# Probabilistic diffusion tensor tractography of human spinal cord and spinal nerves at 3T.

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## Introduction

In planning of surgical removal of the spinal cord lesion, preserving sensory and motor functions of a subject is of the utmost importance. Recent studies show promising value of diffusion tensor imaging (DTI) in image guided resection of brain tumours in proximity of white matter tracks, by improving outcomes and reducing postoperative complications [1, 2]. Diffusion tensor imaging in spinal cord remains a challenge at clinically used MR field strengths. Images usually suffer from off-resonance distortions, inadequate in- and through-plane resolution, subject's motion and poor SNR. Hence, the fibre tracking is commonly limited to reconstruction of the spinal cord tracts. This information may however, be insufficient in an attempt to avoid critical fibre bundles. In the present study we demonstrate a probabilistic tractography [3] of the human spinal cord extending the tracts towards the spine nerve roots.

## Methods

Spinal cord studies were carried out on a 3T Philips Achieva MR system in 4 healthy control subjects and 2 patients with intramedullary tumor of the cervical spinal cord (ganglioglioma, ependymoma). Diffusion-weighted (DW) images (b = 700 s/mm$^2$, 15 DW directions) were acquired in the axial plane using a 16-channel neuro-vascular coil and a single-shot spin-echo EPI sequence (TR/TE = 11700/79 ms, SENSE factor = 2, NSA = 2, phase-encoding direction in AP). Seventy-five slices with acquisition resolution 1.3 x 1.3 x 2 mm$^3$ covered the entire cervical spine, starting at the level of the medulla oblongata. To minimize the impact of a subject's motion, DW images were coregistered with respect to the b = 0 s/mm$^2$ image using non-rigid registration, driven by normalized mutual information cost function [4-6]. Probabilistic diffusion tensor fiber tracking was performed using FSL 3.3 [3, 5]. Here, for the estimation of the fiber connectivity distribution along the spinal cord, regions of interest (ROI) covering the whole cross-section of the spinal cord were placed at the level of C1 and C6 (axial orientation). The spinal nerves (left/right) were tracked by placing a lateral ROI (left/right) along the spinal channel (sagittal orientation) and an ROI either at the level of C1 or C6 (axial orientation). Placing the ROIs at either C1 or C6 ensured more reliable reconstruction of the spinal nerves.

## Results

In the control subjects, probabilistic tractography revealed 81% (71% to 85%) of the cervical spinal nerves bilaterally (Fig. 1A). The majority of the detected spinal nerves appeared to emerge from the posterior root, while we were able to distinguish anterior root only in 18% of the identified nerves (Fig. 1C). The location of the origins of all the tracked roots within the spinal cord column was in very good correlation with known anatomy (Fig. 1B, C), i. e. in the vicinity of the lateral horns and was consistent along the spinal cord. In the tumour cases, the tractography was challenging. Nevertheless, preserved fibres passing through the lesion or pushed aside were successfully reconstructed (Fig. 2A) in the ganglioglioma tumour case. In the ependymoma patient, no fibres passing through the superior and inferior ROIs were found, which was in contradiction to the physiological status of the patient, who did not present any motor deficit. Interestingly, combination of the lateral and superior or inferior ROI resulted in reconstruction of the nerves and fibres along the cervical spine (Fig. 2B), which were apparently displaced by the lesion.

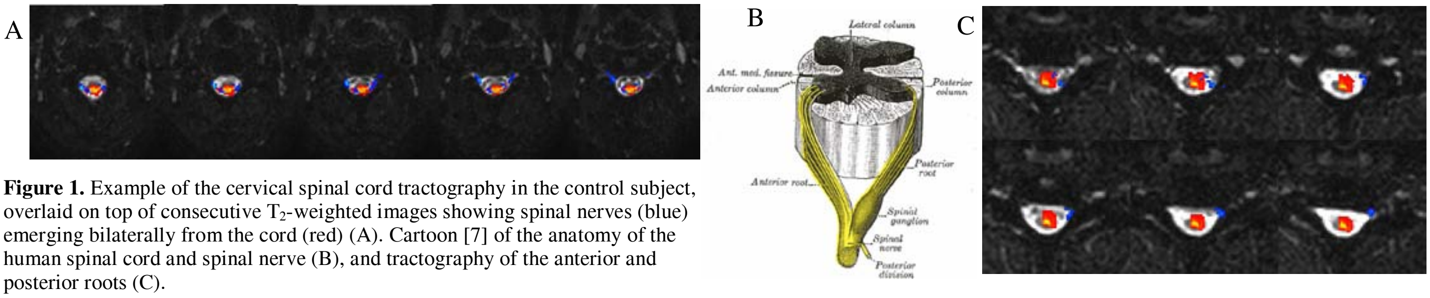

**Figure 1.** Example of the cervical spinal cord tractography in the control subject, overlaid on top of consecutive $T_2$-weighted images showing spinal nerves (blue) emerging bilaterally from the cord (red) (A). Cartoon [7] of the anatomy of the human spinal cord and spinal nerve (B), and tractography of the anterior and posterior roots (C).

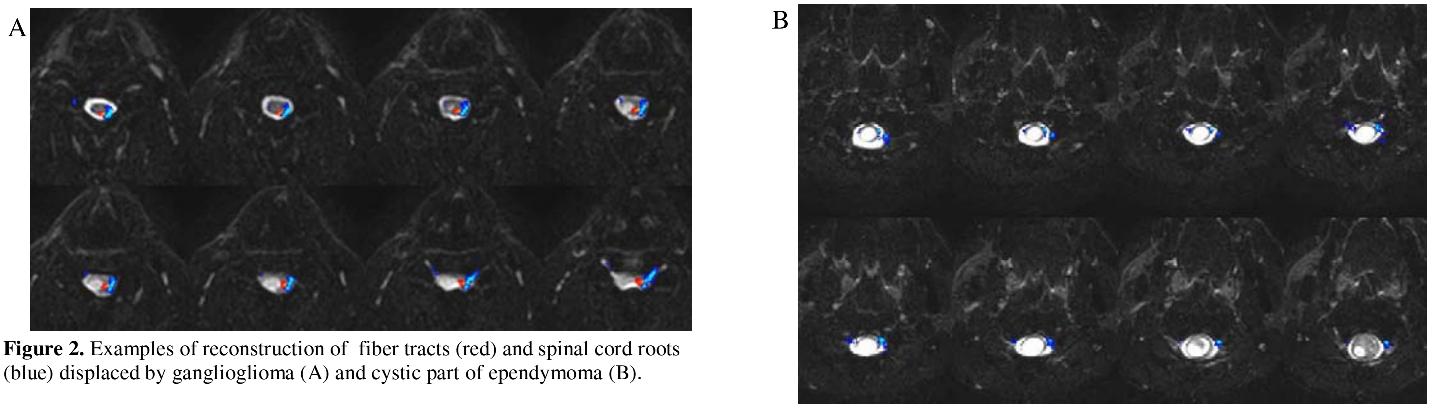

**Figure 2.** Examples of reconstruction of fiber tracts (red) and spinal cord roots (blue) displaced by ganglioglioma (A) and cystic part of ependymoma (B).

## Discussion

The posterior roots of the cervical nerves are approximately three times as large as the anterior roots, with exception of the first cervical root. This anatomic feature could partially explain why the nerves from the posterior roots are more frequently depicted in our analysis. Also, we expect that by careful positioning of the lateral ROIs, one could potentially detect the nerves missed in the present study.

## Conclusions

Using a 3T, high spatial and angular resolution, together with parallel imaging, we acquired DTI data with a 16 channel coil and after post-processed with non-rigid registration, spinal cord tractography including most of the posterior roots and some anterior nerve roots were obtained in both healthy volunteers and tumor patients. The inclusion of cervical nerve roots in high-resolution spine tractograms may represent an important step towards more effective surgical planning of the cord lesions.

## Acknowledgements

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## References

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