Regional Increases in Diffusion Anisotropy after Traumatic Brain Injury: A Quantitative Diffusion Tensor Imaging Study

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Abstract

We use diffusion tensor imaging to quantitatively characterize fiber degradation and reorganization of white matter in the brain of a patient who emerged after 19 years in a minimally conscious state. To summarize the information obtained in these images, white matter changes are characterized by histograms of average diffusion constants and anisotropy values and compared with values obtained from 20 normal subjects. Furthermore, FA-directionality diagrams are introduced. We identified severe atrophy accompanied by altered diffusivity and decreased anisotropy, as expected, but there are also regions with increased anisotropy.

Introduction

Diffusion tensor imaging[1] (DTI) has proven to be a powerful and white matter tract specific[2] imaging modality which is capable of characterizing specific tissue pathologies such as atrophy and patterns of diffuse axonal injuries. Unlike conventional MRI, DTI can provide quantitative, reproducible results, when obtained on the same scanner[3]. We examined DTI measurements from a 40 year-old man who had remained 19 years in a minimally conscious state (MCS) following a severe traumatic brain injury prior to unexplained emergence from the condition. The patient had a motor vehicle accident initially producing one to two months of a comatose state followed by further recovery to a vegetative state and subsequently MCS within the first year of injury. Although gradual improvements in responsiveness were noted during MCS, the patient was unable to communicate using gesture or verbal output. Limited head nodding and grunting were only inconsistently present. Eight months prior to evaluation with DTI he spoke a first word, followed by a recovery over a several day period of fluent but dysarthric speech and reliable communication.

Methods

All normal subjects were scanned on the same GE 3T whole body scanner, within 9 weeks before and after the patient. A DTI sequence with 26 diffusion gradient directions was used. Histograms of average diffusion constant (D_{av}) and fractional anisotropy (FA), and FA color maps[4] were obtained. In FA color maps, color is composed of red, blue and green, depending on whether anisotropy is most pronounced from left-to-right, superior-to-inferior, or anterior-posteriorly, respectively. Additionally, FA-directionality diagrams, graphs of FA vs. the absolute value of the *x*-component of the largest eigenvector of the diffusion ellipsoid, $|v_x|$, were computed. Like FA, $|v_x|$ is normalized between 0 and 1 and was chosen to characterize the right-left diffusivity in the brain. It is assumed that the preferential diffusion axis coincides with fiber orientation[5]. FA diagrams were computed over a region of interest corresponding to the marked region in Fig. 1b, through the same sagittal slice in each subject. Reproducibility of this method was tested by random repeated application of this procedure.

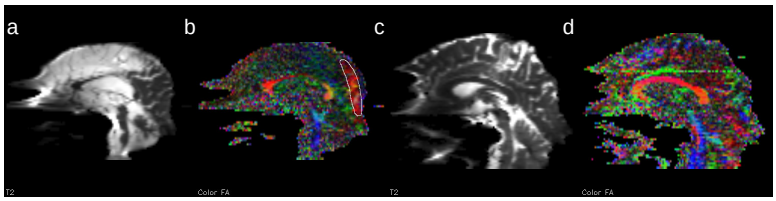

Figure 1: Midsagittal T2 weighted images and FA color maps of the patient (a,b) and the normal subject that has the strongest occipital FA values among all the normals (c,d). In (b), the medial-parietal occipital (MPO) ROI is outlined in white. The green line in (d) is a white pixel artifact confined to a single slice.

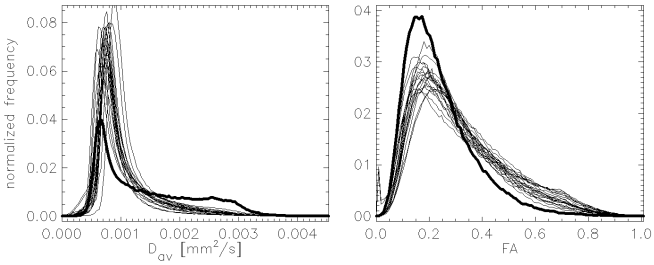

Figure 2: Histograms of average diffusion constant (left) and fractional anisotropy values (right) of the patient (bold line) and 20 normals (thin lines).

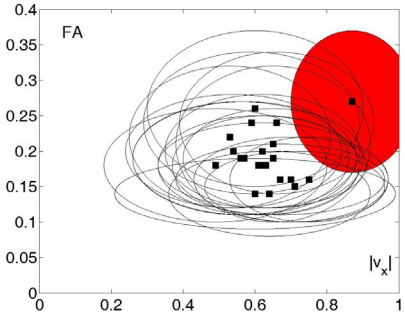

Figure 3: FA-directionality diagram for the MPO region. Shown are mean values over the specified ROI (dots) with error ellipses over the ROI, for the 20 normals (open ellipses) and the patient (filled ellipse).

Results

The T2 weighted images exhibit severe white matter atrophy over significant parts of the brain (Figs. 1a,c). Color anisotropy maps demonstrate a marked reduction of volume and diffusion anisotropy of the patient's corpus callosum compared with normal subjects (n=20) (Figs. 1b,d). Histograms of D_{av} and FA indicate that the patient has suffered a global injury consistent with a shift toward lower D_{av} values in white matter[6] and an increased cerebrospinal fluid (CSF) compartment[7] (Fig. 2); overall, diffusion is increased, as expected[8], whereas anisotropy is decreased. Quantitative comparison of the corpus callosum indicates the anisotropy loss across sub-structures; whereas the genu c.c. has normal FA values, the splenium c.c. ($FA_{patient}$=0.65, FA_{normal}>0.69) and medial c.c. ($FA_{patient}$=0.38, FA_{normal}>0.63) are lower than in all control subjects. These values are consistent with severe diffuse axonal injury (Grade 3 DAI) and serve as a proxy for the aggregate injuries incurred to the cerebral hemispheres of this patient. For CSF, both anisotropy and diffusion values are normal. The occipital right-left connections in the medial-parietal occipital (MPO) area in the midsaggital plane are significantly increased (Fig. 3).

Discussion

Although the FA mapping and directionality analysis demonstrate the unexpected result that a large region of increased anisotropy is present bilaterally in the medial-parietal occipital region, the relationship to the patient's clinical course is unknown. Since earlier studies are not available we cannot rule out that this novel feature may not have pre-existed prior to injury. Late remyelination in posterior occipital cortices has been suggested in studies of aging in non-human primates[9]. The observation raises the possibility that a slow recovery of intra-regional connectivity may play some role in very late recoveries of function in patients with severe brain injuries[10]. It is not clear how such changes, if present, might relate to the late recovery of language without further studies.

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