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Diffusion tensor tractography measurement of the distance between corticospinal tracts in patients with spontaneous intraventricular haemorrhage

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Abstract

Objective: The difference in the widest distance between corticospinal tracts (CST) on diffusion tensor tractography (DTT) in stroke patients with hydrocephalus was investigated retrospectively.

Methods: Distances were measured on an axial slice of the corona radiata, which provided the widest distance between CSTs. Two distances were measured, the absolute distance – the distance between the most medial point of the CSTs and the relative distance – calculated as a percentage of the absolute distance.

Results: The absolute distances of CSTs were 55.34 mm for the patient group and 46.75 mm for the control group. The relative distances of the CSTs were 44.12% and 35.96% for the patient group and the control group. Significant differences in the absolute and relative distances of CSTs were observed between the patient and the control group.

Conclusion: These results suggest that the absolute and relative distances between CSTs might be used to diagnose hydrocephalus in stroke patients.

Keywords

Hydrocephalus, diffusion tensor imaging, corticospinal tract, intraventricular haemorrhage

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Introduction

Hydrocephalus, dilatation of the brain's ventricular system, is usually accompanied by an elevated intraventricular pressure.[1–4] Patients with hydrocephalus show various neurological manifestations, including

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impairment of cognition, gait and urinary control.[1–4] Brain ultrasonography, computerised tomography and conventional magnetic resonance imaging have been used historically for the diagnosis of hydrocephalus.[1,3] However, it is not always easy to estimate the effect on the white matter adjacent to the ventricle with these techniques.[5,6] Diffusion tensor imaging (DTI) allows the evaluation of white matter by visualising water diffusion characteristics within the tissue. In normal white matter, water molecules move relatively freely in a direction parallel to nerve fiber tracts but are restricted moving across tracts. The resulting diffusion anisotropy allows changes in the white matter to be explored.[5–11] Several studies have reported on the usefulness of DTI in the diagnosis of hydrocephalus,[5–11] focusing on the change of DTI parameters, such as the fractional anisotropy (FA) value.

Diffusion tensor tractography (DTT), which is derived from DTI, has a unique advantage in enabling three-dimensional reconstruction of neural tracts in the subcortical white matter.[12] This study measured the distance between neural tracts in the periventricular white matter between hemispheres to determine if this might be indicative of the presence or degree of hydrocephalus in stroke patients. The maximal distance between right and left corticospinal tracts (CSTs) at the corona radiata around the lateral ventricle was measured with DTT and compared between stroke patients with hydrocephalus and controls.

Patients and methods

Patients

Consecutive patients with hydrocephalus following a stroke who were admitted to the Department of Neurosurgery of Yeungnam University Hospital and transferred to the Rehabilitation Department of the same hospital and age- and sex-matched controls with no history of neurological or psychiatric disease, recruited from the local population (Nam-gu, Daegu, Korea) were enrolled for this retrospective study. Patients and controls received DTT between March 2008 and August 2012. A prior pilot study, used to determine the minimum sample size for this study, was analysed using G*Power 3.1 (Heinrich-Heine-Universität Düsseldorf, available from: http://www.gpower.hhu.de/). The information from the pilot study suggested that to achieve an effect size of 3.96, the minimum sample size would be seven in each group with a power or 0.9. This study included patients following their first-ever stroke (spontaneous intraventricular haemorrhage (IVH)), with hydrocephalus confirmed by a neuroradiologist,[13] and who had undergone a shunt operation for hydrocephalus after DTI scanning and for whom DTI scanning had occurred in the chronic stage of the stroke (>1 month after the stroke). Patients were excluded if they showed any brain lesion on conventional MRI except IVH with hydrocephalus.

All patients and controls provided written informed consent, and the study protocol was approved by the Institutional Review Board of Yeungnam University Hospital.

Diffusion tensor image tractography

Data was collected with a 1.5 T Philips Gyroscan Intera system (Philips Healthcare, Best, The Netherlands), equipped with a Synergy-L Sensitivity Encoding (SENSE) head coil and using a single-shot, spin-echo planar imaging pulse sequence. For each of the 32 non-collinear diffusion sensitising gradients, 60 contiguous slices parallel to the anterior commissure/posterior commissure line were acquired. Imaging parameters were as follows: acquisition matrix = 96×96, reconstructed to matrix = 192×192, field of view = 240 mm × 240 mm,

repetition time = 10,398 ms, echo time- = 72 ms, parallel imaging reduction factor (SENSE factor) = 2, echo planar imaging factor = 59 and b = 1000 s/mm^2, number of excitations = 1, thickness = 2.5 mm. Eddy current-induced image distortions were removed using software from the Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB) Software Library (FSL: www.fmrib.ox.ac.uk/fsl). The CST was evaluated using DTI-Studio software (CMRM, Johns Hopkins Medical Institute, Baltimore, MD, USA). The CST was reconstructed using fibers passing through two regions of interest (ROI) on the colour map using an axial image. The first ROI was drawn at the upper pons (portion of anterior blue colour) and the second at the mid pons (portion of anterior blue colour). Termination criteria for fiber tracking were fractional anisotropy < 0.2, angle $< 60^\circ$.[14]

Measurement of CST distance

Distances were measured on an axial slice of the corona radiata. The absolute distance was measured as the distance between the most medial point of both CSTs in the medial lateral horizontal direction. The relative distance was calculated as the percentage of the absolute distance divided by the distance between both lateral margins of the brain at the same horizontal line of both CSTs on the same axial image (Figure 1). The CST distance was calculated in pixel units (1.73 mm) and then converted to millimeters.

Statistical analysis

Statistical analyses were performed using SPSS® software (version 15.0; SPSS Inc, Chicago, IL, USA). An independent *t*-test was used to determine the variance in distance between CST of patients and controls. A *P*-value of < 0.05 was considered statistically significant.

Results

The pilot study results suggested that a minimum sample size of seven patients and seven controls was needed to detect a significant difference in CST distance. This produced a CST absolute distance in patients of 58.38 ± 1.60 and in controls of 46.96 ± 3.74 and a relative distance in patients of 46.19 ± 2.43 and in controls of 36.49 ± 3.14.

For this study, 15 patients with hydrocephalus (eight females, seven males; mean age: 63.18 ± 14.9 years; range: 39 – 75 years) and 15 age- and sex-matched controls (eight females, seven males; mean age: 56.33 years $\pm$ 8.59; range: 39–74 years) who had no history of neurological or psychiatric disease (Table 1) were analysed.

All patients had a spontaneous intracerebral haemorrhage (ICH) and one patient had had a subarachnoid haemorrhage. Data from DTI were acquired 4.9 ± 3.8 months (mean data) after IVH onset.

A summary of the absolute and relative distances of CSTs in both patients and controls is shown in Table 2. Significant differences were observed in absolute distances and relative distance between patients and controls ($P < 0.05$ for both).

Discussion

In the current study, differences in the widest distance between CSTs on DTT in stroke patients with hydrocephalus following IVH were investigated. Our findings showed that both the absolute distance and the relative distance was wider in the patient group with hydrocephalus than in the control group. These results suggest that the absolute and relative distances between CSTs could be used as parameters for the diagnosis of hydrocephalus in stroke patients. Further studies would confirm our finding.

Since the introduction of DTI, studies have reported on hydrocephalus in stroke

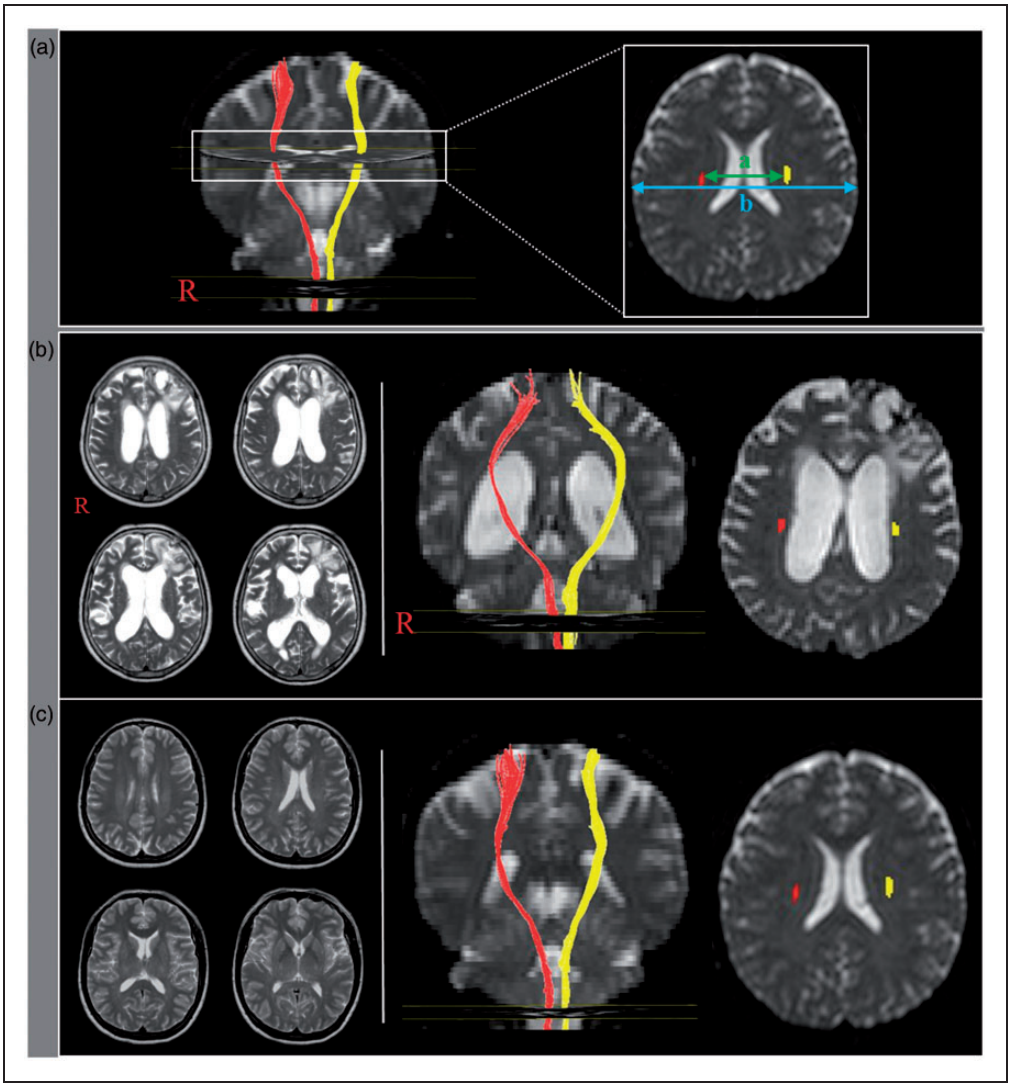

Figure 1. (a) Measurement of the distance either side of the corticospinal tract (CST): green line (a) distance across the CST; sky-blue line (b) diameter across the brain. (b) T2-weighted MRI of a patient showing hydrocephalus and the result of DTT for a CST. (c) MRI of a control, showing no definite lesions and the result of DTT for a CST.

patients.[5,8,10] In 2006, Assaf measured DTI parameters in various periventricular areas around the lateral ventricle before and after surgery for hydrocephalus in seven patients with acute hydrocephalus (six patients with a congenital brain anomaly and one with IVH), and found that FA values decreased after the operation.[5] In 2011, Jang and Kim reported on changes of DTI parameters in a patient with hydrocephalus following ICH

in the right fronto-temporal area due to the rupture of a right middle cerebral artery bifurcation aneurysm.[8] FA values in the adjacent structures of the lateral ventricle, which were increased before the shunt operation, were decreased after the surgery. Yeo *et al*, 2013 investigated the effect of hydrocephalus on periventricular white matter in 14 patients with hydrocephalus following an ICH.[10] DTI parameters were estimated in six ROIs in periventricular white matter: anterior corona radiata, posterior corona radiata, genu of the corpus callosum, splenium of the corpus callosum, anterior limb of the internal capsule and posterior limb of the internal capsule. The results showed that the FA value of the anterior corona radiata in patients was significantly higher than in control subjects. They concluded that the anterior corona radiata was more compressed by hydrocephalus than the other five regions of periventricular white matter.

Table 1. Characteristics of study hydrocephalus patients.

Patient	Sex	Age (years)	Time from IVH to DTI (weeks)	Hydrocephalic drainage
1	M	52	12	X
2	F	55	11	X
3	F	58	6	X
4	M	60	7	O
5	M	62	5	X
6	F	64	6	X
7	F	67	20	X
8	M	70	29	O
9	M	70	5	X
10	F	70	4	O
11	F	73	5	X
12	M	74	25	X
13	F	74	5	X
14	F	75	9	O
15	F	76	7	X
Mean		66.6	10.5	

M, male; F, female; IVH, intraventricular haemorrhage; DTI, diffusion tensor imaging.

The limitations of this study should be considered. Firstly, only a small number of patients and controls were studied. Additional complementary, larger-scale studies are warranted. Secondly, although DTI is a good anatomic imaging tool, which can demonstrate gross fiber architecture, it can produce both false positive and negative results due to crossing fibers or partial volume effects. Further studies to overcome these limitations should be encouraged.

In conclusion, using DTT, we investigated the difference in the distance between CSTs in patients with hydrocephalus following IVH compared with controls, and found that the absolute and relative distances between CSTs were wider in patients with hydrocephalus than in controls. We believe that our results will be useful for diagnosis and management of hydrocephalus and could provide a measure of therapeutic effect following shunt surgery.

Table 2. Measurement of corticospinal tract mean distance and percentage measured at the upper corona radiata.

	Patient group	Control group	Statistical significance
Absolute distance (mm)	55.34 (±4.53)	46.75 (± 3.01)	$P < 0.001$
Relative percentage (%)	44.12 (± 3.72)	35.96 (± 2.27)	$P < 0.001$

Values represent mean (± standard deviation); statistical test: independent t-test

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Declaration of conflicting interest

The authors had no conflicts of interest to declare in relation to this article.

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