Conventional magnetic resonance and diffusion tensor imaging in diffuse axonal injury after traumatic brain injury

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Learning objectives

Our objective is to show iconographic examples characteristic of axonal injury using Magnetic Resonance Imaging (MRI) and Diffusion Tensor Imaging (DTI). To show the utility of the DTI in the diagnosis of this entity.
Background

Axonal injury is a condition that can occur after traumatic brain injury (TBI). It is difficult to diagnose and can generate cognitive and mnemonic disorders.

DTI is a magnetic resonance imaging sequence that assesses the movement of water molecules through the axons. Water molecules in the white matter follow the direction of axons. On DTI, if the water molecule moves in the cephalocaudal sense and vice versa, the fibres of the white matter will be seen in blue (example: corticospinal beam). If the water molecules move in a transverse way, the fibre colour will be red (example: corpus callosum), and if the movement is anterior-posterior or vice versa, the fibres will be green (example: fronto-occipital fascicle).

DTI can also provide quantitative assessment of the white matter, through the measurement of the anisotropic fraction (AF), which in the normal white matter presents a value ranging from 0.3 to 1. Values below 0.3 suggest compromise of the white matter fibres (demyelination, infiltration, injury or disruption).

We selected 10 patients with age range of 12 to 37 years, 9 male and 1 female. Inclusion criteria: history of TBI and cognitive impairment post trauma. Exclusion criteria: cardiovascular disease, diabetes mellitus and arterial hypertension. All 10 patients were evaluated with MRI. 7 patients underwent DTI, which measured the anisotropic fraction of normal and pathological white matter. DTI was performed 3 to 6 months after cranial trauma.
Imaging findings OR Procedure details

Cranio-encephalic trauma background: 6 patients had had a car accident, 2 patients had had a motorcycle accident without wearing a helmet, 1 patient suffered a trauma during sport practice and 1 during a seizure.

Lesions by shearing (axonal injury) are usually seen as hyperintense on T2 and Flair, they can be unique, but they are generally multiple. Immediately after cranial trauma, lesions can be diagnosed with the diffusion technique, where images will be seen with restriction to the movement of water molecules, hyperintense on DWI and hypointense on ADC (fig. 1 on page 9). Diffusion is the most sensitive method to diagnose acute axonal injury.

In 6 patients, on gradient echo sequence, multiple hypointense lesions were identified, which suggested petechial bleeding, a finding which can also be observed in axonal injury (fig. 2 on page 9). Gradient echo sequence reveals the presence of hematic residues. In some cases, shearing lesions cause small bleedings which are evidenced by CT scan as small hyperdense images, and on gradient echo (GRE) magnetic resonance imaging as small hypointense foci.

**Sites of axonal injury:**

The most frequent sites of axonal injury in our study are: 8 lesions in the corpus callosum, 6 in subcortical white matter, 6 in periventricular white matter, 4 in centrum semiovale, 4 in internal capsules, 4 in the corona radiata and 3 in the brainstem (graph 1 on page ).
The corpus callosum is the most affected site, their most compromised sectors being the posterior and splenium (fig. 3 on page 10). For its diagnosis, sagittal T2-weighted or Flair sequences are useful, since they identify these lesions better.

The periventricular white matter can also be one of the most affected sites. These may be seen as small lesions or large periventricular hyperintense areas. (fig. 4 on page 11). To diagnose these lesions, the axial plane is more sensitive.

In corona radiata and centrum semiovale, shearing lesions may also be found, the axial plane being the most sensitive for their visualisation (fig. 5 on page 12 and 6 on page 13). In these sites there can also be areas of gliosis and vascular lacunar sequels, which in adult patients are difficult to differentiate from axonal injury. For the present study, we selected young patients without cardiovascular antecedents, so as to avoid this diagnostic problem.

In the anterior capsule, the most compromised sector is usually the posterior limb (fig. 7 on page 14). The significance of this is that fibres of the corticospinal beam go through this area. The axial plane is the most sensitive for its diagnosis.

In our study, we found only 3 patients with lesions of the brainstem; these represent a bad prognosis since the corticospinal beams go through it, and that in the bulb are the
respiratory and cardiovascular centres, and a great number of nuclei. The planes used for their identification were axial and sagittal (fig. 08 on page 15).

**DTI assessment of axonal injury:**

7 patients were evaluated 3 and 6 months afterwards with DTI on a 1.5T high-field resonator. FA was measured at the site shown by the hyperintense images on T2 and Flair (fig. 09 on page 16), and values below 0.3 were confirmed (range 0.07 - 0.3).

To measure FA, T2-DTI or FLAIR-DTI fusion technique (fig. 10 on page 17) was applied to perform the measurement at the correct site of the lesion and, therefore, to minimise measurement errors, since if FA is measured in a subarachnoid or cistern space, or in a ventricle, it will be low.

**Lesions diagnosed by DTI not identified on conventional sequences:**

On table 1 on page FA measurements in patients with axonal injury are shown.

Three patients were diagnosed injuries by DTI which were not seen in the conventional study which highlights the importance of the use of this sequence to diagnose axonal injury (fig. 11 on page 18 and 12 on page 19).
Table 1: DTI. FA measurements in patients with axonal injury. FA is below 0.3 in the lesions identified on conventional sequences. Focal lesions with lowered FA were found in 3 patients, which are not identified on conventional sequences (light blue background), which demonstrates higher DTI sensitivity in the diagnosis of these lesions than by conventional MRI.

<table>
<thead>
<tr>
<th>CORONA RADIATA</th>
<th>CENTRUM SEMIOVALE</th>
<th>CORPUS CALLOSUM</th>
<th>INTERNAL CAPSULES</th>
<th>PERIVENTRICULAR WHITE MATTER</th>
<th>SUBCORTICAL WHITE MATTER</th>
<th>BRAINSTEM</th>
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**Fig.:** Table 1: DTI. FA measurements in patients with axonal injury. FA is below 0.3 in the lesions identified on conventional sequences. Focal lesions with lowered FA were found in 3 patients, which are not identified on conventional sequences (light blue background), which demonstrates higher DTI sensitivity in the diagnosis of these lesions than by conventional MRI.

**References:** Neuro MR, Fundacion Cientifica del Sur - Buenos Aires/AR

A patient underwent magnetic resonance imaging 3 days after cranial trauma, which revealed a lesion in the splenium of corpus callosum. 3 months after the trauma, the MRI scan of the brain was repeated, which did not show the lesion in the corpus callosum. We evaluated the patient with DTI and found that in the sector where the lesion identified post-trauma (spleenium) had been, there was a decrease in FA. On tractography, a lower quantity of fibres at the level of splenium was also observed (fig. 13 on page 20).

**Assessment of apparently normal white matter:**

The apparently normal white matter of the 7 patients studied with DTI was assessed measuring FA at the level of the brainstem (protuberance), internal capsules, corona radiata, centrum semiovale, periventricular white matter and corpus callosum. The FA values recorded were compared with a control group table (with healthy volunteers); there
were no differences in FA values between our patients with axonal injury and the control group. In only one case, in a 12-year-old male patient, lower FA values were identified in the corona radiata and centrum semiovale, with respect to the control group (Tables 2 and 3 on page ).

<table>
<thead>
<tr>
<th>SEX</th>
<th>AGE</th>
<th>CORONA RADIATA</th>
<th>CENTRUM SEMIOVALE</th>
<th>CORPUS CALLOSUM</th>
<th>INTERNAL CAPSULES</th>
<th>PERIVENTRICULAR WHITE MATTER</th>
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<td>25</td>
<td>0.35 - 0.75</td>
<td>0.34 - 0.79</td>
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<td>0.43 - 0.71</td>
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<td>12</td>
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<td>0.54 - 0.71</td>
<td>0.4 - 0.75</td>
<td>0.51 - 0.77</td>
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Table 2: FA in white matter of patients with head trauma history

<table>
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<tr>
<th>SEX</th>
<th>AGE</th>
<th>CORONA RADIATA</th>
<th>CENTRUM SEMIOVALE</th>
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<td>0.56 - 0.62</td>
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<td>0.58 - 0.8</td>
<td>0.47 - 0.89</td>
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<tr>
<td>M</td>
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<td>0.59 - 0.90</td>
<td>0.39 - 0.86</td>
<td>0.36 - 0.79</td>
</tr>
</tbody>
</table>

Table 3: FA in the white matter control group

Fig.: Tables 2 and 3: FA measurement (range) in the apparently normal matter (without lesions evidenced on conventional sequences). Comparison with FA values in control group (Table 3). Low FA values were identified in only one 12-year-old male patient, at the level of the corona radiata and centrum semiovale (red letters), when compared with the control group.

References: Neuro MR, Fundacion Cientifica del Sur - Buenos Aires/AR
Fig. 0: Diffusion in a patient with recent encephalic trauma. Hyperintense images are identified on DWI and hypointense on ADC, suggesting focal lesions with a certain degree of restriction of water molecules. Finding confirmed in acute axonal injury.

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**Fig. 0:** Petechial bleeding. On gradient echo sequence, punctate and hypointense images are observed due to the presence of micro bleedings caused by shearing of the white matter beams.

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Fig. 0: Axonal injury in corpus callosum. In case 1, the corpus posterior sector is involved, showing a hyperintense image on T2. In case 2, the splenium of corpus callosum is compromised. Note that the sagittal T2-weighted sequence shows the lesion better than the axial T2-weighted sequence. In case 4, there is a lesion compromising the corpus posterior sector and the splenium. The sagittal plane diagnoses this lesion with higher sensitivity.

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Fig. 0: Axonal injury in the periventricular white matter: in case 2, large hyperintense areas are identified on T2 adjacent to the frontal prolongations of the lateral ventricles (white arrows). In case 8, a small hyperintense image on T2 and Flair in the periventricular white matter adjacent to the frontal prolongation of the right lateral ventricle (white circle) can be observed.

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**Fig. 0:** Axonal injury in semioval centres. An example of axonal injury in the right semioval centre (white arrow) is shown, which is hyperintense on T2 and Flair.

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**Fig. 0:** Axonal injury in corona radiata. Hyperintense punctate images on T2 and Flair (white arrows) located in the right corona radiata of a young patient with antecedent of encephalic trauma due to car accident, without cardiovascular background.

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Fig. 0: Axonal injury in internal capsule. On T2-weighted and Flair sequences, a hyperintense image in the posterior limb of the right internal capsule (white arrow) is observed, which suggests axonal injury. The patient had a motor sequel post encephalic trauma.

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Fig. 0: Axonal injury in brainstem. Hyperintense lesions are observed on T2 in the mesencephalus on axial plane (red circle) and sagittal plane (white arrows).

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Fig. 0: DTI in axonal injury. On sagittal T2-weighted sequence, a lesion located in the posterior sector of the corpus callosum is identified. This is evaluated with DTI, and it presented FA decrease (0.2).

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Fig. 0: T2-DTI fusion. DTI assessment of the lesion located in the posterior sector and splenium of corpus callosum is performed, applying the fusion T2-DTI technique, FA yielding a measurement of 0.15.

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**Fig. 0:** A decrease in FA is identified, with a value of 0.27 in the splenium of corpus callosum. On conventional T2-weighted and Flair sequences, no lesion is observed.

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**Fig. 0:** In the periventricular white matter adjacent to the occipital prolongation of the left lateral ventricle, FA decrease is identified, with a value of 0.18. On conventional T2-weighted and Flair sequences, faint signal changes are observed.

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Fig. 0: 18-year-old patient who suffered encephalic trauma with loss of consciousness during a seizure. He was admitted to ICU due to serious general condition and cognitive deterioration. Three days after the trauma, MRI was performed, which identified a lesion in the splenium of corpus callosum with left lateralisation. Three months after the trauma, a new MRI control was performed, without evidence of lesion. DTI was performed, which confirms a decrease in FA (0.28) in the splenium of corpus callosum, at the site of the previous lesion. On tractography, lesser fibre reconstruction was identified in the splenium of corpus callosum.

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Conclusion

The most frequent sites of axonal injury lesions are the corpus callosum, subcortical white matter and periventricular white matter. DTI found a decrease below 0.3 FA. DTI was diagnosed injuries were not seen in the conventional study.
Personal Information

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References