Fully Automated Straightening of the Spinal Cord using Fiber Tractography

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Introduction

Several traumatic or neurodegenerative diseases can affect the spinal cord and MRI is becoming an important tool for determining its integrity at several levels. Conventional radiological examinations aim at finding abnormalities through a visual assessment. However, the curvature of the spinal cord in the antero-posterior direction makes it difficult to obtain a full coronal or sagittal picture of the spinal cord and this may hamper the a proper evaluation. The curvatures of the spinal cord are subject-dependent and therefore group studies are hard to achieve at the spinal level. This highlights the need for a method to straighten the spinal cord so that individual images can be compared and eventually pooled. To achieve such straightening, recent studies [1] and manufacturers propose methods based on manual delineations of the spinal cord, followed by a 3D reconstruction of the volume by interpolating each slice perpendicular to the curve. Although very straightforward, these procedures are time consuming and user-dependent. Moreover, only a planar delineation of the cord is achieved, providing straightening of the cord in only two dimensions. In this paper we propose a fully automatic method to straighten the spinal cord, based on diffusion tensor imaging (DTI) tractography. A prototype white matter fiber is robustly selected from the spinal cord and the image is re-sampled perpendicularly to it.

Materials and methods

Data acquisition. MRI acquisitions were conducted in one *in vivo* cat [3] and two healthy humans. Images of the cat were acquired in the thoraco-lumbar region (T6-L7). The anatomical scan consisted of a T2-weighted turbo spin echo (TSE) sequence (turbo factor of 13), TR/TE=7490/78ms at 0.55x0.55x1.1mm^3 spatial resolution. DW data were acquired with a twice refocusing pulse single-shot spin echo planar imaging (EPI) sequence, iPAT=3 (to minimize susceptibility artifacts), sagittal orientation, 2mm slice thickness, 128x128 matrix, 1.5x1.5mm^2 in-plane resolution, TR/TE = 9500/109ms, b-value = 1000s/mm^2, 64 directions. We used respiratory gating to limit motion and susceptibility effects close to the lungs. In humans, images were acquired in the cervico-thoracic region (C1-T4). The anatomical scan was a T2-weighted SPACE sequence with TR/TE=1500/120ms at 0.9x0.9x0.9mm^3 spatial resolution. The DW sequence was similar to that one used in the cat, with TR/TE=3000/85ms, 1.8x1.8x2mm^3 spatial resolution, b-value=1000s/mm^2 and 60 directions, acquisition time <4 minutes. To demonstrate the robustness of the method, DW data were subsampled at 12 directions and processed the same way.

Data processing. Following acquisition of DW MRI data, a streamline tractography algorithm using a tri-linear Log-Euclidean interpolation method was performed. This fully automatic process was performed using MedInria and considering every voxel of the reference volume as a seed-point. As a result, most fibres running along the spinal cord were reconstructed and an efficient Gaussian process framework [2] is then used to automatically recover in a robust way the most representative or prototype fibre from the set of white matter fibres traversing the spinal cord. This robust procedure is equivalent to select the median fiber of the considered set of spinal cord fibers, which is finally used to interpolate and straighten the spinal cord image and fibres. Our method is fairly robust due to the large presence of longitudinal tracts in the spinal cord, allows to reliably reconstruct straightened animal and human spinal cord and clearly opens new opportunities and perspectives for SC-MRI applications.

Results

Fig. 1 On the top shows a sagittal slice of the T2 image of the cat with the fibres obtained by tractography in green and the prototype fibre retrieved in red. The bottom row shows the result of the straightening procedure. Fig 2 shows the result for two human subjects: on the left, sagittal slices of T2 images and, on the righ, the respective results after straightening. In the case of the subject at the top, three axial slices selected from different vertebral levels are shown in the middle column to demonstrate the three-dimensional alignment.

Discussion

We present a fully automatic method to straighten the spinal cord, allowing better visualization of the structure and enabling group analysis. The method uses DTI tractography to delineate the spinal cord and an advanced algorithm to robustly find the central line along the spinal cord. The method has been tested in humans and cats at 3T, but can be applied to other mammals. *Robustness* We demonstrated the feasibility of straightening the cord with 60 directions DW acquisitions acquired in 4 minutes. To study the robustness of the algorithm with lower sampled DW data, we sub-sampled the human DW dataset into 12 directions and applied the straightening method. Results showed a very satisfactory straightening of the cord for both subjects (data not shown). This DW acquisition time could be less than a minute, therefore could easily be plugged into an imaging protocol.

References: [1] Stroman et al J. Mag Res Imaging, 2005. [2] Wassermann et al MICCAI Workshops 2009. [3] Cohen-Adad et al. Neuroimage 2008 [4] Fillard et al Similar Tensor Workshop 2006

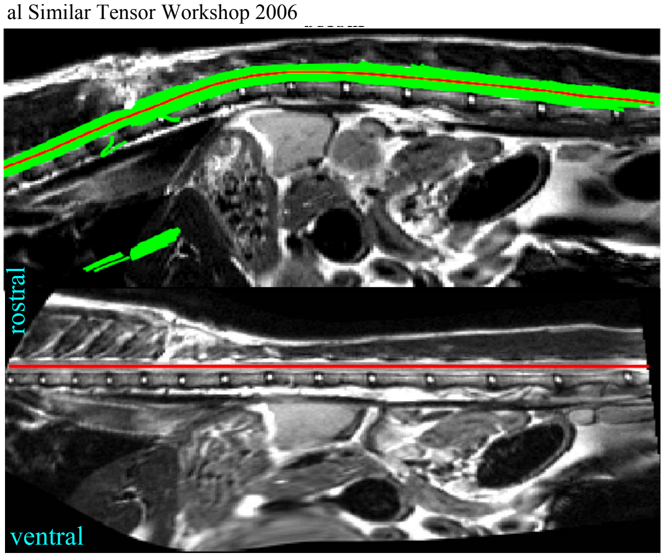

Fig 1. Top, sagittal slice of an anatomical image of a cat with the tractography in green and the prototype fiber in red. Bottom, straightened sagittal image.

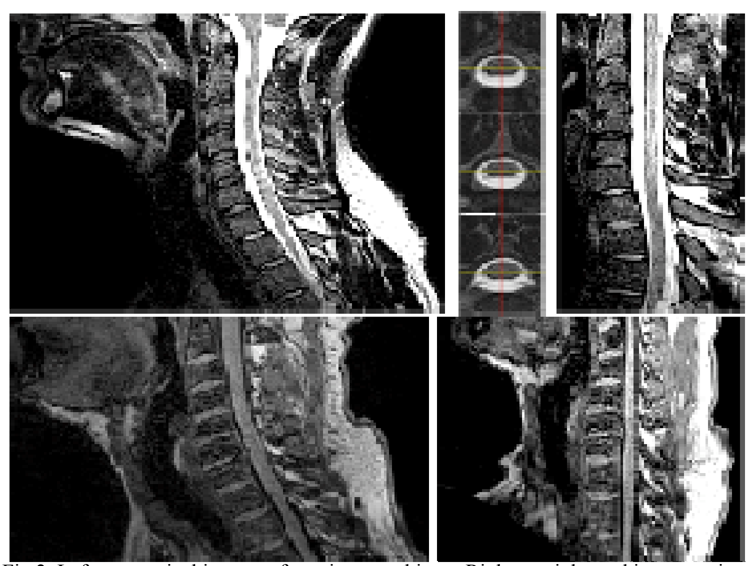

Fig 2. Left, anatomical images of two image subjects. Right, straightened images using our method. Top center, three axial slices shown to exhibit the three-dimensional alignement.