Clinical application of diffusion tensor tractography for elucidation of the causes of motor weakness in patients with traumatic brain injury

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Abstract. Diffusion tensor tractography (DTT) is useful for elucidating the status of the corticospinal tract (CST). The purpose of this study was to investigate the usefulness of DTT for determining the causes of motor weakness in patients with traumatic brain injury (TBI). Five patients with TBI were recruited for this study. DTT was performed using 1.5-T with a Synergy-L Sensitivity Encoding (SENSE) head coil. DTT was obtained with termination criteria of FA \(< 0.2\) and an angle change \(> 45^\circ\).

On the DTT of patient 1, who had diffuse axonal injury, the focal lesion was detected in the left pons, and was not detected on routine brain images. In patients with deep cerebral hemorrhage, the integrity of the CST of patient 3 was preserved, although the lesion was more extensive than that of patient 2, who showed severe degeneration with the disruption of the CST at the lesion site. In patient 4, the integrity of the left CST was disrupted by a left transtentorial herniation. Although the CST of the affected hemisphere was connected at the cortex level in patient 5, who had a cortical contusional hemorrhage, the motor function of the lower extremity was worse than that of the upper extremity according to the involvement of the somatotopic area of the primary motor cortex. DTT would be useful in elucidating the causes of motor weakness in patients with TBI at the subcortical level, including conditions such as diffuse axonal injury, deep intracerebral hemorrhage, and transtentorial herniation.

Keywords: Brain injury, diffusion tensor tractography, corticospinal tract, motor function

1. Introduction

The motor weakness in patients with traumatic brain injury (TBI) could result from four injury mechanisms: diffuse axonal injury (DAI), deep cerebral hemorrhage, transtentorial herniation, and focal cortical contusion [2,13,14,21]. An understanding of the underlying mechanisms of injury of motor weakness in patients with TBI is important, because it would enable us to set scientific rehabilitative strategies and predict motor outcomes. The corticospinal tract (CST) is the major neuronal pathway that mediates voluntary movements, and the preservation or recovery of the CST is necessary for good recovery of impaired motor function in patients with brain injury [4,23,26]. Therefore, clarification of the state of the CST is needed to elucidate the causes of motor weakness in patients with TBI.
Many researchers have attempted to elucidate the causes of motor weakness in patients with TBI using various methods, including clinical manifestation, brain CT, conventional brain MRI, or transcranial magnetic stimulation [2,11,14,21]. However, these techniques are limited in that they do not allow for direct visualization of the CST. In contrast, diffusion tensor tractography (DTT), a recently introduced technique, can be used to visualize the architecture and integrity of the CST in three dimensions [1,9,10,12,15,19,20]. The validity and reliability of DTT for the CST has been well-demonstrated in previous studies [5,6,8,19,20]. Therefore, DTT seems to have an advantage to enable us to assess the causes of motor weakness in patients with brain injury.

In the current study, we attempted to investigate the usefulness of DTT for elucidating the causes of motor weakness in patients with TBI.

2. Materials and methods

2.1. Subjects

We recruited five hemiparetic patients (3 men, mean age 41 years (22–67)) for this study (Table 1). Patients with peripheral nerve injury on the electrodiagnostic testing were excluded from this study.

The Motricity Index (MI) was used to measure the motor function of the affected extremities, with a maximum score of 100. The reliability and validity of the MI are well-established [7].

2.2. Diffusion tensor imaging

Diffusion tensor image (DTI) data were acquired with a 1.5-T Philips Gyroscan Intera system equipped with a synergy-L Sensitivity Encoding (SENSE) head coil using a single-shot, spin-echo planar imaging pulse sequence. For each of the 32 noncollinear and noncoplanar diffusion-sensitizing gradients, we acquired 60 contiguous slices parallel to the anterior commissure-posterior commissure line. The imaging parameters were: matrix = 128 × 128 matrix, field of view = 221 × 221 mm², TE = 76 ms, TR = 10,726 ms, SENSE factor = 2; EPI factor = 67 and b = 600 mm²s⁻¹; NEX = 1; and a slice thickness of 2.3 mm.

We also evaluated fiber connectivity using FACT (fiber assignment by continuous tracking), a 3-D fiber reconstruction algorithm in Philips PRIDE software [19]. The termination criteria used for fiber tracking were fractional anisotrophy(FA) < 0.2 and an angle change >45° [16]. A seed region of interest(ROI) was drawn in the CST portion of the anterior mid-pons on a number of 2-D FA color maps. On each of the 2-D FA color maps, another ROI was drawn in the CST portion of the anterior lower pons. Fiber tracts passing through both ROIs were designated as the final tracts of interest. The 3-D fiber tract was also superimposed on T2-weighted axial images.

3. Results

3.1. Patient 1

A 38-year-old, right-handed man who had suffered a traffic accident underwent conservative management for TBI. The patient lost consciousness for 4 days following onset. Brain CT and T2-weighted brain MR images (8 weeks after onset) showed no specific lesion along the pathway of the CST (Fig. 1-A, B). The weakness of the left extremities was 75 (MI, full mark: 100 points) at the time of DTI scanning (8 weeks after onset). The DTT showed that the CST, which originated from the sensorimotor cortex, passed through the known CST pathway (Fig. 1-C). However, disruption was observed in the right pons (Fig. 1-A).

3.2. Patient 2

A 31-year-old, right-handed woman was admitted for conservative management of traumatic intracerebral hemorrhage (ICH) at the right basal ganglia caused by a traffic accident. A brain CT that had been taken at...
Fig. 1. (A) Brain CT images at onset show a hematoma in the left basal ganglia (patient 2, 3), left corona radiata (patient 3), left transtentorial herniation (patient 4-arrow), and left frontal area including the primary motor cortex (patient 5). (B) T2-weighted images at chronic stage reveal leukomalacic changes in the left basal ganglia and corona radiata (patient 2, 3), left cerebral peduncle (patient 4), and left frontal lobe (patient 5). (C) Diffusion tensor tractography for the corticospinal tract at chronic stage (coronal view (left) and axial view (right)). The tracts of both hemispheres passed through the known pathway of the corticospinal tract (affected hemisphere: purple; unaffected hemisphere: yellow). However, the tract of the affected hemisphere in patient 3 passed through the posterior portion of the leukomalacic lesion (arrow), and that of patient 5 originated from the posterior cortex of the lesion (arrow). The tracts of the other patients were disrupted at the left pons level (patient 1, arrow) and the left pons level (patient 4). In addition, the tract of patient 2 did not reach the lesion level due to degeneration (arrow).

the time of onset showed ICH in the right basal ganglia (Fig. 1-A). T2-weighted images at 8 weeks after onset showed leukomalacic changes in the right corona radiata and basal ganglia (Fig. 1-B). The patient presented with complete weakness of the left extremities at onset (MI: 0), and was given an MI score of 48 at
the time of DTI scanning (8 weeks from onset). The CST on the DTT for the affected (right) hemisphere showed degeneration to the right brainstem level, with disruption at the lesion site (Fig. 1-C).

3.3. Patient 3

A 22-year-old, right-handed woman underwent conservative management for traumatic ICH at the corona radiata and basal ganglia, as well as intraventricular hemorrhage in the lateral ventricle caused by a car accident (Fig. 1-A). Leukomalacic changes were observed in the right corona radiata and basal ganglia on T2-weighted images (8 weeks from onset) (Fig. 1-B). She presented with moderate weakness of the left extremities at onset (MI: 58), and the weakness had improved to mild weakness (MI: 75) at the time of DTI scanning (8 weeks from onset). On the DTT, the integrity of the CST was preserved through the posterior portion of the leukomalacic lesion of the right corona radiata and basal ganglia (Fig. 1-C).

3.4. Patient 4

A 48-year-old, right-handed man underwent conservative management for traumatic cerebral contusion and brain edema in the left fronto-parieto-temporal area caused by a traffic accident. The brain CT at onset showed left transtentorial herniation and T2-weighted images at 34 months after onset, as well as a leukomalacic lesion in the left cerebral peduncle and wallerian degeneration in the left pons (Fig. 1-A, B). The weakness of right extremities was 26 (MI) at the time of DTI scanning (34 months after onset). On the DTT, the integrity of the CST of the right hemisphere was well-preserved. However, that of the opposite side showed degeneration to the left pons level, with disruption at the lesion site (Fig. 1-C).

3.5. Patient 5

A 67-year-old, right-handed man who had been involved in a traffic accident underwent conservative management for a contusional hemorrhage on the right frontal lobe (Fig. 1-A). T2-weighted images (5 weeks after onset) showed a leukomalacic lesion in the right frontal area, including the primary motor cortex from the midline to the medial portion of the precentral knob (Fig. 1-B). The weakness of the left extremities was 70 (MI) at the time of DTI scanning (5 weeks after onset), and there was a considerable difference between the upper (MI: 92) and lower extremity (MI: 47). The CST of the affected (right) hemisphere passed through the known corticospinal tract pathway after originating from the posterior cortex of the lesion (Fig. 1-C).

4. Discussion

In the current study, we attempted to investigate the usefulness of DTT for elucidating the causes of motor weakness in patients with TBI. On the DTT of patient 1, who had DAI, a focal lesion that could not observed on the conventional brain MRI was detected in the right pons. In patients with deep cerebral hemorrhage (patients 2 and 3), we could confirm that the integrity of the CST of patient 3 had been spared, although the lesion was more extensive than that of patient 2, who showed severe degeneration with the disruption of the CST at the hematoma level. In patient 4, transtentorial herniation had occurred at the left midbrain, and we could confirm that a disrupted CST with wallerian degeneration to the left pons was the cause of severe motor weakness. In patient 5, who had a cortical contusional hemorrhage, the lesion was mainly located at the somatotopy of the lower extremity in the primary motor cortex, and the lateral portion of the precentral knob that acts as the center of hand motor function was partially spared [27]. Although the CST of the affected hemisphere was connected at the cortex level, the motor function of the lower extremity was worse than that of the upper extremity, coinciding with the involvement of the somatotopy area. Therefore, in the case of the patient with a cortical lesion, the DTT could not accurately explain the characteristics of motor weakness. In brief, DTT could be useful to elucidate the causes of motor weakness in the cases of DAI, deep cerebral hemorrhage, and transtentorial herniation, but might not be useful in cases of cortical lesion such as focal cortical contusion. Therefore, it seems that the DTT may be useful for elucidating the causes of weakness at the subcortical level.

Many studies have attempted to elucidate the causes of weakness using routine brain imaging techniques such as brain CT and conventional brain MRI [2,14, 21]. DTI and DTT comprise a recently introduced technique that allows the evaluation of the integrity of white matter tracts by virtue of its ability to image water diffusion characteristics [3,9,19,24]. Recently, three DTI and/or DTT studies reported that these methods are useful in detecting lesions in patients with DAI, which is not detected on conventional MRI [1,9,17]. Lee et
al. demonstrated the diagnostic usefulness of DTI for patients with DAI in 2006 [17]. Other studies have demonstrated that the focal lesion of the brainstem can be detected in patients with DAI, and the recovery can be demonstrated with DTI and DTT, respectively [1, 9]. On the other hand, Yasokawa et al. demonstrated that DTT with a motor-evoked potential obtained by transcranial magnetic stimulation can be a valuable tool for estimating its severity of DAI [25]. In the current study, we were able to measure DTI parameters (FA and apparent diffusion coefficient values) along with the CST pathway using the ROI method. However, it was impossible to measure the DTI parameters accurately because the CSTs of three patients (patient 1, 2, 4) were completely disrupted at the brainstem. Therefore, we performed this study using DTT data without DTI parameter data.

5. Conclusions

In conclusion, DTT is useful for elucidating the cause of motor weakness in the cases of DAI, deep ICH, and transtentorial herniation. Therefore, it would be helpful in determining the cause of motor weakness at the subcortical level in patients with TBI. We think the combined study of DTT and fMRI would be required to compensate for the weakness of DTT at the cortex level, because fMRI is capable of precisely identifying cortical activation sites due to its excellent spatial resolution at the cortex level [18]. Further studies combined with transcranial magnetic stimulation are needed because it can provide important information about the CST status through the presence or characteristics of motor-evoked potentials [22].

Acknowledgement

This work was supported by a grant of the Korea Healthcare Technology R&D Project, Ministry of Health, Welfare & Family Affairs, Republic of Korea (A084177).

References

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