
Methods

Patients

Fourteen patients (9 males, 5 females, aged 44-76 years) referred for cardiac MR imaging agreed to the acquisition of an additional ECG-gated DWI sequence. Seven patients had a recent MI (range: 3-15 days), 3 patients had chronic MI (6 months), and 4 patients had valvular heart disease without MI. The latter 4 patients were included as control subjects.

MRI

The MR examinations were performed on a 1.5 Tesla MR scanner (Signa Twinspeed HDX, GE Healthcare, Milwaukee, Wis) using an 8-channel heart coil. All acquisitions were ECG-gated. A fast localizer SSFP breath hold sequence was acquired in all three orthogonal planes to enable cardiac imaging along the true anatomical cardiac axes. DWI sequences were obtained in the axial, sagittal and coronal planes relative to the presumed location of the MI. To avoid in-plane
Cardiac diffusion MRI of acute and chronic myocardial infarction: preliminary results

Distortions, the lowest TE was selected, in part from the use of parallel imaging with an acceleration factor of 2. The acquisition parameters were: SE EPI, TR/TEeff 3 000-4 000/50-80 ms based on heart rate, b-factor of 300 sec/mm², FOV of 4x4x4 cm, 7 mm slice thickness with 1 mm interslice gap, bandwidth of 167 kHz, and acquisition time of 16-24 seconds. Improvements made to the sequence parameters to reduce in-plane distortion and achieve better sensitivity to diffusion included the use of 3-6 RR intervals based on heart rate to allow a TR of at least 4 000 ms in all 3 directions, a FOV of at least 35 cm enabling a reduction of the TEeff to less than 60 ms, a 92x160 matrix to allow breath hold acquisition. To allow evaluation of edema, a triple IR black-blood T2W sequence was used (TR=2RR, TE 64, TI 140 ms, 8 mm slice thickness with 2 mm interslice gap, 256x256 matrix, 34-38 cm FOV). SS-FP cine-breath hold MR images were acquired along the short, long and four-chamber axes. The FOV was typically 380x380 mm, with a 256x192 matrix with an 8 mm slice thickness. FPE perfusion imaging was usually based on the acquisition of a T1-multishot IR SSFP sequence, usually repeated 35 times, as a function of heart rate. A bolus of 0.2 mmol/kg of gadolinium based contrast agent (Dotarem®, gadopentetate meglumine, Guerbet, Aulnay-sous-Bois, France) was administered intravenously at 4 ml/sec followed by a 20 ml saline flush also at 4 ml/sec. After 10 to 12 minutes, DE MR imaging was acquired using a T1-multishot IR GRE sequence along the short, long and four-chamber axes (3D acquisitions, TR 3.9 ms, TE 1.4 ms, FA 25°, TI 200-240 ms, FOV 270 x 340 mm, matrix 192x256, 10 slices of 7-8 mm thick along the short axis with TA of 19 sec).

Criteria for image review

Qualitative interpretation was performed by 3 reviewers by consensus. Diffusion data were obtained by using isotropic diffusion in all 3 planes. DWI images were compared to T2W, FPE and DE images. MI was defined as an area of increased signal with or without thickening on T2W images, a perfusion defect on FPE images and an area of increased signal sometimes associated with an area of lower signal or no-reflow on DE images. Because the purpose was simply to evaluate MI detectability on DWI, post-processing consisted of co-registration of DWI and DE images using the AW software (GE Healthcare, Milwaukee, Wis). The latter was performed by orthogonal reformatting of DWI data along the double obliquity of DE images. The left ventricular myocardium was thus divided into 8 parts as opposed to 17 segments due to the differences in acquisition planes: base and anterior apical, septal, inferior and lateral left ventricular portions. Co-registration was achieved with the help of fiducial markers. Apparent diffusion coefficient (ADC) maps were calculated with the Functool software using regions of interest (ROI) centered over areas of hyperintensity detected on b=300 sec/mm² images as well as distant regions of normal appearing myocardium on b=0 sec/mm² images. A statistical analysis of these preliminary data was not performed.

Results

In all patients with recent MI (with ST elevation or STEMI, or without ST elevation or NSTEMI), DWI showed increased signal at the infarct site with corresponding reduced ADC signal compared to normal appearing myocardium on 3 separate modes of myocardial diffusion (table 1), irrespective of urgent coronary reperfusion procedures (n=5) or not (n=2), perfectly correlating to areas of signal abnormality on T2W, FPE and especially DE images (fig. 1 to 3). The average number of involved parts was 2.57±0.97 on DWI, 2.29±0.75 on FPE and 2.71±0.11 on DE images. The lower average noted for DWI compared to DE was related to under-estimated extent of an inferior wall MI. DWI on patients with chronic MI showed no area of abnormal signal, and normal ADC values. FPE imaging showed no enhancement, and DE imaging showed increased transmural enhancement in the non-viable portion of the infarct. DWI, ADC maps, T2W, FPE and DE imaging were normal in patients with valvular disease.

Table I

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>Diffusion</th>
<th>T2W</th>
<th>FPE</th>
<th>DE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Homogeneous hyperintensity (reduced ADC)</td>
<td>Hyperintensity (edema)</td>
<td>Transient perfusion defect (low-reflow)</td>
<td>Transmural hyperintensity</td>
</tr>
<tr>
<td>3</td>
<td>Subendocardial and subepicardial hyperintensity with increased ADC around a central hypointense region with low ADC</td>
<td>Hyperintensity (edema)</td>
<td>Persistent perfusion defect (no-reflow)</td>
<td>Subendocardial and subepicardial hyperintensity around a central hypointense region (necrosis)</td>
</tr>
<tr>
<td>2</td>
<td>Homogeneous subendocardial or transmural hyperintensity (reduced ADC)</td>
<td>Normal</td>
<td>Normal</td>
<td>Homogeneous subendocardial or transmural hyperintensity</td>
</tr>
</tbody>
</table>

Discussion

Our preliminary data indicate that DWI MR imaging is able to detect areas of infarction in MI, irrespective of reperfusion procedures, and to differentiate necrotic from viable myocardium, whereas it normalizes in chronic infarcts. DWI is one of the main MR imaging sequences for diagnosis of acute stroke syndromes (1). Due to its sensitivity in detecting ischemia, it allows detection of infarcts within a few hours of clinical onset. ADC maps improve the diagnostic accuracy by providing a map of cytotoxic edema (supposed to correspond to irreversible ischemia), characteristic of peripheral vasogenic edema at risk. The potential advantage of cardiac DWI is that the heart possesses a larger blood volume than the brain (3). Since DWI of the heart was first described, several studies have been published, including one on animals. These publications demonstrated changes in diffusion in isolated perfused rabbit hearts following ligation of the left anterior descending coronary artery, allowing detection of areas of hypoperfusion.

JP Laissy et al.

J Radiol 2009;90
Cardiac diffusion MRI of acute and chronic myocardial infarction: preliminary results

Fig. 1: Inferior MI.

a  Sagittal diffusion-weighted image of the heart showing hyperintense signal along the inferior wall (arrows) compared to the normal anterior wall (arrows).

b  Color-coded ADC map showing a 50% reduction in ADC values (green, arrows) compared to the normal anterior wall (red, arrows).

c-d  T2W image (c) showing edema of the inferior wall, whereas transmural enhancement of the inferior wall (arrows) is demonstrated on long axis DE images (d) in the same region.

Fig. 2: Lateral MI.

a  Axial diffusion-weighted image showing two areas of hyperintensity, subendocardial and subepicardial, surrounding an area of hypointensity at the lateral wall (arrow). ADC values in the hypointense zone are decreased by 50% compared to the normal septum, whereas they are increased by a factor of 2 in the hypointense subendocardial zone (not illustrated). Short axis FPE images confirmed the absence of subendocardial enhancement at the lateral wall (not illustrated).

b-c  Four-chamber (b) and short axis (c) DE images showing subendocardial and subepicardial hyperintense signal with hypointense area corresponding to the image in (a).

In humans, diffusion tensor MR imaging was used to study left ventricular myocardial remodeling (5) after MI. A single case of acute MI following reperfusion recently reported that diffusion abnormalities during acute MI could be related to myocardial edema (6). Our study has multiple limitations. First, double oblique DWI was not possible on our early patients and DWI could only be acquired in the axial, sagittal or coronal planes. This probably explains the under-estimated extent of an inferior wall MI in one patient. Second, we used a relatively low b number of 300 sec/mm², even though it seemed to provide a good compromise between SNR and T2 suppression. Co-registration of DWI and DE imaging data was approximate due to the strict orthogonal plane acquisitions for DWI data; this was partly resolved by image reformatting. Image distortion was reduced by the use of a smaller FOV and wider bandwidth allowing the use of short TEs. We have recently been able to acquire double oblique images using a b value of 500 sec/mm² in a small number of patients, and we have started to compare these images with those obtained in the current study to determine their added value. Finally, several cases of acute myocarditis imaged using similar sequences (work in progress) have shown abnormal diffusion with reduced ADC values, which could be a limitation for the characterization of myocardial pa-
Cardiac diffusion MRI of acute and chronic myocardial infarction: preliminary results

JP Laissy et al.

Our study confirms that recent MI can be assessed using ECG-gated breath hold DWI, usually acquired in less than one minute in clinical practice. This technique is simpler and much faster than other pulse sequences routinely used for cardiac MR. The different DWI characteristics of recent STEMI, NSTEMI and chronic MI could allow differentiation between necrotic, viable and scarred myocardium. This first clinical trial suggests that DWI MR imaging could be useful for rapid evaluation of patients with recent MI. The acquisition of diffusion imaging software would then become valuable if not essential should the results from this study be confirmed. Additional studies are required to establish its role in patients with acute coronary syndromes, especially NSTEMI, where it could potentially become the most valuable imaging modality, and to establish its value in myocardial viability assessment compared to other imaging modalities. Additional studies are needed to confirm these preliminary data.

The authors disclose no conflict of interest.

References

6. Okayama S, Uemura S, Saito Y. Detection of infarct-related myocardial edema using cardiac diffusion-weighted magnetic resonance imaging. Int J Cardiol 2007 Dec 17; (Epub ahead of print)