DIFFUSION WEIGHTED MR IMAGING ON A LOW-FIELD OPEN MAGNET

Comparison with findings at 1.5T in 18 patients with cerebral ischemia


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SUMMARY
Diffusion-weighted MR imaging (DWI) is particularly sensitive for the detection of acute stroke. Until recently, DWI was performed with EPI technology. We compared 18 patients with clinical suspicion of acute stroke on a standard 1.5T unit and an open low-field MR scanner. Eighteen patients with 20 lesions of acute stroke were studied retrospectively with DWI and ADC mapping on both systems. The technique used was a rotating fast-spin echo T2 at low-field and an EPI sequence at 1.5T. Both examinations were performed within 24 hours and analyzed by two neuroradiologists. We obtained the same results on DWI sequences on both systems, regarding high intensity lesions on DWI. Interpretation of the ADC maps proved to be difficult on low-field MR near the lateral ventricles (3/18). We experienced the same difficulty of interpretation at low and high field in the cerebellum, in the temporal fossa and in cortex situated near bone, due to susceptibility artifacts. Chronic lesions were better visualized at low than at high field. In our opinion, DWI on a low-field open MR scanner is a good technique to evaluate subacute stroke and was as reliable as when performed on a 1.5T MR system.

Key words: stroke, low-field MR imaging, diffusion-weighted imaging.

INTRODUCTION
Stroke is increasingly considered to be a neurological emergency, with treatment options being offered that are potentially effective [5, 7, 8, 24]. Even if the concept of a rigid time window might at times be challenged [1], it is emerging that it is necessary to dispose of a sensitive method that can be used with ease in this emergency situation. CT scanning allows to demonstrate hematomas, and has been shown to be able to demonstrate early signs of ischemia in well-trained hands [25-27] but is at times not easy to reliably interpret in the emergency situation. Also, in order not to treat patients with non-ischemic diseases, it is above all necessary to demonstrate ischemia itself before starting thrombolysis. Diffusion-weighted MR imaging (DWI) is particularly sensitive for the detection of acute stroke [6, 11-13, 20, 21, 28, 29]; DWI has been successfully used to detect cerebral ischemia in animals and humans; the lesions found do correlate with clinical signs and have been used to triage patients for intervention and to monitor efficacy of treatment [9, 10, 23], despite reports of false-negative scans [18]. Until recently, DWI was performed with echo-planar technology. However echo-planar technology is not readily available at all institutions. Diffusion imaging, while necessitating strong gradients, does not necessarily require high magnetic field strengths. It has been shown to be performable...
at lower field strengths using a variety of technologies, such as line-scan imaging, fast spin-echo imaging (such as HASTE) or even echo-planar imaging [14]-[16]. We wanted to assess the ability of an open low-field scanner to perform DWI in patients with suspected cerebral ischemia.

MATERIALS AND METHODS

Patients

The study was performed between April 2001 and April 2002. Patients were referred from the emergency department of our institution with a high degree of suspicion of having an acute stroke, after having been examined by a neurologist trained in the diagnosis of stroke. In order to exclude hematoma, CT had been performed in all cases, however our institution being the referral hospital also for a neighboring country, CT was done in our institution in only 8 cases, and the CTs were no longer available in the remaining cases. There was no hemorrhage visible in any case. We studied 18 patients (15 men and 3 women). The mean age was 69 years 8 months with a range between 43 years and 88 years of age; 55% of our patients were less than 70 years old. Clinical symptoms are summarized in the Table I.

Time to MRI

Mean time after onset of symptoms was 5 days with 60% of the MRI being performed between the 6th and 7th day. All patients were first imaged on the 1.5T scanner (range 24 hours to 7 days) and later on the low-field system (range 25 hours to 7 days). Minimum time between scanning on both systems was 1 hour and maximum time was 24 hours. The earliest MRI was performed at 24 hours after onset of symptoms and the latest at 7 days.

MR Imaging

Patients were examined on a 1.5T echo-planar system (Eclipse, Marconi) and on an open low-field 0.23T scanner (Outlook, Marconi).

The technique used was a rotating fast-spin echo T2 at low-field and an EPI sequence at high-field MR.

### Table I. – Clinical Status and results of Diffusion analysis in 18 patients/20 lesions.

<table>
<thead>
<tr>
<th>ID</th>
<th>Clinical status</th>
<th>Location</th>
<th>Size mm</th>
<th>Diffusion Results</th>
<th>Diffusion Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HF Signal/value</td>
<td>LF Signal/value</td>
</tr>
<tr>
<td>1</td>
<td>L. leg paresis</td>
<td>R. internal capsule</td>
<td>12×33</td>
<td>DWI=2 ADC=–2</td>
<td>DWI=2 ADC=–2</td>
</tr>
<tr>
<td>2</td>
<td>L. hemiparesis</td>
<td>R. temporo-parietal lobe</td>
<td>37×55</td>
<td>DWI=2 ADC=–1</td>
<td>DWI=2 ADC=–1</td>
</tr>
<tr>
<td>3</td>
<td>R. hemiparesis</td>
<td>L. internal capsule</td>
<td>6.5</td>
<td>DWI=2 ADC=0</td>
<td>DWI=2 ADC=0</td>
</tr>
<tr>
<td>4</td>
<td>L. hemiparesis</td>
<td>R. internal capsule</td>
<td>8×12</td>
<td>DWI=2 ADC=–2</td>
<td>DWI=2 ADC=–2</td>
</tr>
<tr>
<td>5</td>
<td>Lesion 1</td>
<td>Headache Vertigo</td>
<td>L. hemicerebellum</td>
<td>35×32</td>
<td>DWI=2 ADC=–1 in center ADC=1 peripher</td>
</tr>
<tr>
<td>6</td>
<td>Lesion 2</td>
<td>Headache Vertigo</td>
<td>L. peduncle</td>
<td>25×13</td>
<td>DWI=2 ADC=–1</td>
</tr>
<tr>
<td>7</td>
<td>L. Wallenberg syndrom</td>
<td>L. peduncle</td>
<td>7</td>
<td>DWI=2 ADC=–2</td>
<td>DWI=1 ADC=0</td>
</tr>
<tr>
<td>8</td>
<td>Vertigo with L. hemiparesis</td>
<td>R. precentral gyrus</td>
<td>12×8</td>
<td>DWI=2 ADC=1</td>
<td>DWI=2 ADC=1</td>
</tr>
<tr>
<td>9</td>
<td>Dysarthria</td>
<td>L. internal capsule</td>
<td>8</td>
<td>DWI=2 ADC=–2</td>
<td>DWI=2 ADC=0</td>
</tr>
<tr>
<td>10</td>
<td>R arm ataxia Paresis</td>
<td>L. internal capsule</td>
<td>37×13</td>
<td>DWI=2 ADC=–2</td>
<td>DWI=2 ADC=–1</td>
</tr>
<tr>
<td>11</td>
<td>Walking instability</td>
<td>R. internal capsule</td>
<td>11</td>
<td>DWI=2 ADC=–1</td>
<td>DWI=1 ADC=0</td>
</tr>
<tr>
<td>12</td>
<td>Dysarthria and instability</td>
<td>L. peduncle</td>
<td>12×8</td>
<td>DWI=2 ADC=–1</td>
<td>DWI=1 ADC=0</td>
</tr>
<tr>
<td>13</td>
<td>Recurring TIA</td>
<td>L. internal capsule</td>
<td>7</td>
<td>DWI=2 ADC=1</td>
<td>DWI=2 ADC=0</td>
</tr>
<tr>
<td>14</td>
<td>Aggravation of a right-sided stroke</td>
<td>R. occipital lobe</td>
<td>12</td>
<td>DWI=2 ADC=–2</td>
<td>DWI=2 ADC=–1</td>
</tr>
</tbody>
</table>

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The whole brain was imaged using a multi-slice technique: on the 1.5T system a total of twenty-two 5mm thick axial slices were acquired with b values of 0 and 1000s/mm², field of view: 260mm, 128×128 matrix, TR: 5629ms, TE: 100ms, NEX: 1. The diffusion gradients were applied in the x, y and z directions and trace images were generated. ADC values were generated using a pixel-to-pixel analysis (normal mean values obtained in 10 volunteers: 1.25×10⁻³mm²/s for grey matter and 1.30×10⁻³mm²/s).

On the low field the parameters were: a total of twelve 10mm thick axial slices were acquired with b values of 0 and 700s/mm², FOV: 300mm; matrix: 216×216 pixels, TR: 1440, TE: 110, NEX: 1. The diffusion gradient was applied in the z direction only. ADC values were automatically generated by the console software using a pixel-to-pixel analysis (normal mean values obtained in the same 10 volunteers: 1.111×10⁻³mm²/s for grey matter and 1.117×10⁻³mm²/s).

Data analysis

The examinations were transferred to the PACS system of our institution where they were anonymized. The 1.5T and low field examinations were analyzed independently by two neuroradiologists and presented in random order. Lesion volume was planimetrically determined on the console software by drawing regions of interest with the integrated software.

On DWI, we considered as positive any hyperintense lesion with a radiological (FLAIR, T2 or follow-up examination) and clinical correlate. This hyperintensity was scored 2 if it was clear, 1 if it was found to be of intermediate brightness, and with a score of 0 if no hypersignal was present. The ADC was also classified into five degrees of intensity between –2 (clear hyposignal) to +2 (clear hypersignal).

In order to define a gold standard for the final diagnosis, a consensus reading was performed by three neuroradiologists who had at this time diffusion-weighted examinations, T2, FLAIR as well as the CT scan or follow-up MRI (with post-contrast T1-weighted series) available.

RESULTS

The ADC was decreased in all strokes examined before 5 days on both machines. The relative ADC was found to be between 0.8 and 1.2 on the open machine and 0.75 and 1.3 on the 1.5 system.

Concordance study with both radiologist

Both observers obtained the same results for the presence of high signal intensity lesions on both systems.

Analysis of the results

Lesions: a total of 20 high signal intensity lesions were recorded Table I.

Localization

8 (40%) of the lesions were cortical (fronto-temporo-parieto-occipital), 8 (40%) were localized in the internal capsule and 2 (20%) were in the posterior fossa and brainstem.

Size

The lesion size was found to be between 6.5 and 55mm with a mean diameter of 17mm. Five (25%) of the lesions were less than one centimeter in diameter, 35% (7/20) were between 1 and 2cm and 40% (8/20) of the lesions were more than 2cm in diameter.

Lesion signal

Nineteen of 20 lesions were visible on the T2 and 20 on the FLAIR.

At high field and low field all lesions were seen with a complete concordance, i.e. all 20 were detected equally well by both methods (i.e. in 100%: figure 1).

For the analysis of the degree of the signal intensity of the lesion, 4/20 discordant signals at high field were classified as clear, whereas it was intermediate at low field.

The signal intensity discordance corresponds to 4 lesions equal to or less than one centimeter in diameter. They were localized in the internal capsule (n=2) the occipital lobe (n=1) or in a peduncle (n=1) with lower signal intensity of the lesion on the diffusion sequence at low field.

The concordance on the ADC maps was lower: 65% (13/20 cases) of concordance (figure 2).

The 7 discordances are for 57% (4/7 cases) located in the internal capsule, where the ADC is at 0 at high field, the other lesions being located cortically close to a large chronic lesion and 2 were peduncle lesions.

DISCUSSION

We have demonstrated that DWI, when performed on a low-field open interventional scanner, can demonstrate subacute ischemia equally well as a conventional echo-planar MR scanner. This is surprising since the overall image quality of the low-field machine was judged lower than that of the high-field system. This also is correlated to the ADC measurements which show that the acute infarction stage corresponds to a decrease in values initially. Open-field systems have the distinct advantage of allowing better patient access for monitoring the patient if he is unconscious but also allows better access if quick interventions might be needed, e.g. anesthesia or even if intravenous thrombolysis has to be started on the MR table. In this study we have demonstrated that DWI can be easily performed on an open low-field scanner. Indeed, while very motion-sensitive, DWI is independent of the field strength being used and diffusion experiments can be performed at low field [17]. We see that DWI on such a system was able to provide us with images of
good diagnostic quality and which showed comparable results to those seen when using our state-of-the-art echo-planar scanner. Echo-planar imaging also has the disadvantage of presenting important image distortions and artifacts close to the skull base due to susceptibility artifacts, not present on imaging performed with the low-field unit [4]. Even if the image quality obtained with the low-field system was not the same as the one observed on the high-field system, this did not diminish its ability to serve as a screening tool for patients with suspected stroke. This is extremely important since on the one hand low-field systems are quite widely available due to their lower cost compared to high-field systems, especially in non-industrialized countries. One disadvantage is that whole-brain perfusion-weighted MR imaging is not available on the low-field system, meaning that exploration of the penumbra believed to be located in the area of DWI-Perfusion mismatch cannot be imaged [22]. Another disadvantage of the low-field methods is the significantly longer scan time to achieve a set of whole-brain DWI data: this time might be critical in a situation where decisions must be taken quickly and is also problematic because of the increased possibility of patient motion-induced artifacts or even image degradation. Also, the slices are thicker on the low-field than on the high-field; therefore small lesions might be missed if they are smaller than a slice, as might occur in smaller lacunar strokes; this was however not the case in our series. It is generally considered state-of-the-art imaging to perform trace DWI images in order to exclude false interpretation of anisotropy effects in the corona radiata for example; we only acquired DWI images with the gradients in one direction; this has however been proven to provide DWI images of sufficient diagnostic accuracy for the acute evaluation of stroke patients [3]. While the possibility of so-called T2-shine through effects is possible in any DWI image acquired subacutely, the calculation of ADC maps is helpful and the interpretation of the generated images necessary [2, 19] in

**FIG. 1.** – Patient with left-sided hemiparesis: imaging was done at 36 hours after onset of symptoms. Axial T2-weighted image: hyperintensity in the posterior part of the internal capsule on the right. b) axial diffusion-weighted image at a high b value on the 1.5T system showing a hyperintensity in the corresponding area in the posterior part of the internal capsule. c) axial ADC map obtained on the 1.5T system showing a decrease in signal intensity in the posterior part of the right internal capsule. d) axial diffusion-weighted image at the high b value on the low-field system performed two hours later (38 hours after onset) displaying the same hyperintensity in the posterior part of the right internal capsule. e) axial ADC map generated on the low-field system at the same level with a hypointensity in the posterior part of the internal capsule on the right.
order to exclude the shine-through effect. In conclusion, in our opinion, DWI performed on a low-field open MR scanner is an interesting approach to image patients with acute stroke syndrome and provided images of similar clinical usefulness compared to those obtained on a 1.5T echo-planar MR system. While echo-planar systems remain the state-of-the-art units to perform functional MR examinations such as diffusion-weighted imaging, this method may represent an acceptable clinical compromise for obtaining DWI if no other alternative is readily available.

RÉFÉRENCES


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