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Clinical Study

Longitudinal study of diffusion tensor imaging properties of affected cortical spinal tracts in acute and chronic hemorrhagic stroke

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ABSTRACT

This study investigated the clinical value of diffusion tensor imaging (DTI) in predicting the motor outcome in patients with basal ganglia hemorrhage. This prospective study included 23 patients assessed with DTI to measure the fractional anisotropy (FA) value in affected cortical spinal tract (CST) at three time points: day 0, day 30 and day 90 after onset. The motor function score (MFS) was applied to evaluate motor function and patients were divided into good and poor outcome groups according to the MFS on day 90. The mean FA value on day 0 was significantly lower in the poor outcome group than in the good outcome group ($p < 0.01$). FA value gradually decreased in the poor outcome group until day 90 after onset, while it continuously increased in the good outcome group. The MFS obtained at day 90 after onset was significantly correlated with the initial FA value in the affected cerebral peduncle ($r = -0.926$, $p < 0.01$). Receiver operating characteristic curve analysis showed that the FA value on day 0 could predict motor function outcome with a sensitivity of 88.89% and specificity of 92.86% at the initial FA value of 0.45. The FA value of affected CST in acute cerebral hemorrhage may valuably predict the motor function outcome and its dynamic change may represent the Wallerian degeneration in motor tracts after hemorrhagic stroke.

1. Introduction

Stroke is one of the most common causes of death and disability in developed and developing countries [1]. Approximately 13% of strokes are caused by hypertensive intracerebral hemorrhage (ICH). Patients with ICH are sometimes treated surgically in order to save their lives, and surgery can reduce mortality rates to some extent [2]. Recently, it has been reported that the long-term disability rate is associated with impairment of the cortical spinal tract (CST) in patients with basal ganglia hemorrhage [3]. Furthermore, neuropathologic studies have shown that neuronal degeneration of the CST can occur as early as several hours after cerebrovascular disease [4,5]. Thus, an early assessment of this degeneration may be of value in predicting the long-term motor function outcome.

Neuroimaging assessment of the CST with methods such as CT scan or conventional MRI has evolved in recent years. However, it is difficult to identify neuronal degeneration in the central nervous system with these traditional methods [6–8]. Diffusion tensor imaging (DTI), a MRI based technique, has proved to be a valuable tool in detecting, visualizing and quantifying the integrity of the cerebral microstructure by measuring the diffusion of water in tissue [9]. Fractional anisotropy (FA) is a quantitative index to identify white matter lesions and evaluate the integrity of white matter tracts [10,11]. In addition, the FA value is reported to be very sensitive in detecting Wallerian degeneration [12]. Both FA values and the integrity of the CST in patients with ICH have also been reported to be associated with the motor function outcome in several studies [13,14]. However, these studies focused on the relationship between initial parameters and the final motor function outcome. To our knowledge, the dynamic changes of the FA of the CST following hemorrhagic stroke has not been well addressed [15].

We hypothesized that the dynamic change of the FA value in the CST might predict motor function outcome in patients with hemorrhagic stroke and represent the Wallerian degeneration of the CST following ICH. Therefore, in this prospective study, we sought to observe the dynamic changes of FA in CST and correlate this to the motor function outcome.

2. Material and methods

2.1. Patients

This study included 25 patients with basal ganglia hemorrhagic stroke confirmed by CT scan in our department within 24 hours of

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onset between January 2010 and December 2010. Of these patients, two were excluded because of missing data. The study population consisted of 23 patients, comprising 15 men and eight women, aged 34–67 years (mean 54 ± standard deviation [SD] 9 years). DTI data were prospectively collected within 24 hours of onset. The initial head CT scan confirmed the hemorrhagic stroke within the basal ganglia. We excluded patients with previous stroke history and medical history of other brain diseases. All of our patients were treated with conservative medical therapies. All patients underwent our current imaging protocol that was approved by the local Ethics Committee after obtaining signed informed consent documents from the patient or responsible relatives.

2.2. DTI

All enrolled patients underwent MRI at three time points: on day 0, day 30 and day 90 after the onset of ICH. MRI was performed on a 1.5 Tesla Signa Excite II scanner (GE Healthcare, Milwaukee, WI, USA). All patients underwent T1- and T2-weighted imaging using short inversion time inversion recovery sequences prior to DTI with the following parameters: inversion time 100 ms, matrix 512 × 384, field of view (FOV) 240 mm, 6.5 mm thickness, and 2 mm gap, as reported previously [14]. For DTI, we applied a single shot spin echo diffusion-weighted echo planar imaging sequence with diffusion gradients applied in six directions (echo time = 64.8 ms, repetition time = 8000 ms, matrix size = 128 × 128, FOV = 240 mm, slice thickness = 3.5 mm, b values of 0 and 1000 s/mm^2, no intersection gap).

2.3. Image analysis

The Volume-One and dTV software (Tokyo University, Tokyo, Japan) were used to perform the imaging post-processing. A seed region of interest was drawn in the CST portion of the affected cerebral peduncle on a T1- or T2-weighted image (Fig. 1, 2). An examiner who was blinded to the patient's data calculated the FA value with the dTV software.

2.4. Motor function assessments

All patients underwent motor function score (MFS) examinations before each MRI at day 0, day 30 and day 90 after onset by an experienced neurosurgeon blinded to the DTI data. All patients underwent the standard physical and post-stroke occupational therapy [14]. The MFS is calculated according to the National Institutes of Health Stroke Scale, which is frequently used to measure the motor function with a score range of 0–8 [16]. Higher scores reflect worse motor deficit [17].

2.5. Statistical analysis

One-way analysis of variance and multivariate testing were employed to compare the FA values, MFS and other clinical characteristics between two groups using the Statistical Package for the Social Sciences version 20.0 software (SPSS, Chicago, IL, USA). To determine the relationship between motor function and the status of CST injury, we performed a Pearson analysis of MFS against the FA value of the affected CST. The receiver operating characteristic (ROC) curve was established to determine significant factors for predicting the outcome. A statistical threshold of $p < 0.05$ was used.

3. Results

The clinical and imaging characteristics of the 23 enrolled patients are shown in Table 1. The good and poor outcome groups included 14 and nine patients, respectively.

The dynamic changes of FA values are shown in Figure 3. The mean FA value gradually decreased until day 90 in the poor outcome group, while it greatly increased in the good outcome group. The mean FA value on day 90 was statistically different between the two groups ($p < 0.01$). The initial FA value was significantly lower ($p < 0.01$) in the poor outcome group (0.491 ± SD 0.040) than in the good outcome group (0.403 ± SD 0.037). Most patients with an initial FA value lower than 0.45 were included in the poor outcome group. In contrast, patients with an initial FA value over 0.45 were mostly included in the good outcome group (Fig. 4).

The results of univariate and multivariate logistic analysis are shown in Table 2. There were no statistical differences in the distribution of patient age, sex, hematoma location, hematoma volume and patients with or without ventricular hemorrhage between the two groups ($p > 0.05$). The FA value on day 0 was the most independent factor for predicting the motor function outcome at day 90 after onset ($p = 0.021$), while the MFS on day 0 did not predict the motor function outcome ($p = 0.101$).

The MFS obtained at day 90 after onset was significantly different between the two groups ($p < 0.05$), and it was negatively correlated with the initial FA value ($r = -0.926$, $p < 0.01$) (Fig. 5).

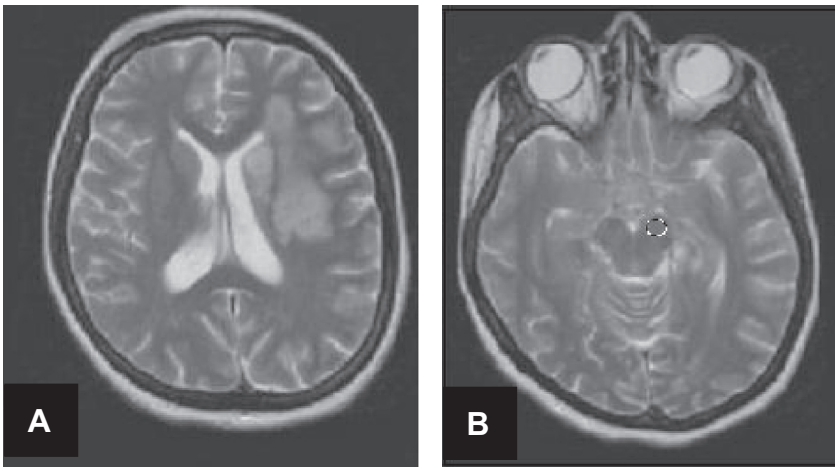

Fig. 1. (A) T2-weighted axial MRI of a patient with a left basal ganglia hemorrhage in the poor outcome group. (B) Regions of interest in the cerebral peduncle (circle) on the lesion side were drawn manually on the MRI.