

Microstructure-driven tractography in the human brain

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Introduction:

Diffusion-weighted (DW) magnetic resonance imaging (MRI) tractography has become the tool of choice to probe the human brain's white matter (WM) in vivo. However, the relationship between the resulting streamlines and underlying WM microstructure characteristics, such as axon diameter, remains poorly understood. In this work, we reconstruct human brain fascicles using a new approach to trace WM fascicles while simultaneously characterizing the apparent distribution of axon diameters within the fascicle. This provides the mean to estimate the microstructure characteristics of fascicles while improving their reconstruction in complex tissue configurations.

Methods:

We used the deterministic tractography algorithm AxTract [Girard et al., 2015] to simultaneously trace axonal fascicles and estimate their axon diameter characteristics. The main hypothesis driving AxTract is that the mean diameter of the axons composing a fascicle varies slowly along its pathway [Aboitiz et al., 1992; Debanne et al., 2011]. AxTract locally selects the peak of the fiber Orientation Distribution Function (ODF) that better follows microstructural information estimated in previous propagation directions. The microstructural information is estimated using the ActiveAx model [Alexander et al., 2010] generalized to multiple fiber populations per voxel [Auria et al., 2015], implemented in the efficient Accelerated Microstructure Imaging via Convex Optimization [Daducci et al., 2015] (AMICO) framework. AxTract estimates, in each fiber ODF peak directions, the mean diameter associated to signal fitted cylinder response functions: the axon diameter index [Alexander et al., 2010; Dyrby et al., 2012; Panagiotaki et al., 2012; Daducci et al., 2015; Auria et al., 2015]. The axon diameter index is then used in the selection of the next propagation direction.

We report results on subject mgh_1001 of the Human Connectome Project MGH adult diffusion dataset [Setsompop et al., 2013]. The diffusion acquisition scheme consists of 552 volumes with b-values up to $10,000\text{s/mm}^2$, ($\delta=12.9\text{ms}$, $\Delta=21.8\text{ms}$). The diffusion data was acquired at 1.5mm isotropic voxel size using a Spin-echo EPI sequence (TR/TE=8800/57 ms). We used the provided pre-processed DWIs corrected for motion and EDDY currents. Fiber ODFs were obtained from spherical deconvolution on a single b-value shell of 3000s/mm^2 using Dipy. A T1-weighted 1mm isotropic resolution 3D MPRAGE (TR/TE/TI 2530/1.15/1100 ms) image was also acquired. The T1-weighted image was parcellated using FreeSurfer. Five streamlines were initiated per voxel of the WM volume. Fascicles were obtained using the TractQuerier software [Wassermann et al., 2013]. We report the axon diameter index estimated at each segment of the tracking process and the median along each streamline.

Results:

Figure 1 shows the axon diameter index estimation along three WM fascicles: the corticospinal tract (CST), the inferior fronto-occipital fasciculus (IFOF) and the uncinate fasciculus (UF). Figure 2 shows the same information for the superior part of the corpus callosum (CC). The CC is split in 5 sub-fascicles using the FreeSurfer parcellation. Finally, a midsagittal cut of the same CC is shown in Figure 3. The highest axon diameter index (green) can be observed in the central part of the CC using segment-wise estimation.

Conclusions:

AxTract enables the characterization of the axon diameter index along WM fascicles in-vivo. Axon diameter index estimated with AMICO are similar in fascicles of both hemispheres (see Figure 1) and seems to be spatially coherent both on segments and on the median along streamlines (see Figures 1 and 2). The axon diameter index observed in the CC (see Figure 3) follows the trend observed in histology [Aboitiz et al., 1992], with lower values in the splenium and genu, and higher value in the body of the CC. However, this is visible only in the midsagittal slice of the CC. Further investigation is needed to understand this effect.

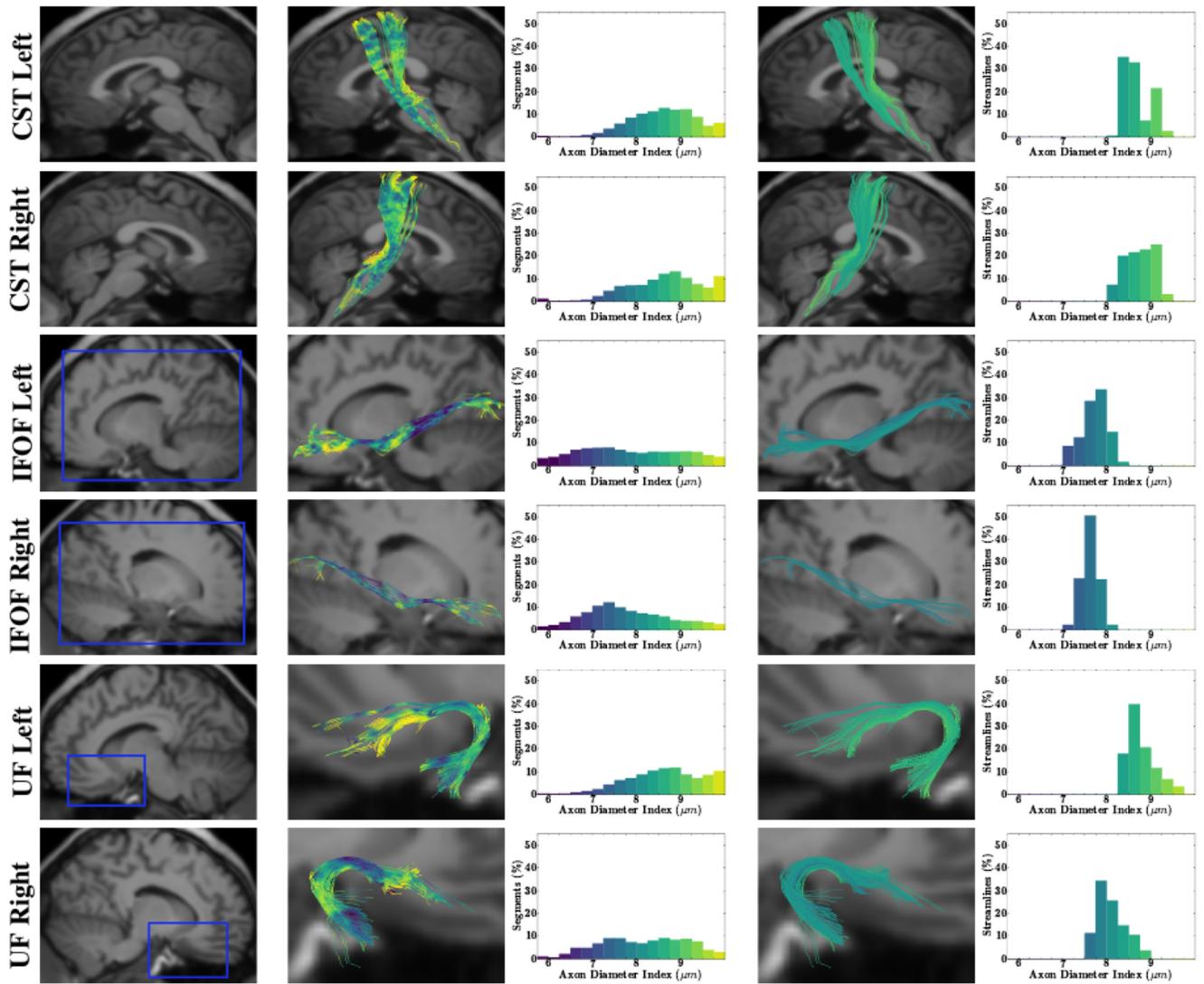


Figure 1. Axon diameter index along fascicles. Column 2 shows fascicles colored by the axon diameter index estimated per segment, with the histogram in column 3. Columns 4 and 5 show respectively fascicles with streamlines colored by their median axon diameter index and the histogram of median axon diameter index along each streamline.

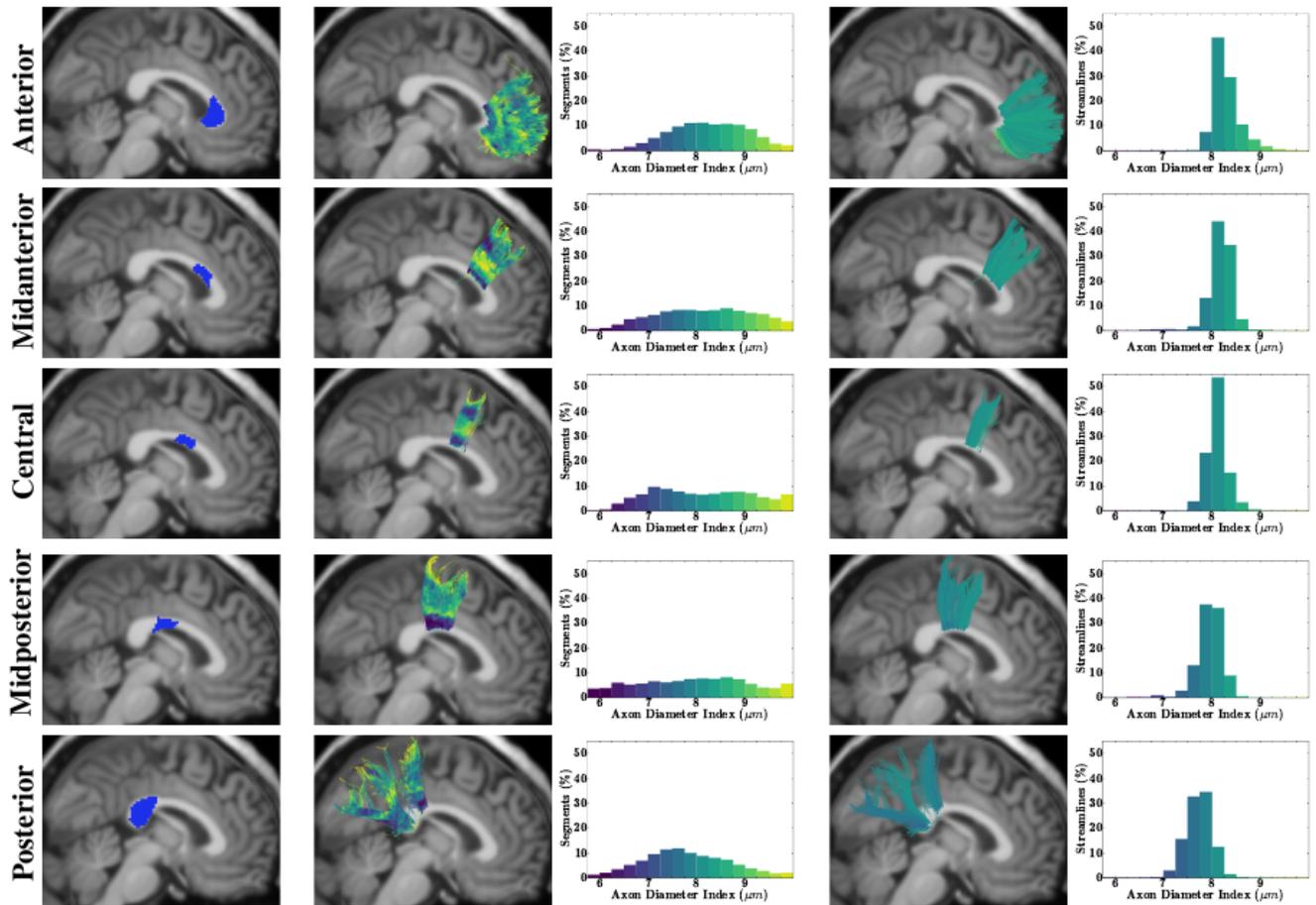


Figure 2. Axon diameter index along the corpus callosum sub-fascicles. Column 1 shows the regions used to split the fascicle. Column 2 shows sub-fascicles colored by the axon diameter index estimated per segment, with the histogram in column 3. Columns 4 and 5 show respectively sub-fascicles with streamlines colored by their median axon diameter index and the histogram of median axon diameter index along each streamline.

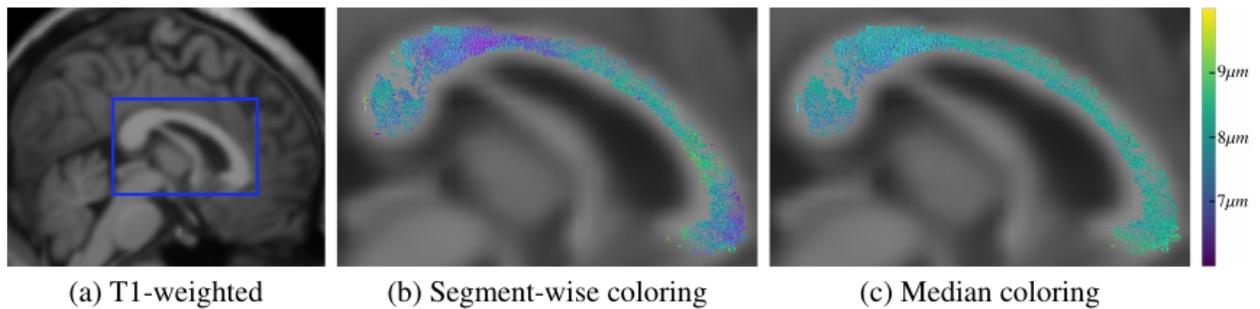


Figure 3. Sagittal cut of the streamlines going through the midsagittal slice of the corpus callosum. Streamlines colored using (b) the axon diameter index estimated per segment and (c) the median axon diameter index along each streamline

Imaging Methods:

Diffusion MRI²

Modeling and Analysis Methods:

Keywords:

MRI
Tractography
White Matter
WHITE MATTER IMAGING - DTI, HARDI, DSI, ETC
Other - Microstructure

¹²Indicates the priority used for review

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For human MRI, what field strength scanner do you use?

3.0T

Which processing packages did you use for your study?

FSL
Free Surfer
Other, Please list - Dipy, TractQuerier

Provide references in author date format

- Aboitiz, F., (1992), 'Fiber composition of the human corpus callosum', *Brain Research*, 598(1-2), pp. 143–153.
- Alexander, D. C., (2010), 'Orientationally invariant indices of axon diameter and density from diffusion MRI', *NeuroImage*, 52(4), pp. 1374–1389.
- Auría, A. R., (2015), 'Accelerated Microstructure Imaging via Convex Optimisation for regions with multiple fibres (AMICOx)', In *IEEE International Conference on Image Processing*, Québec, Canada.
- Daducci, A., (2015), 'Accelerated Microstructure Imaging via Convex Optimization (AMICO) from diffusion MRI data', *NeuroImage*, 105, pp. 32–44.
- Debanne, D., (2011), 'Axon physiology', *Physiological Reviews*, 91(2), pp. 555–602.
- Dyrby, T. B., (2012), 'Contrast and stability of the axon diameter index from microstructure imaging with diffusion MRI', *Magnetic Resonance in Medicine*, 72(2013), pp. 711–721.
- Girard, G., (2015), 'AxTract: Microstructure-Driven Tractography Based on the Ensemble Average Propagator', In *Information Processing in Medical Imaging*. Isle of Sky, Scotland, pp. 675–686.
- Panagiotaki, E., (2012), 'Compartment models of the diffusion MR signal in brain white matter: A taxonomy and comparison', *NeuroImage*, 59(3), pp. 2241–2254.
- Setsompop, K., (2013), 'Pushing the limits of in vivo diffusion MRI for the Human Connectome Project', *NeuroImage*, pp. 220–233.
- Wassermann, D., (2013), 'On describing human white matter anatomy: the white matter query language', In *Medical Image Computing and Computer-Assisted Intervention*, Nagoya Japan, 16(Pt 1), pp. 647–654.

