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Identification of spinothalamic tract and its related thalamocortical fibers in human brain

Ji Heon Hong, Su Min Son, Sung Ho Jang*

Department of Physical Medicine and Rehabilitation, College of Medicine, Yeungnam University, 317-1, Daemyungdong, Namku, Daegu, 705-717, Republic of Korea

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ABSTRACT

Little is known about the spinothalamic tract (STT) and its related thalamocortical fibers. In the current study, we attempted to identify the STT and related thalamocortical fibers in the human brain, using diffusion tensor tractography (DTT). We recruited 23 healthy volunteers for this study. Diffusion tensor images (DTIs) were scanned using 1.5-T, and the STT and medial lemniscus (ML) were obtained using FMRIB software. Normalized DTI tractography was reconstructed using the Montreal Neurological Institute (MNI) echo-planar imaging (EPI) template supplied with the SPM. The STT began at the posterolateral medulla and ascended to the ventral posterior-lateral (VPL) nucleus of the thalamus, through the pontine tegmentum posterolateral to the ML, and through the mesencephalic tegmentum posterior to the ML. STT-related thalamocortical fibers originated from the VPL nucleus of the thalamus and ascended through the posterior limb of the internal capsule and the posterior portion of the corona radiata, terminating at the primary somatosensory cortex. We identified the STT and its related thalamocortical fibers using DTT. These results would be helpful in the clinical field and also in research on somatosensory function in the human brain.

Anatomical information is the basis of both clinical neuroscience and neuroscientific research. In the past, identification and visualization of the neural tract in the live human brain was impossible. The recent development of diffusion tensor tractography (DTT), which is derived from diffusion tensor imaging (DTI), allows visualization and localization of neural tracts at the subcortical level in three dimensions [14]. Many DTT studies have been published on identification of neural tracts in the human brain, including the corticospinal tract, fornix, cerebellar peduncles, somatosensory tracts, optic radiation, transcallosal fibers and so on [7,9,10,12,18,19,23,27]. Although the detailed anatomy of many neural tracts is already well known, identification of a neural tract in the live human brain using DTT can provide helpful and important information for clinicians in evaluating the state of a neural tract and for predicting clinical outcomes, or to set up scientific management strategies for patients with brain injury.

Somatosensory function has several clinical implications in patients with brain injury in terms of higher incidence of somatosensory dysfunction, association with functional impairment, and accompanying complications, such as abnormal movements or central pain [3,4,6,24]. There are two main somatosensory pathways in the human brain: the spinothalamic tract (STT) and the medial lemniscus (ML) [8]. Since the introduction of DTT, there have been several studies on identification of the ML and its related thalamocortical fibers [9,12,23,25,27]. However, little is known about the STT and its related thalamocortical fibers [12].

In the current study, using DTT, we attempted to identify the STT and related thalamocortical fibers in the human brain.

Twenty-three healthy subjects (male: 13, female: 10, mean age: 26.4 years, range: 20–33 years) with no previous history of neurological, psychiatric, or physical illness were enrolled in this study. All subjects understood the purpose of the study and provided written, informed consent prior to participation. The study protocol was approved by the local Institutional Research Board.

Diffusion-weighted imaging data were obtained using a 1.5-T Philips Gyroscan Intera system equipped with a synergy-L Sensitivity Encoding (SENSE) head coil with two diffusion sensitizing gradients. DTI data were collected using a single shot spin echo planar imaging sequence at a 1.73 mm × 1.73 mm × 2.3 mm. For each of the 32 non-collinear diffusion sensitizing gradients: (Gx,Gy,Gz) = [1,0,1], [0,1,0], [0,0,1], [−0.042,−0.115,−0.993], [0.175,−0.200,−0.964], [0.232,−0.163,−0.959], [0.368,0.026,−0.930], [0.190,0.374,−0.908], [−0.117,0.833,−0.540], [−0.200,0.253,−0.947], [−0.496,0.134,−0.858], [−0.014,−0.628,−0.778], [−0.744,−0.148,−0.651], [−0.761,0.320,−0.564], [−0.181,0.925,−0.335], [−0.680,−0.422,−0.600], [0.777,0.471,−0.418], [0.924,−0.104,−0.368], [0.468,−0.767,−0.438], [0.882,−0.189,−0.432],

* Corresponding author. Tel.: +82 53 620 3269; fax: +82 53 620 3269.
E-mail addresses: strokerehab@hanmail.net, belado@med.yu.ac.kr (S.H. Jang).

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[0.690,0.706,−0.157], [0.239,0.757,−0.608], [−0.058,0.984,0.170], [−0.537,0.836,−0.113], [−0.992,−0.121,−0.042], [−0.997, 0.071,−0.038], [−0.872,0.478,−0.101], [−0.249,0.933,0.258], [0.118,0.992,−0.047], [0.338,0.841,0.422], [0.529,0.841,0.116], [0.997,0.055,−0.057], we acquired 67 contiguous slices parallel to the anterior commissure–posterior commissure line. The imaging parameters used were as follows: matrix = 128 × 128 matrix, field of view = 221 mm × 221 mm, TE = 76 ms, TR = 10,726 ms, SENSE factor = 2; EPI factor = 67 and b = 1000 s/mm^2, NEX = 1, with 2.3 mm slice thickness. For each subject, the SNR_{SENSE} was measured in non-diffusion-weighted images in brainstem. The mean ± standard deviation was measured to be 24.99 ± 13.79.

Diffusion-weighted imaging data were analyzed 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 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) [1,2,21]. The seed region of interest (ROI) in the STT and ML was located according to known anatomy, as described in a brain atlas [7,16,18,19] (Fig. 1A). The target ROI of the STT and ML was located in the primary somatosensory cortex (S1) on the non-diffusion-weighted (b0) image. The values of fractional anisotropy (FA) and mean diffusivity (MD) were measured for the STT and the ML.

Images were subsequently analyzed using the SPM2 software (http://www.fil.ion.ucl.ac.uk). Non-diffusion-weighted (b0) images were normalized to the Montreal Neurological Institute (MNI) echo-planar imaging (EPI) template supplied with the SPM2 (Wellcome Department of Imaging Neuroscience, London, UK) software. After tracking the STT and ML, fiber tracking

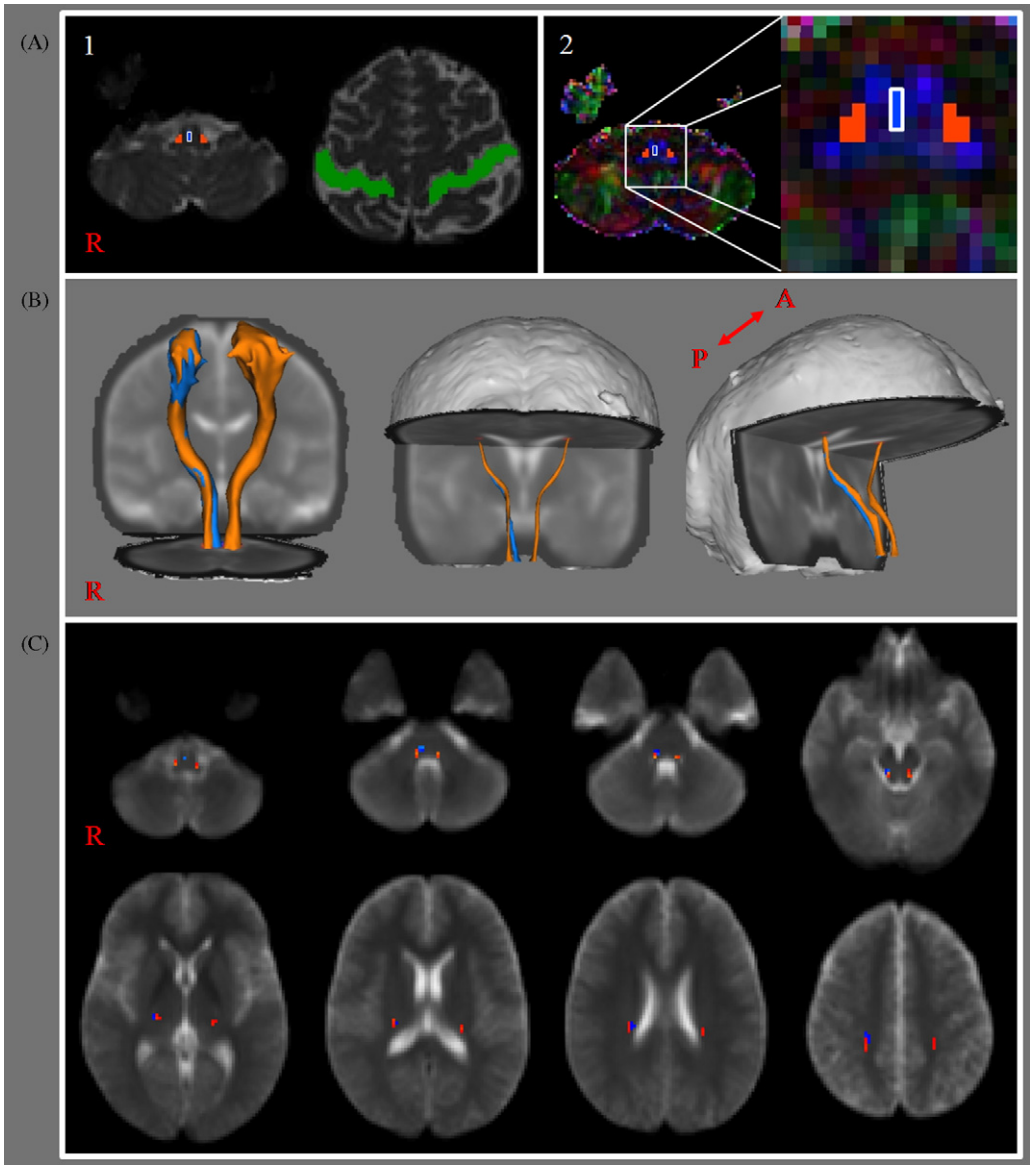

Fig. 1. (A) 1: Seed regions of interest (ROIs) are given at the posterolateral medulla for the spinothalamic tract (red color) and anteromedial medulla for the medial lemniscus (white-lined blue color). Target ROI (green) is located in the primary sensory cortex. 2: color coded image for Fig. 1A-left and enlarged image of Fig. 1A-2-left. Fig. 1A-2-right was magnified the left Image 16.7 times. The target ROI was located at the postcentral gyrus for both spinothalamic tract related thalamocortical fibers. (B) The left image shows voxels color coded from 10 (red or blue) to 100 (yellow or light blue) samples passing through the voxel (red color: spinothalamic tract, blue color: medial lemniscus). Middle and right images show high intensity projection of voxels color coded from 40 (red or yellow) to 100 (yellow or light blue). (C) Axial high intensity projection images of voxels color coded from 40 to 100. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)