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Short communication

Aging of corticospinal tract fibers according to the cerebral origin in the human brain: A diffusion tensor imaging study

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HIGHLIGHTS

- We investigated the differences of aging of CST fiber according to cerebral origin.
- The fiber number of CST from secondary motor cortex was decreased in 70s age group.
- Our results would be helpful for development of strategies with aging of the CST.
- The main function of the secondary motor cortex is motor planning and coordination.

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ABSTRACT

The corticospinal tract (CST) is known to originate from multiple cerebral areas, including the primary motor cortex (M1). In this study, using diffusion tensor imaging (DTI), we attempted to investigate the differences of aging of CST fibers according to the cerebral origin in the human brain. Sixty healthy subjects aged from the 20s to the 70s were recruited, and 10 subjects were assigned to each age group. CST fibers were reconstructed from the M1 (Broadmann's area [BA] 4), the secondary motor area (M2, BA 6), and the primary somatosensory cortex (S1, BA 1–3), respectively. Values of fractional anisotropy (FA), mean diffusivity (MD), and tract volume (TV) of CST fibers from each cerebral area were measured. Significant differences in the TV values of CST fibers from the M2 were observed between the 70s age group and the other age groups, except the 60s age group ($p < 0.05$). However, no significant difference in the values of FA and MD of CST fibers from the M2 were observed between age group ($p > 0.05$). No significant differences in the values of FA, MD, and TV of CST fibers from the S1 and M1 were observed between age groups ($p > 0.05$). We found that the fiber number of CST fibers from the M2 was decreased in the 70s age group compared with the 20s–50s age groups. Because the main function of the M2 is motor planning and coordination, our results would be helpful in development of strategies for coping with aging of the CST.

1. Introduction

Aging of the human brain is inevitable. Detailed knowledge about aging of the human brain would be helpful to understanding the aging process, and to develop of strategies for coping with aging in the elderly. Therefore, many studies have attempted to elucidate the aging of the human brain [7,30,32]. Motor function, along with cognitive function, is important in performance of the activities of daily living. Many studies have reported on the aging of motor function in the human brain, however, the aging process of the neural tracts for motor function has not been clearly elucidated so far [11,15,27,30].

In the human brain, the descending motor pathways are classified according to the corticospinal tract (CST) and non-CST [8,33]. The CST, a major neural tract for motor function in the human brain, is mainly concerned with execution of movement of distal extremities, particularly motor function of the hand [8,12,33]. The CST is known to originate from multiple cerebral areas, including the primary motor cortex (M1), the secondary motor area (M2), and the somatosensory cortex [8,29,33]. The multiple cerebral origins of the CST are important because the function and characteristics of CST fibers are known to differ according to the origin of the cerebral cortex [16,18,22,26,28]. In addition, several studies have suggested

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Table 1
Demographic data for the patient and control groups.

	20s	30s	40s	50s	60s	70s
Age (year)	23.7 (±3.23)	33.7 (±2.21)	44.6 (±2.59)	53.3 (±1.89)	66.3 (±2.21)	73.6 (±2.07)
Sex (male/female)	5/5	5/5	5/5	5/5	5/5	6/4
Handness, (right/left)	10/0	10/0	10/0	10/0	10/0	10/0

that vulnerability to aging could differ according to the brain area or structure: for example, white matter of the prefrontal region, frontal gray matter, or the genu of the corpus callosum have been reported as vulnerable areas with aging [10,17,24].

Recently introduced diffusion tensor imaging (DTI) has enabled evaluation of the integrity of white matter tracts by virtue of its ability to image water diffusion characteristics [2,20]. Diffusion tensor tractography, a three-dimensional visualized version of DTI, has enabled three-dimensional visualization of the architecture and integrity of neural tracts at the subcortical level [2,20]. A few studies have reported on aging-related changes of the CST [11,15,27]. However, these studies focused on the longitudinal changes with aging of the whole CST and no study on aging of the CST according to the cerebral origin has been reported. We hypothesized that aging of the CST might differ according to the cerebral origin because the function and characteristics of CST fibers differ according to the origin of the cerebral cortex [16,18,22,26,28]. Therefore, in the current study, using DTI, we attempted to investigate differences of aging of the CST according to the cerebral origin in the human brain.

2. Methods

2.1. Subjects

Sixty right-handed healthy subjects (males: 30, females: 30, mean age: 49.2 years; range: 20–78 years) with no previous history of psychiatric, neurological, or physical illness, and no brain lesion on conventional MRI (T1-weighted, T2-weighted, fluid attenuated inversion recovery [FLAIR], and T2-weighted gradient recall echo [GRE] images), confirmed by a neuroradiologist, were enrolled in this study. Subjects were divided according to age intervals of 10 years. Ten subjects were recruited for each group. The Edinburg Handedness Inventory was used for evaluation of handedness (Table 1 [23]. All subjects provided written informed consent prior to the start of the study, and the study protocol was approved by the Institutional Review Board of a university hospital.

2.2. Data acquisition

DTI data were acquired using a Synergy-L SENSE head coil on a 1.5T Gyroscan Intera system (Philips, Best, The Netherlands) equipped with single-shot echo-planar imaging. 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, field of view = 221 × 221 mm^2, TR = 10,726 ms, TE = 76 ms, parallel imaging reduction factor (SENSE factor) = 2, EPI factor = 49 and b = 1000 s/mm^2, NEX = 1, slice gap = 0 mm, and slice thickness = 2.3 mm. (acquired voxel size 1.73 × 1.73 × 2.3 mm^3).

2.3. Fiber tracking

The Oxford Center for Functional Magnetic Resonance Imaging of the Brain (FMRIB) Software Library was used for analysis of diffusion-weighted imaging data. Affine multi-scale two-dimensional registration was used for correction of head motion effect and image distortion due to eddy current. A probabilistic tractography method based on a multi-fiber model was used for fiber tracking, and applied in the current study utilizing tractography routines implemented in FMRIB Diffusion (0.5 mm step lengths, 5000 streamline samples, curvature thresholds = 0.2) [3,4,14,31].

The CSTs for Brodmann's areas (BA) 1–4, and 6 were determined by selection of fibers passing through seed and target regions of interest (ROI). The seed ROI was located at the ponto-medullary junction on the color map (anterior blue portion) [28]. Target ROIs were placed as follows: (1) the primary somatosensory cortex (S1); BA 1, 2, and 3 (anterior boundary: central sulcus, posterior boundary: postcentral sulcus, medial boundary: the midline between the right and left hemispheres), (2) the M1; BA 4 (anterior boundary: precentral sulcus, posterior boundary: central sulcus, medial boundary: the midline between the right and left hemispheres), and (3) the M2; BA 6 (anterior boundary: vertical line to the anterior commissure, posterior boundary: anterior margin of the primary motor cortex, medial boundary: midline between the right and left hemispheres) (Fig. 1) [6]. Out of 5000 samples generated from each seed voxel, results for each contact were visualized threshold, and weightings of tract probability at a minimum of one streamline through each voxel for analysis. The values of fractional anisotropy, mean diffusivity, and tract volume of each CST were measured [29,31]. The value of fractional anisotropy indicates the degree of directionality of water diffusion, and represents the white matter organization: in detail, the degree of directionality and integrity of white matter microstructures such as axons, myelin, and microtubules, and the value of mean diffusivity indicates the magnitude of water diffusion [2,21]. The value of tract volume is determined by counting the number of voxels contained within a neural tract and, reflects the total number of fibers in a neural tract [25].

2.4. Statistical analysis

SPSS software (v.15.0; SPSS, Chicago, IL) was used for data analysis. Using multivariate analysis of variance (MANOVA) with LSD post-hoc test, we determined the differences in values for each DTI parameter (fractional anisotropy, mean diffusivity, and tract volume) between age groups. Spearman's correlation analysis was performed for assessment of any significant correlations between DTI parameters (fractional anisotropy, mean diffusivity, and tract volume) of the CST and age. The independent t-test was used for determination of the difference in values of each DTI parameter from each CST between right and left hemispheres, and between male and female. The significance level for the p value was set at 0.05.

3. Results

A summary of mean values of DTI parameters of the CST fibers from each cerebral cortex in each age group is shown in Table 2. Result of MANOVA showed significant difference in the tract volume from the M2 ($p < 0.05$). Significant differences in the value of tract volume of CST fibers from the M2 were observed between the 70s age group and the other age groups, except the 60s age group ($p < 0.05$). However, no significant difference in the values of fractional anisotropy and mean diffusivity of CST fibers from the M2 was observed between age groups ($p > 0.05$). No significant dif-