Magnetic Resonance Diffusion Imaging of the Human Cervical Spinal Cord *in vivo*

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Introduction

MR diffusion imaging is an important technique for the investigation of tissue structure and orientation and has been used extensively to characterise normal brain tissue and pathology (1). Although diffusion imaging has been used to study rat (2) and human (3) spinal cord *in vitro*, to the best knowledge of the authors, no report has been made of diffusion imaging in the human spinal cord *in vivo*. Conventional imaging methods must provide high spatial resolution and utilise a motion suppression technique in order to achieve adequate visualisation of the cord *in vivo*. Diffusion imaging must also satisfy these criteria, the latter of which is generally more stringent due to the increased motion sensitivity of a diffusion-weighted sequence. Here we report on preliminary results obtained in the spinal cord using a navigated pulsed gradient spin echo (PGSE) sequence for diffusion imaging.

Method

The navigated PGSE sequence was implemented on a 1.5T Signa Echospeed MRI system (General Electric, Milwaukee) as described previously (4). A single element posterior cervical spine coil was used for both RF transmission and reception of the NMR signal. All images were acquired with a 5mm slice thickness, 24cm square FOV, 1 NEX, 256×256 matrix. 4 sagittal slices were acquired with diffusion sensitisation along the anterior-posterior (AP) direction (perpendicular to the white matter fibres) with TE=75/89ms, δ=25ms, Δ=31ms, G=22mT/m (b=720s/mm^2) following an acquisition with b=0. Phase encoding was in the AP direction to avoid wrap around artefacts. Cardiac gating was used and image acquisition was triggered from every second R-wave monitored using a pulse oximeter. Images were acquired either 13ms or 135ms after the R-wave. Imaging time was approximately 15 minutes depending on heart rate. The cervical spines of 4 healthy volunteers were scanned. Imaging was repeated on a separate occasion using the same imaging parameters but with diffusion sensitisation along the SI direction (parallel to the white matter fibres) with TE=61/75ms, δ=21ms, Δ=28ms, G=22mT/m (b=321s/mm^2). ADC maps were constructed from the navigated DWIs by calculating the ADC using the Stejskal-Tanner formula on a pixel by pixel basis. Spinal cord ADCs were estimated in regions of interest (ROI) on ADC maps derived from DWIs with minimal motion artefact as judged by visual inspection and positioned to avoid partial volume errors from CSF.

Results

Values of ADC$_{AP}$ and ADC$_{SI}$ obtained in ROIs are given in Table 1. ADC$_{AP}$ and ADC$_{SI}$ maps of a healthy volunteer are shown in Figure 1. High ADC$_{SI}$ values (> 8.0×10^{-3} mm^2/s) were noted in the CSF, presumably due to flow which is known to occur predominantly in the SI direction.

subject	ADC$_{AP}$	ADC$_{SI}$
1	0.56 ± 0.02	1.80 ± 0.04
2	0.57 ± 0.02	2.00 ± 0.07
3	0.68 ± 0.02	2.16 ± 0.04
4	0.67 ± 0.04	2.21 ± 0.04
mean (range)	0.62 (0.56 - 0.67)	2.04 (1.80 - 2.21)

Table 1 - ADC estimated with diffusion sensitisation in the AP (ADC$_{AP}$) and SI direction (ADC$_{SI}$) ($\times 10^{-3}$ mm^2/s ± standard error of the mean).
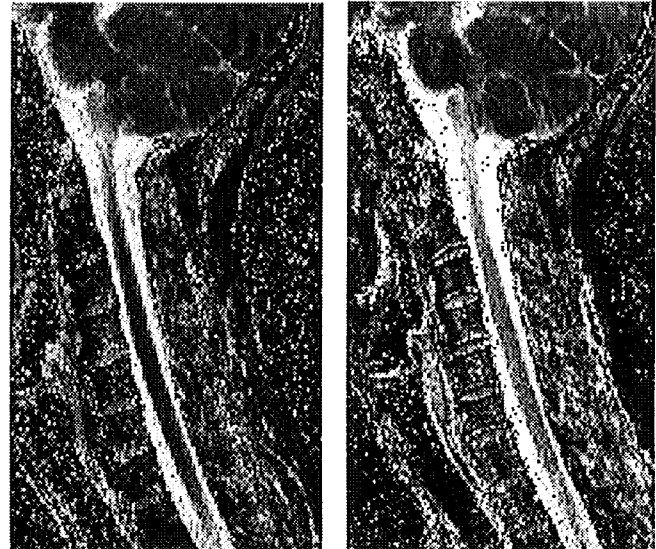

Figure 1 - ADC$_{AP}$ (left) and ADC$_{SI}$ (right) maps of the healthy human cervical spinal cord.

Discussion

The results indicate that water diffusion in the spinal cord is anisotropic, (mean ADC$_{SI}$ / mean ADC$_{AP}$ = 3.29) presumably reflecting the directionality of white matter fibres in the cord. This finding is in agreement with *in vitro* studies; ADC$_{SI}$ / ADC$_{AP}$ = 3.39 in excised human cord white matter (3).

The navigated PGSE sequence was used to provide ADC maps with an in-plane resolution of 0.9mm. However, imaging time is relatively long and an orientationally dependent ADC, based on only one direction of sensitisation was provided. The use of tetrahedral diffusion encoding may be appropriate in the cord which may be considered to be axially symmetric. This methodology can be used to provide diffusion parameters that are rotationally invariant. Faster sequences such as a diffusion-weighted FSE (6) may facilitate such an approach within a reasonable imaging time.

The two main obstacles to accurate assessment of spinal cord ADC *in vivo* is the presence of residual motion artefact and partial volume errors from CSF that surrounds the cord. Further research is required to improve the reliability and accuracy of ADC maps of the cord. The use of spatial presaturation bands, optimised trigger delays or CSF suppression may be used to achieve these requirements.

Conclusion

This preliminary study has shown that it is possible to obtain good quality ADC maps of the human cervical spinal cord *in vivo*. Subsequent improvements in the accuracy and reliability of the technique may lead to clinical studies of the structural characteristics of spinal cord pathology *in vivo*.

References

(1) D.Le Bihan *et al Am J Roentgen* **159**, 591 (1992).
(2) J.Chetley Ford *et al Magn Reson Med* **32**, 379 (1994).
(3) J.P.Mottershead *et al* (unpublished data).
(4) C.A.Clark *et al Proceedings 5th ISMRM* **3**, 1715 (1997).
(5) T.E.Conturo *et al Magn Reson Med* **35**, 399 (1996).
(6) S.Brockstedt *et al Proceedings 3rd SMR* **2**, 905 (1995).