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The anatomical characteristics of the stria terminalis in the human brain: A diffusion tensor tractography study

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ABSTRACT

The stria terminalis (ST) connects the amygdale (AM) with the hypothalamus, anterior commissure, preoptic area, and septal region. Many animal studies have reported on the anatomy and function of the ST; in contrast, little is known about its anatomy and function in the human brain. In the current study, we attempted to investigate the anatomical characteristics of the ST in the normal human brain, using diffusion tensor tractography. We recruited 30 healthy volunteers for this study. Diffusion tensor images were scanned using 1.5-T, and the ST was obtained using FMRIB software. Values of fractional anisotropy, mean diffusivity, and tract volume of the ST were measured. STs passed from the AM to the anterior hypothalamus, through the region, around to the anterior margin of the temporal horn of the lateral ventricle, over the posterior and superior margin of the thalamus, behind the anterior commissure. No differences according to the side of the hemisphere and sex in terms of fractional anisotropy, mean diffusivity, and tract volume of the ST ($P < 0.05$) were observed. We identified the ST and observed the anatomical characteristics of the ST in the normal human brain. We believe that the methodology and results reported here would be helpful to researchers and clinicians in this field.

The stria terminalis (ST) is one of the major efferent pathways from the amygdala (AM); it connects the AM with the hypothalamus, anterior commissure, preoptic area, and septal region [1,2,4,7,10,11,15,18,28,32,33,35]. It is known to be involved in modulation of memory, emotional responses, sexual behavior, and sex identification [3,12,13,19,20,23,26,30,41]. Many animal studies have reported on the anatomy and function of the ST [1,10–16,23,26,29,30,33,34]; in contrast, little is known about its anatomy and function in the human brain [18,32]. For clarification of the physiology and pathology of any neural tract, research on the anatomical characteristics of the neural tract should be performed first, ahead of other research. Anatomical study of the ST in the human brain has been difficult due to its anatomical characteristics: long, thin, C-shaped, and indistinguishable from adjacent neural structures on conventional brain MRI.

Recent developments in diffusion tensor tractography (DTT), which is derived from diffusion tensor imaging (DTI), allow visualization and localization of neural tracts at the subcortical level in three dimensions [24]. Many neural tracts that could not be identified clearly on conventional brain MRI have been identified three dimensionally by DTT [8,17,21,24,36,38,39]. However, no DTT study of the ST in the human brain has been conducted.

In the current study, we attempted to investigate the anatomical characteristics of the ST in the normal human brain, using DTT.

We recruited 30 healthy subjects (male: 15, female: 15, mean age: 33.73 years, range: 20–50 years) with no previous history of neurological, physical, or psychiatric illness. All subjects understood the purpose of the study, and provided written, informed consent prior to participation. The study protocol was approved by our local Institutional Research Board.

A 6-channel head coil on a 1.5-T Philips Gyroscan Intera (Philips, Ltd., Best, The Netherlands) with single-shot echo-planar imaging was used for acquisition of DTI data. For each of the 32 non-collinear diffusion sensitizing gradients, we acquired 67 contiguous slices parallel to the anterior commissure-posterior commissure line. Imaging parameters were as follows: acquisition matrix = 96×96; reconstructed to matrix = 128×128 matrix; field of view = 221 mm × 221 mm; TR = 10,726 ms; TE = 76 ms; parallel imaging reduction factor (SENSE factor) = 2; EPI factor = 49; $b = 1000 s/mm^2$; NEX = 1; and a slice thickness of 2.3 mm (acquired isotropic voxel size $2.3 \times 2.3 \times 2.3\ mm^3$) (Table 1).

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Table 1
Diffusion tensor imaging parameters of the stria terminalis.

	FA	MD	Tract volume
Hemisphere			
Right	0.37 (0.02)	1.12 (0.13)	153.30 (71.85)
Left	0.38 (0.02)	1.12 (0.13)	154.03 (82.03)
Both	0.37 (0.02)	1.12 (0.13)	153.67 (76.45)
Sex			
Male	0.37 (0.02)	1.13 (0.13)	163.53 (82.81)
Female	0.37 (0.02)	1.11 (0.13)	143.80 (69.52)
Both	0.37 (0.02)	1.12 (0.13)	153.67 (76.45)

Values represent mean (±standard deviation); FA, fractional anisotropy; MD, mean diffusivity, MD × 10^{-3} (mm^2/s).

The Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB) Software Library (FSL; www.fmrib.ox.ac.uk/fsl) was used for the analysis of diffusion-weighted imaging data. Head motion effect and image distortion due to eddy current were corrected by affine multi-scale two-dimensional registration. Fiber tracking was performed using a probabilistic tractography method based on a multifiber model, and applied in the present study utilizing tractography routines implemented in FMRIB Diffusion (5000 streamline samples, 0.5 mm step lengths, curvature thresholds = 0.2) [5,6,31]. STs were determined by selection of fibers passing through three regions of interest (ROIs). The seed ROI was placed on the AM on the axial image (Fig. 1) [9]. We selected two target ROIs. The first target ROI was placed on the ST around the hippocampus (green portion) at the level between upper midbrain and bicommissure on a color map of axial images [25]. The second target ROI was placed on the ST area below the pathway of the body of the fornix on a color map of coronal images [2]. Of 5000 samples generated from each seed voxel, results for each contact were the visualized threshold point at disappearance of the frontal area. Values of fractional anisotropy (FA), mean diffusivity (MD), and tract volume of the ST were measured.

We used an independent *t*-test for determination of variances in the value of FA, MD, and tract volume between the right and left hemispheres, and between males and females. The significant level of the *P* value was set at 0.05.

In the brains of all subjects, STs that originated from the AM, passed posteriorly over the hippocampus, around the anterior margin of the temporal horn of the lateral ventricle, and then extended superior-anteriorly over the posterior and superior margin of the thalamus (Fig. 1). They descended between the posterior limb of the internal capsule and the precommissural fornix, and then terminated in the anterior hypothalamus.

Mean values for FA, MD, and tract volume were 0.37, 1.12, and 153.67, respectively. In terms of FA, MD, and tract volume, no significant differences were observed between hemispheres ($P < 0.05$). In addition, no significant differences in FA, MD, and tract volume were observed between males and females ($P < 0.05$).

In the current study, we identified the ST and observed the following results with regard to the anatomical characteristics of the ST in the human brain. First, the pathway of the ST: the ST passed from the AM to the anterior hypothalamus, through the region, around to the anterior margin of the temporal horn of

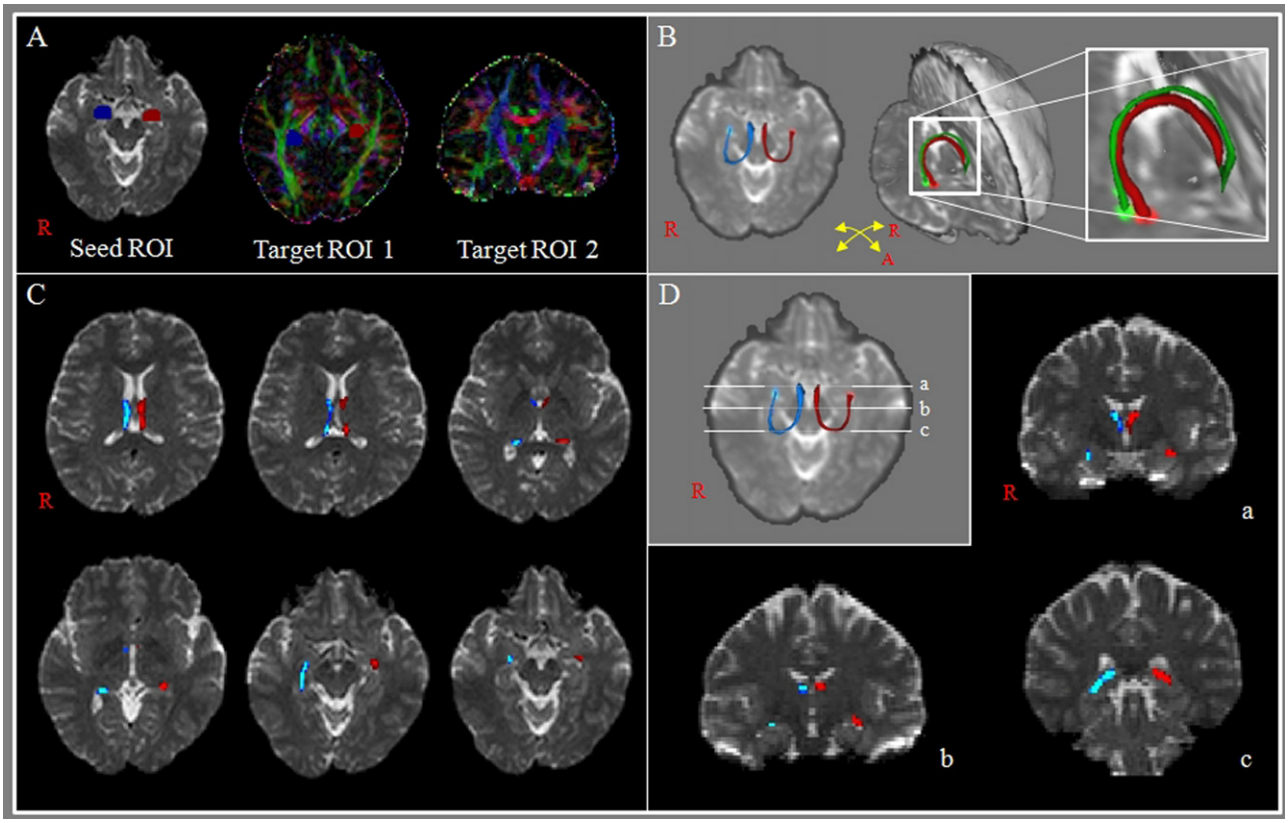

Fig. 1. The region of interest (ROI) and results of diffusion tensor tractography for the stria terminalis (ST). (A) Seed ROI is placed on the Amygdala. The first target ROI is placed on the hippocampus region (green portion) at the level between upper midbrain and bicommissure (Target ROI 1). The second target ROI is placed on the isolated ST area (below the pathway of the body of fornix) (Target ROI 2). (B) STs were constructed in both hemispheres (right: blue color, left: red color). Left fornix (green color) was reconstructed and shows comparison of the left ST. These two structures show parallel relationship. (C) The pathway of the ST is shown at each level of the brain on the axial view. (D) The pathway of the ST is shown at each level of the brain on the coronal view (a: anterior part, b: middle part, c: posterior part). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the lateral ventricle, over the posterior and superior margin of the thalamus, behind the anterior commissure. Our results were compatible with those of previous studies and with text book descriptions [1,2,4,7,10,11,15,18,28,32,33,35]. Second, DTI parameter data of the ST revealed no differences according to the side of the hemisphere and sex in terms of FA, MD, and tract volume of the ST.

Many studies have reported on the anatomy and pathology of the ST [1,10–16,18,23,26,29,30,32–34]. Most of these studies have been performed in lower mammals, such as rat or cat; in contrast, only a few studies of the brain in monkeys and humans have been conducted [1,18,32]. Johnston and Strenge et al. reported on the ST in a human embryo brain and in an adult human brain, respectively [18,32]. In 1952, Adey and Meyer demonstrated the detailed anatomy of seven monkey brains by observation of degeneration following neuronal destruction [1]. They found that the ST arose mainly in the basal nuclei of the AM and was subdivided into supracommissural, commissural, and hypothalamic bundles around the anterior commissure. The hypothalamic component terminated mainly in the ventromedial hypothalamic nucleus. In the current study, we selected three ROIs on the AM (seed ROI) and the ST area (two target ROIs). However, we found only the hypothalamic component of the ST and could not find the ST components to the precommissural area and the anterior commissure. This result might be attributed the fact that the ST components to the precommissural area and the anterior commissure have the characteristics of less directionality than the hypothalamic component. We think that further studies on this topic should be invited in the future.

In conclusion, we identified the ST and observed the anatomical characteristics of the ST in the normal human brain. As far as we are aware, this is the first DTT study of the ST in the human brain. We believe that the methodology and results reported here would be helpful to researchers and clinicians in this field. Several limitations of DTI should be considered. First, the fiber tracking technique is operator-dependent. Second, DTI may underestimate the fiber tracts. DTI is a powerful anatomic imaging tool that can demonstrate the gross fiber architecture, but not the functional or synaptic connections. Third, regions of fiber complexity and crossing can prevent full reflection of the underlying fiber architecture by DTI [22,27,37,40]. We suggest additional studies on clinical correlation, aging, and the validity and reliability of the ST.

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