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Original Article

Prediction of motor outcomes and activities of daily living function using diffusion tensor tractography in acute hemiparetic stroke patients

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Abstract. [Purpose] The efficacy of diffusion tensor imaging in the prediction of motor outcomes and activities of daily living function remains unclear. We evaluated the most appropriate diffusion tensor parameters and methodology to determine whether the region of interest- or tractography-based method was more useful for predicting motor outcomes and activities of daily living function in stroke patients. [Subjects and Methods] Diffusion tensor imaging data within 10 days after stroke onset were collected and analyzed for 25 patients. The corticospinal tract was analyzed. Fractional anisotropy, number of fibers, and apparent diffusion coefficient were used as diffusion tensor parameters. Motor outcomes and activities of daily living function were evaluated on the same day as diffusion tensor imaging and at 1 month post-onset. [Results] The fractional anisotropy value of the affected corticospinal tract significantly correlated with the motor outcome and activities of daily living function within 10 days post-onset and at 1 month post-onset. Tthere were no significant correlations between other diffusion tensor parameters and motor outcomes or activities of daily living function. [Conclusion] The fractional anisotropy value of the affected corticospinal tract obtained using the tractography-based method was useful for predicting motor outcomes and activities of daily living function in stroke patients.

Key words: Stroke, Diffusion tensor tractography, Activities of daily living function

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INTRODUCTION

Although the treatment strategies for stroke patients have improved, these patients retain residual disabilities and require rehabilitation before returning to their communities. However, it is difficult to predict the functional outcome of rehabilitation in stroke patients. Therefore, a method that can be used to predict the possibility of recovery in stroke patients is required.

Recently, diffusion tensor imaging (DTI) has been used as a novel method for predicting motor outcomes[1–8]. However, the most appropriate DTI parameters and analysis methodologies, such as the region of interest (ROI)- or tractography-based method, remain unknown. Moreover, the clinical efficacy of DTI as a predictor of the activities of daily living (ADL) function remains unclear. We addressed these points in the present study.

SUBJECTS AND METHODS

Subjects

Twenty-five stroke patients (11 females, 14 males; mean age 71.5 ± 11.0 years; 16 ischemic strokes, 9 hemorrhagic strokes) were analyzed. The inclusion criteria were: (1) the first ever motor deficit resulting from stroke, (2) unilateral paralysis, (3) a modified Rankin Scale score of 3–5 at the time of admission, (4) collection of initial DTI data within 10 days post-onset, and (5) an absence of serious medical complications during hospitalization. This study was approved by the Araki Neurosurgical Hospital ethical committee, and all patients provided written informed consent (Approval number: 007).

Methods

DTI data were acquired by the 3-T MRI scanner (Philips Healthcare, Amsterdam, The Netherlands) using a single-shot echo-planar imaging sequence. The acquisition parameters were as follows: repetition time (TR)/echo time

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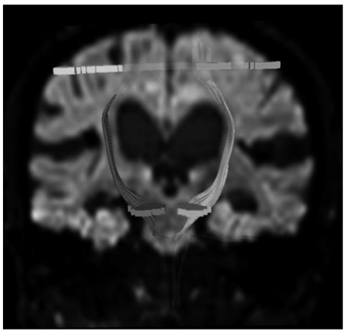

Fig. 1. Location of the ROIs in the corticospinal tract in a normal healthy subject
The first ROI is set at the cerebral peduncle and the second ROI is set at the precentral gyrus.

(TE), 4500–5000/62 ms; motion probing gradient orientations (MPG), 16 axes; b-value, 1000 s/mm2; number of excitations (NEX), 2; bandwidth, 150 kHz; matrix size, 112 × 112; DTI voxel size, 2 mm × 2 mm × 3 mm; and section thickness, 3 mm. The corticospinal tract (CST) was visualized by DTI using FiberTrak software (Philips Healthcare, Amsterdam, The Netherlands). The threshold for stopping propagation was a fractional anisotropy (FA) of <0.15 and an angle change of <27°. DTI data were acquired within 10 days (mean 5.0 ± 3.3 days) post-onset. To image the CST, an ROI was drawn as seeds on the cerebral peduncle and another ROI was drawn as a target on the precentral gyrus (Fig. 1). CST was visualized on both affected and unaffected sides. DTI and clinical data were independently collected by different researchers without knowledge of the other's findings.

The major DTI parameters, including FA, number of fibers, and apparent diffusion coefficient (ADC), were analyzed. The FA and ADC values were obtained for all voxels that comprised the CST (tractography-based method) and each ROI on the axial sections (ROI-based method). The number of fibers was analyzed as the asymmetry index (the number of fibers on the affected side/the number of fibers on the unaffected side).

The motor outcomes and ADL function were evaluated on the same day as the DTI analysis and at 1 month post-onset (mean 27.4 ± 8.8 days), according to the Motricity index (MI)[9], Brunnstrom stage (BR), Barthel index (BI)[10], and Functional independence measure (FIM)[11]. MI is comprised of items for the upper extremities (MI-UE) and lower extremities (MI-LE). BR is comprised of items for the upper extremities (BR-UE), fingers (BR-F), and lower extremities (BR-LE).The total score and motor score (FIM-M) were analyzed with respect to FIM.

The Spearman correlation test was used to determine the relationship between the DTI parameters and clinical outcomes. Statistical analyses were performed using the JSTAT software (Sato, Japan). A p value < 0.05 was considered statistically significant.

Table 1. Correlation between the FA value of the affected CST and clinical outcome within 10 days postonset

Motor outcome	r_s	
MI-UE	0.57	*
MI-LE	0.66	*
BR-UE	0.66	*
BR-F	0.50	*
BR-LE	0.66	*
ADL function	r_s	
BI	0.69	*
BI-gait	0.60	*
FIM	0.66	*
FIM-M	0.65	*
FIM-gait	0.48	*

MI: motricity index; UE: upper extremity; LE: lower extremity; BR: brunnstrom stage; F: finger; ADL: activities of daily living; BI: barthel index; FIM: functional independence measure; FIM-M: motor items of functional independence measure
*: $p < 0.05$

RESULTS

There was a significant correlation between the FA value of the affected CST and motor outcome (BR-UE, BR-F, BR-LE, MI-UE, and MI-LE) within 10 days post-onset (Table 1). In addition, there was a significant correlation between the FA value of the affected CST and ADL function (BI, BI-gait, FIM-M, and FIM-gait) within 10 days post-onset. However, there was either no significant correlation or a low correlation coefficient value between other diffusion tensor parameters (ADC and number of fibers) and function (data not shown).

There was a significant correlation between the FA value of the affected CST and motor outcome (BR-UE, BR-F, BR-LE, MI-UE, and MI-LE) at 1 month post-onset (Table 2). There was a significant correlation between the FA value of the affected CST and ADL function (BI, BI-gait, FIM-M, and FIM-gait) at 1 month post-onset. However, there was no significant correlation between other diffusion tensor parameters (ADC and number of fibers) and function.

DISCUSSION

Regarding the relationship between DTI and motor outcomes during the acute stage, Yamada et al. demonstrated that the DTI findings strongly correlated with the symptoms in subjects with a brain infarction[12]. In addition, Taoka et al. suggested that the degree of the fiber tract damage as estimated by DTI correlated with the severity of Alzheimer disease[13]. In the present study, significant correlations were observed between the FA value of the affected CST and both the motor outcome (BR-UE, BR-F, BR-LE, MI-UE, and MI-LE) and ADL function (FIM, FIM-M, FIM-gait, BI, and BI-gait) within 10 days post-onset. Therefore, our present results also suggest the validity of DTI analysis.

Table 2. Correlation between the FA value of the affected CST and clinical outcome at 1 month postonset

Motor outcome	r_s	
MI-UE	0.65	*
MI-LE	0.60	*
BR-UE	0.61	*
BR-F	0.60	*
BR-LE	0.69	*
ADL function	r_s	
BI	0.72	*
BI-gait	0.65	*
FIM	0.71	*
FIM-M	0.68	*
FIM-gait	0.67	*

MI: motricity index; UE: upper extremity; LE: lower extremity; BR: brunnstrom stage; F: finger; ADL: activities of daily living; BI: barthel index; FIM: functional independence measure; FIM-M: motor items of functional independence measure
*: $p < 0.05$

Regarding the DTI parameters, Kwak et al. used the number of fibers, FA value, and ADC value[14]. Maeshima et al. suggested that the FA value of the affected cerebral peduncle could be used to predict the motor outcomes in patients with intracerebral hemorrhage (ICH)[15]. Kusano et al. reported that in the cerebral peduncle, the ratio of FA between the affected and unaffected sides correlated with the motor outcomes in patients with ICH[16]. Moreover, Zeng et al. reported that the fiber number ratio correlated with the motor outcome at 6 months post ICH onset[8]. Some previous studies have reported the efficacy of the FA ratio or fiber number ratio[8, 16]. Other previous research using DTI analysis showed a change in the CST in the unaffected hemisphere at an early stage of intracerebral hemorrhage[14], suggesting that the CST in the unaffected hemisphere may not be a control for the affected hemisphere. However, there is little evidence regarding the efficacy of ADC. Although there are many previous reports on DTI, the most appropriate DTI parameters and analysis methodologies, such as ROI- or tractography-based method, remain unknown. Murakami et al. reported that compared with the tractography-based method, the ROI-based method was less sensitive for predicting motor outcomes in patients with periventricular leukomalacia[17]. Son et al. reported that the FA value of the CST was a useful functional prediction tool in 2 infants with cerebral palsy[18]. In this study, the FA value of the affected CST significantly correlated with motor outcomes and ADL function in acute hemiparetic stroke patients. Therefore, the FA value of the affected CST was a clinically useful predictive parameter with respect to the motor outcome and ADL function.

In this study, not only the motor outcome in the acute stage but also the long-term motor outcome was investigated using DTI. In previous studies, several authors demonstrated that DTI analysis was useful for predicting the long-term motor outcomes in patients with cerebral infarction[1–5], ICH[6–8], or cervical myelopathy[19]. Puig et al. reported that the ratio of the FA values in pons at 30 days post-onset correlated with the degree of motor deficit at 2 years post-onset[20]. Maeshima et al. reported that the FA value of the affected cerebral peduncle in patients with ICH was useful for predicting the necessity of orthosis at discharge[15]. However, it remains unclear whether DTI analysis can predict ADL function in acute hemiparetic patients. In this study, there were significant correlations between the FA value of the affected CST and both the motor outcome (BR-UE, BR-F, BR-LE, MI-UE, and MI-LE) and ADL function (FIM, FIM-M, FIM-gait, BI, and BI-gait) at 1 month post-onset. These results suggest that DTI analysis can predict not only the motor outcome but also the ADL function. A limitation of this study was that only the CST was analyzed and the observation period was only 1 month. Further studies on other neural fibers and longer-term outcomes are required. In conclusion, we provided novel evidence suggesting that the FA value of the affected CST is a clinically useful parameter for predicting the motor outcome and ADL function in hemiparetic stroke patients.

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