Impact of Low Signal Intensity Assessed by Cine Magnetic Resonance Imaging on Detection of Poorly Viable Myocardium in Patients With Prior Myocardial Infarction

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Summary

Late gadolinium enhancement magnetic resonance imaging (LGE-MRI) has been established as a modality to detect myocardial infarction (MI). However, the use of gadolinium contrast is limited in patients with advanced renal dysfunction. Although the signal intensity (SI) of infarct area assessed by cine MRI is low in some patients with prior MI, the prevalence and clinical significance of low SI has not been evaluated. The aim of this study was to evaluate how low SI assessed by cine MRI may relate to the myocardial viability in patients with prior MI. Fifty patients with prior MI underwent both cine MRI and LGE-MRI. The left ventricle was divided into 17 segments. The presence of low SI and the wall motion score (WMS) of each segment were assessed by cine MRI. The transmural extent of infarction was evaluated by LGE-MRI. LGE was detected in 329 of all 850 segments (39%). The low SI assessed by cine MRI was detected in 105 of 329 segments with LGE (32%). All segments with low SI had LGE. Of all 329 segments with LGE, the segments with low SI showed greater transmural extent of infarction (78 [72 - 84] % versus 53 [38 - 72] %, $P < 0.01$), thinner wall (4.0[3.1 - 4.8] mm versus 6.5 [5.2 - 8.1] mm, $P < 0.01$), and higher WMS (4.0 [4.0 - 4.0] versus 2.0 [2.0 - 3.0], $P < 0.01$). The low SI assessed by cine MRI may be effective for detecting poorly viable myocardium in patients with prior MI. (Int Heart J 2015; 56: 273-277)

Key words: Late gadolinium enhancement, Myocardial viability, Adipose tissue

Late gadolinium enhancement magnetic resonance imaging (LGE-MRI) can accurately detect replacement of viable myocytes by necrosis or fibrosis with high spatial resolution.[1-4] In coronary artery disease, LGE imaging can be performed before coronary revascularization procedures to predict the functional recovery after revascularization.[1,5-7] These studies suggested that dysfunctional segments with LGE, corresponding to infarcted non-viable myocardium, do not improve in terms of function after revascularization. However, dysfunctional segments without LGE, corresponding to viable myocardium, may recover after revascularization, leading to an increase in left ventricular (LV) ejection fraction (EF). Although the clinical utility of LGE-MRI in the detection of infarction is widely understood, the use of gadolinium contrast should be limited in patients with advanced renal dysfunction and dialysis.

Cine MRI has been useful to evaluate cardiac function and morphology without using gadolinium contrast. Although infarct lesions in patients with prior MI are likely to be identified as low signal intensity (SI) in clinical practice, the clinical significance of low SI assessed by cine MRI has fully remained unclarified, especially in terms of myocardial viability.

The aim of this study was to evaluate the relationship between low SI assessed by cine MRI and myocardial viability in patients with prior MI.

Methods

Study population: We retrospectively enrolled 50 patients with a history of prior MI. Patients had changes on their electrocardiogram (ECG) (abnormal Q wave, new onset of left bundle branch block) and abnormalities in regional wall motion on either cine MRI or echocardiography. All patients had LGE from the subendocardium to the epicardium or transmural LGE which were compatible with prior MI. We carefully excluded patients with claustrophobia, significant renal dysfunction (glomerular filtration rate < 30 mL/minute/1.73 m^2), or contraindications for cardiovascular magnetic resonance imaging (CMR) such as metal implants.

This study was approved by the Ethics Committee of Wakayama Medical University and all patients gave their writ-

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ten informed consent.

CMR protocol: All CMR examinations were performed using a 1.5-T clinical scanner (Intera Achieva; Philips Medical Systems, Best, The Netherlands) equipped with a 5-element cardiac phased-array coil for signal reception, as previously described.[8,9] During the examination, patients were continuously monitored on single-lead ECG, repeated blood pressure measurements, and pulse oximetry. With the patient in the supine position, contiguous short-axis cine images covering the LV from base to apex were acquired using a standard steady-state free-precession sequence.

LGE imaging covering the whole ventricle was required 10-15 minutes after intravenous injection of 0.1 mmol/kg gadolinium diethylenetriamine penta-acetic acid (Gd-DTPA; Magnevist, Schering, Berlin, Germany). We used a 3-D inversion-recovery turbo gradient echo sequence, and images were obtained during an end-expiratory breath-hold. Scan parameters were as follows: TR, 4.1 ms; TE, 1.25 ms; flip angle, 15°; FOV, 350 × 350 mm; partial echo; matrix, 224 × 256; and spatial resolution, 1.56 × 2.24 × 10 mm^3 reconstructed to 0.68 × 20.68 × 5 mm^3. Inversion time was adjusted to null the signal from viable myocardium.[10]

CMR image analysis: All analyses were performed by consensus of independent blinded observers (Y.M. and T.Y.) on an off-line workstation (View Forum, Philips Medical System). The LV was divided into 17 segments according to an AHA guideline, and we analyzed a total of 850 segments.

On cine MRI, we assessed visually the presence of low SI and wall motion score (WMS: 1-5 points; 5 = aneurysm, 4 = dyskinesia, 3 = akinesia, 2 = hypokinesia, 1 = normokinesia) in each segment, and calculated the wall motion score index (WMSI = summed wall motion score/total numbers of assessed segments).[11-13] Moreover, for quantification of LV volumes and LVEF, the endocardial border was delineated on the end-diastolic and end-systolic short-axis slices. Interobserver agreement for assessing the presence of low SI was high (r = 0.94).

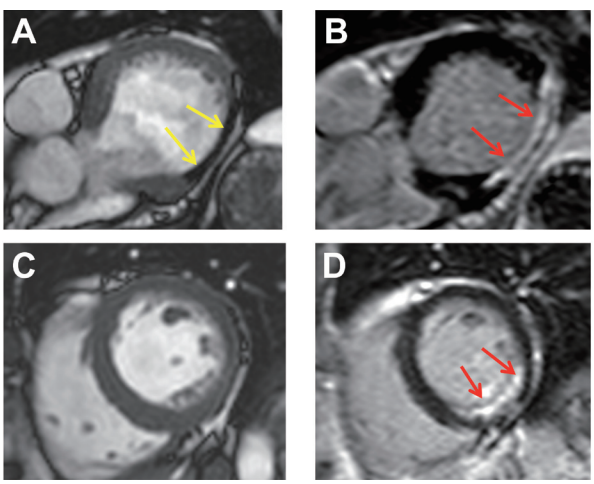

Figure. Two representative cases with prior myocardial infarction. Cine (**A** and **C**) and late gadolinium enhancement (**B** and **D**) magnetic resonance images (MRI) in 2 patients with a history of myocardial infarction. Upper case with the lateral wall infarction (**B**, red arrows) had low signal intensity (SI) on cine MRI (**A**, yellow arrows). Lower case with an inferior wall infarction (**D**, red arrows) had no low SI on cine MRI (**C**).

On LGE-MRI, we assessed the presence of infarct area and transmural extent of infarction (thickness of LGE area/wall thickness × 100) in each segment, and calculated infarct size by automatic summation of all slice volumes of infarct areas and expressed it as a percentage of LV volume.[14] According to a previous study,[15] an infarct area was defined as an area with signal intensity 5 SDs above the mean signal obtained in the remote noninfarcted myocardium on LGE images. Two representative cases with prior MI are shown in the Figure.

Statistical analysis: All statistical analyses were carried out using SPSS version 11.0 (SPSS, Chicago, IL, USA). Categorical variables are presented as frequency counts and percentages. Continuous variables are presented as the median and interquartile range and were compared using the Mann-Whitney U test. A value of P below 0.05 was considered statistically significant.

Results

Patient characteristics: The characteristics of the clinical baseline and MRI of the 50 patients are presented in Table I. The median [interquartile range] of age was 63 [57 - 72] years old and most patients were male (84%). Thirty-three patients (66%) were successfully recanalized with percutaneous coronary intervention or coronary artery bypass graft surgery. The median [interquartile range] of infarct age was 8 [7 - 48] months. All patients had at least one segment with LGE.

Relationship between low SI assessed by cine MRI and LGE: The segments with LGE were 329 of all 850 segments (39%). The segments with low SI assessed by cine MRI were 105 of all 850 segments (12%). All segments with low SI assessed by cine MRI had LGE. The sensitivity, specificity, positive predictive value, negative predictive value, and accuracy to predict the MI by the presence of low SI assessed by cine MRI were

Table I. Characteristics of Clinical Baseline and MRI

Variable	
Number	50
Age, years	63 [57 - 72]
Male gender, *n* (%)	42 (84)
Hypertension, *n* (%)	35 (70)
Diabetes mellitus, *n* (%)	20 (40)
Dyslipidemia, *n* (%)	23 (46)
Current smoker, *n* (%)	24 (48)
Infarct age, months	8 [7 - 48]
Reperfusion therapy (PCI/CABG)	29 / 4
Cine MRI	
WMSI	1.6 [1.3 - 2.1]
LVEDV, mL	119 [97 - 148]
LVESV, mL	57 [40 - 90]
LVEF, %	51 [35 - 57]
Summed segments with low SI (0 / 1-2 / 3-)	27 / 11 / 12
LGE-MRI	
Summed segments with LGE (0 / 1-4 / 5-8 / 9-)	0 / 16 / 18 / 16
Infarct size, %	18 [9 - 27]

Values are presented as *n* (%), as median [interquartile range]. CABG indicates coronary artery bypass graft; LGE, late gadolinium enhancement; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction; LVESV, left ventricular end-systolic volume; MRI, magnetic resonance imaging; PCI, percutaneous coronary intervention; SI, signal intensity; and WMSI, wall motion score index.

32%, 100%, 100%, 70%, and 74%, respectively (Table II).

Characteristics of segments with and without low SI: In all 329 segments with LGE, the characteristics of segments with and without low SI assessed by cine MRI are presented in Table III. The segments with low SI showed greater transmural extent of infarction (78 [72 - 84] % versus 53 [38 - 72] %, $P < 0.01$), thinner wall (4.0[3.1 - 4.8] mm versus 6.5 [5.2 - 8.1] mm, $P < 0.01$), higher WMS (4.0 [4.0 - 4.0] versus 2.0 [2.0 - 3.0], $P < 0.01$), and older infarct age (48 [7.0 - 156] months versus 8 [7.0 - 27] months, $P < 0.01$) than the segments without low SI.

The segments with transmural extent of LGE > 50% were 219 of 329 segments (67%). The segments with transmural extent of LGE ≦ 50% were 110 of 329 segments (33%). The sensitivity, specificity, positive predictive value, negative predictive value, and accuracy to predict LGE > 50% by the presence of low SI assessed by cine MRI were 45%, 95%, 94%, 46%, and 62%, respectively (Table IV).

In the segments with LGE > 50%, infarct age of the segments with low SI assessed by cine MRI was significantly older than the segments without low SI (48 [7.0 - 174] months versus 8.0 [7.0 - 36] months, $P < 0.01$).

Comparison between patients with and without low SI segments: In all 50 patients, the characteristics of patients with and without low SI segments assessed by cine MRI are presented in Table V. Twenty-nine patients had low SI segments (58%). LVEDV, LVESV, and WMSI were significantly greater in the patients with low SI segments than in those without low SI segments (134 [111 - 167] mL versus 104 [88 - 122] mL, $P < 0.01$, 78 [53 - 106] mL versus 42 [37 - 53] mL, $P < 0.01$, 1.9 [1.5 - 2.4] versus 1.3 [1.2 - 1.7], $P < 0.01$, respectively). LVEF was significantly lower in the patients with low SI segments than in those without low SI segments (42 [31 - 51] % versus 56 [55 - 61] %, $P < 0.01$).

Discussion

To the best of our knowledge, this study demonstrates for the first time the relationship between myocardial viability and low SI assessed by cine MRI in patients with prior MI. The major findings of this study are that 1) all segments with low SI assessed by cine MRI had LGE, 2) the segments with low SI had the finding of poor viability (greater transmural extent of infarction, thinner wall, and higher WMS), 3) infarct age of the segments with low SI was older than the segments without low SI, 4) the specificity to predict poor viable myocardium (transmural extent of LGE > 50%) by the presence of low SI was very high (95%), and 5) LVEDV, LVESV, and WMSI were significantly greater in the patients with low SI segments than in those without low SI segments, and LVEF was significantly lower in the patients with low SI segments than in those without low SI segments.

Assessment of MI and viability by LGE-MRI: Multiple experimental studies have demonstrated an excellent spatial correlation between the extent of hyperenhancement on LGE-MRI and areas of MI at histopathology.[4] In patients with prior MI, LGE-MRI has been shown to be highly effective in identifying the presence, location, and extent of MI in both the acute and chronic phases.[16] Moreover, LGE imaging can be performed before coronary revascularization procedures to predict the functional recovery after revascularization.[1] Specifically, there is an inverse relationship between the transmural extent of LGE and the likelihood of wall motion recovery following revascularization. Our study demonstrated that all segments with low SI assessed by cine MRI had LGE, and the segments with low SI showed greater transmural extent of LGE. Additionally, the segments with low SI presented with a thinner wall and higher WMS than those without low SI. These findings suggest that the segments with low SI assessed by cine MRI may have poor viability.

Kim, *et al* reported that 90% of the segments with LGE > 50% before revascularization did not improve after revasculari-

Table II. Relationship Between Low SI on Cine MRI and LGE

	LGE (+)	LGE (-)
Low SI (+), segments	105	0
Low SI (-), segments	224	521

Values are given as *n*. MRI indicates magnetic resonance imaging; LGE, late gadolinium enhancement; and SI, signal intensity.

Table III. Characteristics of Segments with and without Low SI on Cine MRI in 329 Segments with LGE

	Low SI (+) $n = 105$	Low SI (-) $n = 224$	*P*
Transmural extent of infarction, %	78 [72 - 84]	53 [38 - 72]	< 0.01
Wall thickness, mm	4.0 [3.1 - 4.8]	6.5 [5.2 - 8.1]	< 0.01
WMS	4.0 [4.0 - 4.0]	2.0 [2.0 - 3.0]	< 0.01
Infarct age, months	48 [7.0 - 156]	8 [7.0 - 27]	< 0.01

Values are given as median [interquartile range]. MRI indicates magnetic resonance imaging; SI, signal intensity; and WMS, wall motion score.

Table IV. Relationship Between Low SI on Cine MRI and Transmural Extent of Infarction

	LGE > 50%	LGE ≦ 50%
Low SI (+), segments	99	6
Low SI (-), segments	120	104

Values are given as *n*. MRI indicates magnetic resonance imaging; LGE, late gadolinium enhancement; and SI, signal intensity.

Table V. Comparison Between Patients With and Without Low SI Segments

	Patients with low SI $n = 29$	Patients without low SI $n = 21$	*P*
LVEDV, mL	134 [111 - 167]	104 [88 - 122]	< 0.01
LVESV, mL	78 [53 - 106]	42 [37 - 53]	< 0.01
EF, %	42 [31 - 51]	56 [55 - 61]	< 0.01
WMSI	1.9 [1.5 - 2.4]	1.3 [1.2 - 1.7]	< 0.01

Values are given as median [interquartile range]. LVEDV indicates left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction; LVESV, left ventricular end-systolic volume; SI, signal intensity; and WMSI, wall motion score index.

zation.[1] Paulo, *et al* demonstrated that approximately 80% of segments with LGE > 50% had no chance of functional recovery after revascularization.[17] These studies suggested that the segments with LGE > 50% had poor viability according to the wall motion improvement criteria. We demonstrated in this study that the specificity to predict poor viable myocardium (transmural extent of LGE > 50%) by the presence of low SI on cine MRI was very high (95%).

In all segments with LGE, infarct age of the segments with low SI assessed by cine MRI was significantly older than the segments without low SI. Additionally, in the segments with LGE > 50%, infarct age of the segments with low SI assessed by cine MRI was significantly older. Taken together, the low SI was related to not only myocardial viability but also infarct age. These results suggest that cine MRI may be useful to detect poorly viable myocardium in patients with prior MI with older infarct age.

The underlying mechanisms concerning how the low SI assessed by cine MRI was presented in the segments with prior MI were not clarified. Previous studies reported that mature adipose tissue is often found in LV myocardial segments with prior MI.[18,19] Several case reports showed adipose tissue in MI with noninvasive imaging modalities.[20-25] Goldfarb, *et al* have shown that T1-weighted imaging on CMR detected the adipose tissue as high signal intensity in prior MI.[26] It is known that signals of cine imaging are correlated to T2/T1 (signal of T2-weighted imaging/signal of T1-weighted imaging).[27] Myocardial edema followed by acute MI was presented as high SI on T2-weighted imaging.[28] Andreas, *et al* demonstrated that myocardial edema can be detected using cine imaging as high SI according to the elevation of T2/T1 due to elevating the signal of T2-weighting imaging.[29] Similarly, cine imaging might present adipose tissue accompanying prior MI as low SI according to the reduction of T2/T1 due to reducing the signal of T1-weighted imaging. In the current study, T1-weighted imaging was not performed. Further studies would be required to assess the relationship between cine MRI and T1-weighted imaging.

Clinical implications: Several studies have suggested that LGE-MRI was effective at detecting MI and predicting functional recovery after revascularization.[1-7] However, the use of gadolinium contrast is limited in patients with advanced renal dysfunction and dialysis. Cine MRI has been effective to evaluate cardiac function and morphology. Additionally, our study demonstrates that cine MRI is useful for evaluating tissue characteristics noninvasively in patients with prior MI without using gadolinium contrast.

Study limitations: There are several limitations in the present study. First, it was a retrospective observational study. Therefore, the decision as to perform CMR or not was based on the physician's discretion. Second, the presence or absence of low SI assessed by cine MRI was assessed visually and was not quantified. Finally, the number of patients with MI in this study was relatively small. Further prospective studies including a larger cohort of patients would be required to confirm the present results.

Conclusions: The segments with low SI assessed by cine MRI in patients with prior MI showed findings of poor viability as suggested by greater transmural extent of LGE, thinner wall, and higher WMS, and a low SI is effective at detecting poorly viable myocardium noninvasively in patients with prior MI, especially with older infarct age.

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