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DECODING THE SUPERIOR PARIETAL LOBULE CONNECTIONS OF THE SUPERIOR LONGITUDINAL FASCICULUS/ARCUATE FASCICULUS IN THE HUMAN BRAIN

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Abstract—The temporo-parietal (TP) white matter connections between the inferior parietal lobule and superior temporal gyrus as part of the superior longitudinal fasciculus/arcuate fasciculus (SLF/AF) or middle longitudinal fasciculus (MdLF) have been studied in prior diffusion tensor tractography (DTT) studies. However, few studies have been focusing on the higher TP connections of the superior parietal lobule with the temporal lobe. These higher TP connections have been shown to have a role in core processes such as attention, memory, emotions, and language. Our most recent study, for the first time, hinted to the possibility of a long white matter connection interconnecting the superior parietal lobule (SPL) with the posterior temporal lobe in human brain which we call the SLF/AF TP-SPL and for a shorter abbreviation, the TP-SPL. We decided to further investigate this white matter connection using fiber assignment by continuous tracking deterministic tractography and high spatial resolution diffusion tensor imaging on 3T. Five healthy right-handed men (age range 24–37 years) were studied. We delineated the SPL connections of the SLF/AF TP bilaterally in five normal adult human brains. Using a high resolution DTT technique, we demonstrate for the first time, the trajectory of a long fiber bundle connectivity between the SPL and posterior temporal lobe, called the SLF/AF TP-SPL (or the TP-SPL), bilaterally in five healthy adult human brains. We also demonstrate the trajectory of the vertically oriented posterior TP connections, interconnecting the inferior parietal lobule (IPL) with the posterior temporal lobe (TP-IPL) in relation to the TP-SPL, arcuate fasciculus and other major language pathways. In the current study, for the first time, we categorized the TP connections into the anterior and posterior connectivity groups and subcategorized each one into the SPL or IPL connections. Published by Elsevier Ltd. on behalf of IBRO.

Key words: arcuate fasciculus, superior parietal lobule, inferior parietal lobule, temporoparietal, tractography, language pathways.

INTRODUCTION

The superior longitudinal fasciculus/arcuate fasciculus (SLF/AF) is an important bundle of association fibers in the white matter of each cerebral hemisphere connecting the parietal, occipital and temporal lobes with ipsilateral frontal lobe. The SLF/AF pathways are involved in core processes such as attention, memory, emotions and language (Schmahmann et al., 2008). In our most recent study, diffusion tensor tractography (DTT) of five subcomponents of the SLF/AF pathways in the human brain and specifically, tractography of the SLF I were described for the first time (Kamali et al., 2014). The SLF I is a long association pathway connecting the superior parietal lobule (SPL) and the precuneus with the supplementary motor areas of the frontal cortex. The SPL connection of the middle longitudinal fasciculus (MdLF-SPL) was also described concurrently by two separate DTT studies (Wang et al., 2013; Kamali et al., 2014).

Experimental observations in non-human primates described the AF as a component of the SLF complex (Petrides and Pandya, 1984). However, other studies supported the existence of multi-segment components of the AF as a separate entity from the SLF (Deacon, 1992; Catani and Mesulam, 2008; Lawes et al., 2008). According to a study by Catani and Mesulam (Catani and Mesulam, 2008), the arcuate fasciculus (AF) includes three branches, a direct pathway connecting Broca's and Wernicke's area, and an indirect pathway consisting of two segments: an anterior segment linking Broca's territory with the inferior parietal lobule (IPL), and a posterior temporoparietal (TP) segment linking the IPL with Wernicke's territory. The TP fiber connections of the IPL with the caudal and posterior aspect of the superior

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Abbreviations: AF, arcuate fasciculus; AG, angular gyrus; BA, Brodmann area; CG, cingulum; cMRI, conventional MRI; DTI, diffusion tensor imaging; DTT, diffusion tensor tractography; EPI, echo planar imaging; ILF, inferior longitudinal fasciculus; IPL, inferior parietal lobule; MdLF, middle longitudinal fasciculus; ROI, region of interest; SLF, superior longitudinal fasciculus; SLF/AF TP, temporoparietal portion of superior longitudinal fasciculus/arcuate fasciculus; SNR, signal-to-noise ratio; SPL, superior parietal lobule; TP-IPL, inferior parietal lobule with the posterior temporal lobe; TP, temporo-parietal.

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temporal gyrus has been described as the posterior and vertical portion of the AF by some prior DTT studies (Catani et al., 2005; Parker et al., 2005; Frey et al., 2008) and considered as part of the vertically oriented fibers of the SLF complex by others (Fernández-Miranda et al., 2008; Galantucci et al., 2011; Martino et al., 2013; Kamali et al., 2014). Thus, we call these connections the SLF/AF TP-IPL or TP-IPL. However, no connection has been reported between the SPL with the caudal and posterior aspect of the temporal lobe in prior DTI or anatomical studies. Our most recent study hinted to the possibility of a higher SPL interconnection with the posterior temporal lobe in human brain which we call the SLF/AF TP-SPL. In the current study we decided to further investigate this connection and its relationships with adjacent fiber pathways.

Diffusion tensor tractography is a technique based on diffusion tensor MRI which allows delineation of the trajectory and course of the neuronal fiber tracts. This technique may provide information about the course, anatomical connectivity, interruption, or integrity of neural pathways. This information may be helpful in exploring lesion localization and specific connections that are impaired (Mori and van Zijl, 2002).

Numerous anatomical details in brain white matter connectivity have been undetectable or poorly detectable in prior DTI studies. We hypothesized that the extensive crossing fibers at the corona radiata at the level of the lateral ventricles along with lack of adequate imaging spatial resolution, so far, impeded depiction of these higher parietal connections in human brain in prior diffusion tensor imaging (DTI) studies. This work aimed to present for the first time the trajectory, cortical connectivity, and descriptive anatomy of the TP connection of the superior longitudinal fasciculus/ arcuate fasciculus (SLF/AF) connecting the posterior temporal lobe with the SPL using a high spatial resolution DTI technique and deterministic tractography approach.

EXPERIMENTAL PROCEDURES

Study subjects

This work was approved by our institutional review board (IRB) and was health insurance portability and accountability act (HIPAA) compliant. Five right-handed healthy men (age range 24–37 years) were included in this study and written informed consent was obtained from all the subjects.

Conventional MRI data acquisition

All MRI studies were performed on a 3T Philips Intera scanner with a dual quasar gradient system with a maximum gradient amplitude of 80 mT/m, maximum slew rate 200 mT/ms/m, and an eight channel SENSE-compatible head coil (Philips Medical Systems, Best, Netherlands). The conventional MRI (cMRI) protocol included axially prescribed 3D spoiled gradient (repetition time, TR = 8 ms; echo time, TE = 4 ms; and flip angle = 6°), 3-D proton density-weighted (TR/TE/flip angle = 10,000 ms/10 ms/90°) and 3-D T_2-weighted (TR/TE/flip angle = 10,000 ms/60 ms/90°), with a square field-of-view (FOV) = 256 mm × 256 mm and a matrix of 256 × 256 pixels. The slice thickness for the MRI sequences was 1.0 mm with 120 contiguous axial slices covering the entire brain (foramen magnum to vertex).

DTI data acquisition

Diffusion-weighted image (DWI) data were acquired axially from the same graphically prescribed cMRI volumes using a single-shot multi-slice 2D spin-echo diffusion sensitized and fat-suppressed echo planar imaging (EPI) sequence, with the balanced Icosa21 tensor encoding scheme (Hasan et al., 2009; Kamali et al., 2010). *b*-factor = 500 s mm^{-2}, TR/TE = 14460/ 60 ms. Spatial coverage for DTI data matched the 3D cMRI spatial coverage (FOV = 256 mm × 256 mm and slice thickness/gap/#slices = 1 mm/0 mm/120). The EPI phase encoding used a SENSE k-space undersampling factor of two, with an effective *k*-space matrix of 112 × 112 and an image matrix after zero-filling of 256 × 256. The acquisition spatial resolution for DTI data was ~2.29 mm × 2.29 mm × 1 mm, and the nominal resolution after image construction was 1 mm × 1 mm × 1 mm. The number of *b*-factor ~ 0 (b_0) magnitude image averages was four. The total DTI acquisition time was ~7 min for the diffusion-weighted acquisition. The DTI acquisition was repeated three times to enhance signal-to-noise ratio (SNR). The selection of the *b*-factor, parallel imaging, repetition and echo times enabled entire brain coverage using single-shot and interleaved EPI. The thin slice acquisition in space and replication of data in time combined with the DTI encoding provided several quality control options to study SNR and partial volume effects on the DTI tracking results (Hasan and Narayana, 2003; Hasan et al., 2008).

White matter fiber tracking

After data preparation and quality assessment using in-house developed procedures (Hasan et al., 2009), compact WM fiber tracking was performed using DTI Studio software (Johns Hopkins University, Baltimore, Maryland; http://cmrm.med.jhmi.edu/). Fiber tracking was based on the fiber assignment by continuous tracking (FACT) algorithm with a fractional anisotropy (FA) threshold of 0.22 and angle threshold of 60 degrees. Reproducibility of the fiber construction in both hemispheres was tested by two experienced raters on all subjects. The reproducibility of the fibers was confirmed bilaterally on all the subjects by two of the authors (A.K., K.H.) with 8 years of experience in DTT. Two regions of interest (ROIs) were applied to obtain each fiber tract and an "AND" operation was performed to include the fibers passing through both of the ROIs.

The regions of interest for tractography for the subcomponents of the SLF have been described in our most recent study (Kamali et al., 2014).