Cortico-cortical connectivity revealed by DTI-based tractography

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Introduction

Diffusion tensor imaging has been shown to be an effective way to delineate trajectories of the white matter tracts. Anatomy of large white matter tracts in deep white matter has been well documented in histology in the past and many of these tracts can be faithfully reconstructed by DTI-based fiber tracking [1,2,3]. On the other hand, little is known about the anatomy of subcortical white matter. The purpose of this study is to use tractography to identify reproducible short-range cortico-cortical fibers. To perform this study, it is necessary to parcellate the cortex in each subject, use them as regions of interest (ROIs) for fiber tracking, and create statistical map to evaluate the reproducibility of the findings. The cortical parcellation is conducted by transforming the gyral labeling of standard ICBM (International Consortium for Brain Mapping) atlas to the subject. The tractography is performed with brute force and multi-ROI line tracing method based on FACT [4]. Group averaging of the results will be based on 12-mode affine transformation. Ipsilateral and contralateral cortico-cortical connectivity were studied. Based on the contralateral cortico-cortical connectivity information, the midsagittal corpus callosum was further parcellated with gyral connectivity [5].

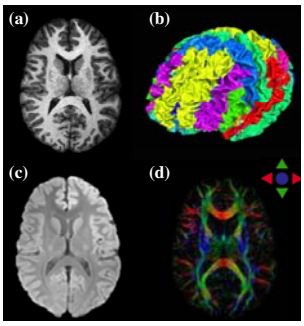

Fig 1: (a) MPRAGE raw data, (b) parcellated cortical surface with ICBM gyral labelings, (c) averaged diffusion weighted image after distortion correction, (d) DTI colormap.

Methods

Data acquisition: In vivo adult human data (n=15) were acquired using a 1.5 T Philips Gyroscan NT system. A single-shot EPI sequence with the SENSE parallel imaging scheme (SENSitivity Encoding, reduction factor R = 2.5) was used for DTI data acquisition. DWI parameters were: FOV=240/240/125mm, in plane imaging matrix = 96× 96 (zero-filled to 256 × 256 with in plane pixel size = 0.9375 × 0.9375mm), axial slices thickness = 2.5 mm, parallel to the anterior–posterior commissure line, 30 independent diffusion weighted directions with b-value = 700 sec/mm^2, 5 additional images with minimal diffusion weighting (b= 33 sec/mm^2). Co-registered magnetization-prepared rapid gradient echo (MPRAGE) images of the same resolution were also recorded for anatomical guidance. ***Cortical parcellation:*** This process starts with T1-weighted (MPRAGE) volumetric brain images with voxel size 0.9375×0.9375×1.25mm (Fig. 1a). CRUISE [6] was applied to generate the outer, central (Fig. 1b) and inner surface. With the ICBM atlas as source image and subject image as target image, a RBF (radial basis function) based registration method was used to acquire the transformation matrix. This transformation matrix was then applied to the ICBM gyral label to get the subject gyral label (Fig. 1b). ***Tensor fitting and DTI tractography:*** DTI tensor fitting starts with raw DWI images (Fig. 1c) after intra-subject AIR registration and distortion correction using manual-based landmark placement (30-40 landmarks per slice) followed by LDDMM (large deformation diffeomorphic metric mapping) transformation. The six independent elements of the 3×3 diffusion tensor (Fig. 1d) were calculated using multivariate linear fitting. Fiber tracking was based on a linear line propagation model (FACT) [1] with FA threshold 0.2 and angle threshold 40°. The region of interests (ROI) used for fiber tracing consists of the voxels with specific gyral label between the shrunk inner surface and outer surface. As this study is interested in the fibers terminating at two cortical ROIs, traced fibers were filtered to only keep those with both end points residing in the two ROIs.

Results

Ipsilateral Cortico-cortical connectivity: As a first step, we began with the study of the connectivity between cortical lobes. The cortical surface was segmented into 5 lobes, namely frontal, parietal, occipital, temporal and limbic lobes by unifying the gyri labeling in the same lobe. For the traced fibers, some are well recorded in the literature, but others are not. For example, fig. 2 shows snapshots of fibers connecting frontal and occipital lobes from lateral view (Fig. 2a) and parietal and occipital lobes from inferior view (Fig. 2b), respectively. As illustrated in Fig 2a, the two white major fiber bundles are well-known superior fronto-occipital fasciculus (sfo) and inferior fronto-occipital fasciculus (ifo). On the contrary, the four short but well organized white fiber bundles indicated by green arrows in fig. 2b are usually simply documented as U-fibers without further specification. ***Contralateral Cortico-cortical Connectivity:*** Contralateral cortico-cortical connectivity is mainly made up by callosal fibers. As a beginning step, we studied the left callosal fibers parcellated with the gyral labeling. As has been pointed out [2], tractography failed to reveal connections to lateral gyri. The dominance map of midsagittal CC is shown in fig. 3. Each pixel of the dominance map of midsagittal cc is color coded with a specific gyrus with which callosal fibers have the maximum fiber count [5].

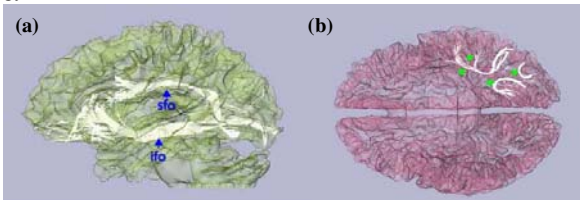

Fig 2: 3D reconstruction of fibers connecting frontal and occipital lobes (a) and parietal and occipital lobes (b).

Fig 3: Dominance map of midsagittal cc based on gyral connections. SFG: superior frontal gyrus, GR: gyrus rectus, MFOG: middle fronto-orbital gyrus, PRCG: precentral gyrus, POCG: postcentral gyrus; SPG: superior parietal gyrus, PCG: precuneus gyrus, SOG: superior occipital gyrus, CUN: cuneus, HIPP: hippocampus, CG: cingulate gyrus. FLL/FLR: left/right frontal lobes, PLL/PLR: left/right parietal lobes, OLL/OLR: left and right occipital lobes, TLL/TLR: left and right temporal lobes, LSL/LSR: left and right limbic system.

	FLL	PLL	OLL	TLL	LSL	FLR	PLR	OLR	TLR	LSR
FLL	*	1.328	0.706	0.265	0.646	2.355	0.012	0.042	0.016	0.004
PLL	1161	*	0.276	1.883	0.434	0.011	2.064	0.032	0	0.063
OLL	426	101	*	1.391	0.305	0.002	0.008	9.943	0	0
TLL	181	839	243	*	0.401	0	0	0	0	0
LSL	482	220	72	127	*	0.312	0	0.003	0	0.351
FLR	2655	10	1	0	240	*	1.612	0.531	0.420	1.117
PLR	8	1314	3	0	0	2087	*	0.292	1.653	0.313
OLR	27	12	1346	0	1	319	104	*	1.925	0.255
TLR	11	0	0	0	0	285	646	790	*	0.356
LSR	3	33	0	0	125	816	139	54	84	*

Table 1: Cortico-cortical fiber count and ratios of fiber count over the cortical surface area.

As illustrated in a way similar to [7], table 1 (see Fig. 3 legend for abbreviation) shows the quantitative cortico-cortical connectivity information between lobes. Among the total 4 blocks of table 1, the ipsilateral connectivity information is listed in the upper left and lower right blocks, and the contralateral connectivity information is listed in the upper right and lower left blocks. The fiber counts are listed in lower triangles of Table 1. Surface area of each lobe was also calculated. To explore how intense the lobe connectivity is, fiber count was divided by the summation of surface areas of two lobes with which the cortico-cortical fibers are connected. These ratios are listed in the upper triangle of Table 1 and ranked with different color paintings. It shows that connectivity between temporal lobe and parietal/occipital lobe is most intense for ipsilateral connections. The contralateral connectivity is almost symmetric with occipital connections most intense.

Discussion

This abstract shows some preliminary results of the cortico-cortical connectivity study. We expect that this technique will help us to identify reproducible axonal bundles in the subcortical white matter and allows us to quantitatively evaluate white matter connectivity. Data from more subjects is under way.

References: [1] Mori, S. et al (2005) MRI atlas of human white matter, Elsevier. [2] Wakana, S. et al (2004) Radiology, 230, 77. [3] Mori, S. (2002) MRM 47, 215. [4] Mori, S. et al (1999) Annal. Neurol. 45, 265. [5] Huang, H. et al (2005) NeuroImage, 26, 195. [6] Han, X. et al (2004) NeuroImage, 23, 997. [7] Tuch, DS. (2002) PhD thesis, Cambridge, MA. **Acknowledgement:** This study was sponsored by NIH grants R01 AG20012 and RR15241.