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Gait Recovery Characteristic According to the Injury Aspect of Descending Motor Pathway in a Chronic Stroke Patient: a Case Study

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Purpose: The stroke patients have gait dysfunction due to impaired neural tracts; corticospinal tract (CST), corticoreticular pathway (CRP), and vestibulospinal tract (VST). In this study, we investigated characteristics of gait pattern according to the injury aspect of the neural track in a stroke patient.
Methods: One patient and six control subjects of similar age participated. A 19-year-old male patient with spontaneous intracerebral hemorrhage on right basal ganglia, thalamus, corona radiata and cerebral cortex due to arteriovenous malformation rupture. Diffusion tensor imaging (DTI) data was acquired 21 months after the stroke. Kinematic and spatio-temporal parameters of gait were collected using a three-dimensional gait analysis system.
Results: On 21 months DTI, the CST and CRP in affected hemisphere showed severe injury, in contrast, the VST in affected hemisphere showed intact integrity. Result of gait analysis, walking distance and speed were significantly decreased in a patient. The stance rate of unaffected lower limb, the swing rate of affected lower limb and the duration of double stance significantly increased compared with normal control. The knee and hip joint angle were significantly decreased in a patient.
Conclusion: We found recovered independent gait ability may be associated with unimpaired VST in a patient with severe injury in CST and CRP.

Keywords: Corticospinal tract, Corticoreticular pathway, Vestibulospinal tract, Gait analysis, Diffusion Tensor Imaging

INTRODUCTION

Stroke patients have multiple impairments contralateral to the brain lesion, including motor deficits, abnormal movements and changes in muscle tone.[1,2] Especially, 20-30% of stroke patients have experienced gait and balance dysfunction related to decrement of joint mobility and stability, and muscle weakness and endurance problem.[3,4] The abnormal gait in a stroke patient is characterized by changes of gait speed, step or stride length, gait variability and joint movement during stance and swing phase of gait.[5-7] Gait analysis provides objective information for spatio-temporal and kinematic parameters that facilitates the quantitative evaluation of an abnormal gait.

Regulation and control of human gait are complex and managed evolutionarily by higher centers, with central locomotor center at the level of the cerebral cortex in conjunction with the basal ganglia and the cerebellum.[8] In addition, many previous studies have reported that human gait is regulated by the corticospinal tract (CST), Corticoreticular pathway (CRP), and lateral and medial vestibulospinal tract (VST).[9-12] The CST is considered essential for skilled gait by modulating the walking pattern in response to environmental influences.[13-15] The CRP mainly mediates proximal and axial muscles and has a major role in relation to walking ability.[16-18] Finally, the lateral and medial VST plays an important role in the control of postural equilibrium and sustentation of vertical posture; specifically, it controls primarily the overall level of postural muscle tone.[11,19,20]

Diffusion tensor tractography (DTT), derived from diffusion tensor imaging (DTI), enables reconstruction of the descending motor pathway three-dimensionally. Several studies have reported on the association between the neural tracts related to walking and gait recovery in stroke pa-

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tients.[21-25] However, little is known about characteristics of spatio-temporal and kinematic parameter of gait according to the injury aspect of the descending motor pathway by stroke. In this study, using a three-dimensional gait analysis and DTT, we investigate characteristics of recovered gait pattern according to the injury aspect of the CST, CRP, and VST in a patent with a chronic stroke.

METHODS

1. Case presentation

One patient with chronic stroke and six control subjects of similar age (four males: mean age 20.2, range 19 to 22) with no history of neurologic disease participated in this study. All subjects provided signed, informed consent, and the study protocol was approved by our institutional review board.

A 19-year-old male patient was diagnosed with spontaneous intracerebral hemorrhage on right basal ganglia, thalamus, corona radiata and cerebral cortex due to arteriovenous malformation rupture at the neurosurgery department of a university hospital (Figure 1A). 21 months after stroke, he was admitted to the rehabilitation department of the other university hospital with moderate motor weakness and gait disturbance. The Motricity Index (MI) score for motor function, with a maximum score of 100, was 48.3 for upper extremity and 51.3 for lower extremity.[26] Functional Ambulation Category (FAC) scale was 3 (needs only verbal supervision for independent gait) and Modified Ashworth scale (MAS) was Grade 1 (slight increment of muscle tone).[27,28] In addition, he maintained good sitting and standing balance, and cognitive function (Mini-mental state examination test: 26 points).[29]

2. Diffusion tensor image

DTI data was acquired 21 months after the stroke using a 6-channel head coil on a 1.5 T Philips Gyro scan Intera (Philips, Best, The Netherlands) and single-shot echo-planar imaging. For each of the 32 non-collinear diffusion sensitizing gradients, 67 contiguous slices were acquired parallel to the anterior commissure-posterior commissure line. Acquired imaging parameters were as follows: acquisition matrix = 96 × 96; reconstructed matrix = 192 × 192; field of view = 240 × 240 mm^2; repetion time = 10,726 ms; echo time = 76 ms; parallel imaging reduction factor = 2; echoplanar imaging factor = 49; b = 1,000 s/mm^2; number of excitations = 1; and a slice thickness: 2.5 mm with no gap (acquired voxel size 1.3 × 1.3 × 2.5 mm^3).

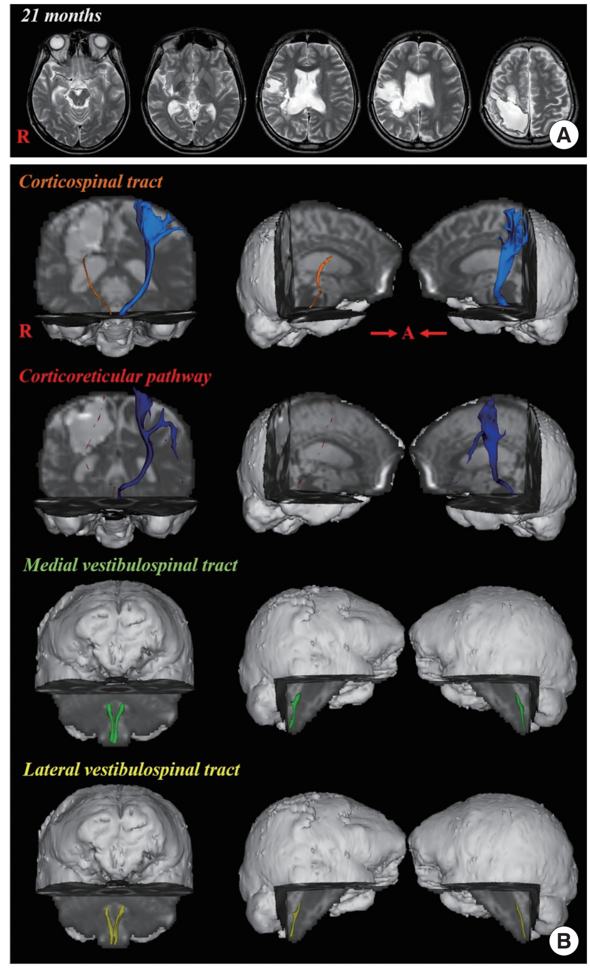

Figure 1. (A) Brain MRI on at 21 months after onset shows injury on the right primary motor cortex, primary somatosensory cortex, corona radiate and basal ganglia due to intracerebral hemorrhage. (B) Diffusion tensor tractography (DTT) of the corticospinal tract (CST), corticoreticular pathway (CRP), medial vestsibulospinal tract (VST) and lateral VST in a patient; the CST and CRP in the affected hemisphere showed severe injury aspect compared with the unaffected hemisphere, by contrast, medial and lateral VST in the affected hemisphere showed intact integrity like the unaffected hemisphere. A: anterior, R: right.

3. Probabilistic fiber tracking

Diffusion-weighted imaging data were analyzed using the Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB) Software Library (FSL; www.fmrib.ox.ac.uk/fsl). Affine multi-scale two-dimensional registration was used for correction of head motion effect and image distortion due to eddy current. Fiber tracking was performed using a probabilistic tractography method based on a multifiber model, and applied in the present study utilizing tractography routines implemented in FMRIB Diffusion (5000 streamline samples, 0.5 mm step lengths, curvature thresholds = 0.2).

Each descending motor pathway was determined by selection of fibers passing through seed and target regions of interest (ROI) as follows; CST: seed ROI- CST portion of the pontomedullary junction on color map, target ROI 1 - CST portion of the anterior mid-pons, target ROI 2 – primary motor cortex;[30] CRP: seed ROI- reticular formation of the medulla, target ROI 1 - the midbrain tegmentum, target ROI 2 - premotor cortex;[17] medial VST: seed ROI-medial vestibular nuclei in the caudal portion of the pons, target ROI - on the posteromedial medulla (corresponding to the medial vestibular nuclei in the medulla);[31-33] lateral VST: seed ROI - the lateral vestibular nuclei in the caudal portion of the pons, target ROI - the posterolateral medulla (corresponds to the reticular formation of the medulla).[31-33] Out of 5,000 samples generated from the seed voxel, results for contact were visualized threshold at a minimum of one streamline through each voxel for analysis.

4. Gait measurement

Kinematic and spatiotemporal parameters of gait were collected using a LEGSys+ wearable device (BioSensics, Cambridge, Massachusetts, USA). Five wearable sensors (5.0 cm × 4.2 cm × 1.2 cm) were connected to a computer by Bluetooth and contained tri-axial gyroscopes, accelerometers, and magnetometers.[34-36] Each sensor was attached by Velcro straps to the anterior surface of both shins 3 cm above the ankle, anterior surface of both thigh 3 cm above the knee, and the low rear center of the posterior superior iliac spine (PSIS). Sampling frequency of sensors used in this study was 100 Hz. Subjects were instructed to walk a 7 m walkway that required five or more strides. The experiment measured each stride's characteristics as they emerged during the gait task. This study obtained kinematic data and spatiotemporal data from the mid-three strides and excluded the first and last strides. We measured range of motion for knee and hip joints, stride length, stride velocity, step length and cadence during the walking (Figure 2). Gait analysis results obtained by automatically calculating spatio-temporal and kinematic parameters for each gait cycle through a LEGsys program and five sensors. Gait parameter showing a deviation of more than two standard deviations (SD) of that of normal control values were defined as abnormal.

RESULTS

On the result DTT in a patient, reconstructed CST, CRP, medial VST and lateral VST in unaffected hemisphere showed intact integrity between each seed and target ROI. In the result of affected hemisphere, the CST was discontinued at level of corona radiata, and CRP showed severe injury aspect between premotor cortex and medullary reticular formation. By contrast, medial and lateral VST showed intact integrity from pontine vestibular nuclei and medullary vestibular areas, like the unaffected hemisphere.

In the spatio-temporal parameters of gait analysis, stride time, swing (%) of affected lower limb, stance (%) of unaffected lower limb, and double support (%) was significantly increased in a patient walking compared

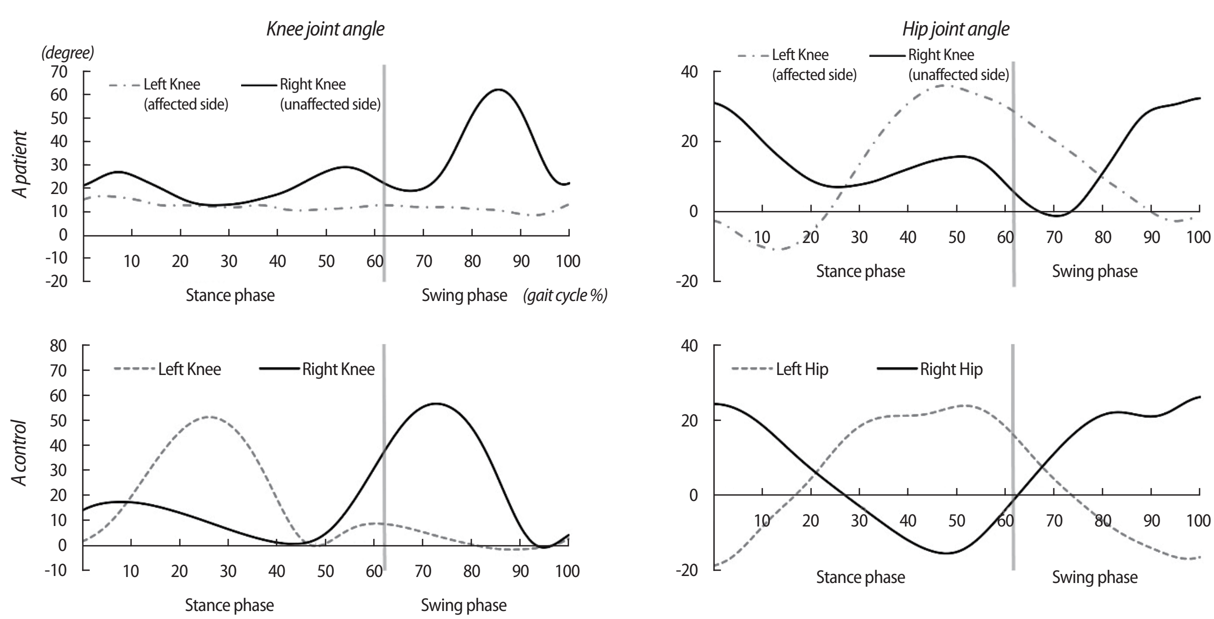

Figure 2. Three-dimensional gait analysis; joint kinematic in the sagittal plane of hip and knee joint in a patient and a control subject (19-year-old male).

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Table 1. Gait spatio-temporal parameters of a patient and control subjects

	Stride length (m)	Stride Velocity (m/s)	Cadence (steps/min)	Step Length (m)	
				Affected (Rt)	Unaffected (Lt)
Patient	0.90*	0.45*	60.52*	0.43*	0.44*
Control (n=6)	1.47 (0.21)	1.41 (0.23)	115.05 (0.93)	0.76 (0.11)	0.71 (0.10)
Normal range	1.89-1.05	1.87-0.94	133.67-96.43	0.98-0.54	0.92-0.50

*is a case not included in the 2SD range.

Table 2. Gait kinematic parameters of a patient and control subjects

	Knee (deg)		Hip (deg)	
	Affected (Rt)	Unaffected (Lt)	Affected (Rt)	Unaffected (Lt)
Patient	51.11*	9.32*	34.29*	48.39
Control (n=6)	62.80 (4.08)	61.54 (3.60)	50.77 (4.61)	50.84 (6.89)
Range	70.96-54.63	68.74-54.33	60.00-41.55	64.61-37.06

*is a case not included in the 2SD range.

with those of control subject (Table 1). By contrast, a patient showed significantly decreased stride length, both step length, gait velocity, cadence, and swing of unaffected lower limb and stance of affected lower limb, compared with control subject. In terms of kinematic parameter, a patient showed significantly decreased movement of knee joint during gait compared with control subject (Table 2). In addition, hip joint movement in affected limb also significantly decreased in a patient compared with subject, without difference of unaffected hip joint movement.

DISCUSSION

In this study, we evaluated injury aspect of descending motor pathway including CST, CRP, medial VST and lateral VST in a chronic stroke patient, and compared difference of gait characteristic between a patient and normal control subject. According to the results of DTT, a patient walked independently despite severe damage to the CST and CRP in affected hemisphere, closely related to gait function. By contrast, the medial and lateral VST in both hemispheres, associated with the balance ability for independent gait, showed normal findings. As a result of gait analysis, a stroke patient showed decreased walking distance (step and stride length) and speed. The ratio of swing to stance phase was also changed compared with normal controls. Especially, the stance rate of the unaffected lower limb, the swing rate of the affected lower limb and the duration of the double stance phase increased remarkably. In addition, the range of movement of the affected and unaffected lower limb considerably decreased. Particularly, it was observed that the knee joint movement in unaffected lower limb was reduced by 85% compared with the normal control group. Consequently, these findings suggest that independent walking is possible even with severe injury to CST and CRP along with stroke, and it may be related to the normal findings of medial and lateral VST that related to the balance control.[37-40] Conversely, severe injury of CST and CRP should be related to deficit of normal control for lower limbs during stance and swing phase of walking.

Several previous studies have reported on stroke patients that walked even after complete injury of the CST and CRP using DTT.[9,13,24] In 2006, Ahn et al.[13] reported 10 patients with stroke that independently walked with complete injury of the lateral CST; the mean value of functional ambulation category score of the patients was 3.5 (0-5). In 2013, Jang et al.[9] also reported that the recovery of independent gait in patients with stroke that showed complete injury of CST and CRP in the affected hemisphere. They suggested that 63% of stroke patients with complete injury of CST and CRP recovered independent walking ability. However, these studies did not provide the level of gait function through quantitative gait analysis and could not accurately define the clinical gait abnormalities. There was only one study that reported gait characteristics according to the injury aspect of the motor descending pathway.[24] In 2014, using motion analysis system and DTT, Seo et al.[24] reported that decreased movement of ankle dorsiflexion, knee internal rotation, and hip flexion can occur by severe injury of the CST and circumduction and abduction gait pattern could be concerned with injury aspect of the CST. However, the changes of gait characteristics according to the injury aspect of the CST and CRP are not well known, and there is scant research on the relationship between medial and lateral VST and gait recovery in stroke patients.

On the other hand, several studies have reported that CST and CRP in the unaffected hemisphere can affect the recovery of gait function in stroke patients.[42,43] In 2013, Jang et al reported functional difference of

CST and CRP in patients with chronic stroke who could walk independently and those who could not walk.[43] They suggested that the patients who walk independently showed significant increment of CRP in unaffected hemisphere compared with patients who could not walk. By contrast the CST in unaffected hemisphere did not differ between two stroke patient group. As a result, it is considered that changes in CRP in the uninjured side hemisphere may have an effect on the recovery of gait function in stroke patients.

In conclusion, we investigated changes of gait characteristic according to the injury of the CST and CRP, and normal findings of medial and lateral VST in a chronic stroke patient. We assumed that changes of spatiotemporal and kinematic gait parameters in a patient should be related with severe injury aspect of the CST and CRP, and restoration of incomplete but independent gait ability may be associated with unimpaired medial and lateral VST. Results of this study can be beneficial in research on analysis of gait ability in patients with stroke and understanding of abnormal gait pattern of patients with brain injury. However, the limitations of this study should be considered. Because it is a case report, the results of this study are limited to generalizations, and no evaluation of DTT in the acute phase. Second, regions of fiber crossing and complexity can interrupt full reconstruction of neural pathway.[41] Third, we could not precisely define the location of ROIs because of the small and cramped size of brainstem nuclei. Last, conduct of further studies with various case of patients should be encouraged because it is a case study.

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