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The usefulness of the apparent diffusion coefficient value in diagnosing acute spinal cord ischemia

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ABSTRACT

The purpose of our study was to assess the usefulness of the apparent diffusion coefficient (ADC) value in differentiating between a normal spinal cord and a spinal cord with acute ischemia. Control group of 113 and 8 acute spinal cord ischemia patients were enrolled in this study. The ADC values were measured when diffusion-weighted imaging was first performed after the onset of acute spinal cord ischemia. The mean ADC value each of the control group and acute spinal cord ischemia patients was 0.99 ± 0.19 × 10^{-3} mm^2/s and 0.70 ± 0.15 × 10^{-3} mm^2/s. The mean ADC value in patients with acute spinal cord ischemia was significantly lower than that in patients with a normal spinal cord ($P < 0.01$). We found the cutoff ADC value (0.86 × 10^{-3} mm^2/s) to be a useful indicator of acute spinal cord ischemia (sensitivity = 100.0%, specificity = 71.7%, AUC = 0.92). In conclusions, it is suggested that the ADC value may be useful in the diagnosis of acute spinal cord ischemia.

Keywords: apparent diffusion coefficient, spine-MRI, acute spinal cord ischemia, spinal cord infarction, diffusion weighted imaging

Abbreviations:
MRI: magnetic resonance imaging
ADC: apparent diffusion coefficient
DWI: diffusion-weighted imaging
ROI: region of interest

INTRODUCTION

Magnetic resonance imaging (MRI) of acute spinal cord infarction usually shows intramedullary hyperintensity on T_2-weighted MR images. However, MRI shows no abnormality in approximately 45% of patients.[1] The apparent diffusion coefficient (ADC) value as a quantitative value can be calculated from diffusion-weighted imaging (DWI) of MRI. The usefulness of the ADC value

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has previously been reported in several diseases. DWI has recently been reported to be useful for diagnosing acute spinal cord infarction[2-4]; however, diagnosing this is not easy because the normal spinal cord also shows a relatively high signal intensity on DWI.[5,6] Therefore, we hypothesized that not only the high-signal findings of the spinal cord on DWI images but also the ADC values could be used as a reference to differentiate normal spinal cord from acute spinal cord ischemia. The purpose of our study was to verify the usefulness of the ADC value in the normal spinal cord and acute spinal cord ischemia.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of our institution (approval number: 1347). The need for informed consent was waived because of the retrospective nature of the study.

Subjects

The subjects underwent MRI within 7 days of symptom onset, and 8 patients (mean age 75.3 years) were diagnosed with acute spinal cord ischemia. The subjects with a normal spine included 113 patients (mean age 70.8 years) who were suspected with bone tumors, and spinal cord DWI was performed for the control group. The affected parts of the spine in the acute spinal cord ischemia group were the cervical spine in 2 patients and thoracic spine in 6 patients. The regions of the spine in the control group were the cervical spine in 29 patients (mean age 69.1 years), thoracic spine in 27 patients (mean age 72.4 years), and lumbar spine in 56 patients (mean age 70.9 years). Additionally, no cases of suspected acute spinal cord ischemia were included in the control group.

Diagnostic criteria

The diagnostic criteria were as follows: (i) segmental bilateral flaccid weakness and sensory loss, and bowel and bladder dysfunction (with no preceding progressive myelopathy) shortly after (within minutes) acute non-traumatic myelopathy with sudden back pain; (ii) absence of spinal cord compression; (iii) absence of vessel abnormalities with spinal cord lesion; (iv) positive intramedullary T_2-hyperintense spinal cord lesion; (v) DWI/ADC restriction, associated vertebral body infarction, and arterial dissection/occlusion adjacent to the lesion on MRI.[7]

None of the patients were shown spinal cord compression on the MR images. Patients in this study were diagnosed with acute spinal cord ischemia by a neurologist in our hospital. They exhibited neurological symptoms of the disorder of acute onset. They had lesions with high signal intensity that were consistent with the levels of neurological symptoms of the disorder on DWI. Other spinal diseases were ruled out. It has been reported that acute spinal cord infarction is a clinical diagnosis characterized by a sudden onset of paralysis, loss of pain and temperature perception, and bladder dysfunction.[8] All patients had acute-onset pain in this study.

DWI imaging parameter

All examinations were performed on 1.5 T MR scanner (Signa Excite HDxt, GE Healthcare, Connecticut, USA) using spine coil. We used the single shot EPI-DWI parameters: TR = 4000 ms, TE = 71.4 ms, slice thickness = 5.0 mm, bandwidth = 500 kHz, matrix size = 128 × 192, field of view (FOV) = 280–320 mm, phase FOV = 0.5, number of excitations = 6, fat suppression method = short TI inversion recovery, diffusion sensitization gradients oriented along three orthogonal directions at two *b*-values = 0 and 700 s/mm^2, total acquisition time = approximately 100 s.

Data analysis

The ADC value was calculated based on the signal intensity of each region of interest (ROI) at b = 0 s/mm^2 and b = 700 s/mm^2. Three circular ROIs (area: 10 mm^2) at different levels of the spinal cord were set at the site of acute spinal cord infarction, where a high intensity signal was identified by DWI. (Fig. 1) Moreover, the average of the ADC values obtained at the three locations was estimated and used as the actual ADC value, and a radiologist with 10 years of experience performing MRI conducted the ROI setup.

The signal strength was measured with the viewer equipment included in the MR device. The ADC value was calculated using Microsoft Excel (Microsoft, WA, USA).

Statistical analysis

Statistical analyses have performed by Mann Whitney U test and receiver-operating characteristic curve. P-values were $P < 0.05$ were considered statistically significant. R software (version 3.4.1, R Foundation, Vienna, Austria) was used for statistical analysis.

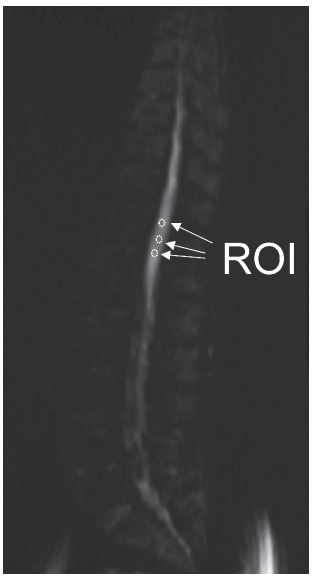

Fig. 1 An example of an ROI setting
ADC values of areas at three different levels (arrows) was measured using a circular ROI of about 10 mm^2.
ROI: region of interest
ADC: apparent diffusion coefficient

RESULTS

Figure 2 shows an example in which the difference in the ADC values between a patient with a normal spinal cord and a patient with acute-phase spinal cord infarction was useful.

Table 1 shows the ADC values for all patients, and Figure 3 shows an example of a difference in the ADC values between a patient with a normal spinal cord and a patient with acute-phase spinal cord infarction. Acute DWI scans were obtained an average of 40.8 ± 60.4 hours (median 6 hours) after symptom onset. In Figure 3, the ADC value was calculated based on the DWI of

the first MR image of acute spinal cord infarction. The mean ADC value in the control group was 0.99 ± 0.19 × 10^{-3} mm^2/s (median: 0.93 × 10^{-3} mm^2/s). The mean ADC value of first MR image of acute spinal cord ischemia was 0.70 ± 0.15 × 10^{-3} mm^2/s (median: 0.75 × 10^{-3} mm^2/s); thus, the ADC value in the acute spinal cord ischemia group was significantly lower than that in the control group ($P < 0.001$) (Fig. 3).

Figure 4 presents the receiver-operating characteristic curve of the ADC values among the patients with a normal spinal cord and acute spinal cord ischemia. We found the cutoff value (0.86 × 10^{-3} mm^2/s) of the ADC value to be useful in acute spinal cord ischemia [sensitivity = 100.0%, specificity = 71.7%, area under the curve = 0.92 (95% confidence interval = 0.84–1)].

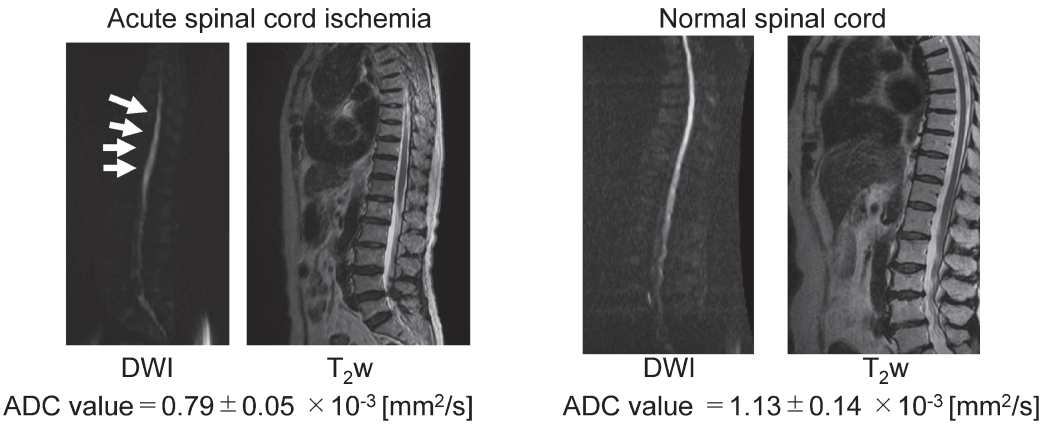

Fig. 2 Differences in ADC values among the patients with a normal spinal cord and acute spinal cord ischemia
The DWI high-intensity signal is indicated by the arrows. On DWI, acute spinal cord ischemia is more commonly observed than normal spinal cord ischemia. Moreover, acute spinal cord ischemia does not exhibit a high intensity signal on T_2-weighted imaging.
ADC: apparent diffusion coefficient
DWI: diffusion-weighted imaging

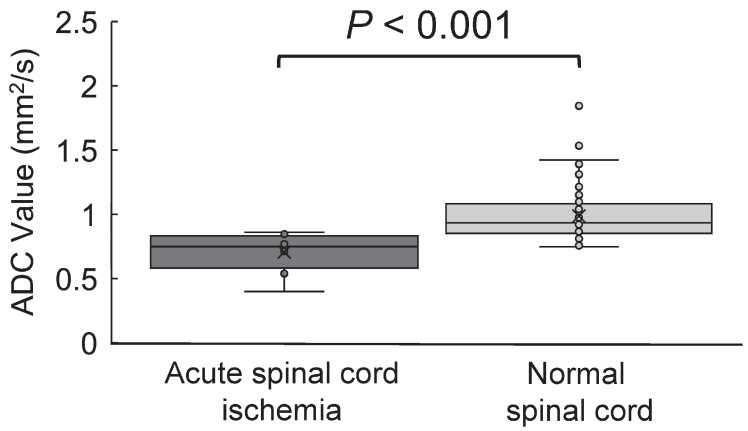

Fig. 3 Differences in ADC values among the patients with a normal spinal cord and acute spinal cord ischemia
Patients with acute spinal cord ischemia had lower ADC values than participants in the control group. ($P < 0.001$)
ADC: apparent diffusion coefficient

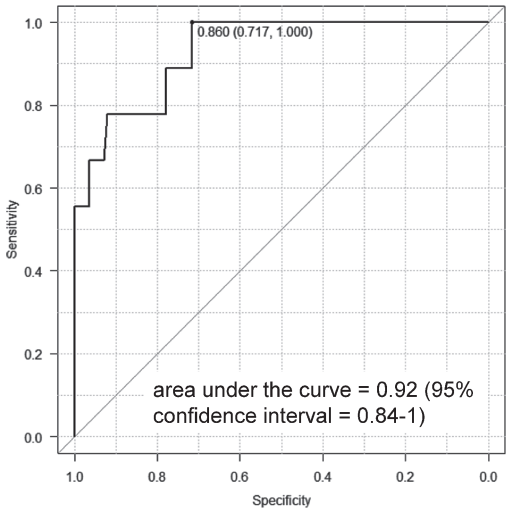

Fig. 4 Receiver-operating characteristic curve of ADC values among the patients with a normal spinal cord and acute spinal cord ischemia

When the cutoff value for ADC values was set at 0.86 × 10^{-3} mm^2/s, sensitivity, specificity, and area under the curve were 100%, 71.7%, and 0.92, respectively (95% confidence interval = 0.84–1).

ADC: apparent diffusion coefficient

Table 1 ADC values of all patients

Patient number	Age (y)	Level of ischemia	Time from onset to initiation of imaging Mean ADC (×10^3 mm^2/s)				
No.1	54	C6–Th3	40 hours 0.39 ± 0.06	Day 7 0.51 ± 0.01	Day 14 0.48 ± 0.03	Day 21 0.55 ± 0.05	Day 34 0.48 ± 0.06
No.2	69	Th11–L1	5.5 hours 0.77 ± 0.04	Day 3 0.83 ± 0.06	Day 10 0.81 ± 0.12	7 month 1.11 ± 0.10	
No.3	78	Th7–L1	4.5 hours 0.79 ± 0.05	29 hours 0.68 ± 0.03	Day 7 0.48 ± 0.04		
No.4	82	C1–7	3 hours 0.54 ± 0.05	27 hours 0.58 ± 0.04			
No.5	82	Th5–7	Day 7 0.86 ± 0.10	Day 8 0.91 ± 0.06			
No.6	92	Th10–L1	5 hours 0.73 ± 0.06	91 hours 1.04 ± 0.05			
No.7	63	Th10–12	6.5 hours 0.71 ± 0.05				
No.8	82	Th9–12	Day 5 0.85 ± 0.07				

ADC: apparent diffusion coefficient

DISCUSSION

It has been reported that abnormal high signal intensity and swelling of the spinal cord on T_2-weighted images become apparent 1 to 2 days after the onset, and the abnormal contrast effect will be delayed before the spinal cord appears.[9] However, this study suggests that it is possible to diagnose acute spinal cord ischemia at an early stage based on the ADC value because it is considered that a decrease in the ADC value can be detected quickly by its evaluation.

In addition, previous studies reported that acute spinal cord infarction might decrease ADC values.[2-4] However, no studies have compared the control group with patients other than those with spinal cord infarction; therefore, prior measurement of ADC values in the control group (normal spinal cord group) may be helpful for diagnosis.

Pseudo-normalization of the ADC in cerebral infarction is considered to be caused by cellular edema. Therefore, it is conceivable that ADC normalization in spinal cord ischemia also occurs as in cerebral infarction.[2,10] However, it has been reported that low ADC values persisted for seven days based on animal studies.[11]

Although it has been reported that DWI shows a high signal intensity in other spinal cord diseases, it has been reported that early-phase spinal cord injury shows a clear decrease in the ADC value.[12-14] However, it may be possible to easily distinguish between the two based on the presence or absence of a history of trauma. Our study suggests the clinical usefulness of DWI and the ADC value for the early detection of acute spinal cord ischemia. However, in rare cases, it is expected that early diagnosis of patients is difficult based on image diagnosis, and therefore, frequent follow-up using MRI including DWI is desirable based on the clinical course such as onset symptoms.

There are limitations to our study. First, the ADC value is affected by the ROI localization, so care must be taken when generating the ROI. ADC values have been reported to depend on the spinal level because we need to measure the cutoff values of the ADC in each spinal region (the cervical spine, thoracic spine, and lumbar spine) in the future.[15,16] Second, patients with a history of cancer and possible metastatic bone tumors were categorized under the control group for this study; however, there were no spinal cord signal changes in DWI, and the patients were considered eligible as a control group compared to healthy participants. Finally, it has been reported that the ADC value depends on the imaging parameters.[17] Therefore, it is necessary to measure the normal ADC values at different hospitals.

CONCLUSION

It is suggested that the ADC value may be useful for the diagnosis of acute spinal cord ischemia.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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