32 ± 22

infarction (MI) were included in the study. Patients were excluded if contraindications to MRI were present, but no patients were excluded due to impaired image quality by either method. Clinical data and infarct characteristics are displayed in Table 1.

Patients were examined with late gadolinium enhancement MRI and echocardiography typically 9 months following the index MI. The echocardiographic and MRI studies were performed on the same day. Patients were hemodynamically stable during imaging studies. All study subjects had sinus rhythm with QRS width <120 msec. None had significant valvular dysfunction as defined by echocardiography. The study was approved by the Regional Committee for Medical Research Ethics (REK Sør, Oslo, Norway), and all subjects gave written informed consent.

MRI

MRI was performed using 1.5 T units (Magnetom Vision Plus or Magnetom Sonata, Siemens, Erlangen, Germany) using a phased array body coil. During breath-hold, cine images were acquired in long and short axis views with either a segmented spoiled gradient echo sequence; fast low angle shot (FLASH) (29 subjects) or fast imaging with steady state free precession (true Fisp). The FLASH sequence was performed with flip angle (FA) 20°, echo time (TE) 3.3–4.8 msec, and temporal resolution 50 msec or less. True Fisp was performed with FA 77–80°, TE 1.2 msec, and temporal resolution 28 msec. For all cine imaging slice thickness was 6 mm, field of view (FOV) varied between 35 × 28 and 40 × 36 cm due to patient size and spatial resolution was 1.4 × 1.4 mm. Short axis slice increment was 10 mm. Late gadolinium enhancement images were obtained 10–20 minutes after intravenous injection of 0.2 mmol/kg gadopentetate dimeglumine (Magnevist, Schering, Berlin, Germany) in multiple short axis slices covering the left ventricle with a breath-hold segmented magnetization-prepared turbo gradient echo sequence. FA was 30°, the inversion time was chosen to null the signal from normal myocardium and varied from 220 to 300 msec, TE was 4.3 msec, FOV was in the range between 30 × 30 and 39 × 35 cm, with spatial resolution 1.2 × 1.2 – 1.5 × 1.5 mm, slice thickness was 7 or 8 mm, with short axis slice increment 10 mm.

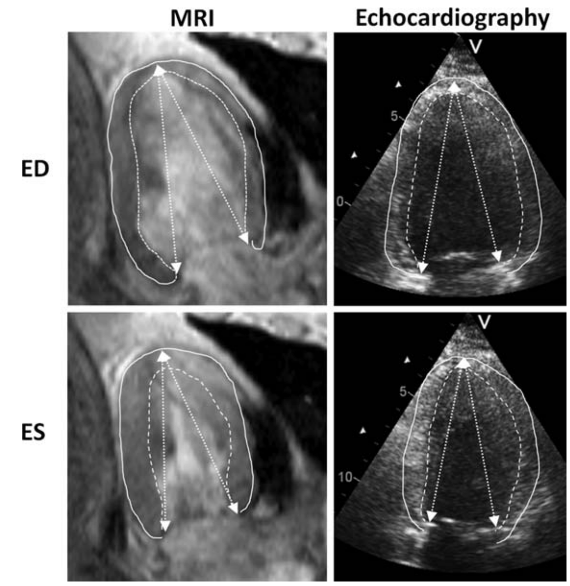

Figure 1. MRI (left) and echocardiographic (right) images from a representative participant during end diastole (ED, top) and end systole (ES, bottom). Measurements of LV length from the epicardium of the apex to the mitral valve insertions are displayed with arrows. Epicardium (solid line) and endocardium (dotted line) are delineated. In this patient, LAS was 9.6% by MRI and 10.2% by echocardiography.

Healthy myocardium and infarcts were manually delineated, guided by a threshold pixel intensity of infarcted myocardium of more than 2 SDs above the mean pixel intensity of normal myocardium within the same slice (13). The total myocardial volume and the infarct volume were calculated (PACS, Sectra, Sweden) and mass was obtained by converting volumes by the specific density of myocardium (1.05 g/mL). LVEF was assessed from short axis cine loops.

Echocardiography

Patients were examined in the left lateral decubitus position and studies were performed with Vivid 7 scanners (GE Vingmed Ultrasound, Horten, Norway), using phased-array transducers. Three consecutive heart cycles from standard apical views (4-chamber and 2-chamber) were obtained by conventional 2D grayscale echocardiography, using a narrow sector angle and adjusting the depth to include the mitral annulus. The average frame rate was 48 ± 21 frame sec^{-1}. The digital loops were stored and analyzed by EchoPac software (v. 6.0, GE Vingmed Ultrasound, Horten, Norway).

Myocardial Deformation

The distances from the mitral valve insertions to the epicardial apex were measured from apical 2-chamber and 4-chamber views, and the LV length was calculated as the average of the four measured walls in end diastole (peak R in echocardiography) and in end systole, respectively. The same method was applied in both echocardiography (A.A.) and MRI (E.H.) (Fig. 1). LAS was calculated as the difference between end

Table 2
LAS-calculation

$$\text{LAS} = 100\% * \frac{(\text{LV-Length}_{\text{ED}} - \text{LV-Length}_{\text{ES}})}{\text{LV-Length}_{\text{ED}}}$$

diastolic and end systolic LV length, as the percentage of the end-diastolic LV length (Table 2), thus corresponding to a long axis fractional shortening (12). All evaluators were new to the LAS-method, but experienced within their field. Typically, all measurements could be performed within 2 minutes. Global longitudinal strain was assessed by speckle tracking echocardiography from 2-chamber and 4-chamber apical views in the human subjects using EchoPac software as previously described (O.G.) (12).

Statistical Analysis

The data were analyzed using standard statistical software (SPSS v. 17, Chicago, IL). Continuous variables are expressed as mean ± SD and were compared with one-way analysis of variance (ANOVA). Bonferroni correction was applied for post-hoc tests. LAS by echocardiography and MRI were compared for interchange ability in correlation and Bland–Altman plots (14). Inter- and intraobserver variability were blindly evaluated for consistency described by the intraclass correlation coefficient for LAS assessed by echocardiography (A.A. and O.G.) and MRI (E.H. and O.G.) in the same 25 randomly selected patients, using a two-way mixed model. For all statistical comparisons, $P < 0.05$ was considered significant.

RESULTS

Myocardial infarct size ranged from nondetectable to a maximum of 121 g, corresponding to 42% of the LV mass. The mean infarct mass was found to be 37 ± 26 g. In 81 patients (70%), at least one segment (3.4 ± 1.9 segments) was transmurally infarcted. The total number of infarcted LV segments per patient was 8.1 ± 3.1 when averaged over all patients. In the study, all assessments were feasible in all individuals. However, by echocardiography, only segments with acceptable tracking quality were included in the global strain assessment.

There was a good correlation between LAS assessed by cardiac MRI and echocardiography ($r = 0.77$, $P < 0.01$; Fig. 2), although LAS was slightly but significantly underestimated when assessed by MRI relative to echocardiography (10.2 ± 2.6% vs. 10.9 ± 2.5%, $P < 0.01$). Infarct mass correlated well with LAS assessed by MRI ($r = 0.55$, $P < 0.01$) and by echocardiography ($r = 0.56$, $P < 0.01$). Global longitudinal strain assessed by speckle tracking echocardiography correlated significantly with LAS MRI ($r = -0.74$, both $P < 0.01$). LAS also correlated well with LVEF ($r = 0.66$, $P < 0.01$).

The measured LV length at end diastole ranged from 8.2 to 12.4 cm, similar by both methods (10.3 ± 0.8 cm vs. 10.2 ± 1.2 cm, P = ns), and was associated with patient's height ($r = 0.54$, $P < 0.01$). The unadjusted LV shortening was found to correlate to a less extent with LV infarct mass ($r = 0.48$, $P < 0.01$).

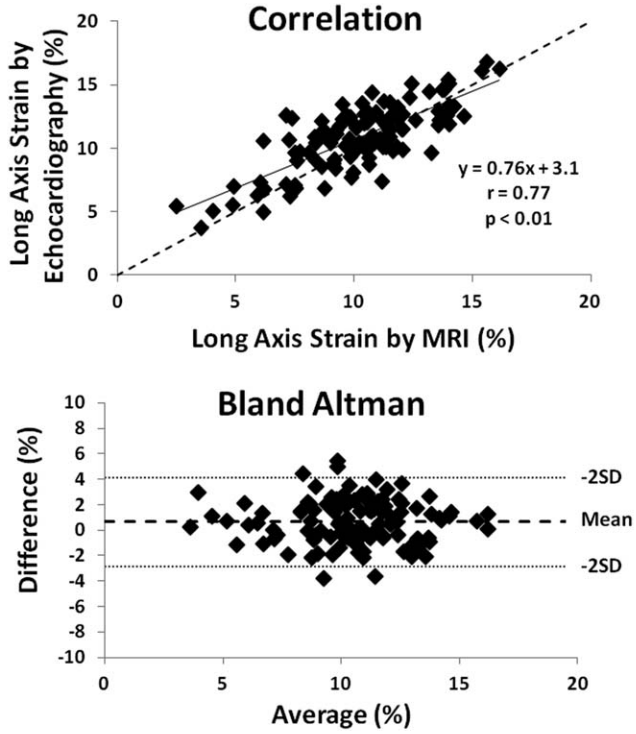

Figure 2. Correlation and Bland–Altman plots. Difference is expressed by echocardiography minus MRI.

Reproducibility and Feasibility

The intraclass correlation coefficient (ICC) for LAS was 0.88 vs. 0.86 for interobserver, and 0.90 vs. 0.88 for intraobserver reproducibility by MRI and echocardiography, respectively. When the same reader assessed corresponding MRI and echocardiography studies, the ICC was 0.90. A total of 9.1% of LV segments were excluded from the strain analysis due to reverberations or poor tracking, thus adding to the total time consumption of the speckle tracking strain assessment. In contrast, all mitral valve insertions were easily identified and included in all subjects.

DISCUSSION

We compared the assessment of LAS by echocardiography and MRI in a postmyocardial infarct patient population. Assessment of LAS was highly reproducible, and results were comparable across the applied methods.

Assessment of cardiac function provides important information to guide the diagnosis of cardiac disease, predict outcomes, and to evaluate the effect of patient treatment. Deformation indices like strain and strain rate represent new and sensitive tools for the quantitative analysis of regional as well as global LV function, and provide added information to the assessment of infarct size (1).

Myocardial fiber orientation changes smoothly across the LV wall, with a predominantly longitudinal fiber orientation in the subepicardium and subendocardium, and a more circumferential orientation in the mid-LV-wall (15). Wall stress is considered to be higher in the subendocardial layer compared to the midmyocardial and subepicardial layers, and due to the longitudinal orientation of the endocardial muscle fibers, indices of deformation in the long axis direction has been proposed to be the most sensitive to early changes in LV function (16).

During systole, the longitudinal deformation of individual LV-segments contributes to pull the mitral annulus towards the apex (7), whereas the displacement of the apex is relatively modest with the pericardium intact (17). Assessment of deformation along the axis represents an approximation of the true myocardial deformation, but is less vulnerable to artifacts compared to assessment by tagged MRI or speckle tracking echocardiography (12).

Previous studies have shown that patients with acute or chronic infarction have reduced long axis shortening when compared to controls (11,18), and more reduced in infarct-related LV walls when compared to remote LV walls. Long axis deformation has been shown to correlate well with LVEF, indicating that mitral annulus displacement is a good index of global LV performance (7), a finding that was confirmed by the present study. Moreover, mitral annulus displacement has been demonstrated to predict future events in patients with myocardial infarction, heart failure, or hypertensive heart disease (8–10).

We found the end-diastolic LV length to range between 8 and 12 cm, and to significantly correlate with patient height. Measurement of LV shortening does not, however, take this normal variation of the heart size into account. LAS, on the other hand, is a measure of relative displacement, and is therefore considered less dependent on cardiac size. In accordance with this, we demonstrate a higher correlation with infarct mass for LAS compared to unadjusted shortening, and we have previously suggested that mitral annulus displacement normalized to end diastolic LV length could represent an alternative to global LAS measurements (12). Alam et al (19) compared ejection fraction with mitral valve displacement, unadjusted and adjusted to end diastolic LV length, and found excellent correlations with both measures. In our material, the indices were also found to correlate significantly with ejection fraction.

The present study demonstrated a good correlation between assessments of LV long axis function using conventional MRI cine images or 2D echocardiographic images, and it therefore allows for comparison across imaging modalities.

Strain assessed by echocardiography and tagged MRI requires advanced study protocols or dedicated software for postprocessing. Moreover, strain indices are vulnerable to poor acoustic window and motion artifacts, mainly because artifacts tend to cause an underestimation of the true deformation (1). Assessment of LAS, on the other hand, requires visualization of the mitral annulus and apex only, and is potentially more robust in the presence of reverberations or when parts of the LV wall are poorly visualized.

Both the scan time and the postprocessing time can be reduced using LAS, when compared to strain measurements using tagged MRI or speckle tracking echocardiography. LAS thus represents a low threshold, easy available tool for the assessment of global long axis LV function, and introduces an easy available method for the assessment of long axis function using conventional cine cardiac MRI images. Assessment of long axis deformation by tagged MRI, on the other hand, is time-consuming and therefore primarily a method used for research protocols.

The potential for risk stratification is well established for mitral annulus displacement (8), but further studies are needed in order to establish normal values and threshold values for LAS, and to test the method's ability to predict events and stratify risk in population studies and in outcome studies.

All known indices of global LV-function are load-dependent (1). Measurements were therefore performed during stable hemodynamic conditions.

LAS is an index of global long axis LV function, but does not provide reliable information on segmental and regional deformation due to tethering of adjacent LV walls. In the present study, LAS was slightly underestimated when assessed by MRI compared to echocardiography. Several factors may have contributed to this finding: First, the frame rate of cine images obtained with MRI is lower compared to that of echocardiography. Higher temporal resolution increase the likelihood of capturing the true maximal shortening, and a lower frame rate thus introduces a tendency to underestimate the true deformation. Second, there is an inherent tendency to foreshorten the apical views images by echocardiography. The LV lengths at end diastole did not differ between the methods, but any systolic foreshortening may increase the echocardiographic LAS measurement. Care was taken to avoid foreshortening, and by visual assessment, this did not seem to represent a problem.

In conclusion, measurement of LAS was fast, feasible, and reproducible by echocardiography and cine MRI. The methods demonstrated comparable results. Measurement of LAS may represent a reliable and easily available tool for the assessment of long axis left ventricle deformation in the clinical setting, without the need for specific study protocols or postprocessing software.

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