# Crossing fibers in lateral white matter of the cervical spinal cord detected with diffusion MRI in monkey postmortem

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## Introduction

The corticospinal control of the spinal cord is the key for understanding generation of voluntary motion and might be essential for functional recovery of spinal cord injuries in humans. The course of the corticospinal tract in the dorsolateral parts of the white matter (WM) column is here of interest [8]. This tract contains fibers crossing the main superior-inferior direction as they branch off towards the gray matter (GM). The aim of this study is to evaluate the possibility of using Diffusion weighted imaging (DWI) to investigate those fibers. As a good model of the human, the green monkey was used. The animal was perfusion fixed, the spinal cord was excised and scanned postmortem. Postmortem acquisitions benefits from high-field scanners, long scanning times and thereby low noise and high spatial resolution and no physiological noise. Three different methods were used to reconstruct the fiber orientation: the diffusion tensor (DT) and two multifiber reconstruction techniques Q-ball imaging (QBI) and Persistent Angular Structure (PAS). One of the methods, PAS, resolved crossing fiber structures in the corticospinal tract.

## Methods

*Image acquisition: A* cervical spinal cord sample was excised from a green monkey (age: 3.5 years), which was perfusion fixed and prepared as in [1]. All procedures followed guidelines for the care and use of experimental animals according to the local ethic committee on the island of StKitts and postmortem scanning was approved by the Danish Animal Experiments Inspectorate. DWI was obtained on an experimental 4.7 T Varian Inova scanner using a small one channel surface coil. The spinal cord was rinsed in PBS-buffer to remove residual fixative and thereafter drained to reduce signal from surrounding liquid. To reduce mechanic and thermal transient effects, the DWI dataset used was obtained 9 hours after the scanning session was started. A diffusion weighted spin-echo sequence was used with TE: 68 ms; TR: 2500 ms; axial matrix: 65x64x10; voxel size: 0.23x0.23x0.8 $mm^3$. Diffusion weighting b-value of 4090 s/$mm^2$ was used as found optimal for detecting crossing fibers in postmortem tissue [2]. Each DWI dataset consisted of 3 non-DW and 61 non-colinear DW image volumes. Three repetitions resulted in a SNR of 33 in lateral white matter. *Data analysis:* One axial slice centered over the cervical enlargement was selected for the analysis. Three different fiber reconstruction methods where used to assess the underlying fiber orientations: i) DT [4]; ii) QBI [5] represented by $4^{th}$ order spherical harmonics and iii) PAS with radial basis functions [6]. The fiber orientations where extracted from the peaks of the fiber distribution estimated with QBI and PAS with a maximum of three fiber directions. All methods used in this study are available in the Camino diffusion toolkit [7].

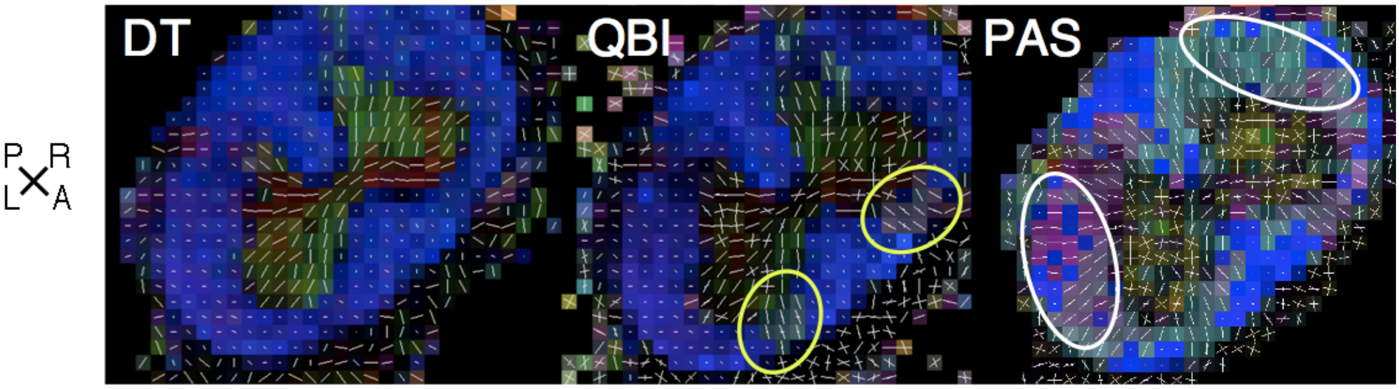


**Figure 1: Fiber orientations estimated using DT, QBI and PAS of an axial slice at the cervical enlargement overlaid on FA (DT) and GFA (QBI and PAS), note the diagonal orientation of the spinal cord. Ventral roots and terminating fibers from the corticospinal tract marked with green and white ellipses respectively.**

## Results

The first eigenvector of the DT analysis clearly show the orientation of descending and ascending tracts in WM (colored blue in fig. 1). An in plane symmetric structure of fiber orientations in GM with the dorsal roots is also visible. In addition to that, the QBI reconstructed the fiber crossings of the motorneurons in the ventral roots (green ellipses in fig 1). This is in agreement with earlier findings [3, 9]. In addition to the orientations found by DT and QBI, PAS was able to detect consistent structures of crossing fibers in the corticospinal tract resulting in a changed color coded GFA (white ellipses in fig 1). The additional fiber orientation in WM is fibers radially entering GM. A visual inspection of fiber distributions estimated by PAS were in general sharper than those of QBI (results not shown). PAS also found more voxels with two or three fiber orientations, though some were found in GM with less consistency.

## Discussion

Fiber reconstruction has been carried out on a green monkey spinal cord postmortem using an experimental high-field scanner with a DWI protocol optimized for postmortem tissue. Crossing fiber structures of the corticospinal tract with good correlations to histological studies were resolved using the PAS reconstruction method only. The position of those fibers indicate the termination points in gray matter and is crucial for understanding motorcortical interaction in generation of motion in normal subjects and may help to better understand mechanisms involved in rehabilitation of spinal cord injuries.

**References:** [1] Dyrby, T. B., et al, Neuroimage, 37, 1267-1277, 2007. [2] Dyrby, T. B. et al, 16th ISMRM, Toronto, Canada, 2008. [3] Cohen-Adad, J., et al, Neuroimage, 42(2), 739-749, 2008. [4] Basser PJ, et al, Journal of Magnetic Resonance, 103, 247-54, 1994. [5] Tuch DS, Q-ball imaging MRM, 52(6), 1358-1372, 2004. [6] Jansons K.M., et al, Inverse Problems, 19, 1031-1046, 2003. [7] Cook, P. A., et al, 14th ISMRM, Seattle, USA, 2006. [8] Porter, R., Lemon, R., Corticospinal Function and Voluntary Movement, Oxford University Press, 1993. [9] Özarslan, E., Neuroimage Jul 1;31(3):1086-103, 2006.