Implications of Physiological Motion on DTI Values in the Cervical Spinal Cord

C. Nahanni[1], and P. W. Stroman[1,2]

[1]Centre for Neuroscience Studies, Queen's University, Kingston, Ontario, Canada, [2]Departments of Diagnostic Radiology and Physics, Queen's University, Kingston, Ontario, Canada

Introduction

Diffusion Tensor Imaging (DTI) has emerged as a powerful technique for assessing the architecture and integrity of white matter (WM) tracts in the central nervous system of living subjects. Diffusion Weighted Imaging (DWI) is already a common clinical diagnostic tool and DTI will likely have a similar place in the clinical setting in the near future. The potential of the technique as both a clinical and research tool has fed the feverish pace of its development.

In the present study, the effects of physiological bulk motion on DTI values in the cervical spinal cord were examined through an analysis of Apparent Diffusion Coefficient (ADC) values and tensor values. The DTI signal is inherently sensitive to artifacts and has a low SNR. The published work to date demonstrates that adequate image quality and diffusion sensitivity can be obtained, but the images are affected by the motion of the cerebrospinal fluid (CSF) and spinal cord to an extent that is, as yet, undetermined [1,2,4,5]. It has been established that periodic cord motion, due to the cardiac cycle, is maximal at the C6/C7 cervical spinal cord segments. The cord displaces on average 0.6 mm in the A/P and R/C directions shortly after systole [1]. In the lumbar segments of the spinal cord, however, motion is negligible [2]. Therefore, accurate quantitative DTI can be obtained from this region and used as a basis of comparison to quantify the effects of physiological motion on the cervical cord. Traditionally, cardiac gating is used to compensate for the effects of physiological motion. Using this method in the current study did not reduce or improve the corruptive effects. Two components of the error introduced by bulk motion have been hypothesized: 1) partial volume effects at the WM/GM and WM/CSF boundaries and 2) random dephasing effects caused by moving the diffusing protons back and forth through the magnetic field gradient.

Methods

The cervical and lumbar spinal cord regions of 4 healthy volunteers were imaged in a 3 Tesla Siemens Magnetom Trio using a phased-array spine receiver coil with subjects lying supine. Data were acquired using diffusion-weighted spin-echo EPI with a diffusion-weighting (b-value) of 700 s/mm^2 and SENSE parallel imaging with an acceleration factor of 2. Twenty averages were acquired in 12 diffusion directions and each image was constructed using the signal from a 3 mm thick axial slices with 1.6x1.6 mm^2 in plane resolution. The peripheral pulse was recorded throughout. Four acquisitions in total were performed on each subject. Two for each section of the cord (cervical and lumbar), one gated to the peripheral pulse, the second set by the even timing of an external trigger. The resulting images were analyzed using proprietary Siemens software as well as custom made software written in MatLab. The diffusion weighted (DW) images were binned according to the the phase of the cardiac cycle at which they were acquired and these sub-groups of DW images were used to reconstruct tensor fields at different phases of the cardiac cycle. Cardiac bins were defined as 10% of the distance between two cardiac peaks. Therefore, there were 10 cardiac bins in total. Analysis of tensor fields (average and variability) was done using the methods outlined in [3]. ADC values in the cervical and lumbar cord were collected from 4 subjects. The values were acquired from consistent positions in the spinal cord relative to an anatomical marker (C6 in the cervical cord, T12 in the lumbar cord) and were averaged together and plotted in Figure 1.

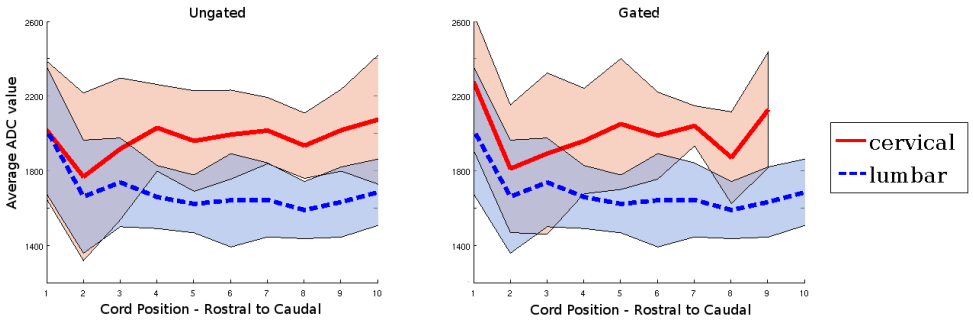

Figure 1. Average ADC values in the cervical and lumbar spinal cord. The left plot shows the results for ungated data. The right plot shows results for cardiac binned data. There is no appreciable difference. Cardiac gating does not improve the results. In the absence of motion the two line plots (for cervical and lumbar) would have been approximately the same.

Results and Conclusions

ADC values from the cervical cord were found to be consistently greater than those in the lumbar cord (Figure 1). Had there been no effect due to motion these series would have had similar means. Furthermore, cardiac gating the image acquisition to the peripheral pulse did not reduce the disparity between cervical and lumbar ADC values. To compensate for the motion, the DTI data was binned according to the phase of the cardiac cycle at which it was acquired. In the lumbar cord, where motion is negligible, the variability of the tensors in the WM was found to be less than those in the cervical cord. These results indicate that motion has a measurable impact on DTI values in the cervical spinal cord. Because this corruption has negative implications for the reliability of DTI and tractography in this region of the cord, corrective measures are needed to compensate for this effect.

References

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