Tension of White Matter Tracts Measured by Diffusion Tensor Magnetic Resonance Imaging

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Introduction

Pressure to the white matter may lead to disability due to significant loss of neuronal transmission, demyelination and axonal loss (1-3). Such pressure might be a consequence of a growth of a tumor or enlarged ventricle space leading to deviation and tension of the fibers. In both pathologies a certain volume of the intra-cranial space is being occupied by the lesion or CSF, thus, displacing the rest of the tissue, including the white matter. We have studied here the diffusion characteristics of white matter fibers affected by mechanical pressure in extra-axial tumors and hydrocephalus.

Methods

4 patients with massive meningiomas (extra-axial tumor) and 4 patients with acute hydrocephalus were scanned in order to investigate the effect of mechanical pressure on white matter fibers. All patient had no evidence of edema within white matter regions. Age matched healthy volunteers served as controls for the patient group. MRI was performed on a 1.5T MRI scanner (GE, Milwaukee). DTI experiments were performed using a diffusion-weighted spin-echo echo-planar-imaging (DWI-EPI) pulse sequence. The experimental parameters were as follows: TR/TE=10000/98ms, Δ/δ=31/25ms, b=1000 s/mm^2 with six diffusion gradient directions. 48 slices with thickness of 3mm and no gap were acquired covering the whole brain with FOV of 240mm^2 and matrix of 128x128. Number of averages was 4, and the total experimental time was about 6 minutes.

Results

Diffusion anisotropy was found to be higher in areas of pressed white matter as compared with similar areas of normal subjects. This increase was a result of a decrease in the eigen value representing the diffusion perpendicular to fibers and an increase in the eigen value representing the diffusion parallel to the fibers. Based upon this observation we defined a new index ($PS=D_{\perp}/D_{//}$) that might be more sensitive for the effect of pressure. Figure 1 shows MRI diffusion data set of a patient (F/37y) with a large meningioma. The pressed fibers surrounding the lesion show high FA and PS values (Figs. 1C and 1E). Notice that the PS index is much more sensitive to pressure than FA (while FA values increase by about 30%, the PS values increase by more than 150%). Table 1 summarizes the ROI analysis of the sub-cortical white matter and the pyramidal tract measured for the meningioma patient group compared to their contralateral hemisphere and healthy control group. Figure 2 shows MRI diffusion data set for a girl (12y) suffering from acute hydrocephalus and high intracranial pressure (ICP). The FA and PS values of this patient were extremely high. In fact the FA values approached values of 1 in certain areas (more than 200% higher than control age matched values). This result is even more extraordinary since such high anisotropy values are rarely found even in adult white matter.

Table 1	ROI	FA	ADC x10^{-5} cm^2/s	λ_3 x10^{-5} cm^2/s	λ_2 x10^{-5} cm^2/s	λ_1 x10^{-5} cm^2/s	PS
Sub-cortical White Matter	Deviated	0.60±0.06	0.69±0.06	0.25±0.09	0.66±0.14	1.17±0.09	4.7±1.0
	Contralateral	0.43±0.04	0.71±0.02	0.43±0.04	0.63±0.07	1.06±0.05	2.5±0.2
	Control	0.46±0.06	0.72±0.03	0.40±0.04	0.65±0.08	1.08±0.10	2.7±0.3
Pyramidal Tract	Deviated	0.75±0.11	0.72±0.02	0.21±0.13	0.44±0.07	1.51±0.23	7.2±2.8
	Contralateral	0.58±0.09	0.70±0.02	0.32±0.09	0.56±0.05	1.23±0.14	3.8±0.7
	Control	0.57±0.07	0.68±0.03	0.34±0.04	0.50±0.05	1.18±0.09	3.5±0.3

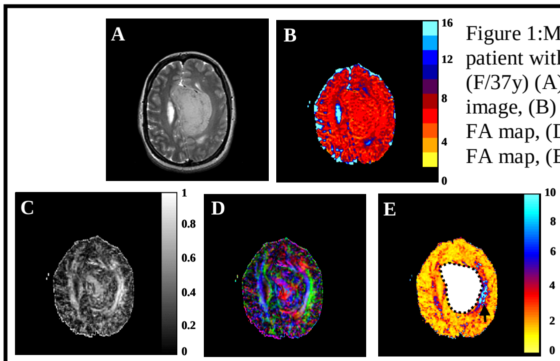

Figure 1:MRI data set of a patient with meningioma (F/37y) (A) T2 weighted image, (B) ADC map, (C) FA map, (D) Color Coded FA map, (E) PS map.

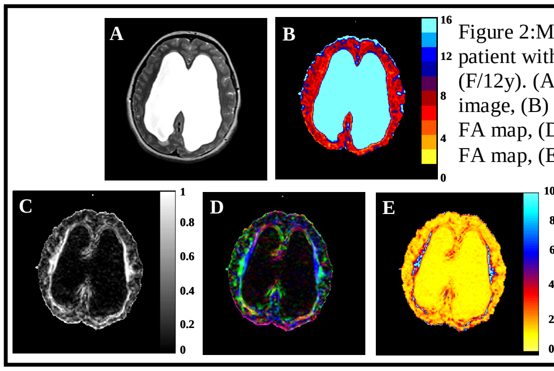

Figure 2:MRI data set of a patient with hydrocephalus (F/12y). (A) T2 weighted image, (B) ADC map, (C) FA map, (D) Color Coded FA map, (E) PS map

Discussion

In most WM pathologies, the diffusion anisotropy is decreased. This is mainly due to degeneration processes of the neuronal fibers (e.g. demyelination). Here we report on a significant increase in fractional anisotropy caused by mechanical pressure to the neuronal fibers. We found that the diffusion parallel to the fibers is increased while the diffusion perpendicular to the fibers is decreased. The increase in the diffusion parallel to the fibers maybe the results of the tension that streches the fibers leading to faster diffusion parallel to the fibers. In addition the density of the fibers per unit area is larger leading to decrease in the diffusion perpendicular to the fibers. Despite the large changes in the FA and eigen values, the mechanical pressure does not influence the ADC values. That observation may be attributed to the fact the $D_{\perp}$ and $D_{//}$ change in opposite manner and hence when averaged this effect is cancelled.

Conclusions

Diffusion tensor imaging was shown to be helpful in characterizing the effect of pressure on white matter fibers. The measurement of the diffusion parallel and perpendicular to fibers (as given by the eigen values of DTI analysis) might help in differentiating between tensed and packed (dense) white matter fibers. These measurements may also be used for following on white matter outcome after surgical intervention.

References

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