● RESEARCH ARTICLE

Traumatic axonal injury of the medial lemniscus pathway in a patient with traumatic brain injury: validation by diffusion tensor tractography

Traumatic brain injury (TBI) is a common disability-causing neurological disorder. For successful rehabilitation of TBI patients, a thorough evaluation of the presence and extent of neural injury is essential for determining the optimal rehabilitation strategy and accurate prognosis. However, it is difficult to determine the status of neural tracts.

Diffusion tensor tractography (DTT), derived from diffusion tensor imaging (DTI), enables visualization of neural tracts three-dimensionally (Mori et al., 1999; Yamada et al., 2003; Jang and Seo, 2014). DTT has been used to detect lesions located in various neural tracts including the fornix, cingulum, corticospinal tract, and spinothalamic tract in patients with TBI (Nakayama et al., 2006; Sugiyama et al., 2007; Wang et al., 2008; Choi et al., 2012; Kim et al., 2015). However, few studies have been performed on injury of the medial lemniscus and its thalamocortical pathway, which involves the proprioception (Carey et al., 1993).

In the current study, we reported a patient with injury of the medial lemniscus pathway (ML) following TBI using DTT. A 24-year-old man who was injured in a traffic accident and underwent conservative treatment for contusional hemorrhage in both frontal lobes at the Department of Neurosurgery in Yeungnam University Hospital, Republic of Korea (**Figure 1**).

The patient lost consciousness for 14 days after the accident. Brain MRI at 1 month after onset revealed focal encephalomalatic lesions located in both frontal lobes. Mini-Mental State Examination showed 30 points at 1 month and 7 years after onset. The patient complained of proprioceptive impairment of his left extremities since the onset of TBI. The subscales for tactile sensation and kinesthetic sensation of the Nottingham Sensory Assessment (NSA) were used to determine somatosensory function (Carey et al., 1993). The reliability of the NSA is well-established (Lincoln et al., 1998). In right extremities, any impairment of somatosensory function was not observed at 1 month and 7 years after onset. However, regarding the left extremities, at 1 month after onset, his kinesthetic sensation score indicated impairment (17 [shoulder-3, elbow-3, wrist-2, hand-1, hip-3, knee-2, ankle-2, and foot-1] out of a possible 24 points). At 7 years after onset, his kinesthetic sensation score indicated impairment (20 [shoulder-3, elbow-3, wrist-2, hand-2, hip-3, knee-3, ankle-2, and foot-2] out of a possible 24 points). In contrast, the tactile sensation score was normal at 1 month and 7 years after onset. The patient gave signed, informed consent, and the study protocol was approved by institutional review board of Yeungnam University Hospital, Republic of Korea.

DTI data were acquired at 7 years after onset using a 1.5T MRI system (Gyroscan Intera; Philips Medical Systems, Best, the Netherlands). Sixty-seven consecussive slices were acquired parallel to the anterior commissure-posterior commissure line with 32 gradients. DTI parameters were as follows: acquisition

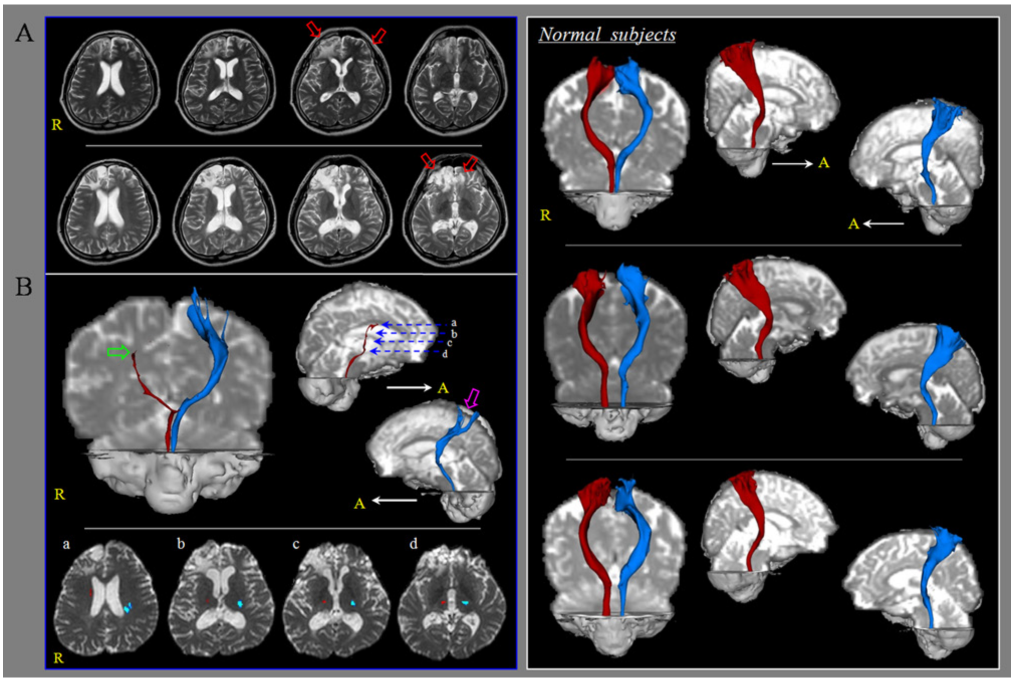

Figure 1 T2-weighted MR images and DTT images of a 24-year-old male patient with traumatic brain injury.
(A) Brain T2-weighted MR images obtained at 1 month (upper row) and 7 years (lower row) after onset showing focal encephalomalatic lesions in both frontal lobes (red arrows). (B) DTTs acquired at 7 years after onset show reconstructed medial lemnisci and their related thalamocortical pathways (MLP) in both hemispheres of the patient. The right MLP in the patient was thinner and discontinued (green arrow) at the corona radiata level compared with the left MLP. In addition, the left MLP showed partial tearing (purple arrow) at the centrum semiovale level (a: upper corona radiata, b: lower corona radiata, c: posterior limb of the internal capsule, d: thalamus). Normal subjects: DTT images of MLP in three normal control subjects (25.6-year-old male, range: 24–27 years old). Green arrow: thinner and discontinued MLP in the right hemisphere at the corona radiate level; purple arrow: partial tearing of MLP in the left hemisphere at the centrum semiovale level. MR: Magnetic resonance; DTT: diffusion tensor tractography; R: right; A: anterior.

matrix = 96 × 96, reconstructed to matrix = 192 × 192, field of view = 240 × 240 mm^2, repetition time = 10,398 ms, echo time = 72 ms, echo-planar imaging factor = 59, b = 1,000 s/mm^2, number of excitations = 1, and a slice thickness of 2.5 mm. The Functional Magnetic Resonance Imaging of the Brain (FMRIB) Software Library (Oxford, UK, FSL; www.fmrib.ox.ac.uk/fsl) was used to analyze DTI data. Eddy current correction was applied. FMRIB Diffusion Software with routine option (0.5 mm step lengths, 5,000 streamline sample, 0.2 curvature thresholds) was used for fiber tracking. Two regions of interest (ROIs) were placed to reconstruct MLPs. Seed ROI was placed in the medial posterior region of the medullary pyramids (Jang and Kwon, 2013). The target ROI was given at the ventroposterolateral nucleus of the thalamus (Jang and Kwon, 2013). The right MLP in the patient was thinner and discontinued at the level of the corona radiata compared with the left MLP, and the left MLP showed partial tearing at the level of the centrum semiovale.

In the current study, the patient showed proprioceptive impairment in the left extremities. On 7-year DTT, discontinuation and narrowing was observed in the right MLP and partial tearing was observed in the left MLP. These findings indicate severe injury of the right MLP and mild injury of the left MLP. Therefore, we believe that injury of the right MLP was ascribed to the proprioceptive impairment of the left extremities and injury of the left MLP did not accompany proprioceptive impairment because the integrity of the left MLP was preserved and injury of the left MLP was only partial tearing at the centrum semiovale level. We consider that diffuse TBI is the most plausible mechanism for right MLP injury because this patient met the diagnostic criteria of diffuse axonal injury (significant acceleration/deceleration injury during a motor vehicle accident, loss of consciousness for 14 days after injury without a lucid interval, and no specific lesion along pathways of both MLPs) (Adams et al., 1982; Parizel et al., 1998).

In summary, injury of the MLPs was demonstrated in a patient with proprioceptive impairment following TBI, using DTT. Our experience with this case suggests that DTT is valuable for detection of MLP injury which cannot be detected on conventional brain MRI after TBI. Although a few previous studies reported on stroke patients with MLP injury by DTT (Hong and Jang, 2010; Seo and Jang, 2014), this is the first study to demonstrate MLP injury in a patient with TBI. However, this study is limited because of a single case report. In addition, use of multi-tensor DTT could generate false positive and negative DTT findings due to crossing fibers in a voxel throughout the brain. Further complementary studies involving larger numbers of patients are warranted.

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