Whole post-mortem spinal cord imaging with diffusion-weighted steady state free precession at 7T

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Introduction: Post-mortem imaging has begun to attract interest as a method for anatomical investigation that can achieve higher resolution than in-vivo imaging and be directly compared against histological gold standards. As with brain imaging studies, high quality data has been acquired of post mortem spinal cord; this is particularly interesting given the difficulty obtaining reasonable in-vivo data due to the diminutive structures and high degree of physiological noise. However these studies sampled thin sections[1] or non-human sections[2]. In this work we demonstrate the acquisition of whole, post-mortem human spinal cord MR data. High-resolution diffusion data were acquired to compare with fibre architecture identified using polarized light images (PLI), respectively. These measurements lay groundwork for a non-destructive view of whole cord anatomy. This work describes the technical aspects of whole cord imaging as well as demonstrates results of the aforementioned acquisitions.

Methods: Whole MS spinal cord (n=2) and MND cervical cord section (n=1) were imaged at 7T using a 24 and 16 channel receive coil, respectively (QED, 15x17cm and Rapid, 9x9cm). Whole specimens were placed in a home built holder and submerged in fluorinert for susceptibility matching (Fig. 1). Proton-density-weighted structural data were acquired using a 2D spin echo sequence (TR/TE=3500ms/15ms, bandwidth=200Hz/px, 0.12x0.12.1mm). DW-SSFP was acquired at 0.5mm isotropic resolution with diffusion weighting along 240 (MND) and 200 (MS) directions. DW-SSFP scans targeted q=300 cm^{-1} to achieve the effective contrast of b_{eff}=5150 s/mm^2 (DW-SSFP has a well defined q-value, but not b-value, and b_{eff} is quoted only to give a feeling for contrast in our data). Whole spinal cord data were acquired over two acquisitions where the superior half of the cord was imaged with the complete protocol, followed by the inferior half. Spinal cord data was straightened using the Spinal Cord Toolbox[3]. Following an established pre-processing pipeline[4], first and second fibre orientation populations were estimated using a modified version of BEDPOST that includes the DW-SSFP signal model. Halves were stitched together by manual and automated affine registration (FLIRT). Polarized light images were acquired with a Leica DM4000 microscope, upgraded with a linear polarizer, a quarter wave plate and a rotatable analyzer. PLIs were acquired at 18 different orientation of the rotatable analyzer (10˚ increments from 0-170˚). PLI-based fibre orientation maps were processed using custom MATLAB code to fit the 3D PLI signal model[5].

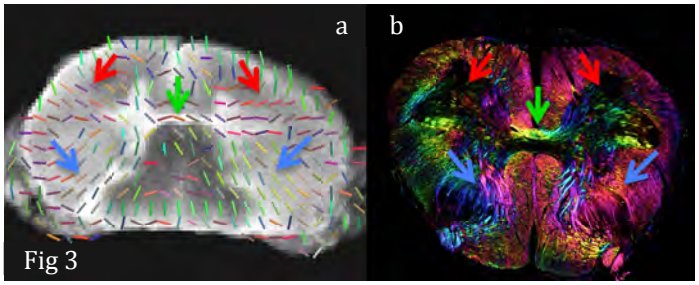

Fig 3

Results: Figure 2 demonstrates tractography of the lateral corticospinal tract along a whole cord length. Continuity of the tract as well as preservation of laterality is clearly seen, demonstrating the fidelity of the DTI data. Figure 3 shows collateral fibres overlain on MRI structural data (a) and PLI reference orientations (b). Collateral fibres were produced from a 1cm section of cord where all primary or secondary fibres with a significant in-plane component were identified and projected axially to a single slice. Red arrows indicate fibre projections via the dorsal horn to the peripheral nervous system; blue arrows, for the ventral horn. Green arrow indicates fibres following the commissure.


Fig 1

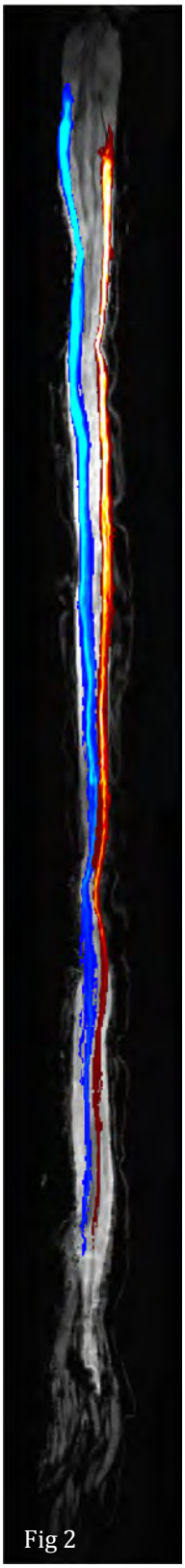
Fig 2

Discussion: These results demonstrate feasibility of acquiring high fidelity post mortem spinal cord MRI data. Correlation with PLI data demonstrates the potential for validating collateral fibre orientations detected using DW-SSFP. This method potentially allows for detection of spinal cord disease such as identification of MS lesions or changes in fibre integrity in MND. Detection of such biomarkers could prove to be highly translatable to clinical application and potentially aid in improved diagnosis of suspected neurodegenerative disorders.

References: [1]Nijeholt *et al.*, Brain 2001; [2]Lundell *et al.*, NeuroImage, 2011; [3]Chohen-Adad, *et al.*, OHBM, 2014; [5]Foxley *et al.*, NeuroImage 2014; [5]Axer *et al.*, Neuroinformatics, 2011