Atlas-Guided Automated Tract Reconstruction of the White Matter Anatomy

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Introduction: Diffusion tensor imaging (DTI) and tractography has been widely used to reconstruct major white matter pathways in the brain, information from which can be used for studying white matter anatomy and tract-specific quantitative analyses. However, the dependency on manually defined regions of interest (ROIs) at unique anatomical location leads to two major limitations of current tractography methods: 1) reproducibility relies on subjective and experts' judgment of ROI placement and 2) only a small amount of tracts can be identified readily. Consequently, there are many important tracts that could not be studied in a systematic manner, especially for short association fibers located subcortically. In this study, we established a comprehensive and whole brain tractography system by using our human brain white matter atlas [1], in which 130 gray and white matter areas are defined. Using this system, tracts that are previously difficult to reconstruct can now be tracked automatically and consistently. The accuracy and reproducibility of the system have been evaluated. We used the system to perform the first ever comprehensive examination of white matter tracts in the brain and created probabilistic maps of 59 white matter tracts, including those previously not well studied short association tracts.

Methods: DTI data from 20 healthy subjects (age 36.4 ± 13.3 years old; 10 males, 10 females, right-handed) were included in the study. Data were acquired on a 1.5 T MR scanner (single-shot SENSE EPI, FOV=240 mm x 240 mm, slice thickness=2.5mm, acquisition matrix=96x96, reconstruction matrix=256x256, TR>4s, TE=80ms, b value=1,000s/mm2). The DTI data were skull-stripped, distortion corrected, and re-sampled to 181x217x181 with 1 mm isotropic resolution. Mappings between the pre-processed data and our single subject DTI atlas [1] were obtained by affine transformation followed by LDDMM [2], using non-diffusion weighted images and fractional anisotropy (FA) images as inputs. Anatomical units defined in the single subject atlas were selected and mapped to subject data. The mapped units were used as ROIs for fiber tracking in the subject data using the FACT method. Once each brain is automatically segmented, white matter tracts of interest can be extracted by combining multiple segmentations of the automatic segmentation results, which belong to the two destinations of the brain. Automated fiber tracking results from the 20 subjects were then mapped back into the space of the atlas, and the spatial distributions (probabilistic maps) of each tracts in the atlas space were generated. Results of manual fiber tracking of the 8 tracts (CST, IFO, ILF and UNC in both hemispheres) were used as gold standard to evaluate the accuracy of our technique. The spatial matching between automated and manual fiber tracking results were quantified by Kappa value (k), with the k value of 0.81-1.0 is “almost perfect” agreement, and 0.61-0.80 is “substantial”.

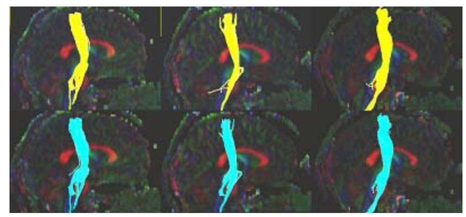

Fig.1 Comparison of manual (upper row, yellow) and automated (lower row, cyan) results in rCST: three individual cases

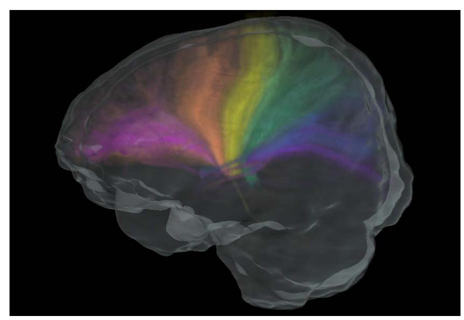

Fig.2 Probabilistic maps of thalamic radiations in left hemisphere. Components connecting thalamus and cerebral cortices are shown respectively by different colors.

Results and Discussion: The tracts reconstructed in this study include 12 commissural tracts, 10 projection tracts, 8 long association tracts, and 29 short association tracts. Comparison between manual and automated reconstruction results showed good agreement, with all kappa values greater than 0.6, indicating substantial to almost perfect agreement. Fig.1 shows the spatial agreement of automated and manual results of right-side cortico-spinal tract (rCST). Fig.2 shows probabilistic maps of the left side thalamic radiations generated from tractography results of 20 normal subjects. Depending on the destination of the trajectory, the thalamus was parcellated into 9 subdivisions in a highly reproducible manner. This type of white matter parcellation could be very time-consuming and error prone if one uses manual ROI placement. Automated fiber tracking was also applied to searching for previously not well documented cortico-cortical connections between neighboring cortical regions (short association fibers). We detected 29 subcortical connections that show high reproducibility among the normal population. Fig.3 shows four such tracts in individual subject and the probabilistic maps. It is important to note that DTI is simplified model and the method described here cannot resolve crossing fibers. The automated ROI placement, however, can be combined with more sophisticated tract tracing algorithms. In summary, the atlas-based system provides consistent fiber tracking results and is an important tool to investigate white matter pathways in the human brain.

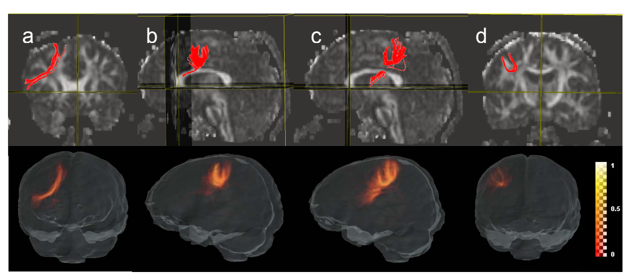

Fig.3 The 4 reconstructed short association fibers: individual cases (upper row) and probabilistic maps (lower row) of 20 subject data.

References: 1. K. Oishi, et al., Neuroimage 46 (2009) 486-499. **2**. C. Ceritoglu, et al., Neuroimage 47(2) (2009) 618-627.

Grant Support: This study is supported by NIH R01AG20012, P41RR15241, NIH/NIA R21AG05146 and JHU/ADRC P50AG033774. We would like to thank research groups in International Consortium of Brain Mapping (ICBM).