Diffuse Axonal Injury with Selective Involvement of the Corticospinal Tract

A Diffusion Tensor Imaging Case Study

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SUMMARY – *The identification of diffuse axonal injury (DAI) can be difficult, especially using conventional imaging (CT or MRI), which usually appears normal. Diffusion tensor imaging (DTI) is useful in identifying white matter abnormalities in patients with DAI. We describe the case of a 17-year-old female with severe closed head injury and right-side hemiparesis, studied with DTI and MR-tractography. In this case, DTI was useful to detect focal and diffuse signs of DAI.*

Introduction

Diffusion tensor imaging (DTI) is useful in identifying white matter abnormalities in patients with diffuse axonal injury (DAI) even if conventional imaging (CT or MRI) appears normal. We describe the case of a patient with severe closed head injury and right-side hemiparesis in which DTI showed white matter changes from DAI involving the corticospinal tract.

Case Report

A 17-year-old female was referred to our hospital for a severe closed head injury; she was brought to the emergency room, unconscious (GCS=5) with right-side hemiparesis.

MRI examination (1.5 T, Sonata, Siemens, Erlangen, Germany) disclosed a subtle hyperintense lesion in the left cerebral peduncle on FLAIR and T2-weighted images (Figure 1A,B). Restricted diffusion was also found in the same region (Figure 1C-E).

One week later a follow-up MRI, including DTI, was performed with 12 non-collinear directions (b value= 0 and 1000 s/mm²) (TE 86

ms, TR 9,200 ms, matrix 128×128, FOV 240 mm, slice thickness 1.9 mm, 60 slices). Tractography post-processing was performed using TrackVis software (Version 0.5.1, Ruopeng Wang, Van J. Wedeen Athinoula A. Martinos Center for Biomedical Imaging Massachusetts General Hospital, Boston, MA, USA). Colour maps were used to define a specific region of interest (ROI) for the tractography procedure. First of all, a complete white matter tractographic reconstruction was obtained (fractional anisotropy (FA) threshold 0.2, angle 35°) (Figure 1A). Secondly, two ROIs were positioned in both the cerebral peduncle and posterior limb of the internal capsule to reconstruct trajectories compatible with the corticospinal tracts (CST). Apparent diffusion coefficient (ADC) and FA values of white matter tracts and left and right CST were obtained. All results were compared with those obtained from five normal control subjects.

Comparing our patient and the control group, significantly different FA and ADC parameters were detected in the whole brain using an automated function of software without a ROI (patient mean values: FA: 0.44, ADC: 0.00088, $p<0.05$; control mean values: FA: 0.50, ADC: 0.00082, $p<0.05$). A reduced 3D representation

Figure 1 A small hyperintensity in the left cerebral peduncle is visible on FLAIR and T2-weighted images on axial planes (A,B) corresponding to a bright signal in DWI images is evident (C, arrow) with a low signal in ADC maps (F, arrow). The same finding is appreciable in coronal DWI images (E, arrow). Comparison between our patient (A) and control subject n° 2 (B) by 3D reconstruction of the white matter tract. A different representation of fibres is evident in our patient due to the reduced FA and the increased ADC values compared to the control subjects (F,G). On colour-coded maps a change in normal blue in the left corticospinal tract is visible (H, arrow; I) and an increase in FA values was noted in the same site (J). All alterations were reversible on the last MR control, both in DWI and colour-coded maps (K-N). O) A schematic representation of fibre swelling due to increased glutamate and calcium levels that could justify the increase in FA and the reduction of ADC.

of trajectories, compatible with white matter tracts of the brain, was also demonstrated (Figure 1F,G).

Colour-coded FA maps showed the usual lack of predominant blue voxels in the area with restricted diffusion (from the cerebral peduncle to the posterior limb of the internal capsule) which were replaced by violet voxels (Figure 1H,I). In this specific segment of CST, the mean FA was higher than in the contralateral side and in the control subjects (0.63 vs 0.57, $p=0.03$) (Figure 1J). Follow-up MRI, performed a week later, showed a reduction of the DWI signal in the left cerebral peduncle (Figure 1K,L), with a normalization of colour maps inside the left CST (Figure 1M,N). FA values

in the same tract were also reduced (mean FA value: 0.52). Two weeks later the patient was discharged with the diagnosis of permanent right hemiplegia.

Discussion

Diffuse axonal injury (DAI) is microscopically characterized by widespread axonal damage on the subcortical white matter caused by the shear strain created by rotational acceleration and deceleration¹. The identification of DAI can be difficult, especially using conventional imaging (CT or MRI), which usually appears normal². Deep white matter involvement

has been reported in more severe cases (corpus callosum, internal capsule and brainstem)³. In our patient, CST involvement occurred in the midbrain rather than in the supratentorial location with a good correlation with the clinical symptoms².

DTI is a technique derived from diffusion-weighted imaging applied to several studies. It is used to infer microstructural cerebral characteristics⁴ and to allow a better evaluation of FA reduction due to local loss of structural integrity⁵.

Three main aspects should be emphasized from the observation of this case. First, the decrease of FA values in the whole brain white matter and increase in the corresponding ADC in the whole brain of patients with DAI is probably related to an abnormal accumulation of water in the interstitial space⁶. This could be caused by misalignment of the axonal membranes, thus responsible for reductions of anisotropy⁷. Second, there was a focal restricted area in DWI located in the left cerebral peduncle. Chan et al.⁸ reported that high signal DWI can be observed in patients examined in the early stages of DAI. This finding is thought to represent cellular swelling, cytotoxic oedema² and even possible excitotoxic mechanisms⁹. Excessive extracellular glutamate leads to axonal swelling and cytotoxic oedema of glial cells,

which together may contribute to diffusion abnormalities resulting in necrosis, axonal degeneration and gliosis^{9,10}. Some authors described a specific involvement of the CST after DAI¹¹. Third, the focal increase in FA in the region of damage encountered in our patient is strictly related to the pathogenesis of DAI. The development of axonal swelling in the early stage of DAI may reduce the interstitial space and thereby increase FA, raising the local "density" of fibres (Fig 1O).

In our patient the DWI alteration was reversible. Takayama et al. described transient DWI and ADC abnormalities in diffuse brain injury and suggested the presence of cytotoxic oedema¹. On the other hand, the persistent reduced FA values in the left CST confirmed the irreversible damage to the tract. This was correlated to the patient's persistent motor deficit. Joining the three observations, it could be argued that during the acute phase of DAI, FA increases because of the reduced interstitial water from cyto-excitotoxic oedema. Later, FA will decrease probably because of axonal/myelin damage correlated to persistent symptoms.

Following these points, DTI represents an accurate method of assessing the presence of DAI, its extension, its characteristics and its possible prognostic significance.

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