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Neural connectivity of the lateral geniculate body in the human brain: Diffusion tensor imaging study

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HIGHLIGHTS

- Neural connectivity of the lateral geniculate body (LGB).
- LGB provides a relay station for all axons of retinal ganglion cells.
- LGB was connected with the contralateral target areas via the corpus callosum.
- LGB showed high connectivity with the ipsilateral hemisphere: temporal lobe, V1.

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ABSTRACT

A few studies have reported on the neural connectivity of some neural structures of the visual system in the human brain. However, little is known about the neural connectivity of the lateral geniculate body (LGB). In the current study, using diffusion tensor tractography (DTT), we attempted to investigate the neural connectivity of the LGB in normal subjects. A total of 52 healthy subjects were recruited for this study. A seed region of interest was placed on the LGB using the FMRIB Software Library which is a probabilistic tractography method based on a multi-fiber model. Connectivity was defined as the incidence of connection between the LGB and target brain areas at the threshold of 5, 25, and 50 streamlines. In addition, connectivity represented the percentage of connection in all hemispheres of 52 subjects. We found the following characteristics of connectivity of the LGB at the threshold of 5 streamline: (1) high connectivity to the corpus callosum (91.3%) and the contralateral temporal cortex (56.7%) via the corpus callosum, (2) high connectivity to the ipsilateral cerebral cortex: the temporal lobe (100%), primary visual cortex (95.2%), and visual association cortex (77.9%). The LGB appeared to have high connectivity to the corpus callosum and both temporal cortexes as well as the ipsilateral occipital cortex. We believe that the results of this study would be helpful in investigation of the neural network associated with the visual system and brain plasticity of the visual system after brain injury.

1. Introduction

The visual system is a complex neural system comprising various neural structures, including the retino-geniculo-striate visual pathway, visual processing system, and ocular motor system [1,6,8,16,28]. The visual system is known to have the characteristic of high potential in brain plasticity [9,15,23,30,38]. Unmasking of a latent neural connection is an important mechanism of brain plasticity following brain injury and many studies have reported on this topic in patients with brain injury [2,3]. Therefore, elucidation of the neural connectivity of a neural structure is important in research on normal visual function and brain plasticity of the visual system following brain injury.

Many studies have reported on the neural connectivity of the visual system in both animal and human brain using various techniques including the post-mortem, electromyography, transcranial magnetic stimulation, and functional MRI [7,20,25,31,32,34–36]. However, these techniques have a common limitation in that three-dimensional visualization and localization of neural tract. Recently developed diffusion tensor imaging (DTI) enables evaluation of the integrity of white matter tracts in three-dimensional by virtue of its ability to image water diffusion characteristics [26]. In addition, diffusion tensor tractography (DTT), which is derived from DTI, has an advantage for research on the neural connectivity of a neural structure. Therefore, many studies have reported on the

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neural connectivity of the neural system for motor and memory function in the human brain [14,17,42,43]. Regarding the visual system, a few studies have reported on neural connectivity of some portions of the visual system, such as the pulvinar and superior colliculus in the normal human brain [22–24].

The classic retino-geniculo-striate visual pathway, which terminates in the primary visual cortex (V1, the striate cortex), is associated with visual discrimination and perception [1,6]. The lateral geniculate body (LGB) provides a relay station for all axons of retinal ganglion cells and is connected to the V1 through the optic radiation [8]. The LGB is also connected to the pretectal area, superior colliculus, and pulvinar, which are important in visual attention and eye movement [6,7,24,33]. In addition, the LGB is known to be connected to the parietal and temporal lobes for unconscious vision (blindsight) [15]. Therefore, the LGB has been suggested to have an important role in brain plasticity of the visual system following brain injury [15,19,25]. However, little is known about the neural connectivity of the LGB in the human brain.

In the current study, using DTT, we attempted to investigate the neural connectivity of the LGB in normal subjects.

2. Methods

2.1. Subjects

We recruited 52 healthy subjects (males: 29, females: 23, mean age: 32.1 years, range: 20–55 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 the Institutional Review Board of a university hospital.

2.2. Data acquisition

A 6-channel head coil on a 1.5 T Philips Gyroscan Intera (Philips, Ltd, Best, The Netherlands) with single-shot echo-planar imaging (EPI) 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 matrix = 128 × 128; field of view = 221 × 221 mm^2; TR = 10,726 ms; TE = 76 ms; parallel imaging reduction factor (SENSE factor) = 2; EPI factor = 49; $b = 1000\ \text{s/mm}^2$; NEX = 1; and a slice thickness of 2.3 mm (acquired voxel size 1.73 × 1.73 × 2.3 mm^3).

2.3. Probabilistic fiber tracking

Analysis of diffusion-weighted imaging data was performed using the Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB) Software Library (FSL; www.fmrib.ox.ac.uk/fsl). 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 multi-fiber model, and applied in the current study utilizing tractography routines implemented in FMRIB Diffusion (5000 streamline samples, 0.5 mm step lengths, curvature thresholds = 0.2) [4,5,37]. We used two regions of interest (ROIs) in order to elucidate the connectivity of the LGB. For the seed ROI, we reconstructed the optic radiation on each hemisphere and we then identified and drew the LGB, which could clearly be seen, in accordance with known anatomical location on the FA map with axial slice [27,31,40]. The second ROI was drawn on the midline of the posterior part of the occipital lobe in order to exclude the possibility of inexistent connectivity between hemispheres. Out of 5000 samples generated from a seed voxel, results were visualized at the threshold of 5, 25, and 50 streamlines through each voxel for analysis. Connectivity represented the percentage of connection in all hemispheres of 52 subjects.

2.4. Determination of connection between the LGB and target brain areas

Connectivity was defined as the incidence of connection between the LGB and target brain areas: the parietal cortex (Brodmann areas 5, 7, 39, 40), prefrontal cortex (Brodmann area 9, 10, 11, 12), V1 (Brodmann area 17), visual association cortex (Brodmann area 18, 19), temporal cortex (Brodmann area 20, 21, 22, 27, 28, 34, 35, 36, 37) corpus callosum, anterior commissure, and posterior commissure [10,11].

3. Results

A summary of the connectivity of the LGB is shown in Table 1. Regarding the ipsilateral hemisphere at the threshold of 5, 25, and 50 streamlines, the LGB showed connectivity with the target ROI, in order, to the temporal cortex (100%, 100%, and 100%), V1 (95.2%, 86.5%, and 80.8%), corpus callosum (91.3%, 76%, and 67.3%), visual association cortex (77.9%, 64.4%, and 62.5%), prefrontal cortex (59.6%, 41.3%, and 35.6%), parietal cortex (46.2%, 25%, and 19.2%), posterior commissure (45.2%, 38.5%, and 29.8), and anterior commissure (43.3%, 22.1%, and 17.3), respectively (Fig. 1).

A summary of the connectivity between the LGB and contralateral target brain areas is shown in Table 2. The LGB was found to be connected with the contralateral target areas via three kinds of passage structures (the corpus callosum, anterior connissure, and posterior commissure). First, the LGB was connected with the contralateral target brain areas via the corpus callosum at the threshold of 5, 25, and 50 streamlines—to the temporal cortex (56.7%, 26.9%, and 15.4%), visual association cortex (32.7%, 11.5%, and 6.7%), parietal cortex (28.9%, 4.8%, and 4.8%), V1 (26.9%, 11.5%, and 6.7%), prefrontal cortex (10.6%, 1.9%, and 1.9%), and posterior commissure (8.7%, 1.9, and 0.9%), respectively. Second, via the posterior commissure at the threshold of 5, 25, and 50 streamlines, it was found to be connected with the temporal cortex (16.4%, 4.8%, and 1.9%), corpus callosum (4.8%, 2.9%, and 0%), V1 (2.9%, 0.9%, and 0%), parietal cortex (0.9%, 0%, and 0%), and visual association cortex (0.9%, 0%, and 0%), respectively. However, regarding the anterior commissure, the LGB did not show any connectivity with the contralateral target

Table 1
Incidence of connectivity between the lateral geniculate body and target areas.

th	Parietal cortex		Prefrontal cortex		Primary visual cortex		Visual association cortex		Temporal cortex		Corpus callosum	Ant. Com	Post. Com
	I	C	I	C	I	C	I	C	I	C			
5	46.2	28.9	59.6	10.6	95.2	28.9	77.9	32.7	100	61.5	91.3	43.3	45.2
25	25	4.8	41.3	1.9	86.5	12.5	64.4	11.5	100	26.9	76	22.1	38.5
50	19.2	4.8	35.6	1.9	80.8	6.7	62.5	6.7	100	16.3	67.3	17.3	29.8

Connectivity (%), Ant. Com: anterior commissure, Post. Com: posterior commissure, th: threshold, I: ipsilateral, C: contralateral.