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CLINICAL RESEARCH

Cardiac magnetic resonance demonstrates myocardial oedema in remote tissue early after reperfused myocardial infarction

Mise en évidence par IRM d'un œdème myocardique précoce en zone saine après infarctus reperfusé

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KEYWORDS

MRI;
No-reflow;
Oedema;
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Summary

Background. – Cardiac magnetic resonance can detect myocardial oedema using myocardial transverse relaxation time (T2)-weighted sequences but quantitative data are lacking in patients evaluated early after acute myocardial infarction.

Aim. – To assess the spatial distribution of T2 in patients with recent acute myocardial infarction.

Methods. – Twenty-four consecutive patients (mean age 60 ± 11 years) with acute myocardial infarction (anterior, $n = 12$; inferior, $n = 12$) were evaluated prospectively. T2 was determined using a series of breath-hold T2-weighted segmented half-Fourier turbo-spin echo sequences. No-reflow was defined as the association of early hypoenhancement and delayed enhancement in an akinetic region after a bolus injection of DOTA-Gd (0.2 mmol/kg).

Results. – No-reflow was present in 13 (54%) patients and absent in 11 (46%) patients. Mean T2 was increased in the infarct region (84.9 ± 23.7 ms) compared with in the remote

Abbreviations: T1, Myocardial longitudinal relaxation time; T2, Myocardial transverse relaxation time; TE, Echo time; TIMI, Thrombolysis in myocardial infarction; NS, Not significant.

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MOTS CLÉS

IRM ;
No-reflow (NR) ;
 Œdème ;
 Infarctus du
 myocarde

myocardium (62.8 ± 10.3 ms, $p=0.0001$) and in control subjects (55.7 ± 4.6 ms, $p<0.0001$), but also in the remote myocardium compared with control subjects ($p<0.02$). In patients with no-reflow, T2 was further increased within the infarcted subendocardium compared with in patients without no-reflow (97.9 ± 24.8 ms vs 76.3 ± 24.7 ms, $p<0.03$). Peak troponin correlated with T2 ($r=0.47$, $p<0.02$) and was higher in patients with no-reflow (297.9 ± 249.7 $\mu\text{g/L}$) than in patients without no-reflow (42.4 ± 43.1 $\mu\text{g/L}$, $p=0.003$).

Conclusion. – T2 was lengthened in both infarcted and remote myocardium and was influenced by the occurrence of no-reflow.

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Résumé

But. – Le but de cette étude a été d'évaluer la distribution spatiale du temps de relaxation T2 à la phase aiguë de l'infarctus du myocarde.

Méthode. – Vingt-quatre patients consécutifs (âge : 60 ± 11) hospitalisés pour un infarctus du myocarde (antérieur : 12, inférieur : 12) ont été prospectivement évalués. Le temps de relaxation T2 a été déterminé par résonance magnétique. Le *no-reflow* (NR) a été défini par l'association d'un hyposignal précoce et d'un hypersignal tardif dans les zones akinétiques après une injection de DOTA-Gd (0,2 mmol/kg).

Résultats. – Un NR a été constaté chez 13 patients (NR+ : 54%) et absent chez 11 (NR– : 46%). Le temps de relaxation T2 a été augmenté d'une part dans la zone de l'infarctus ($84,9 \pm 23,7$ ms) comparé au myocarde normal ($62,8 \pm 10,3$ ms, $p=0,0001$) et comparé aux témoins ($55,7 \pm 4,6$ ms, $p<0,0001$) et, par ailleurs, dans le myocarde normal comparé aux témoins ($p<0,02$). Chez les patients NR+, le temps de relaxation T2 a été augmenté dans le territoire sous-endocardique de la nécrose comparé aux patients NR– ($97,9 \pm 24,8$ ms vs $76,3 \pm 24,7$ ms, $p<0,03$). Le pic de troponine a été corrélé au temps de relaxation T2 ($r=0,47$, $p<0,02$) et a été plus élevé chez les patients NR+ ($297,9 \pm 149,7$ $\mu\text{g/L}$) comparé aux patients NR– ($42,4 \pm 43,1$ $\mu\text{g/L}$, $p=0,003$).

Conclusion. – Dans cette étude, le temps de relaxation T2 était augmenté à la fois dans le territoire de nécrose et dans le territoire sain et était influencé par la survenue d'un phénomène de NR.

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Introduction

Myocardial oedema occurs at a very early stage of myocardial infarction but its significance remains unclear. Cardiac magnetic resonance is able to differentiate infarcted from normal myocardium and can detect myocardial oedema using myocardial transverse relaxation time (T2)-weighted sequences [1–3]. T2-weighted spin-echo sequences allow accurate assessment of T2 and are able to quantify T2 lengthening related to acute heart transplant rejection in humans [4]. However, quantitative data are lacking in patients evaluated early after acute myocardial infarction.

The no-reflow phenomenon refers to persistent microvascular obstruction after the infarct-related coronary artery has been opened successfully [5]. No-reflow has been identified as a marker of ventricular remodelling and poor clinical outcome [6]. Animal studies have suggested that, in the setting of myocardial infarction, the intensity of myocardial oedema is related to reperfusion and infarct-related artery patency [3,7]. The aim of this study was to assess the modification of T2 values in patients with recent myocardial infarction compared with in normal subjects and to examine the impact of the no-reflow phenomenon on T2.

Methods**Patients**

Consecutive patients admitted to the coronary care unit at our institution with the diagnosis of a first acute myocardial infarction were studied prospectively. Acute myocardial infarction was defined as follows: acute chest pain lasting greater than 30 minutes; ST elevation greater than 1.0 mm in two contiguous precordial electrocardiogram leads; and an increase in troponin I greater than 1 $\mu\text{g/L}$. Patients were included if they had no history of myocardial infarction, were reperfused (by thrombolysis and/or percutaneous coronary intervention), were clinically stable, had no contraindications to magnetic resonance imaging and could be imaged within 1 week of their admission. Patients with a low likelihood of coronary artery disease (<5%) and no evidence of left or right ventricular abnormalities formed a control group for T2 measurement. Informed consent was obtained from all patients.

Cardiac magnetic resonance image acquisition

Magnetic resonance imaging was carried out on a 1.5-T magnet (Symphony, Siemens, Erlangen, Germany).

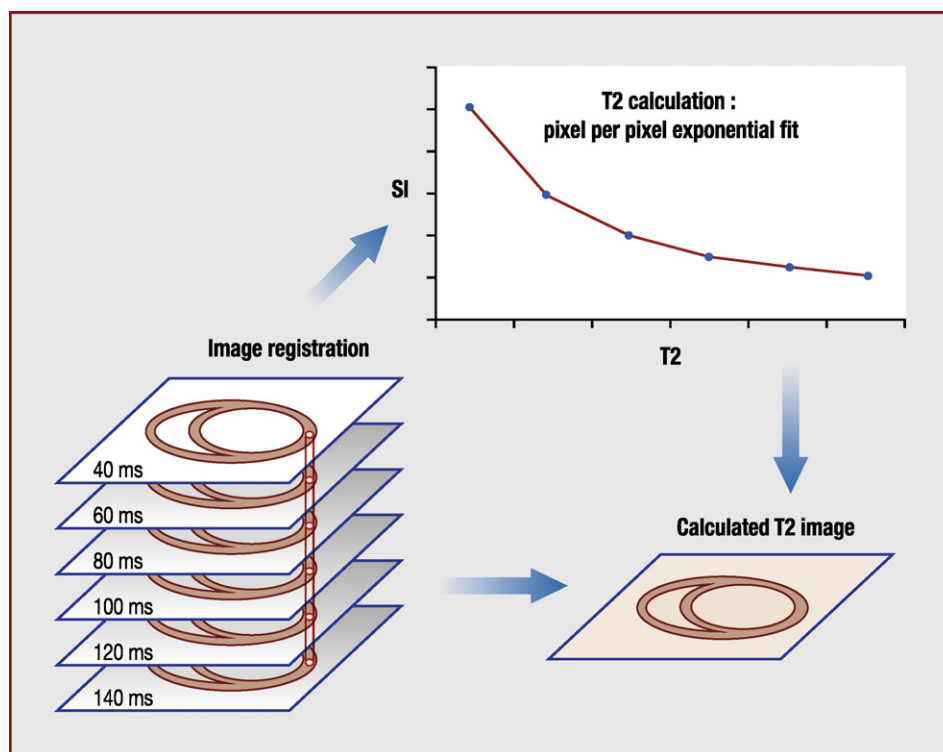


Figure 1. Pixel per pixel T2 calculation based on the exponential fit applied to the myocardial signal intensity in each echo (TE) image (from 40 ms to 140 ms). T2 values are reported in a final parametric image coding the T2 values for each pixel.

Electrocardiogram gated sequences were acquired during breath hold via a phased array cardiac coil placed over the thorax and coupled with phased array spine coils. The imaging protocol started with a multislice pilot scan orientated into three orthogonal planes. The interventricular septum was used as a landmark on axial scans to obtain vertical long-axis images on a single breath-hold T2-weighted segmented half-Fourier turbo-spin echo sequence with black-blood pulse—a sequence that provides images with a clearly delineated cavity [8]. Acquisition parameters were as follows: 256×212 matrix; field of view 398×398 mm; slice thickness 10 mm (voxel size $1.9 \times 1.6 \times 10$ mm); flip angle 117° . Image acquisition was gated to the R wave. Thereafter, horizontal long-axis and short-axis slices of the left ventricle were obtained using the same single breath-hold sequence. Bright-blood cine magnetic resonance images (two-dimensional gradient echo or steady-state free precession sequence) were acquired using contiguous short-axis slices (10 mm thickness) throughout the left ventricle.

A T2-weighted segmented half-Fourier turbo-spin echo sequence with a black-blood single short-axis slice allowing a clear view of the akinetic myocardium was chosen for evaluating T2 and six echoes were acquired with echo times (TEs) of 40, 60, 80, 100, 120 and 140 ms. A contrast agent was then injected (DOTA-Gd, 0.2 mmol/kg) at 3 cc/sec and short-axis myocardial longitudinal relaxation time (T1)-weighted inversion-prepared turboflash images were acquired sequentially at three locations (base, mid and apex) beginning with contrast injection, repeated every 10 s for 2 min. The presence of delayed enhancement was assessed 15 min after injection, with the time to inversion set to null the signal in the normal myocardium. The infarct region was defined as a

myocardial region showing segmental wall motion abnormality and the presence of delayed enhancement after DOTA-Gd injection. No-reflow was defined as areas of early hypo-enhancement in the infarct region relative to surrounding myocardium on first-pass imaging [9,10]. In patients with anterior or anterolateral infarction, the posterobasal and inferior regions were considered to be remote from the infarcted region; in patients with inferior infarction, the anterior and anterolateral regions were considered to be remote.

Image analysis

T2-weighted images were stored in a Dicom3 format and transferred to a G4Macintosh computer for quantitative analysis using the ImageJ 1.29w software (Rasband WS, ImageJ, National Institute of Health, Bethesda, MD, USA; <http://rsb.info.nih.gov/ij/>). For each series, the 40 ms TE image was used as a landmark. Further images were coregistered to this reference image using a 4-point rigid registration algorithm, in order to obtain a registered image stack. As described previously [4], T2 calculation was performed with a standard exponential fit applied on the myocardial signal on each echo image in a pixel per pixel analysis. This exponential fit was based on the equation

$$M(\text{TE}) = M_0 e^{-\text{TE}/T_2}$$

$M(\text{TE})$ being the signal from each pixel of the corresponding registered TE images. Then, a resulting parametric image coding the T2 values for each pixel was obtained and used for regional quantification (Fig. 1). Using this paramet-

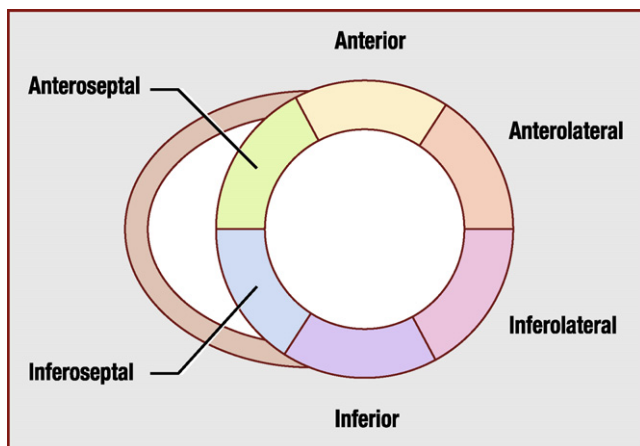


Figure 2. Six-segment model of a midventricular short-axis slice.

ric image, T2 was measured within the subendocardium and the subepicardium of both infarct and remote myocardial regions, using freehand regions of interest. Within the remote myocardium, the location of T2 measurement was limited to one segment. Moreover, the analysis was performed per patient, considering only one infarcted, one no-reflow and one remote region per patient. Similarly, only one sub-endocardial and one subepicardial region of interest were analysed per patient.

Myocardial thickness was measured within the infarct and remote regions on a T2-weighted short-axis slice (acquired at TE = 40 ms). Finally, regional left ventricular function was assessed semiquantitatively on a midventricular short-axis cine magnetic resonance slice using a four-point grading system and a six-segment model (Fig. 2). Each segment was graded as 1 (normal), 2 (hypokinesia), 3 (akinesia) or 4 (dyskinesia). Attention was paid to choose the short-axis cine magnetic resonance slice that matched the slice used for T2 quantification exactly. All measurements were made by an experienced reader (AM) blinded to any clinical data.

Statistical analysis

Data are expressed as mean values \pm 1 standard deviation. Differences between quantitative variables were calculated using an appropriate paired or unpaired *t* test. The impact of qualitative variables on continuous data was evaluated by analysis of variance. The correlations between quantitative variables were studied using linear regression. Statistical analysis was performed using the Statview software (SAS Institute). A *p*-value less or equal to 0.05 was considered to be statistically significant.

Results

Patient characteristics

Twenty-four patients (mean age, 60 ± 11 years; 22 men) with the diagnosis of a first acute myocardial infarction were included in the study. The control group for T2 measurement constituted 15 patients (mean age, 55 ± 12 years; 13 men).

Cardiac magnetic resonance was performed 2.3 ± 2.5 days after the myocardial infarction. The myocar-

dial infarction was anterior in 12 (50%) cases and inferior in 12 (50%) cases. All patients had prehospital thrombolysis and an early coronary angiogram within 2 h after admission. The infarct-related artery was the left main coronary artery in one case, the left anterior descending artery in 13 cases, the circumflex artery in four cases and the right coronary artery in six cases. On coronary angiography, 15 patients had a patent infarct-related artery (thrombolysis in myocardial infarction [TIMI] grade 2 or 3 flow). Nine patients had a reduced coronary flow and were treated by percutaneous coronary intervention and coronary stenting of the infarct-related lesion. At the end of the procedure, all patients had a TIMI grade 3 flow. Mean left ventricular ejection fraction was $52 \pm 12\%$ on contrast left ventricular angiography. Peak troponin was $185.8 \pm 227.9 \mu\text{g/L}$. First-pass imaging after the bolus injection of DOTA-Gd showed a no-reflow phenomenon in 13 (54%) patients. In all cases, the no-reflow involved only the subendocardial layer of the infarct region.

T2 measurement

Image quality was suitable for analysis in all cases. T2 was increased significantly in the infarct region (84.9 ± 23.7 ms) compared within the remote region (62.8 ± 10.3 ms, $p = 0.0001$) and in control subjects (55.7 ± 4.6 ms, $p < 0.0001$). T2 was also increased significantly in the remote region in patients with acute myocardial infarction compared with in control subjects ($p < 0.02$).

There was no global difference in T2 values between subendocardial and subepicardial regions (infarct region: subendocardial T2 = 88 ± 26.6 ms and subepicardial T2 = 81.7 ± 23.7 ms [not significant (NS)]); remote region: subendocardial T2 = 63 ± 10.6 ms and subepicardial T2 = 62.7 ± 10.3 ms [NS]). However, in the infarct region, patients with no-reflow had a further T2 lengthening within the subendocardium (97.9 ± 24.8 ms vs 76.3 ± 24.7 ms, $p < 0.03$), but not within the subepicardium (84 ± 19 ms vs 78.9 ± 28.8 ms, $p = \text{NS}$) compared with patients without no-reflow (Fig. 3).

Finally, linear regression demonstrated a significant correlation between peak troponin and T2 ($y = -176.343 + 4.395x$, $r = 0.47$, $p < 0.02$) and peak troponin was higher in patients with no-reflow ($297.9 \pm 249.7 \mu\text{g/L}$) than in patients without no-reflow ($42.4 \pm 43.1 \mu\text{g/L}$,

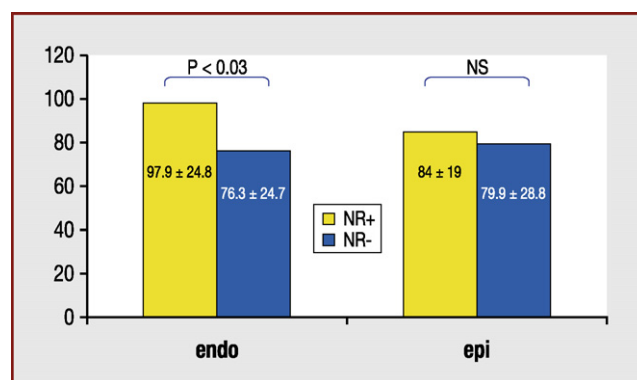


Figure 3. Comparison of T2 in patients with (NR+) or without (NR-) no-reflow according to the measurement site. Endo: subendocardium; epi: subepicardium.

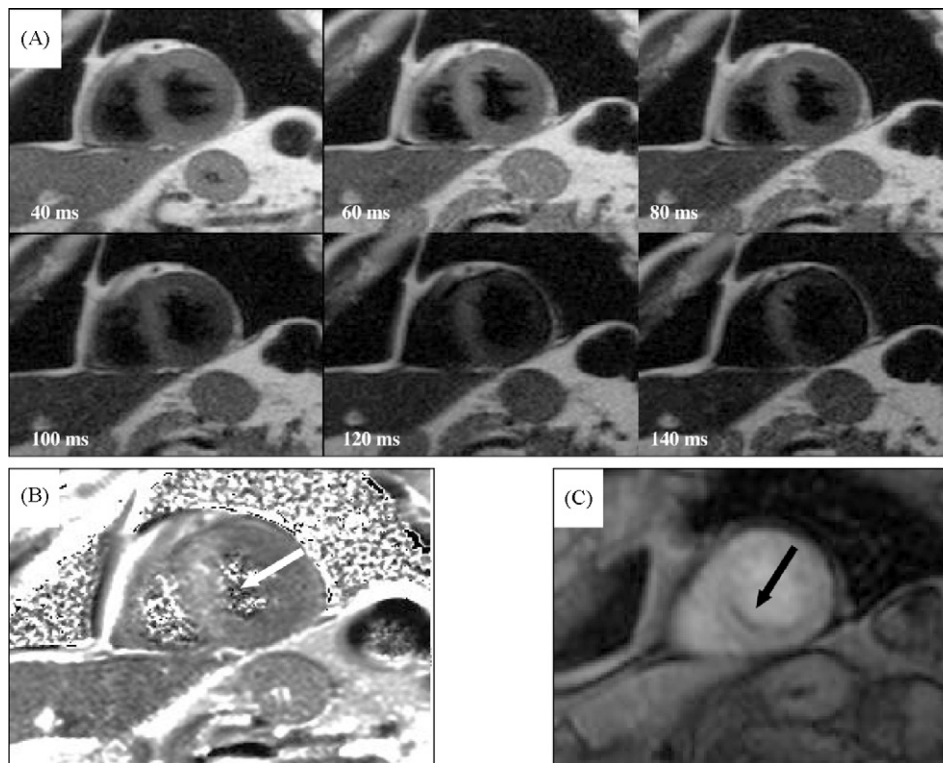


Figure 4. Example of a patient with acute myocardial infarction involving the interventricular septum. A shows the original half-Fourier turbo-spin echo images acquired with increasing TE from 40 ms to 140 ms. B displays the calculated parametric image coding T2 values, showing the distribution of myocardial oedema (white arrow). C shows the presence of no-reflow (black arrow) after the bolus injection of DOTA-Gd.

$p=0.003$). Fig. 4 shows a patient with acute myocardial infarction involving the interventricular septum, with a subendocardial no-reflow phenomenon.

Impact on myocardial thickness and left ventricular function

Myocardial thickness was increased significantly in the infarct region (15.2 ± 3.3 mm) compared with in the remote region (12.2 ± 2.3 mm, $p=0.0008$) and in control subjects (11.3 ± 1.8 , $p=0.0002$). Within the infarct area, myocardial thickness was increased slightly but not significantly in patients with no-reflow (16.3 ± 3.3 mm) compared with in patients without no-reflow (13.9 ± 3 , $p=0.08$, NS). There was a significant correlation between peak troponin and myocardial thickness within the infarct area ($y = -345.349 + 347.055x$, $r=0.51$, $p<0.02$). Segmental wall motion evaluated by wall motion score was similar in patients with and without no-reflow (1.564 ± 0.21 and 1.424 ± 0.390 , respectively, $p=NS$). Wall motion score did not correlate with either myocardial thickness ($y = 1.321 + 0.118x$, $r=0.13$, $p=NS$) or T2 in the infarct zone ($y = 1.529 - 3.36 \cdot 10^{-4} \cdot x$, $r=0.03$, $p=NS$).

Finally, left ventricular ejection fraction did not correlate with T2 within the infarct zone ($y = 43.566 + 0.099x$, $r=0.20$, $p=NS$) or with the infarct myocardial wall thickness ($y = 68.893 - 11.135x$, $r=0.31$, $p=NS$).

Discussion

This study confirms the feasibility of in vivo measurement of T2 in patients at an early stage of myocardial infarction. The results showed T2 lengthening in the infarct region compared with in the remote myocardium and T2 lengthening in the remote myocardium compared with in the control group. Experimental data showed that T1 and T2 both increased at an early stage of myocardial infarction [11,12]. In an animal model of acute myocardial infarction, Higgins et al. [11] demonstrated that an increased signal on T2-weighted magnetic resonance images correlated with myocardial oedema. Furthermore, Dymarkowski et al. [13] found a significant relationship between a high T2 signal pattern and myocardial oedema and showed that the myocardial extent of oedema exceeded that of myocardial scar assessed by contrast-enhanced T1-weighted imaging. After an intravenous injection of paramagnetic contrast agent, first-pass perfusion defects (related to no-reflow) and late enhancement (related to ischaemic injury) may occur in both acute and chronic infarction [2,9]. In contrast, the increase in T2 occurs within 1 day after myocardial infarction but disappears after 3 months [14–16], as a marker of oedema resolution [17,18].

Under experimental conditions, myocardial oedema appears immediately within the infarct region after reperfusion [7,19] and is responsible for an abrupt increase in myocardial wall thickness. Garcia-Dorado et al. [7] compared T2 and water content in animals immediately after either a 78-minute coronary occlusion without reperfusion

or a 48-minute coronary occlusion followed by 30 min of reperfusion. They showed that T2 was increased in reperused animals compared with in non-reperused animals and found a close correlation between myocardial water content and T2 in reperused hearts ($r=0.89$).

Wisenberg et al. [20] studied the time course of T2 signal after myocardial infarction by serial magnetic resonance examinations. After reperfusion, there was an abrupt increase in T2 that returned progressively to baseline value within days. These authors also observed that in the absence of reperfusion, T2 increased further and reached its maximum at day 5, although water content was not modified.

Our results demonstrated that, in patients explored at day 2.3 ± 2.5 , subendocardial T2 was increased within the infarct region in patients with no-reflow. In addition, we found that patients with no-reflow had larger myocardial infarctions, according to cardiac enzyme release, and that T2 correlated positively with peak troponin values. These results are in agreement with Wisenberg et al.'s data [20], suggesting that after the early phase of myocardial infarction, T2 in non-reperused myocardium probably reflects structural modification and inflammatory reaction related to the healing process as well as tissue water content. In a study evaluating myocardial oedema by ^{23}Na imaging in no-reflow and infarcted area, Rochitte et al. [6] found that sodium arrival was slower in the no-reflow area than in fully reperused myocardium, suggesting that there might be less rather than more oedema in no-reflow areas. However, sodium arrival was evaluated only 20 min and 6 h after infarction and their results do not conflict with the delayed oedema described by Wisenberg et al. [20].

Few data are available regarding T2 lengthening within the remote area in patients with recent myocardial infarction. A group from Leiden evaluated 19 patients with a 10-day-old myocardial infarction and 10 normal subjects using T2-weighted cardiac magnetic resonance with echo times increasing from 30 ms to 120 ms [21]. This group found increased T2 values in the infarcted myocardium compared with in the remote territory. In this study, T2 was 74 ms in the infarct region, 67 ms in the remote region and 47 ms in control subjects. Although the statistical comparison between T2 in the remote region and in control subjects was not reported in their manuscript, these results are very similar to our findings, emphasizing the hypothesis of T2 lengthening in the remote area in acute myocardial infarction. Abbate et al. assessed the presence of activated cells in the unaffected remote myocardium of 16 patients who died 1 to 13 weeks after acute myocardial infarction [22]. A myocardial inflammatory infiltrate with activated T-lymphocytes was found in remote regions in 11 of 16 (69%) cases, in the peri-infarct zone in all cases (100%) and in none of the control hearts. We suggest that these changes associated to inflammatory infiltrate could play a role in the alteration of the magnetic resonance signal in the non-infarcted myocardium.

Finally, in accordance with previous results [19,23], we found that wall thickness was increased significantly in the infarcted myocardium compared with in the remote myocardium. Moreover, the infarcted wall thickness correlated with peak troponin release. Similarly, Schroeder et al. [24] demonstrated a significant increase in left ventricular mass index at day 5 in patients compared with in control sub-

jects, which was related to end-diastolic wall thickness in infarct-related regions and correlated positively with peak creatine kinase MB value.

Study limitations

In this study, T2 mapping was performed only on one short-axis slice and not within the whole heart. Consequently, we cannot conclude on the ventricular extent of myocardial oedema in both the normal myocardium and the infarcted area. Moreover, we cannot exclude that T2 may be influenced by the presence of haemorrhage and iron accumulation in no-reflow areas. Iron deposition is responsible for a decrease of T2 signal, as observed in haemorrhage and iron overload [25]. In the absence of histological data, we cannot exclude that the T2 values reported in this study may have been influenced by the occurrence of intramyocardial haemorrhage within the no-reflow areas.

Conclusion

Quantitative analysis of T2 is feasible in vivo. In patients with acute myocardial infarction, T2 was elevated significantly in the infarcted region compared with in the non-infarcted region. T2 lengthening was influenced by the occurrence of a no-reflow phenomenon. However, the main finding of this study was that T2 in patients with acute myocardial infarction was elevated significantly in the remote region compared with in the control population, probably due to early structural changes and widespread inflammatory infiltrate.

Conflicts of interests

None.

Acknowledgements

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References

- [1] Kim RJ, Fieno DS, Parrish TB, et al. Relationship of MRI delayed contrast enhancement to irreversible injury, infarct age and contractile function. *Circulation* 1999;100:1992–2002.
- [2] Simonetti OP, Kim RJ, Fieno DS, et al. An improved MR imaging technique for the visualization of myocardial infarction. *Radiology* 2001;218:215–23.
- [3] Tscholakoff D, Higgins CB, Sechtem U, Caputo G, Derugin N. MRI of reperused myocardial infarct in dogs. *AJR Am J Roentgenol* 1986;146:925–30.
- [4] Marie PY, Angioi M, Carteaux JP, et al. Detection and prediction of acute heart transplant rejection with the myocardial T2 determination provided by a black-blood magnetic resonance imaging sequence. *J Am Coll Cardiol* 2001;37:825–31.

- [5] Rezkalla SH, Kloner RA. No-reflow phenomenon. *Circulation* 2002;105:656–62.
- [6] Rochitte CE, Kim RJ, Hillenbrand HB, Chen EL, Lima JA. Microvascular integrity and the time course of myocardial sodium accumulation after acute infarction. *Circ Res* 2000;87:648–55.
- [7] Garcia-Dorado D, Oliveras J, Gili J, et al. Analysis of myocardial oedema by magnetic resonance imaging early after coronary artery occlusion with or without reperfusion. *Cardiovasc Res* 1993;27:1462–9.
- [8] Pislaru SV, Ni Y, Pislaru C, et al. Noninvasive measurements of infarct size after thrombolysis with a necrosis-avid MRI contrast agent. *Circulation* 1999;99:690–6.
- [9] Gerber BL, Garot J, Bluemke DA, Wu KC, Lima JA. Accuracy of contrast-enhanced magnetic resonance imaging in predicting improvement of regional myocardial function in patients after acute myocardial infarction. *Circulation* 2002;106:1083–9.
- [10] Rochitte CE, Lima JA, Bluemke DA, et al. Magnitude and time course of microvascular obstruction and tissue injury after acute myocardial infarction. *Circulation* 1998;98:1006–14.
- [11] Higgins CB, Herfkens R, Lipton MJ, et al. Nuclear magnetic resonance imaging of acute myocardial infarction in dogs: alterations in magnetic relaxation times. *Am J Cardiol* 1983;52:184–8.
- [12] Johnston DL, Brady TJ, Ratner AV, et al. Assessment of myocardial ischemia with proton magnetic resonance: effects of a three-hour coronary occlusion with and without reperfusion. *Circulation* 1985;71:595–601.
- [13] Dymarkowski S, Ni Y, Miao Y, et al. Value of t2-weighted magnetic resonance imaging early after myocardial infarction in dogs: comparison with bis-gadolinium-mesoporphyrin enhanced T1-weighted magnetic resonance imaging and functional data from cine magnetic resonance imaging. *Invest Radiol* 2002;37:77–85.
- [14] Miller S, Helber U, Kramer U, et al. Subacute myocardial infarction: assessment by STIR T2-weighted MR imaging in comparison to regional function. *MAGMA* 2001;13:8–14.
- [15] Nilsson JC, Nielsen G, Groenning BA, et al. Sustained postinfarction myocardial oedema in humans visualised by magnetic resonance imaging. *Heart* 2001;85:639–42.
- [16] Schulz-Menger J, Gross M, Messroghli D, Uhlich F, Dietz R, Friedrich MG. Cardiovascular magnetic resonance of acute myocardial infarction at a very early stage. *J Am Coll Cardiol* 2003;42:513–8.
- [17] Abdel-Aty H, Zagrosek A, Schulz-Menger J, et al. Delayed enhancement and T2-weighted cardiovascular magnetic resonance imaging differentiate acute from chronic myocardial infarction. *Circulation* 2004;109:2411–6.
- [18] Sakai Y, Tsunoda K, Ishibashi I, Miyazaki Y, Takahashi O, Masuda Y. Time course of left ventricular remodeling after myocardial infarction: a two-dimensional echocardiographic study. *Jpn Circ J* 2000;64:421–9.
- [19] Pislaru C, Bruce CJ, Seward JB, Greenleaf JF. Distinctive changes in end-diastolic wall thickness and postsystolic thickening in viable and infarcted myocardium. *J Am Soc Echocardiogr* 2004;17:855–62.
- [20] Wisenberg G, Prato FS, Carroll SE, Turner KL, Marshall T. Serial nuclear magnetic resonance imaging of acute myocardial infarction with and without reperfusion. *Am Heart J* 1988;115:510–8.
- [21] Krauss XH, van der Wall EE, van der Laarse A, et al. Follow-up of regional myocardial T2 relaxation times in patients with myocardial infarction evaluated with magnetic resonance imaging. *Eur J Radiol* 1990;11:110–9.
- [22] Abbate A, Bonanno E, Mauriello A, et al. Widespread myocardial inflammation and infarct-related artery patency. *Circulation* 2004;110:46–50.
- [23] Turschner O, D'Hooge J, Dommke C, et al. The sequential changes in myocardial thickness and thickening which occur during acute transmural infarction, infarct reperfusion and the resultant expression of reperfusion injury. *Eur Heart J* 2004;25:794–803.
- [24] Schroeder AP, Houliand K, Pedersen EM, Nielsen TT, Egeblad H. Serial magnetic resonance imaging of global and regional left ventricular remodeling during 1 year after acute myocardial infarction. *Cardiology* 2001;96:106–14.
- [25] Anderson LJ, Holden S, Davis B, et al. Cardiovascular T2-star (T2*) magnetic resonance for the early diagnosis of myocardial iron overload. *Eur Heart J* 2001;22:2171–9.