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Subacute myocardial infarction: assessment by STIR T2-weighted MR imaging in comparison to regional function

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Abstract

Purpose: Increased T2 signal intensity (SI) can be regularly observed in myocardial infarction. However, there are controversial reports about the relationship of elevated T2 SI to myocardial viability and some authors propose that high T2 SI serves as a sign of irreversible myocardial injury. This study investigates increased T2 SI compared to myocardial function in patients with reperfused subacute myocardial infarction. Preserved function was used as criterion for viability.

Methods: Ten healthy volunteers and 17 patients with myocardial infarction and patent infarct related coronary artery were examined on a 1.5 T Magnetom Vision system (Siemens). For T2-weighted MR imaging a breath-hold STIR sequence with dark-blood preparation was used. Cine FLASH 2D imaging was applied to assess myocardial function. Signal-to-noise (S/N) in STIR T2 images was measured in normal and infarcted regions and subsequently identified by two independent observers. Based on a 20 segment model of the left ventricle findings were compared to regional myocardial function.

Results: Elevated STIR T2 SI was found in all 17 patients and observed in 27% (204/754) of segments. S/N of normal myocardium was 5.1 ± 0.7 in volunteers and 4.9 ± 0.8 in patients ($P = \text{NS}$). Infarcted myocardium presented with significantly increased S/N 12.8 ± 1.9 ($P < 0.0001$). Significant transmural elevation of T2 SI was noted in 32% of segments with preserved systolic function.

Conclusion: Increased STIR T2 SI can be observed transmurally in post-ischemic myocardial regions with preserved function. It therefore cannot be used as an exclusive marker for the non-viable region.

Keywords: MR imaging; Edema; Inversion recovery; Myocardial infarction; Myocardial function

1. Introduction

Magnetic resonance (MR) imaging is widely used to investigate the state of post-ischemic myocardium including myocardial infarction [1]. The imaging approach may involve both functional and perfusion aspects, allowing assessment of regional viability and the 'area at risk' [2–4]. Also, pharmacological stress or late myocardial enhancement following injection of a contrast have been applied to investigate this issue [5–8].

In this context, also T2-weighted imaging has been applied. Increased T2 signal intensity (SI) has regularly been observed in post-ischemic myocardium and is proposed to serve as a sensitive marker of regional injury in the early phase after ischemia [9,10]. However, controversial results are reported regarding the extent of elevated T2 SI in relation to 'true' infarct size. Depending on the pathophysiological setting of the study, elevated T2 SI was found to either match or overestimate infarct size. The phenomenon of increased SI has been attributed to different myocardial processes such as hemorrhage, alteration of interstitial space, augmentation of tissue water, change of protein content and fatty infiltration [11–13].

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Many in vivo investigations have been performed using conventional spin-echo pulse sequences. Using these techniques artifacts due to respiratory motion and blood flow can occur, even when ECG-gating is applied. Motion and flow related artifacts in turn can deteriorate the quality of T2-weighted images and influence quantitative analyses of relaxation times [14]. In order to overcome these problems, very fast pulse sequences for cardiac gated T2-weighted dark-blood imaging have been designed which allow data acquisition in a single breath-hold [15]. This type of sequence was recently reported to provide improved image quality and high accuracy for the analysis of cardiac morphology and tissue alterations [16]. High resolution fast T2-weighted imaging, therefore, may reveal new information about regional signal changes in post-ischemic myocardium in comparison to other high quality imaging techniques such as functional cine imaging [17].

The purpose of this study was to investigate the relation between T2 SI and regional myocardial function in patients with reperfused, subacute myocardial infarction.

2. Methods

2.1. Patient and control group

To acquire data for baseline T2 SI in normal myocardium, 10 healthy volunteers (mean age 27 ± 2 years) were examined. Cardiac disease was excluded by ECG and echocardiography in all subjects.

Seventeen patients (14 men, 3 women, mean age 52.7 ± 8.6 years) with first event myocardial infarction were examined 4–12 days (mean 6.2 ± 2.8 days) after onset of clinical symptoms. Inclusion criteria were: characteristic clinical symptoms of acute myocardial infarction, typical ECG-changes, significant elevation of the creatine phosphokinase (exceeding the upper limit + 2SD) and patency of the infarct related coronary artery, as proven by invasive coronary angiography. In all patients, reperfusion therapy was performed by thrombolysis. Informed consent was obtained in each subject and studies were carried out in accordance with the institutional review board. Coronary angiography and cine ventriculography were performed prior to MR imaging.

2.2. MR imaging

MR imaging was performed with knowledge of the patients clinical history including infarct localization in the ECG and CPK maximum. Imaging data were acquired supine with cardiac and respiratory gating in end-expiration using a phased-array coil on a 1.5 T whole body MR system (Magnetom Vision, Siemens, Erlangen). The automated shim adjustment of the system was used. After positioning of the heart using a turbo-FLASH 2D localizer, imaging planes were adjusted to the anatomic cardiac axes in order to obtain standard long and short axis views. The left ventricle was then imaged with both, T2-weighted and cine sequences along all three axes. Two or more slices were positioned in the long axis direction in order to cover the apex and six or more slices were measured in the short axis orientation. For breath-hold T2-weighted single slice imaging, a fast spin echo pulse sequence was applied that uses radio frequency pulses for spin inversion of the blood pool and inversion recovery preparation for fat saturation (STIR sequence [15]). To avoid the influence of cardiac motion, the data acquisition window was shifted to diastole and the sequence parameters were as follows: TR = RR + 800 ms, TE = 76 ms, length of echo train = 23, matrix 196–256*256, 280–320*280–320 mm field of view, 6 mm slice thickness, one acquisition. Subsequently, identical slice positions were measured to study regional myocardial function with a flow compensated cine FLASH 2D pulse sequence (cine sequence): TR 100 ms, length of echo-train = 9 (effective TR 11 ms), TE 4.8 ms, flip angle 25°, matrix196–256*256, 280–320*280–320 mm field of view, 6mm slice thickness. In addition to the segmented data acquisition, this sequence operates with a k-hole technique for image reconstruction increasing the temporal resolution to 50 ms.

2.3. MR image analysis

MR images were accessible on films and optical discs. The system software (Numaris version 3 B 31A, Siemens, Erlangen) was used for further evaluation. Qualitative findings from cine studies and T2 weighted images were compared based on a 20 segment model dividing four chamber and septum parallel long axis views in six segments and short axis views in eight segments(Fig. 1). Regions that were represented in both scanning orientations were used to confirm imaging findings but were not considered twice for the evaluation of the total number of segments.

Myocardial wall motion was assessed from cine images by consensus reading of two observers. Regional function was qualitatively categorized into normokinesis (> 30% wall thickening), hypokinesis (10–30% wall thickening), akinesis (0–10% wall thickening) and dyskinesis (systolic bulging of the myocardial wall) and documented for each segment. Preserved myocardial function (normo- and hypokinesis) was used as a criterion for the presence of preserved viability.

Myocardial SI and background noise were measured directly on the T2-weighted STIR images by one observer manually drawing regions of interest (approx. $0.2cm^2$ area) into myocardial regions of the anterior,

lateral, inferior and septal wall of short and long axis images in the volunteer group. These values were taken as normal T2 SI of control myocardium. Signal to noise ratios (S/N) were calculated. In patient studies, segments with normal and increased SI were identified by one observer and myocardial SI and background noise were measured. Normal and elevated STIR T2 SI was measured similar to the volunteer group and pathological SI was defined as an increase of more than mean SI + 2SD of normal myocardium. Afterwards, qualitative film reading for detection of normal and abnormal myocardial segments was performed by visual analysis of two independent observers. Increased SI of abnormal segments was categorized into transmural and non-transmural.

2.4. Statistical analysis

The interobserver agreement for qualitative assessment of pathological SI in T2-weighted STIR images was determined by kappa-statistics as chance corrected proportional agreement. The difference of S/N in normal and infarcted regions was tested using a two-tailed Student's t-test. A P-value of < 0.05 was considered statistically significant.

3. Results

In all individuals diagnostic image quality was achieved. Normal myocardial T2 SI was homogeneous and hypointense in the control group of healthy volunteers (Fig. 2). Elevated STIR T2 SI was present in all 17 patients after myocardial infarction. An average of 6.5 slices per patient and a total of 754 segments were available for combined analysis of regional function and STIR T2 SI.

3.1. Myocardial signal intensity in STIR images

Measurements of myocardial SI in STIR images were available for normal and abnormal regions in three or

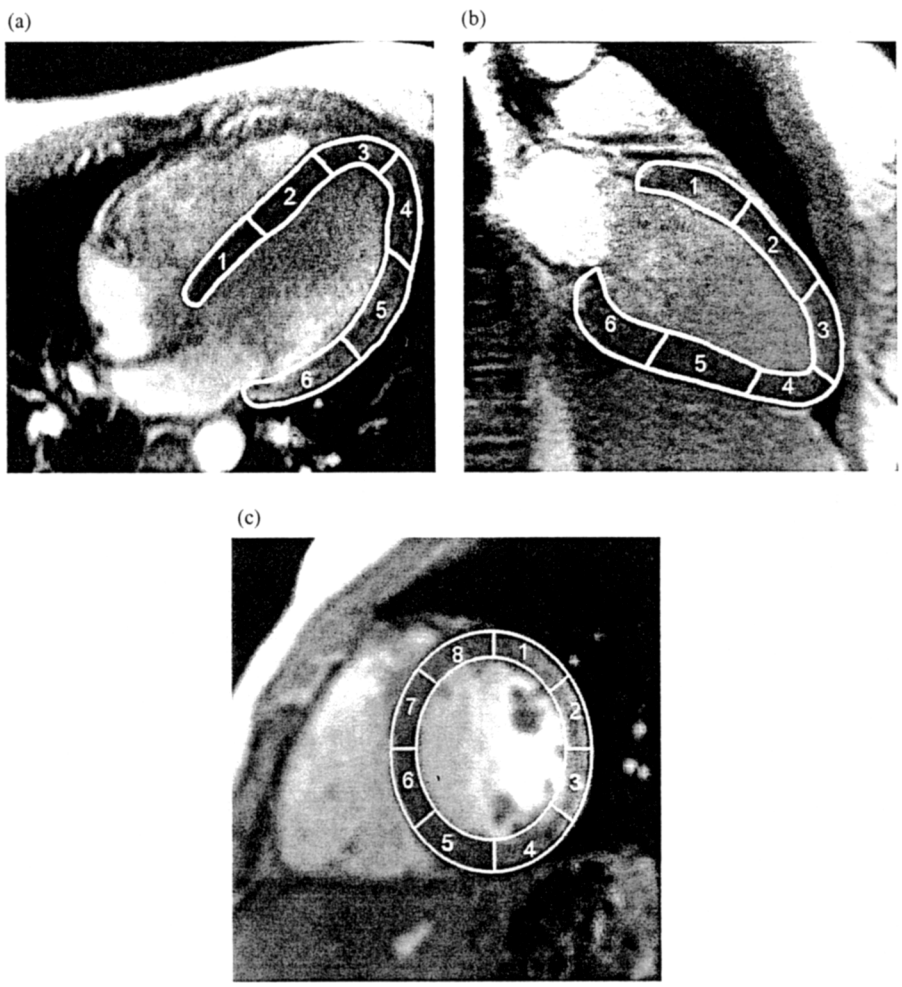

Fig. 1. Evaluation model of 20 myocardial segments. Left ventricular model of 20 myocardial segments. Short axis images were divided in eight segments. Septum parallel and four chamber view long axis views were divided into six segments each.

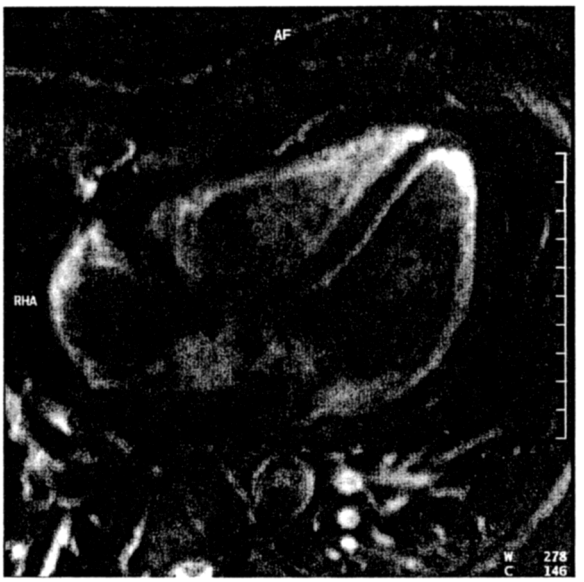

Fig. 2. Short axis dark-blood STIR T2-weighted fast spin-echo image in a normal volunteer with homogeneous hypointense SI of the myocardium.

more slices of both volunteers and patients. The S/N of normal myocardium was 5.1 ± 0.7 in volunteers (60 measurements) and 4.9 ± 0.8 in patients (P = not significant, 162 measurements, Fig. 3). In post-ischemic myocardium, S/N was significantly elevated at 12.8 ± 1.9 ($P < 0.0001$, 112 measurements) and this was observed in 27% (204/754) of segments. In most of these segments the increase of SI was found to be transmural (166/204 segments, 81%) but in 4 of 17 patients there was also presence of non-transmural SI elevation (Fig. 4).

3.2. Myocardial function in relation to T2 STIR SI

In 65% of all segments (490/754) wall motion was staged normal, 18% (135/754) were hypokinetic, 13%

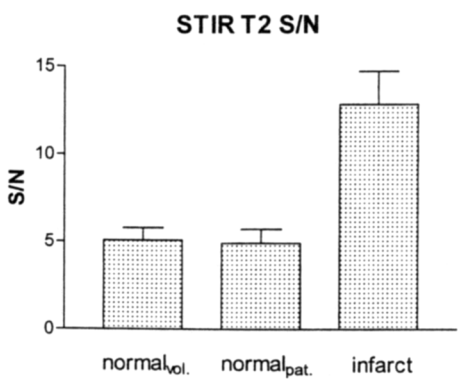

Fig. 3. S/N of normal and infarcted myocardium. S/N of normal and infarcted myocardium: normal$_{vol.}$ = S/N of normal control myocardium in volunteers; normal$_{pat.}$ = S/N of normal regions in patients; infarct = S/N of infarcted myocardium.

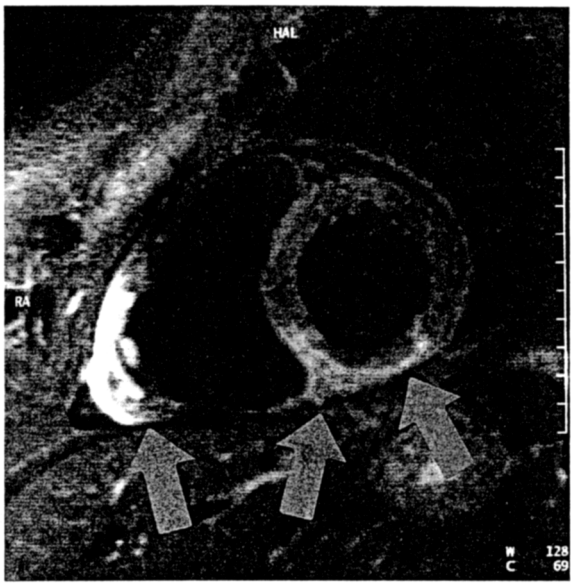

Fig. 4. Patient with non-transmural STIR T2 SI elevation. Short axis dark-blood STIR T2-weighted fast spin-echo image in a 56 year old male with non-transmural inferior wall infarction. High signal intensity can be noted subepicardially at the inferior left ventricular wall and transmurally at the caudal aspect of the right ventricle (arrows).

(98/754) akinetic and 4% (31/754) dyskinetic. The STIR T2 SI was clearly elevated in segments with akinesis and dyskinesis (129/129 segments). However, elevation of SI was also noted in 47% of segments with hypokinesis (63/135) and 2% of segments with normokinesis (12/490). Because of preserved function, by definition these regions were considered to include viable myocardium. Non-transmural elevation of STIR T2 SI was present in 7.4% of segments with hypokinesis (10/135) and the 2% of segments with normokinesis (12/490). Figs. 5 and 6 illustrate the prevalence and provide an example of normal and abnormal myocardial function in regions with elevated STIR T2 SI. Interobserver agreement for the localization of elevated STIR T2 SI was $\kappa = 0.89$.

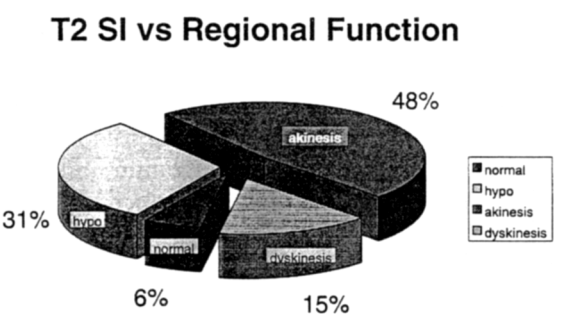

Fig. 5. Prevalence of STIR T2 SI elevation in comparison to myocardial function. Prevalence of STIR T2 SI elevation in comparison to myocardial function: normal = normal function; hypo = hypokinesis. Elevated T2 SI can be noted in 37% of segments with hypo- or normokinesis

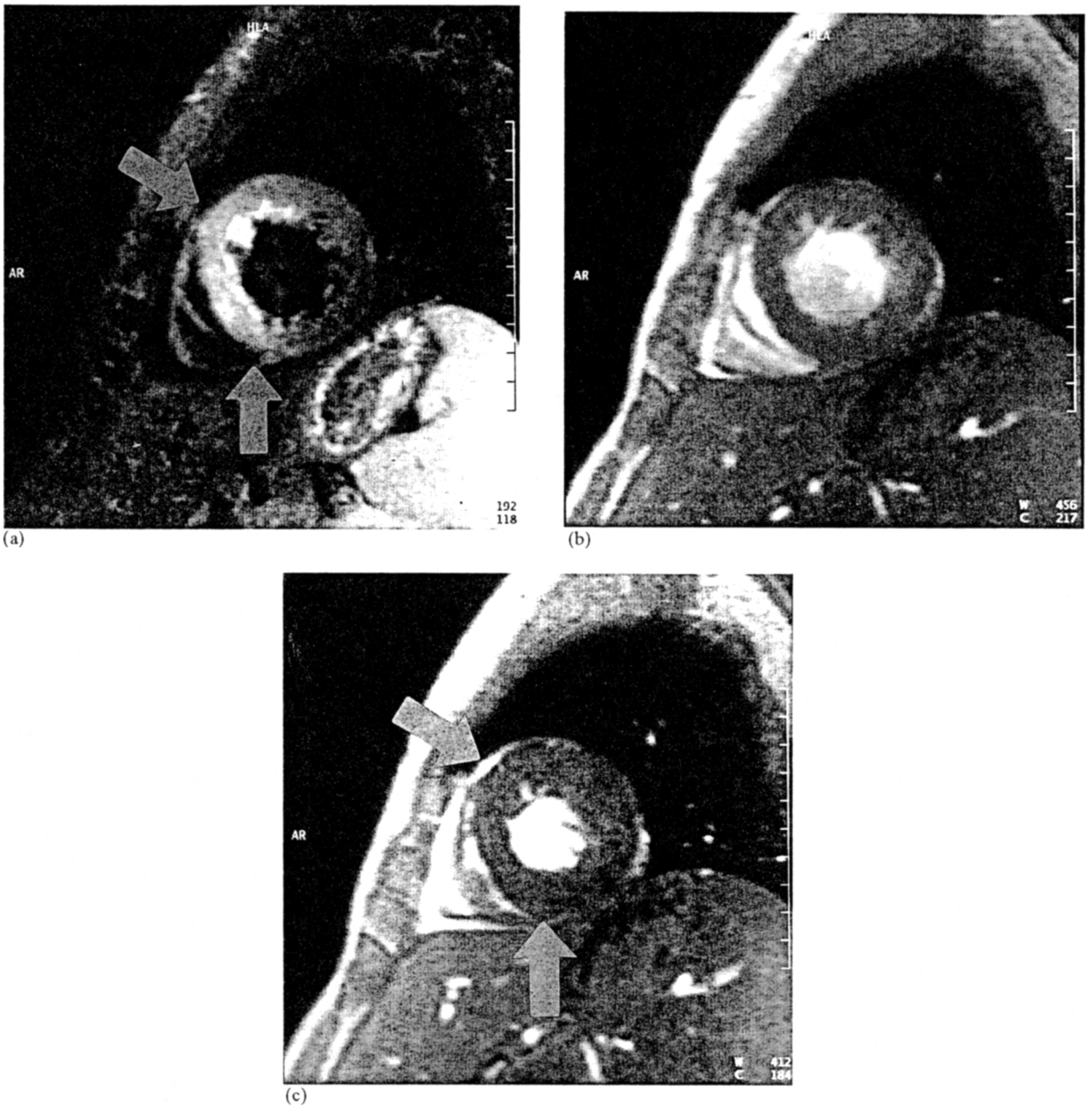

Fig. 6. Patient with transmural STIR T2 SI elevation but preserved function. Dark-blood STIR T2-weighted fast spin-echo image in a 53 year old female with transmural increase of SI (a). Cine images in end-diastole (b) and end-systole (c) reveal preserved myocardial function with wall thickening.

4. Discussion

MR imaging is playing an emerging role for post-ischemic myocardial tissue characterization and may become a routinely used diagnostic procedure for the detection of myocardial viability [18,19]. In this context, T2-weighted MR imaging may be of specific interest for the examination of myocardial damage: while late enhancement and first pass perfusion deficits may occur in both acute and chronic infarction [20], T2 relaxation time is at maximum during the acute phase after infarction (days to weeks) but decreases significantly in the chronic phase (> 6 months, [21]). It may therefore be possible to differentiate between acute and chronic injury using T2 weighted images.

Elevated STIR T2 SI was observed as a regular finding in all of our patients with a very good interobserver agreement ($\kappa = 0.89$). High SI at the endocardial wall from slow flowing blood, as described by Lim et al. [22] could be clearly differentiated from myocardial SI elevation and did not affect diagnostic image quality in long axis views in our study. There was no elevation of STIR T2 SI in the control group. Thus, causes for SI elevation, other than post-ischemic injury, can be excluded. Eventually, reduced T2 SI was observed in volunteers and patients as well and could be due to

myocardium with high contractility moving from outside into the imaging slice after being saturated by the dark-blood saturation pulse of the sequence.

Several studies have been investigating 'real' infarct size based on T2-weighted images. However, study designs assessing reperfused or occlusive ischemia, animal or human models and time interval between ischemic event and MR imaging are different and the conclusions about increased signal intensity in T2-weighted images in relation to infarct size are controversial [10,21,23–27].

In our study, STIR T2-weighted MR imaging was used in patients with patent infarct related coronary arteries who had undergone proven myocardial infarction and thrombolytic therapy within an appropriate time interval. Therefore, reperfused myocardial infarction presumably is the underlying pathological mechanism in our patient group. The MR examination was performed during the subacute phase after the first acute ischemic event and myocardial signal changes due to prior infarction cannot be expected. One limitation of our study is the range of time intervals between infarct event and MR imaging, which was 4–12 days. As a consequence, different stages of infarct repair have to be presupposed as underlying the histological tissue alteration at these points of time.

Preserved function was found in 49% of segments with elevated STIR T2 SI (47% with hypokinesis, 2% with normokinesis). In a sub-fraction of 17% (22 segments) SI elevation was *non-transmural* indicating non-transmural myocardial injury. Thus, *transmural* SI elevation was observed in 32% (49%–17%) of segments with preserved systolic function. This can be interpreted as a sign of preserved viability in a myocardial region with ischemic injury where an unknown percentage of the myocardial wall presumably is still non-viable but cannot be differentiated only by analysis of T2 SI. On the other hand, the number of segments with preserved viability but abnormal STIR T2 SI may be underestimated in our study, since akinesis at rest was an exclusion criterion for viability and low-dose dobutamine stress imaging might have revealed additional regions with contractile reserve.

Different post-ischemic changes of the myocardial ultra-structure have been reported to influence T2 SI with increase in tissue water serving as a major and linearly correlated factor. The increase in tissue water can be intra- or extracellular and may be found in reversible and irreversible injury as well [27,28]). Also fatty tissue changes can occur after myocardial infarction and raise the T2 relaxation time [13]. Since STIR T2-weighted imaging includes inversion recovery preparation, signal of fatty tissue can be excluded as a source of increased SI in our study. However, we cannot exclude hemorrhage as a cause for high SI, because the T2-weighted STIR technique has relevant T1-weighting that might be sensitive to intra-myocardial hemorrhage. During the phase of infarct 'healing' — which means transition into scar tissue — a relation between elevated T2 SI and fluid content in granulation and even fibrous tissue was also observed [29], again emphasizing the role of tissue water content. In irreversible myocardial damage, additional reperfusion, as was probably present in our patients, was found to enhance edematous tissue changes [30]. We therefore assume, that increased tissue water content — either intra- or extracellular — is the main cause for elevated STIR T2 SI in our patient group.

In summary, elevated STIR T2 SI was observed transmurally in post-ischemic myocardial regions with preserved function. Increased T2 SI therefore is not an exclusive marker for the non-viable region.

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