Strain-Encoded Magnetic Resonance Imaging for Evaluation of Left Ventricular Function and Transmurality in Acute Myocardial Infarction

Neizel et al.: SENC in Acute Myocardial Infarction

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Abstract

Background. Strain-encoded imaging (SENC) is a new technique for myocardial deformation analysis in cardiac magnetic resonance imaging (CMR). The aim of the study was therefore to evaluate whether myocardial deformation imaging performed by SENC allows for quantification of regional left ventricular function and is related to transmurality states of infarcted tissue in patients with acute myocardial infarction (AMI).

Methods and Results. CMR was performed in 38 patients with AMI 3±1 days after successful reperfusion using a clinical 1.5 Tesla MR-scanner. Ten healthy volunteers served as controls. SENC is a technique that directly measures peak circumferential strain from long-axis views and peak longitudinal strain from short axis views. Measurements were obtained for each segment in a modified 17 segment model. Wall motion and infarcted tissue were evaluated semi-quantitatively from SSFP cine sequences and contrast-enhanced-MR-images and were then related to myocardial strain. Comparison of peak circumferential strain assessed by SENC and MR-tagging was performed.

In total, 456 segments were analysed. Peak circumferential and longitudinal strain calculated from SENC-images was significantly different in regions defined as normokinetic, hypokinetic or akinetic (p<0.001). A cut-off peak systolic circumferential strain value of -10% differentiated non-transmural from transmural infarcted myocardium with a sensitivity of 97% and a specificity of 94%. Strain-analysis of SENC and MR tagging correlated well (r=0.76) with narrow limits of agreement (-9.9-8.5%).

Conclusions. SENC provides rapid and objective quantification of regional myocardial function and allows discrimination between different transmurality states in patients with AMI.

Key words: myocardial infarction, myocardial strain, strain-encoded magnetic resonance imaging, viability
Introduction

Identification of the extent and degree of contractile dysfunction and infarcted tissue in patients after acute myocardial infarction (AMI) has important prognostic implications.\(^1\),\(^2\) Different imaging modalities can be used to analyze viability such as stress-echocardiography or nuclear imaging techniques.\(^3\)\(^-\)\(^5\) However, for improved evaluation of viability, a combination of assessment of objective regional myocardial function and the extent of infarcted tissue would be desirable.

Cardiac magnetic resonance (CMR) imaging has emerged as a technique that allows accurate assessment of myocardial function and myocardial scar.\(^6\)\(^-\)\(^8\) Whereas contrast-enhanced MR imaging (CE-MRI) can be used to distinguish between reversible and irreversible myocardial ischemic injury, myocardial deformation imaging allows of objective description of myocardial function.

The currently applied reference method for analysis of myocardial deformation in CMR is MR tagging.\(^9\),\(^10\) However, this method has some disadvantages for example long breath-hold acquisition times and time-consuming post-processing.\(^11\) Thus, for a routine comprehensive evaluation of myocardial function and viability other methods are needed.

Recently, strain encoded imaging (SENC) has been introduced as a novel MR-technique to measure myocardial deformation expressed as myocardial strain.\(^11\)\(^-\)\(^14\) SENC has proved to allow accurate quantification of myocardial function in healthy volunteers and in patients with myocardial infarction, however in small patient samples.\(^12\) The advantages of SENC are the relatively short acquisition time, no need for time-consuming post-processing and high temporal resolution.

The aim of this study was to evaluate weather myocardial deformation parameters derived from SENC allow accurate and objective assessment of myocardial function and discrimination of transmurality states in patients with AMI.
Methods

Patients presenting with AMI were screened over a 10 month period (June 2007 to March 2008) at the University Hospital of Heidelberg. To be included, the patients had to have a first-time AMI with a clearly identified culprit coronary vessel. Moreover, patients with severe hemodynamic compromise or patients requiring inotropic support were excluded from the study. In addition, patients with contraindication to MRI or gadolinium-based contrast agent were excluded from the study.

All patients received successful reperfusion therapy by percutaneous coronary intervention (PCI). AMI was diagnosed by history, electrocardiographic changes, cardiac biomarker abnormalities and coronary angiography in accordance with the consensus of the American College of Cardiology and the European Society of Cardiology.\textsuperscript{15}

In 10 healthy volunteers reference values for peak circumferential and longitudinal strain were established. These volunteers were screened by clinical history, physical examination, 12-lead ECG, blood testing, glucose intolerance testing, resting blood pressure measurement (<145/90 mmHg) and MR-stress testing.

The study protocol complies with the Declaration of Helsinki and was approved by the local institutional ethical committee. Written informed consent was obtained from each patient. The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Imaging Protocol

Patients were investigated in a clinical 1.5 Tesla whole body MR-scanner (Achieva, Philips, Best, The Netherlands) 3±1 days after successful mechanical reperfusion of the infarct related vessel using a 5-element phased array cardiac synergy coil. The overall CMR imaging time of the entire study was 45±10 min.

Cine-imaging
Assessment of resting left ventricular (LV) function was determined by cine images using a steady-state-free precession sequence in 10-12 8mm-thick slices covering the whole left ventricle from base to apex as well as long axis 2-and 4-chamber views (TE 1.39ms; TR 2.8ms; Flip angle 60°; spatial resolution 2.4x2.5x8mm³; 35 phases per cardiac cycle) with a breath-hold time of 7-10s per image. The pulse sequence was prospectively gated.

**Myocardial deformation imaging**

Strain encoded images as well as tagged MR images, as reference standard for measurement of myocardial strain, were acquired sequentially in all subjects to calculate myocardial strain. Strain is expressed as the percentage of shortening or lengthening of myocardium in relation to its original length.

**Strain encoded MR imaging**

SENC is a special modification to the MRI scanner software that enables the quantification of regional deformation of tissue as a result of cardiac motion. The technique produces images whose intensity depends on the degree of tissue deformation, measured by the strain—which is the change in length per unit length of tissue. Therefore, the resulting anatomical images of the scanner are encoded with the strain values of the deformations. To calculate myocardial strain, SENC uses tag planes parallel and not orthogonal to the image plane. Thus, 2-and 4 chamber views in the same plane orientation as the CINE-images are generated to calculate circumferential strain and three short-axis views (basal, midventricular, apical) are acquired to measure longitudinal strain.

Typical imaging parameters of the prospectively triggered pulse sequence were a 380-mm field of view, a voxel size of 2.5/2.5mm², TR/TE 25/0.9ms, flipangle 30°. Spiral acquisition was used to perform faster image acquisition without sacrificing the signal-to-noise ratio (SNR). SENC as a pulse sequence has relatively lower SNR than conventional CINE acquisition and to supplement the loss, thicker slices (10mm) were used. The temporal resolution was 25 ms and the number of phases (typically 27-35) were adapted to the current
heart rate to cover approximately 100% of the cardiac cycle with a breath-hold time of 8-10 s per image.

2D-Tagged MR imaging

Tagged images were acquired at the same location as the SSFP and SENC images, with 8-mm slice thickness. An electrocardiographically triggered segmented k-space version of the spatial modulation of magnetization (SPAMM) tagging sequence was used to create a tag grid on the images with a tag separation of 7 mm using a FFE multi-shot sequence (TR/TE 3.9/1.7 ms, voxel size 2/2 mm\(^2\), Flip angle 5°, spacing 6.3, tag grid angle 45°) with 10-14 phases per cardiac cycle. 3 short-axis images from base to apex were acquired. The breath-hold time was 14-18 s per image.

Contrast-enhanced-imaging

Ten minutes after gadolinium contrast injection (0.2 mmol/kg body weight of Gadolinium-DTPA (Magnevist®, Bayer, Germany) late enhancement-imaging was performed using a 3D-gradient spoiled turbo fast-field-echo sequence with a selective 180° inversion-recovery pre-pulse triggered to end-diastole acquired in the short axis covering the whole ventricle (TR/TE 3.2/1.16; Flip angle 15°; spatial resolution 1.5x1.7 mm\(^2\)). The acquired 10 mm thick slices are interpolated to 5 mm slices. The inversion time was adapted individually to suppress signal of normal myocardial tissue (typically 200-300 ms).

Data-Analysis

For measurement of circumferential and longitudinal strain the ventricle was divided into 12 segments (septal basal, midventricular, apical; lateral basal, midventricular, apical; anterior basal, midventricular, apical; inferior basal, midventricular, apical) resulting in 456 segments. For comparison of circumferential strain values obtained by MR tagging and SENC, the SENC long axis views were compared to short-axis MR tagging images according to differences in strain quantification between the two techniques. To obtain optimal geometric matching, the LV outflow tract and the papillary muscles were used as landmarks. All strain
measurements were performed using a dedicated software (Diagnosoft MAIN (Version 1.06), Diagnosoft Inc., Palo Alto, California) including HARP for data analysis of tagged images and a special tool for analysis of SENC-images. The analysis was performed in the subendocardium.

In order to compare SENC values to visual assessment of LV function, two experienced observers, blinded to the strain-values, evaluated regional myocardial function by consensus reading considering a 12 segment model of the LV. For each segment myocardial function was described as normokinetic, hypokinetic, a/dyskinetic.

For comparison of strain values and delayed enhancement imaging, segments were categorized in a five-point scale proposed by Kim et al., 7 in which a score of 0 indicated no hyperenhancement, a score of 1 indicated 1-25% hyperenhancement, a score of 2 26-50% hyperenhancement, a score of 3 51-75% hyperenhancement and a score of 4 76-100% hyperenhancement. Transmural was defined as hyperenhancement extending >75% of the myocardium.

Reproducibility

Interobserver variability of the measurements of myocardial strain assessed with SENC and MR tagging was evaluated in 15 randomized patients with AMI (180 segments) by two independent observers who were blinded to the strain results from either SENC or MR tagging.

Statistical Analysis

Data are expressed as mean ± standard deviation. Continuous variables were compared by Student’s t test otherwise comparisons were analysed by Mann-Whitney U test. For method comparison rank correlation and Bland-Altman analysis were performed. Also, concordance correlation coefficient was calculated. For comparison of strain-values across different categories of transmurality and wall motion abnormalities, a linear mixed model was applied to address the issue of multiple observations per patient.
Taking into account that there were 12 segments per patient to be analyzed, a generalized estimating equation (GEE) approach with a binomial distribution, a logit link and a working correlation matrix with exchangeable correlation was used to explore the ability of strain parameters to differentiate between normokinetic, hypokinetic and a/dyskinetic segments as well as hyperenhancement > 75% and < 75%. The output from this analysis allowed the derivation of receiver operating characteristics (ROC) curves, which were used to designate cutoffs and calculate the area under the curve (AUC), sensitivities and specificities.

Interobserver variability was calculated by intraclass correlation coefficient (ICC) and Bland-Altman analysis. A p-value <0.05 was regarded as statistically significant. Statistical analysis was performed using MedCalc (Mariakerke, Belgium, version 9.6.3) and SAS version 9.13 (SAS Institut Inc., Cary, North Carolina, USA).

Results

In total, 118 patients presenting with AMI were screened over a 10 months period. Of these patients, 70 were eligible for participation in the study.

The reason for the exclusion of the remaining 32 patients was severe hemodynamic compromise (n=16) and contraindication to MRI (n=10). Two patients refused to participate and four patients suffered from claustrophobia. Thus, in total, thirty-eight patients (mean age 56±11 years) were enrolled in this study. The patient characteristics are displayed in table 1.

Strain analysis of SENC and tagging

In total, 38 patients were analysed resulting in 456 segments. For strain-analysis of SENC-images, 7 (1.5%) segments for circumferential strain-analysis and 12 (2.6%) segments for longitudinal strain-analysis had to be excluded due to insufficient image quality. In MR tagging, comparably 28 segments (6%) were excluded.

Myocardial strain related to segmental left ventricular function
For visual analysis of wall motion abnormalities, 302 of 456 analysed segments were defined as normokinetic, 82 as hypokinetic, and 72 as a/dyskinetic.

Peak circumferential strain assessed by SENC was significantly decreased in regions defined as hypokinetic or a/dyskinetic by cine MRI compared to normokinetic regions. Furthermore, hypokinetic segments could be distinguished from a/dyskinetic regions by circumferential strain and had significantly different peak circumferential strain values as demonstrated in figure 1 and figure 2 (p<0.001 for all).

For peak longitudinal strain assessed by SENC the strain-values were also significantly different in normo-, hypo- and a/dyskinetic regions of the heart (-20±4%, -14±5%, -10±5%, p<0.001 for all).

Performing ROC analysis, a peak systolic circumferential strain value of <-17% was related to hypokinesia with a sensitivity of 85% and a specificity of 86% (AUC 0.91, 95%CI 0.88 to 0.93, p<0.001) and a peak systolic circumferential strain value <-10% corresponded to a/dyskinesia with a sensitivity of 95% and a specificity of 92% (AUC 0.96, 95% confidence interval=0.94 to 0.98, p<0.0001). Longitudinal strain showed slightly inferior results in ROC-analysis. A peak systolic longitudinal strain value of <-18% was related to hypokinesia with a sensitivity of 85% and a specificity of 80% (AUC 0.86, 95%CI 0.79-0.91) whereas a cut-off value <-14% corresponded to a/dyskinesia with a sensitivity of 74% and a specificity of 88% (AUC 0.887, 95%CI 0.83-0.93).

Circumferential strain was shown to be significantly more precise in detecting hypokinesia (p=0.05). No significant difference was observed in detecting akinesia (p=0.4).

Circumferential strain of remote regions versus circumferential strain in the normal left ventricle

A total of 301 segments of remote myocardium of AMI patients were compared to segments in the left ventricle of healthy volunteers. Remote myocardium was defined as segments without hyperenhancement in the contrast-enhanced images and no wall motion abnormalities
in the cine-images. Strain values of healthy volunteers (mean age 55±9) were slightly heterogeneous in different segments with highest subendocardial strain values anterior and lowest strain values inferior (-22.8±3.4 septal, -23.4±3.1 lateral, -25.3±2.4 anterior, -22.3±3.9 inferior). We found reduced strain parameters in the remote region compared to segments in the normal left ventricle (-21±4.9 versus -23.4±3.6, p<0.001).

*Circumferential and longitudinal strain related to ejection fraction*

Mean myocardial strain values inversely correlated with the ejection fraction. The inverse correlation of mean peak circumferential strain was superior to mean peak longitudinal strain (correlation coefficient r=-0.68 versus r=-0.45).

**Myocardial strain related to infarcted tissue**

Among 456 segments, segmental analysis of CE-MRI indicated non-infarcted tissue in 322 segments, 1-25% hyperenhancement in 17 segments, 26-50% hyperenhancement in 29 segments, 51-75% hyperenhancement in 13 segments and 76-100% hyperenhancement in 75 segments. Transmural infarcted tissue was defined as hyperenhancement ≥75%, resulting in 59 segments with non-transmural infarcted myocardial tissue and 75 segments with transmural infarcted myocardial tissue.

Regarding the non-transmural infarcted segments, in wall motion analysis 70% (32) were classified as hypokinetic, 22% (10) were normokinetic and 9% (4) were akinetic. Regarding the transmural infarcted segments, 73% (64) were defined as akinetic, 20% (18) as hypokinetic and 7% (6) as normokinetic.

Significant differences in peak circumferential strain in non-infarcted, non-transmural infarcted and transmural infarcted segments were observed (-20±6%, -12±7%, -6±7%; p<0.0001).

A cut-off peak systolic circumferential strain value of -10% differentiated non-transmural infarcted myocardium from transmural infarcted myocardium with a sensitivity of 97% and a specificity of 94% (AUC 0.96, 95% CI 0.94-0.98). Peak systolic longitudinal strain achieved
a sensitivity of 64% and a specificity of 85% (AUC 0.76, 95% CI 0.69-0.83) to differentiate between non-transmural infarcted and transmural infarcted myocardium at a cut-off of -17% (figure 3). Circumferential strain was slightly better to differentiate between transmural and non-transmural infarcted myocardium, however not statistically significant (p=0.7).

**Comparison of SENC versus MR-tagging**

Strain parameters measured by SENC and MR tagging correlated well (r=0.76, p<0.0001). The 95% limits of agreement in Bland-Altman plot were -9.9 to 8.5% with a concordance correlation coefficient of 0.80 (figure 4).

**Reproducibility**

A total of 180 segments were evaluated for interobserver variability of SENC and MR tagging. The interobserver variability for SENC was excellent and superior to that of MR tagging (ICC for SENC=0.92, ICC for tagging=0.80). In Bland-Altman plot, the limits of agreement were -7.6 to 7.4% for SENC and -6.5 to 8.1% for MR tagging.

**Scan time**

The total scan duration for SSFP and SENC imaging was 30-40 sec/per patient (2-and 4 chamber view with SSFP and SENC). For a SSFP and MR tagging study the total scan time was 56-74 sec (2-and 4 chamber-view with SSFP, 3 short-axis views with MR tagging).

**Time-spent for data analysis**

The time-spent for strain-analysis per patient was significantly lower for SENC compared to tagging (4.1±0.6 minutes versus 9.2±1.2 minutes, p<0.001)

**Discussion**

The present study demonstrates that (I) SENC allows objective and rapid assessment of myocardial function in patients with AMI, (II) SENC allows discrimination between different
degrees of myocardial hyperenhancement and can therefore distinguish transmural from non-
transmural infarcted tissue in patients with AMI and (III) strain parameter obtained by SENC
closely correlate with MR tagging.

**Objective quantification of regional myocardial function and infarct transmurality**

We have shown that SENC provides accurate regional description of LV function and
transmurality of infarcted myocardium. The results of this study extend data of a previously
published study introducing SENC as a novel MR technique for myocardial function imaging
in AMI.\(^\text{12}\) In that study by Garot et al., longitudinal strain was assessed in 9 patients after
AMI and was compared to infarcted myocardial tissue. In our study, we measured
circumferential as well as longitudinal strain in 38 patients and found that circumferential
strain was more precise in detecting hypokinesia and was also slightly more precise, however
not significantly, to distinguish between non-transmural and transmural infarcted tissue in
patients after AMI.

Previous studies have shown that CE-MRI can not only accurately detect myocardial scar
with higher spatial resolution than nuclear imaging techniques,\(^\text{16}\) but also predict functional
recovery in patients with ischemic heart disease.\(^\text{7}\) In patients with chronic ischemic heart
disease the threshold to regain functional recovery is hyperenhancement <50%.\(^\text{7, 8}\) Choi et al
and others have demonstrated that in patients with AMI even segments with an extent of 51-
75% hyperenhancement exhibit some improvement in contractile function.\(^\text{17-19}\)

Therefore, in the present study segments with hyperenhancement <75% were classified as
having potential to regain functional recovery whereas segments with hyperenhancement
>75% were considered to have low probability for functional recovery.

Circumferential strain values achieved an excellent sensitivity and specificity to differentiate
segments which have potential to regain functional recovery and those which have less.

In contrary to the theory of increased function in remote myocardium early after AMI\(^\text{20}\) we
found impaired strain parameters in all segments, including the remote region, compared to
strain values of the same segments of the left ventricle of healthy volunteers. MR tagging studies showed the same findings using circumferential strain.\textsuperscript{12, 21, 22} Different loading conditions of the infarct-related myocardium may reduce function in the remote myocardium. Reduced function in the noninfarcted myocardium may lead to redistribution of regional wall stress and smaller compliance mismatch between functioning and nonfunctioning myocardium.\textsuperscript{23}

The inverse correlation between global ventricular function and regional myocardial function quantified by strain analysis was higher using circumferential strain compared to longitudinal strain parameters ($r=-0.68$ versus $r=-0.45$). Thus, it is suggested that the level of contribution of circumferential fibers to the LV-function is greater than that of the longitudinal fibers. This may be explained by the fiber architecture and the contraction pattern of the left ventricle.\textsuperscript{24}

\textbf{Advantages of SENC}

The extent and degree of contractile dysfunction and infarcted tissue are both important factors in determining long-term prognosis after AMI. For assessment of regional dysfunction in clinical routine, wall motion analysis and wall thickening are often used parameters.\textsuperscript{25} These parameters are often subjective and have a limited reproducibility. However, objective reproducible methods for quantification of myocardial function are of critical importance for patient management, therapy monitoring and outcome studies.

Myocardial strain imaging in CMR offers a reproducible measure of strain and therefore provides objective assessment of regional myocardial deformation. The current reference standard of myocardial deformation imaging in CMR is tagging. However, MR tagging still has some disadvantages, for example time-consuming post-processing, despite the use of HARP concepts.\textsuperscript{26, 27} We demonstrated that strain-analysis of SENC data is significantly faster than analysis of tagging data, which is in agreement with previous studies.\textsuperscript{11} Furthermore, the reproducibility of MR tagging was also slightly inferior to that of SENC imaging ($\text{ICC}=0.80$ versus $\text{ICC}=0.92$), even though it was in the reported ranges.\textsuperscript{28, 29}
Moreover, SENC provides a short breathhold time and therefore also a shorter overall image time, which may be an advantage, especially when examining acutely ill patients like patients presenting with AMI.

SENC provides spatially resolved imaging and assessment of myocardial strain without the need for complex image postprocessing as this technique offers direct pixel-related imaging and therefore direct assessment of longitudinal and circumferential strain. Our data show that SENC provides reduced breathhold times with improved spatial and temporal resolution as SENC provides pixel-related quantification of myocardial strain, obviating the measure of myocardial strain derived from tags with relevant separation of ~7mm.

**Limitations**

First, as we did not investigate the patients at follow-up it remains to be investigated whether strain-parameters obtained by SENC allow improved prediction of functional recovery at follow up. However, we have shown for the first time in a large patient population that SENC provides accurate assessment of circumferential and longitudinal strain in infarcted, adjacent and remote myocardium and allows distinction between non-transmural and transmural infarcted myocardial tissue. Second, due to the nature of this method we compared SENC long-axis views to MR tagging short-axis views. By using anatomical landmarks we intended to find the same image plane. However, we can not exclude that the image plane was not always exactly the same. Third, longitudinal strain parameters assessed by SENC were not compared to MR-tagging. A close correlation of these two methods has been demonstrated before, however in a small patient population.

**Conclusion**

The present study demonstrates that strain parameters obtained from SENC MR-imaging can be used to assess regional contractile function as well as transmurality states of infarcted myocardial tissue in patients with AMI.
Acknowledgments

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Disclosures

Dr. Nael Osman is a founder and shareholder in Diagnosoft Inc. This is approved by the Conflict of Interest committee at Johns Hopkins University. The other authors have no conflicts of interests to disclose.
Reference List


Figure legends

Figure 1. SENC imaging to differentiate transmurality states of infarcted tissue

Delayed enhancement image (panel A) of a patient with transmural anterior myocardial infarction. The arrows are indicating the infarcted tissue with signs of severe microvascular obstruction.

Colour-coded SENC-image (panel B) in the same orientation to measure circumferential strain. Dysfunctional myocardium appears green (arrows) on the colour-coded strain image whereas normally contracting myocardium appears red. Panel C shows the corresponding strain-curve. Strain values in the infarcted myocardium, which appears green in the colour-coded SENC-image, are nearly zero.

Panel D shows a delayed enhancement image of a patient with a subendocardial inferior myocardial infarction (arrows indicating the infarcted tissue). The colour-coded SENC image (panel E) appears in a different colour as in panel B differentiating the degrees of severity. The corresponding strain-curve (panel F), correspondingly, indicates more deformation in the infarcted tissue than in panel C.

Figure 2. Strain-values obtained by SENC in relation to wall motion analysis

Box-and whisker plot demonstrating significantly different circumferential strain-values as determined by SENC MR-imaging in normokinetic, hypokinetic and a/dyskinetic regions (n= number of analyzed segments).

Figure 3. SENC for distinction between non-transmural and transmural infarcted myocardial tissue

ROC-curve demonstrating that a cut-off peak systolic circumferential strain value of -10% obtained by SENC is able to differentiate non-transmural infarcted myocardium from
transmural infarcted myocardium with a sensitivity of 97% and a specificity of 94%.
Longitudinal strain was less sensitive and specific for distinction between non-transmural and
transmural infarcted myocardial tissue (Sensitivity 64%, Specificity 85%).

**Figure 4. Comparison of SENC and MR tagging**

A) Linear regression analysis of the comparison of SENC and MR-tagging.

B) The Bland-Altman plot shows narrow limits of agreement between SENC and MR tagging
(-9.9 to 8.5%).
Table 1. Patients characteristics

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<td>Age (years)</td>
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<td>Male/female (%)</td>
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<td>STEMI/NSTEMI (%)</td>
<td>32(84%)/6(16%)</td>
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<td>Ejection fraction (%)</td>
<td>54±14</td>
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<td>Infarct size (g)</td>
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Infarct location

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<td>18 (48%)</td>
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<tr>
<td>RCA (%)</td>
<td>13 (34%)</td>
</tr>
<tr>
<td>LCX (%)</td>
<td>7 (18%)</td>
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All data given as mean ±SD or as absolute numbers with corresponding relative percentage.

Abbreviations: STEMI: ST-elevation myocardial infarction; NSTEMI: non ST-elevation myocardial infarction; LAD: left-anterior descending; LCX: left circumflex artery; RCA: right coronary artery.
Circumferential strain (%)

-30 -25 -20 -15 -10 -5 0 5 10

Normokinesis: n=302
Hypokinesis: n=82
A/Dyskinesis: n=72

p<0.001
Circumferential strain (%) - hyperenhancement > 75%

- AUC 0.97
- Sensitivity 97%
- Specificity 94%

Longitudinal strain (%) - hyperenhancement > 75%

- AUC 0.76
- Sensitivity 64%
- Specificity 85%
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