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Diffusion-weighted MRI for monitoring neurovascular interventions

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Abstract Carotid stenting is increasingly considered as treatment for carotid artery disease. A reliable noninvasive method is desirable for assessing the safety of the procedure. Diffusion-weighted MRI (DWI) is sensitive to early brain ischaemia which becoming widely available and might therefore serve this purpose. We prospectively studied 19 patients referred for investigation of carotid artery disease by echo-planar whole-brain DWI before and within 24 h of stenting. The images obtained at a high b value were examined by two independent blinded reviewers for new high-signal areas consistent with ischaemia. We found that 15 patients had no new changes after stenting. One patient showed enlargement of a posterior watershed lesion after the procedure, which correlated with an increase in neurological deficit. Three other patients had presumed small embolic infarcts on DWI; two were asymptomatic and one had weakness at the hand that corresponded to an embolic infarct with a lesion on DWI in the hand notch. There were no false-positive or -negative results on DWI, when compared to clinical findings. DWI is thus a new method that can demonstrate neurologically silent or asymptomatic infants. It can be used to help to assess the safety and efficacy of neurovascular intervention.

Key words Magnetic resonance imaging · Diffusion-weighted · Carotid artery · Stents · Carotid stenosis · Angioplasty

Introduction

With recent advances in understanding of the mechanisms underlying cerebral ischaemia [1, 2], evidence has been gathered that cerebrovascular disease is preventable and potentially treatable [3]. Examples are endovascular or systemic thrombolysis [4, 5], neuroprotection, and surgical treatment of carotid disease. Newer approaches such as percutaneous transluminal angioplasty, stenting [6], or a combination of the two are being considered. To assess the safety and efficacy of these approaches it is desirable to have a noninvasive method for demonstrating areas of acute ischaemia with certainty. Until recently conventional CT and MRI techniques have not been considered reliable enough to demonstrate acute signs of ischaemia: indeed, the well-known early CT signs can be both subtle and nonspecific [7, 8], and while T2-weighted

MRI is sensitive to oedema, it is also not reliable in the first 12 h after the onset of symptoms [9, 10]. MRI has also been considered insensitive to acute haemorrhage, but with susceptibility-sensitive gradient sequences, this may no longer be the case, so that MRI is establishing itself as the modality of choice for patients presenting with signs of acute neurological dysfunction possibly attributable to ischaemia [11, 12].

Diffusion-weighted imaging (DWI) [13], in which diffusion-sensitising gradients are placed on both sides of the 180° pulse of a spin-echo sequence, is a novel modality which reflects microscopic movement of water. At first difficult to implement in the clinical setting due to its inherent sensitivity to motion, the availability of commercial echo-planar imagers has allowed the method to leave the research institutions and move into clinical practice [14]. Other alternative fast imaging methods, such as line-scan imaging, diffusion imaging with HASTE and navigated spin-echo imaging [15, 16, 17], are also becoming available, some of which do not require expensive high-field imagers.

DWI has been shown to demonstrate the appearance of neuronal ischaemia within minutes of onset in animal models of stroke and reversibility of lesions after treatment [18, 19]: indeed, it is postulated that cytotoxic oedema causes an acute drop of the apparent diffusion coefficient of water [20]; this phenomenon is seen as high signal on diffusion-weighted images obtained at a high b value. First results from human studies have shown that DWI can detect ischemic changes early on [21–27] with high sensitivity and specificity [28]. DWI has been applied to monitor the effects of putative neuroprotective drugs, since it has been shown to correlate with clinical status and outcome [29]. Methods such as Doppler ultrasound have been used to monitor vascular interventions [30] and in a few studies conventional MRI has been analysed [31]. Since some groups have advocated the use of protective measures during carotid endovascular treatment [6], our aim was to use DWI prospectively in patients undergoing carotid stenting and to assess its value for monitoring the safety of such interventions.

Materials and methods

We prospectively studied nineteen consecutive patients, 43–83 years old. All were informed about the nature of the procedures (stenting and DWI) and signed a consent form; the procedures were approved by the ethics committee of our university. Before and after intervention they were examined by a certified neurologist specialising in stroke; subsequently the patients were discussed at the our interdisciplinary stroke meeting, where a decision was made on diagnostic management and treatment. A carotid stendosis had been demonstrated by both ultrasound and first-pass gadolinium-enhanced MRA [32].

Carotid angiography and stenting were performed on a unit which allows biplane road mapping and online measurement of real diameters [33]. Our standardized angiographic protocol included digital subtraction studies of the aortic arch and injection of the supra-aortic vessels. The diameter and length of the stenosis and the diameter of the adjacent vessel were measured. For stenting an 8-French guiding catheter was positioned just proximal to the stenosis. The stenosis was normally dilated before stent placement. The size and length of the self-expanding Wallstent depended on the diameter measured on MRA [32] and the angiogram [33]. Postdilation was performed within the stent after placement in all patients.

MRI of the brain was performed before and after invention, within 24 h, the first time on the day before and the second usually on the day of the intervention. It was performed on a 1.5-T whole-body imaging system, with a head coil. At first, T1-weighted images (TE 12, TR 528 ms, matrix 256 × 256, 2 excitations) and T2/protondensity-weighted images (TE 98/16, TR 3176 ms) were acquired; then whole-brain DWI was carried out with an isotropic echoplanar sequence (TR 4000, TE 133 ms, field of view 210 mm, matrix 128 × 128, 4 excitations) with b values of 0 and 972 s/mm^2.

The high-b DWI was imaged on films that contained no due to the patient's identity or date of examination. Two experienced neuroradiologists then reviewed the films independently without any knowledge other than that the patients had undergone carotid stenting; they had to identify high-signal foci that would be a sign of new ischaemic lesions.

Results

There was overall agreement between the reviewers as to the presence or absence of high-signal foci. Of the 19 patients, 15 did not show any new foci on the follow-up study, and had no new neurological lesions related to the interventional procedure. One patient, who already had a symptomatic left-sided ischaemic lesion in the posterior watershed zone (Fig. 1 a), showed clear enlargement of this lesion, and new lesions in the frontal and parietal lobes (Fig. 1 b); he had an increase in his right-sided hemiparesis. A further patient , who had a pre-existing silent infarct in the right frontal cortex (Fig. 2 a), showed an infarct in the right hand-notch area that corresponded to a left hand weakness which developed 1.5 h after stent placement (Fig. 2 b). Two other patients had new lesions on DWI which were, however, neurologically silent: one had multiple small lesions in the periventricular white matter bilaterally (Fig. 3) and one a small cortical lesion in the left frontal lobe.

DWI did not yield any false positive result, i.e, showing lesions that did not correspond to infarcts; it also did not fail to show any new lesions in the patients who had clinically relevant ischaemia (no false-negatives new lesions).

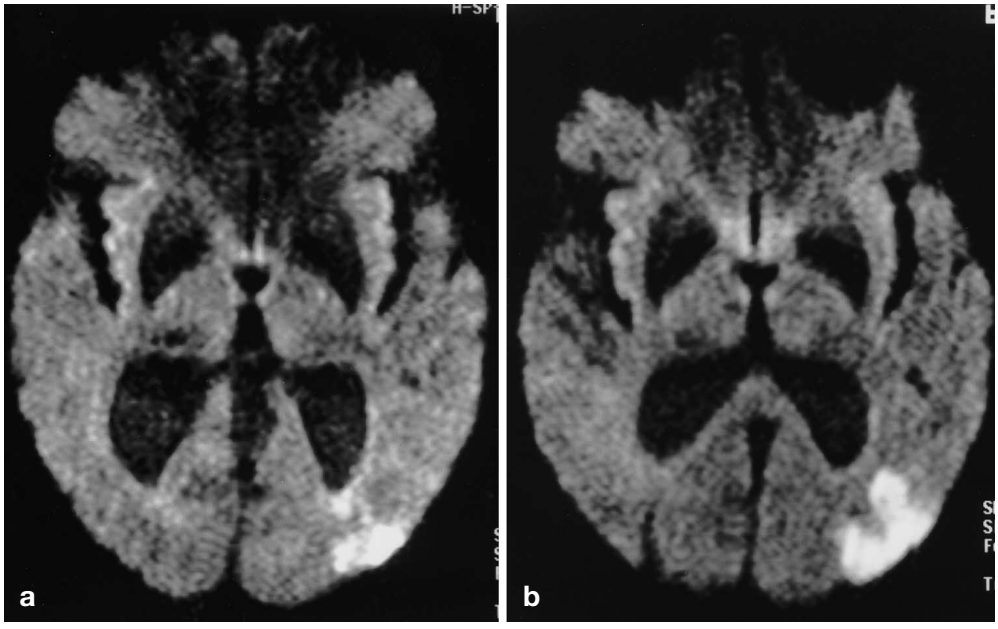

Fig. 1 **a** Diffusion-weighted high b-value echo-planar image (TR 4000, TE 133 ms, field of view 210 mm, matrix 128 × 128, excitations 4) in a 62-year-old man: a small ischaemic lesion is seen in the left posterior watershed region. **b** In the same patient post-stenting the infarct has extended significantly

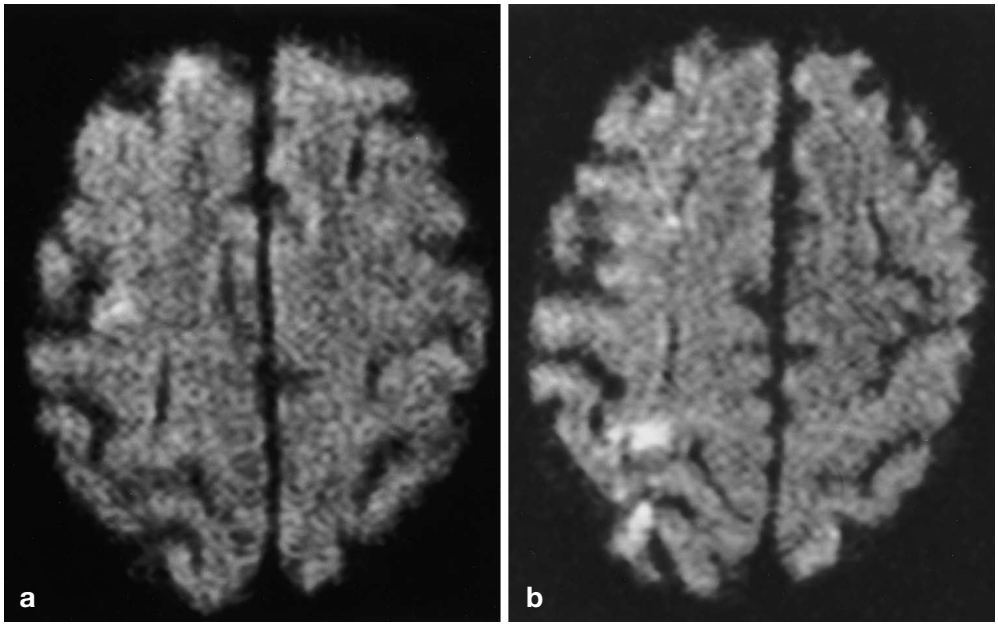

Fig. 2 **a** A 76-year-old man without symptoms: the diffusion-weighted image shows a silent subacute infarct in the right frontal cortex. **b** A diffusion-weighted image the day after intervention shows an infarct in the right hand-notch, corresponding to a new weakness of the left hand

Discussion

Carotid artery disease is now increasingly treated by the endovascular approach; to perform a safe procedure, some groups advocate using protective measures during intervention, so as to prevent embolic infarcts [6]. Noninvasive monitoring methods are desirable to establish the efficacy and safety of these procedures. Doppler ultrasound can be used to detect the passage of emboli during the procedure [30], but a method is needed to establish the presence or absence of structural brain damage at an early stage.

In this study DWI allowed us to detect ischaemic lesions in four cases; in two these infarcts were in silent areas of the brain, and in the other two they were associated with new or progressive symptoms. This confirms the results of a previous study of MRI after coronary artery surgery, where silent infarcts were found in the brain [31].

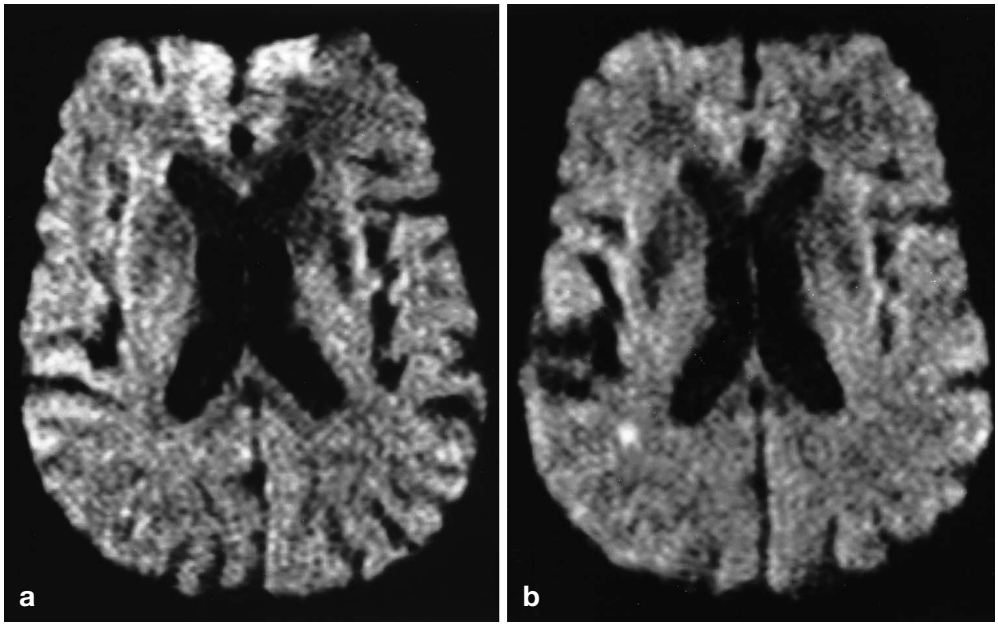

Fig. 3 **a** A 74-year-old asymptomatic man: the diffusion-weighted image shows no infarcts. **b** Following stenting, there is a presumed embolic infarct in the right periventricular white matter

DWI can show subacute infarcts, a risk factor for subsequent ischaemia related to the intervention. In our series the two patients who already had high-signal ischaemic lesions went on to develop further infarcts after the procedure. In one case a new lesion appeared in the motor cortex and in the other lesion progression may have indicated extension of infarction to a pre-existing penumbra. DWI also demonstrated silent infarcts in areas not commonly associated with clinical deficits; however, these cases also suggest the possible benefit of some kind of protetion during an intervention, as well as some kind of monitoring before, after and possibly during procedures.

Further studies are needed to establish the value of the technique. Patients undergoing cerebral angiography for reasons other than cerebrovascular disease should be studied in order to establish the frequency of infarcts. A further group of interest might be patients undergoing carotid surgery for stenosis.

Perfusion-weighted imaging could also be of interest since it could reveal areas of hypoperfusion which could represent a chronic penumbra that might be at greater risk for subsequent intervention-related infarction. A so-called mismatch, in which an area of normal diffusion shows low perfusion could be considered a risk for extension of the lesion.

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