Lateral Asymmetry of Superior Longitudinal Fasciculus: A White Matter Tractography Study

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Introduction

White Matter Tractography (WMT) uses the directional information provided by Diffusion Tensor Imaging to infer patterns of continuity in the brain's diffusion tensor field [1]. WMT may be used to estimate the pathways of specific white matter tracts, thus separating these tracts from other white matter structures. Morphometric quantification of the brain's white matter by Voxel Based Morphometry (VBM) methods are promising for detecting both patterns of white matter development in healthy brains [2] and white matter abnormalities in pathologic brain [3]. However, these methods are highly dependant upon the accuracy of intersubject image registration and only detect local changes or differences, not global differences of a specific white matter structure. WMT offer the advantage of segmenting out specific white matter tracts, which may be used as more precise templates for morphological characterization.

In this study, WMT was used to reconstruct and segment the superior longitudinal fasciculi (SLF) of both the left and the right cerebral hemispheres to test for lateral asymmetries of the SLF volume. Estimations of the major white matter structures using WMT appear to be in good agreement with known white matter anatomy [1]. In particular, it has been shown that WMT is able to reconstruct and segment the major association white matter tracts [4,5], including the SLF, which connects cortical regions of the frontal, parietal, and temporal lobes that are involved in language processing. The SLF is composed of both shorter and longer bundles. The shorter bundles connect neighboring cortical regions and join the tract for only short distances. The SLF starts from the frontal lobe and extends in the posterior direction eventually curving inferiorly and around into the temporal lobe. The SLF trunk in the frontal lobe is lateral to the internal capsule and body of the corpus callosum.

Methods

Subjects The study included ten healthy, right-handed subjects (7 males and 3 females), with ages varying between 19 and 39 years (median=22 years).

Diffusion Tensor Imaging: DTI images were obtained on a 3T MRI scanner using a cardiac-gated single-shot spin-echo EPI pulse sequence with diffusion-weighting gradients applied in 12 uniform distributed encoding directions [6]. The acquisition for each encoding direction was repeated three times and combined using magnitude averaging. Thirty-nine axial slices (3mm thick) were acquired to cover the cerebrum. The original voxel size was 0.94x0.94x3 mm^3, which was interpolated to isotropic dimensions. The total imaging time was 7-8 minutes. Image misregistration from motion and eddy current distortion was corrected using a 2D affine registration algorithm in AIR [7]. Field map correction was subsequently applied to correct for EPI distortions resulting from B_0 inhomogeneities.

White Matter Tractography: Fiber trajectories were estimated using the streamline algorithm [1] with a second-order Runge-Kutta integration method. A complete set of fiber trajectories in the brain's diffusion tensor field was obtained by placing seeds in all the voxels with FA>0.4. The propagation of an individual trajectory was terminated when it reached a voxel with FA<0.2 or when the angle between two consecutive steps was greater than 45°. SLF was separated from the complete set of trajectories by retaining those fibers that intersected pre-defined regions of interest (ROIs). The ROIs were chosen to enclose the right and left SLF cross-sections visible in coronal FA and color maps. A set of three cross-sections was used for each hemisphere and each subject, to capture fiber estimates that joined the tract for either shorter distances or for its entire length. SLF sub-segmentation The trajectories that curved inferiorly to enter the temporal lobe were segmented out from the complete set of SLF trajectories. The SLF volumes defined by the fronto-temporal connections were calculated for both left and right hemispheres.

Results

The estimates of the segmented fiber tracts for six of the subjects are shown in Figure 1. Variability of the shape of the estimated tracts among subjects, and between hemispheres, can be observed. A common feature is the larger volume of the left hemisphere frontal-to-temporal connections, which is apparent by visual inspection of the tractography results. For one subject (Subject 10) no temporal connections of SLF were detected in the right hemisphere, although the cause of this was unclear. The ratios of left to right fronto-temporal connections volumes (depicted in yellow in Figure 1) for the remaining subjects ranged from 1.1 to 6.7, with a median of 1.65.

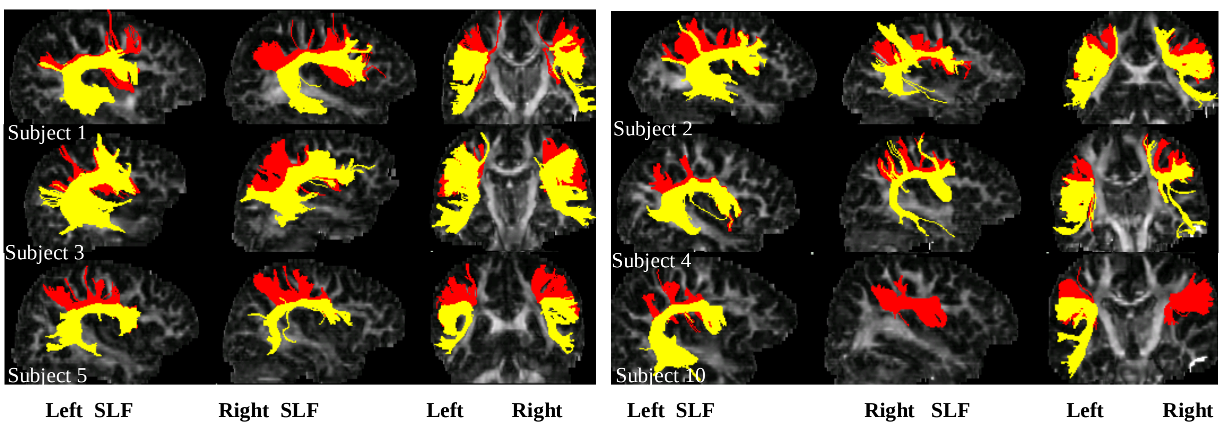

Figure 1. SLF tractograms of the left and right hemispheres for six subjects. The fiber trajectories that connected the frontal and temporal lobes were segmented (depicted in yellow). Tract trajectories that joined only the superior portion (fronto-parietal) of the tract were depicted in red. Combined tractograms were generated by first projecting the superior bundles (in red), and then the fronto-temporal connections (in yellow).

Discussion

In this study, WMT was used to segment out and estimate the hemispheric asymmetry of SLF volumes within subjects. A larger volume of fronto-temporal connections was consistently measured in the left hemisphere. This result was consistent with previous findings of higher white matter density of the left superior longitudinal fasciculus [2]. This asymmetry may be related to the usual dominance of the left-hemisphere for language function. The effects of gender or age were not evaluated because of the limited sample size. This study exemplifies the potential use of WMT for tract segmentation and morphometric characterization. Other metrics, such as tract cross-section, length and curvature, will be used in future studies for further characterization of the tracts shape and size. Non-invasive methods for lateralizing language function would be extremely valuable for minimizing language deficits from surgical interventions.

References: [1] Mori S et al. NMR Biomed 15:468, 2002; [2] Paus et al. Science 283:1908, 1999. [3] Spalletta et al. Schizophr Res 64:15, 2003. [4] Mori et al. Magn Reson Med, 47:215, 2002; [5] Lazar et al. HBM, 18:306, 2003; [6] Hasan et al. J Magn Reson Imaging, 13:769, 2001; [7] Woods et al. J Comp Ass Tom 22:141, 1998.