Preliminary investigation of position dependency of radial diffusivity in the cervical spinal cord

T. Schneider[1], D. C. Alexander[2], and C. A. Wheeler-Kingshott[1]

[1]Department of Neuroinflammation, UCL Institute of Neurology, London, United Kingdom, [2]Computer Science, University College London, London, United Kingdom

Introduction

Diffusion Weighted (DW) and Diffusion Tensor (DT) Imaging are well known methods to provide information about the directionality of tissue structures such as nerve fibers in the spinal cord as shown, e.g., by Hsu et al.[1]. Indices calculated from the DT, such as fractional anisotropy (FA) and mean diffusivity (MD) are sensitive to spinal cord pathology[2] and therefore have a potential diagnostic and prognostic value. Mamata et al.[3] have shown that the second eigenvector of the DT can be used to visualize the collateral fibers, i.e. fibers perpendicular to the longitudinal fibers of the spinal cord. Recently, Fasano et al.[4] introduced a method that sensitizes the acquisition to the diffusion coefficient orthogonal to the main fiber direction, i.e to the radial diffusivity, D⊥, if the principal fibre direction is known a-priori. In this study we have investigated whether parameters derived from DT as well as D⊥ can be related the axial position of the acquired slice in the spinal cord.

Methods

Study description: DW scans were performed at two different levels of the cervical spinal cord of a healthy subject using a 1.5T GE MRI scanner. An axial-oblique T1 weighted (T1w) scan was acquired beforehand to evaluate the structure of the spinal cord at different levels and to position a single slice for the DW acquisition in correspondence of the disk between C2 and C3 where the nerve fibers are expected to leave the spinal cord canal through the foramen (figure1A); A second DW scan was performed with identical parameters, but with the slice positioned within the body of C2 where less sprouting fibres could be identified on the T1 axial-oblique scan (figure 1 B). The same positions on the same subject were rescanned after 1 week. Acquisition Parameters: The T1w scan was acquired using a standard T1-weighted spin-echo sequence (TE = 18ms ,TR = 600ms, No. Slices = 16 , FOV = 20cm , Matrix size = 256x192 , sl thickness = 4mm). For the diffusion imaging, we used a cardiac-gated single shot COZOOM EPI sequence[3] (TR = 5RRs, TE = 95.5ms, 8 distributed diffusion weighted directions interleaved with 4 non-diffusion weighted b0 acquisitions, maximum b factor = 1000smm^{-2}, voxel size = 1x1x5mm^3, repeated 22 times). Data Processing: The dataset was averaged over the 22 repetitions and was 3-D interpolated to a 128x128 image matrix. From the data, the Diffusion Tensor (DT) was estimated, and the eigenvectors ($\mathbf{V}_1$, $\mathbf{V}_2$, $\mathbf{V}_3$), Fractional Anisotropy (FA), and Radial Diffusivity (RD) were calculated. Furthermore, a subset of four co-planar diffusion directions, i.e., perpendicular to the main fibre direction, was used to reconstruct the radial diffusion coefficient (D⊥) as described by Fasano et al[4].

Results

Figure 1 shows the T1w images of both slice positions as well as maps of the second eigenvector $\mathbf{V}_2$, FA and D⊥. In the T1w images (Figure 1 A,B) one can appreciate sprouting fibres (A) while in (B) less fibres leaving the cord can be observed. (Figure 1 C,D) confirms the findings of Mamata et al.[3] who suggest that the second eigenvector $\mathbf{V}_2$ points in the direction of the collateral fibers. However, it can be noted that at position 1 the majority of **V**2 point in the dorsoventral direction while at position 2 areas of $\mathbf{V}_2$ pointing in the lateral direction can be found as well. Quantitative measurements at these two levels show that D⊥ is higher at position 1 with more axial sprouting, which is confirmed by the value of RD calculated from the DT eigenvalues. Table1 compares the average FA, RD and D⊥ over the area of the spinal cord at both positions, measured at two different days on the same subject. It can be seen that there is a difference between the measured values at the two different positions which is 5-10 times bigger than variation between re-scanned parameters at the same position. These findings suggest that D parameters are sensitive to the axial level of the vertebral body where the measurements are performed. The findings of higher D⊥and RD along with the lower of FA at P1 compared to P2 furthermore indicate that this difference is caused by the presence of many collateral fibres in P1.

Discussion and conclusions

This preliminary work focused the attention on a single slice acquisition. This was chosen because the authors wanted to make sure that the signal form the slice was completely recovered after each shot, given that when using the COZOOM sequence T1 relaxation can affect the signal intensity of multiple slices acquisition. Also, by positioning one single slice, it was possible to acquire a spinal cord image axially, i.e. orthogonally to the main spinal cord fibre direction. The next step will be to assess the reproducibility of our results and to apply the described methods to compare measurements made at different levels of the cervical spinal cord in one single acquisition. A profile of the spinal cord could then be generated, based on the measurement of collateral diffusion at different levels. Such a profile would provide important information for assessing spinal cord damage and tract regeneration.

Furthermore, for this acquisition, we used a standard DTI imaging protocol with a maximum b-factor of 1000smm^{-2}. For an optimal estimation of D⊥, Fasano et al[4] suggest a higher maximum b-factor of 2500smm^{-2} as well as 40 diffusion encoding directions. Further studies will investigate whether such protocol is more sensitive to the presence of collateral fibres than the standard DTI acquisition with respect to the vertebral position.

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Reference List: 1. O. Hsu et al., Am J Physiol, no. 274 (1998): 1627-1634; 2. O. Ciccarelli et al., Brain 130, no. Pt 8 (2007): 2220-2231; 3. H. Mamata et al., Neuroimage 31, no. 1 (2006): 24-30; 4. F. Fasano et al., Magn Reson Imaging in Press (2008)

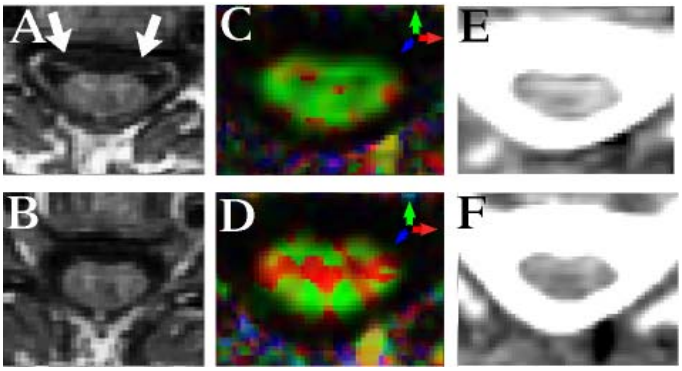

Figure 1: T1w, FA+$\mathbf{V}_2$ and D⊥ acquired at position P1 (upper row) and P2 (lower row). First column shows T1w images, white arrows in (A) mark fibres of the ventral root. The second column displays the FA maps colour coded with the direction of $\mathbf{V}_2$. The third column shows the D⊥ maps of P1 and P2.

	P1		P2	
	1st scan	2nd scan	1st scan	2nd scan
FA	0.494	0.432	0.614	0.61
RD	5.12E-10	4.90E-10	4.04E-10	3.97E-10
D⊥	5.18E-10	4.95E-10	4.01E-10	3.97E-10

Table 1: FA, RD and D⊥ averaged over the area of the spinal cord. The sections P1 and P2 correspond to the different levels of the investigated vertebra C3. The first column in each section shows the values of the first scan, the second column holds the data of the same scan repeated at a different time. The first and second row represent the mean FA and RD derived from the estimated diffusion tensor. The third row holds the mean D⊥.