Probabilistic Atlas of the Adult Human Brain White Matter

Anna Varentsova[1], Shengwei Zhang[2], and Konstantinos Arfanakis[2]
[1]*Physics, Illinois Institute of Technology, Chicago, IL, United States,* [2]*Biomedical Engineering, Illinois Institute of Technology, Chicago, IL, United States*

Target audience: Investigators conducting MRI research of human brain white matter.

Purpose: Digital human brain white matter (WM) atlases play an important role in brain imaging research. Existing WM atlases have been generated either based on anatomical landmarks, thus mixing tracts with substantially different roles, or using DTI tractography, which fails in regions with crossing fibers. The purpose of this study was to develop a probabilistic WM atlas of the adult human brain by performing probabilistic tractography on an artifact-free high angular resolution diffusion imaging (HARDI) brain template constructed in ICBM-152 space.

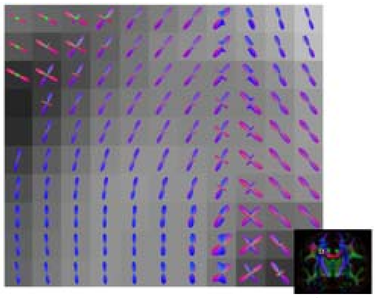

Figure 1. ODFs at the intersection of the corpus callosum with the corticospinal tract.

Methods: Development of the WM atlas involved two steps: 1) development of an artifact-free HARDI template and 2) probabilistic tracking of WM fiber-bundles in the HARDI template. An artifact-free HARDI template: Artifact-free low angular resolution Turboprop diffusion-weighted (DW) data from 67 subjects were used in this work. All datasets were spatially normalized and combined into a single dataset. All DW signals were divided by the corresponding b=0 sec/mm^2 signals. Due to differences in brain shape and head positioning across subjects, the combined DW signals in each voxel corresponded to a large number of unique diffusion directions, equal to the product of the number of subjects and the number of diffusion directions per subject (67 subjects × 12 diffusion directions = 804 diffusion directions). Orientation distribution functions (ODF) were then estimated in the combined dataset with an analytical Q-ball method[1]. Probabilistic mapping of WM fiber-bundles in the HARDI template: Probabilistic tractography was performed in the HARDI template using the MRtrix software[2]. One hundred fibers were mapped from each voxel of the brain having FA > 0.2. No FA threshold was used for tract termination in order to allow mapping through fiber crossings. A multi-ROI approach was then used to segment tracts of interest. Fibers penetrating ROIs associated with the tract of interest were assigned to that tract. The size, shape and position of the ROIs used in this work followed reliable tracking protocols presented previously[3]. Confidence maps were generated for each WM fiber-tract separately, by mapping for each voxel the number of fibers that originated from that voxel and belong to the tract of interest. The following major fiber-bundles were mapped: corpus callosum, corticospinal tract, inferior longitudinal fasciculus, superior longitudinal fasciculus, inferior occipitofrontal fasciculus, cingulum, fornix, uncinate fasciculus, and fibers of the brainstem.

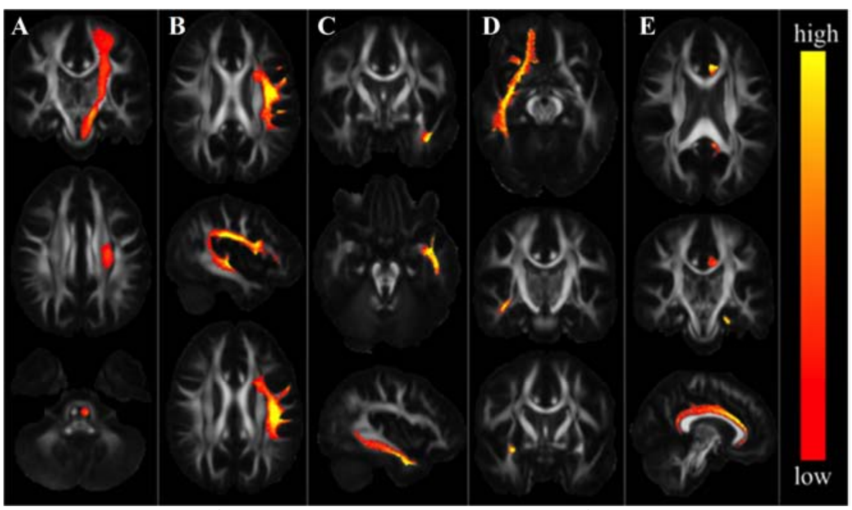

Figure 2. Fiber-tract confidence maps (overlaid on mean FA maps) for the: (A) corticospinal tract, (B) superior longitudinal fasciculus, (C) inferior longitudinal fasciculus, (D) inferior occipitofrontal fasciculus, (E) cingulum. Yellow color was assigned to the maximum confidence level in each tract separately, and therefore, colors should not be compared across tracts.

Results & Discussion: Figure 1 shows an example ODF map from the generated HARDI template, demonstrating resolved fiber-crossings. Examples of fiber-tract confidence maps are shown in Figure 2. The generated probabilistic maps of major fiber-bundles appear to be in agreement with known anatomy. The use of artifact-free data in the construction of the HARDI template allowed robust fiber-bundle mapping in brain regions such as the temporal and frontal lobes. The use of the HARDI template allowed mapping of fibers even through regions with fiber crossings (representative results not shown here).
This is an ongoing project. Current work is focused on a) increasing the number of tracts originating from each brain voxel to generate more robust confidence maps for each tract, b) increasing the number of fiber-bundles mapped by expanding the list of ROIs beyond those from previously published tracking protocols (e.g. using gray matter ROIs from a gray matter atlas located in the same space as the HARDI template), c) quantitatively assessing the accuracy of the information presented in the white matter atlas.

Conclusion: A probabilistic atlas of the adult human brain WM is being constructed based on an artifact-free HARDI template. The new atlas may significantly enhance the accuracy of clinical studies using atlas-based WM segmentation.

References: 1. Descoteaux M, Angelino E, Fitzgibbons S, et al. Regularized, fast, and robust analytical Q-ball imaging. Magn Reson Med. 2007;58(3):497-510. 2. Tournier JD, Calamante F, Connelly A. MRtrix: Diffusion tractography in crossing fiber regions. Int J Imag Syst Tecah. 2012;22(1):53-66.3. Wakana S, Caprihan A, Panzenboeck MM. Reproducibility of quantitative tractography methods applied to cerebral white matter. Neuroimage. 2007;36(3):630-44.