Recovery of an injured corticofugal tract from the supplementary motor area in a patient with traumatic brain injury

A case report

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Abstract

Rationale: We report on a patient with traumatic brain injury who showed motor recovery concurrent with recovery of injured corticofugal tracts (CFTs), diagnosed by diffusion tensor tractography (DTT).

Patient concerns: Four weeks after onset, when the patient started rehabilitation, he showed severe weakness of both upper and lower extremities [Motricity Index (MI, full score: 100/100): 9/30].

Diagnoses: A 29-year-old male patient underwent conservative management for traumatic hemorrhages in both frontal lobes and right thalamus resulting from a car accident.

Interventions: The patient participated in a comprehensive rehabilitative management program, including movement therapy, dopaminergic drugs for improvement of apraxia (pramipexole: 2.5 mg, amantadine: 300 mg, ropinirole: 0.75 mg, and levodopa: 500 mg), and neuromuscular electrical stimulation therapy of the right elbow extensors, finger extensors, both knee extensors, and ankle dorsiflexors.

Outcomes: After 2 months' intensive rehabilitation, his motor weakness rapidly recovered to the point that he was able to move all 4 extremities against some resistance (MI: 75/75). The right supplementary motor area (SMA)-CFT showed narrowing and partial tearing in the upper portion on 1-month DTT, and became thicker on 3-month DTT. Compared to the 12 normal control subjects, the fractional anisotropy (FA) values of the right corticospinal tract and both dorsal premotor cortex-CFT were more than 1 standard deviation lower than those of normal control subjects on both 1- and 3-month DTTs.

Lessons: Although the tract volume of the right SMA-CFT was more than 1 standard deviation lower than normal control subjects on 1-month DTT, it increased to within 1 standard deviation on 3-month DTT. Recovery of the injured SMA-CFT concurrent with motor recovery was demonstrated in a patient with traumatic brain injury.

Abbreviations: CFT = corticofugal tract, CST = corticospinal tract, DTI = diffusion tensor imaging, DTT = diffusion tensor tractography, FA = fractional anisotropy, FMRIB = Functional Magnetic Resonance Imaging of the Brain, LKA = limb-kinetic apraxia, MI = Motricity Index, PMC = premotor cortex, ROI = region of interest, SMA = supplementary motor area, TBI = traumatic brain injury.

Keywords: corticofugal tract, diffusion tensor tractography, limb-kinetic apraxia, traumatic brain injury

1. Introduction

The corticofugal tracts (CFTs) from the secondary motor area are classified according to the CFT from the premotor cortex (PMC) and supplementary motor area (SMA).[1] Because the CFTs are involved in motor planning, injury of the CFTs from the secondary motor area is usually accompanied by limb-kinetic apraxia (LKA).[2] Motor weakness by LKA can be improved by intensive rehabilitation including dopaminergic drugs. Therefore diagnosis of LKA is important in brain rehabilitation.[3–5]

Diffusion tensor tractography (DTT), derived from diffusion tensor imaging (DTI), enables 3-dimensional reconstruction and estimation of the CFTs from the secondary motor area.[1] Several recent studies reported on injury of the CFTs from the secondary motor area,[6–10] although no study has reported on recovery of an injured CFT.

In this study, we report on a patient with traumatic brain injury (TBI) who showed motor recovery concurrent with recovery of the injured CFT, diagnosed by serial DTT.

2. Method

2.1. Participant

One patient and 12 age- and sex-matched normal control subjects (12 men; mean age: 27.1 years, range: 25–30) with no history of neurologic disease were recruited for this study. All subjects provided signed, informed consent, and our institutional review board approved the study protocol.
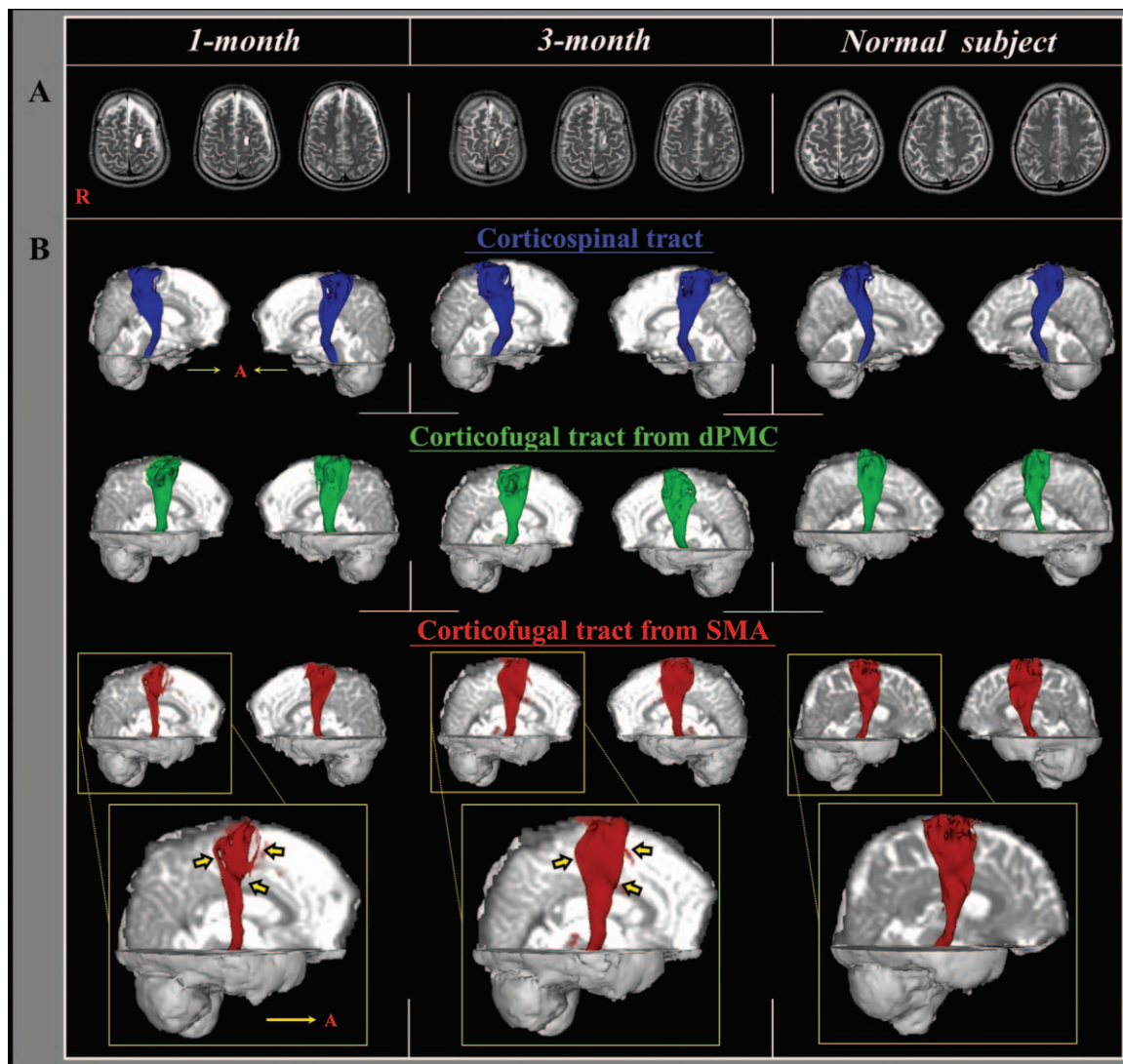
Figure 1. A, T2-weighted brain magnetic resonance (MR) images show a malactic lesion in the left frontal lobe. B, Results of diffusion tensor tractography (DTT). The right corticofugal tract from the supplementary motor area shows narrowing and partial tearing (yellow arrows) in the upper portion on 1-month DTT, with thickening (yellow arrows) on 3-month DTT. dPMC = dorsal premotor cortex, SMA = supplementary motor area.

A 29-year-old male patient who suffered traumatic hemorrhages in both frontal lobes and right thalamus resulting from a car accident underwent conservative management at the department of neurosurgery of a university hospital. The patient was unconscious for approximately 14 days and experienced continuous post-traumatic amnesia from the time of the accident. His Glasgow Coma Scale score was 4 when he arrived at the hospital. Four weeks after onset, he was transferred to the rehabilitation department for rehabilitation. Brain magnetic resonance imaging showed a malactic lesion in the left frontal lobe (Fig. 1A). The patient showed severe weakness of both upper and lower extremities [Motricity Index (MI, full score: 100/100): 9/30][11,12] (Table 1). The patient participated in a comprehensive rehabilitative management program, including movement therapy, dopaminergic drugs for improvement of apraxia (pramipexole: 2.5 mg, amantadine: 300 mg, ropinirole: 0.75 mg, and levodopa: 500 mg), and neuromuscular electrical stimulation therapy of the right elbow extensors, finger extensors, both knee extensors, and ankle dorsiflexors.[3–5] Movement therapy, primarily for improvement of motor function and postural control, was performed 6 days per week (Monday through Friday: 70 min/day, Saturday: 1 h/day). After 2 months' intensive rehabilitation, his motor weakness recovered to the point that he was able to move all 4 extremities against some resistance (MI: 75/75).

Table 1

Motor function changes in the patient.

Duration from onset		Onset	1 mo	3 mo
MRC	Shoulder abductor	0/0	1/3	4/4+
	Elbow flexor	0/0	1/3	4/4+
	Finger flexor	0/0	1/3	4/4+
	Finger extensor	0/0	0/3	4/4+
	Hip flexor	0/0	0/0	4/4
	Knee extensor	0/0	0/0	4/4+
	Ankle dorsiflexor	0/0	0/0	4/4
MI	Upper extremity	0/0	17/59	75/75
	Lower extremity	0/0	0/0	74/74
	Total	0/0	9/30	75/75

MI = Motricity Index, MRC = Medical Research Council.

Table 2

Diffusion tensor image parameter values of the corticospinal tract and corticofugal fibers of the patients and normal control subjects.

		1-mo		3-mo		Normal control subjects	
		Right	**Left**	**Right**	**Left**	**Mean**	**Range of SD**
CST	FA	0.307*	0.376	0.289*	0.366	0.379 (0.020)	0.359–0.398
	Tract volume	6901	6352	6830	6653	6944.9 (1326.0)	5618.9–8270.8
dPMC-CFT	FA	0.306*	0.346*	0.302*	0.329*	0.382 (0.022)	0.360–0.405
	Tract volume	7499	7943	7837	7184	7491.5 (2271.6)	5219.9–9763.1
SMA-CFT	FA	0.361	0.352	0.334	0.336	0.403 (0.057)	0.346–0.459
	Tract volume	2485*	3798	3736	3933	5063.3 (2194.2)	2869.1–7257.5

Control data are presented as mean (±standard deviation).
CFT = corticofugal tracts, CST = corticospinal tract, dPMC = dorsal premotor cortex, FA = fractional anisotropy, SD = standard deviation, SMA = supplementary motor area.
* More than 1 standard deviation of that of normal control values.

2.2. Diffusion tensor tractography

DTI data were acquired twice (1 and 3 mo after onset) using a 6-channel head coil on a 1.5 T Philips Gyroscan Intera (Philips, Ltd, Best, The Netherlands) with single-shot echo-planar imaging. For each of the 32 noncollinear diffusion sensitizing gradients, 70 contiguous slices were acquired parallel to the anterior commissure-posterior commissure line. Imaging parameters were as follows: acquisition matrix = 96×96; reconstructed to matrix = 192×192 matrix; field of view = $240\,mm \times 240\,mm$; TR = 10,398 ms; TE = 72 ms; parallel imaging reduction factor (SENSE factor) = 2; EPI factor = 59; $b = 1000\,s/mm^2$; NEX = 1; and a slice thickness of 2.5 mm (acquired isotropic voxel size $2.5 \times 2.5 \times 2.5$ mm). The Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB) Software Library (FSL; www.fmrib.ox.ac.uk/fsl) was used for analysis of diffusion-weighted imaging data. Affine multiscale 2-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 in fiber tracking, applied utilizing tractography routines implemented in FMRIB diffusion (5000 streamline samples, 0.5 mm step lengths, curvature thresholds = 0.2).[13] For analysis of the CFTs from the dorsal PMC (dPMC-CFT) and SMA (SMA-CFT), the seed region of interest (ROI) was placed on the crus cerebri on the fractional anisotropy (FA) map. The target ROIs were placed on the dPMC (anterior boundary—the line joining the anterior extent of the SMA, posterior boundary—precentral sulcus, medial boundary—the lateral margin of the SMA, lateral boundary—the line passing through the lateral margin of the precentral knob and horizontal to the midline) and the SMA (anterior boundary—the line drawn through the anterior commissure perpendicular to the anterior commissure–posterior commissure line, posterior boundary—anterior margin of the primary motor cortex, medial boundary—midline between the right and left hemispheres, lateral boundary—the line 15 mm lateral from the midline).[14–16] For corticospinal tract (CST) analysis, the seed ROI was placed on the CST portion at the anterior pontomedullary junction on the color map and the target ROI was placed on the primary motor cortex (anterior boundary—precentral sulcus, posterior boundary—central sulcus, medial boundary—the midline between the right and left hemispheres, lateral boundary—the line passing through the lateral margin of the precentral knob and horizontal to the midline).[14] Of 5000 samples generated from each seed voxel, results for each contact were the visualized threshold point at five streamlines through each voxel for analysis. The values of FA and tract volume, determined by counting the voxels of the CST and CFTs, were measured using MATLAB (Matlab R2007b, The Mathworks, Natick, MA).

3. Results

On DTT configuration, the right SMA-CFT showed narrowing and partial tearing in the upper portion on 1-month DTT that thickened on 3-month DTT (Fig. 1B). Compared to the normal control subjects, the FA values of the right CST and both dPMC-CFT were more than one standard deviation lower than those of normal control subjects on both 1- and 3-month DTTs (Table 2). Although the tract volume of the right SMA-CFT was more than 1 standard deviation lower than normal control subjects on the 1-month DTT, it increased to within 1 standard deviation on the 3-month DTT.

4. Discussion

In this study, DTT changes in configuration and parameters of the CST and CFT were tracked in a patient who showed marked motor recovery following severe TBI. The FA values of the right CST and both dPMC-CFT were low on both 1- and 3-month DTTs. By contrast, the tract volume of the right SMA-CFT, which was low on 1-month DTT, increased to within normal range on 3-month DTT. The FA value acts as a proxy measure of white matter organization by indicating the degree of direction-ality of water diffusion, and the tract volume is determined by the number of voxels included in a neural tract.[17,18] Therefore, low FA or tract volume indicates partial injury of a neural tract, whereas tract volume increase indicates recovery of an injured neural tract.[17,18] Persistent low FA values of the right CST and both dPMC-CFTs without reduced tract volume and abnormali-ty of DTT configuration indicates chronicity of mild injury of the right CST and both dPMC-CFT. By contrast, low tract volume and thin and partial tearing of the right SMA-CFT suggested partial injury of the right SMA-CFT on the 1-month DTT, whereas increased tract volume and thickening of the right SMA-CFT indicated recovery of the injured right SMA-CFT on the 3-month DTT. We ascribed the quadriparesis at 1 month after onset in this patient mainly to the injury of the right CST, both dPMC-CFT and right SMA-CFT, whereas the motor recovery of the quadriparesis during the 2 months between months 1 and 3 after the injury was caused primarily by the recovery of the injured right SMA-CFT. The rapid, good recovery of quad-riparesis in this patient is consistent with the resolution of LKA by the recovery of the injured right SMA-CFT.[3–5]

In conclusion, recovery of the injured SMA-CFT concurrent with motor recovery was demonstrated in a patient with TBI. Since the introduction of DTI, several studies have reported on the CFTs from the secondary motor area in the human brain.[6–10] However, to the best of our knowledge, this is the first study to demonstrate

the recovery of an injured CFT from the secondary motor area. However, because it is a case report, this study is limited. Conduct of further complementary studies involving larger numbers of cases is warranted. In addition, several limitations of DTT should also be considered: (1) the fiber tracking technique is operator dependent, (2) DTI may underestimate the fiber tracts. DTI is a powerful anatomic imaging tool that can demonstrate gross fiber architecture, but not functional or synaptic connections, (3) regions of fiber complexity and crossing fibers can prevent full reflection of the underlying fiber architecture.[19,20]

Acknowledgments

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