Original Article
pISSN 1738-2637
J Korean Soc Radiol 2011;65(2):101-108

대한영상의학회지

The Role of Diffusion-Weighted MRI in Differentiation of Idiopathic Acute Transverse Myelitis and Acute Spinal Cord Infarction[1]

특발성 급성 횡단성 척수염과 급성 척수 경색의 감별에 있어서의 확산 강조 MR 영상의 의의[1]

Yeo Goon Kim, MD[1], Joon Woo Lee, MD[1], Jae Hyoung Kim, MD[1], Heung Sik Kang, MD[1], Kyung Seok Park, MD[2]

Departments of [1]Radiology, [2]Neurology, Seoul National University Bundang Hospital, Seongnam, Korea

Purpose: To compare the diffusion characteristics of idiopathic acute transverse myelitis (ATM) and acute spinal cord infarction (SCI).

Materials and Methods: Diffusion-weighted images (DWI) and an apparent diffusion coefficient (ADC) map were prospectively obtained from patients diagnosed with myelopathy between February 2006 and April 2009. Inclusion criteria included 1) the presence of an intramedullary T2-high signal intensity and 2) a final diagnosis of idiopathic ATM or SCI established by one neurologist. In total, 13 patients (M : F = 8 : 5; mean age, 39.5 years; range, 29-50 years) with idiopathic ATM and seven patients (M : F = 2 : 5; mean age, 58 years; range, 48-75 years) with SCI were included in this study. Two radiologists evaluated the DWIs and ADC map in consensus. The extent of the cord signal change was also evaluated on T2-weighted sagittal images.

Results: Among the 16 patients with ATM, 14 patients showed iso-signal on an ADC map, but one case showed restricted diffusion and another showed increased diffusion on the ADC map. Among the seven patients with SCI, five patients showed restricted diffusion.

Conclusion: Idiopathic ATM usually does not demonstrate restricted diffusion, which can be a clue to differentiate it from SCI. However, idiopathic ATM with larger segment involvement can show focal diffusion restriction.

Index terms
Diffusion Weighted Image
Acute Transverse Myelitis
Acute Spinal Cord Infarction

Received April 30, 2011; **Accepted** July 12, 2011
Corresponding author: Joon Woo Lee, MD
Department of Radiology,
Seoul National University Bundang Hospital,
166 Gumi-ro, Bundang-gu, Seongnam 463-707, Korea.
Tel. 82-31-787-7609 Fax. 82-31-787-4011
E-mail: joonwoo2@gmail.com

INTRODUCTION

Diffusion-weighted imaging (DWI) has been widely used in both clinical and research fields. The changes in diffusion signal, which reflects changes in the mobility of water molecules, visualize variable kinds of pathology including acute infarction, abscess, neoplasm, and multiple sclerosis in the brain (1). In the spinal cord, DWI might provide useful information about the same pathologies.

A variety of obstacles exist for diffusion-weighted imaging of the spinal cord (2-4). Specifically, the motion of surrounding cerebrospinal fluid (CSF) can cause gross artifacts in inherent motion-sensitive DWI (5). The small size of the spinal cord also necessitates the use of high-resolution images. In addition, multiple interfaces of bone and soft tissue can induce susceptibility artifacts. With the advent of the navigator guided, multi-shot echo planar technique; the clinical application of DWI in the spinal cord has now become feasible (1-6).

Several different diseases present with acute spinal dysfunction. Clinicians might suspect trauma by patient histories. Intraspinal hemorrhage, arteriovenous malformation, disc herniation, and tumors in the spinal canal can be differentiated by conventional MRI. Multiple sclerosis also can be diagnosed clinically with a history of relapsing episodes, CSF ab-

normality, and concurrent white matter lesions on brain MRI. When the conditions mentioned above can be excluded in patients with acute myelopathy, the remaining possible diagnoses include spinal cord infarction (SCI) and idiopathic acute transverse myelitis (ATM).

Distinguishing these two diseases in the acute stage is crucial for planning treatment, but it is challenging for clinicians and radiologists. Both SCI and ATM exhibit intramedullary high signal intensities on T2 weighted images or may show normal conventional MR findings in up to 45% (7) and 34% of cases (8), respectively. In these cases, DWI can be helpful in differentiation. The value of DWI in SCI has been demonstrated in several papers, by showing diffusion restriction in acute stages (3, 4, 9). However, to our knowledge, no study has yet described the diffusion characteristics of ATM. Therefore, the purpose of the present study is to define the diffusion characteristics of idiopathic ATM and to compare them with the diffusion characteristics of SCI.

MATERIALS AND METHODS

Patients

This study was approved by the institutional review board and informed consent was obtained. From February 2006 to June 2009, DWI and an apparent diffusion coefficient (ADC) map were prospectively obtained for patients who visited the department of neurology in our hospital with symptoms of acute myelopathy. The patients who had definite causes for myelopathy, such as structural abnormality, tumorous lesions in spinal canal, or infection, were initially excluded. Inclusion criteria were: 1) the presence of intramedullary high signal intensity on sagittal T2-weighted images (T2WI), and 2) a final diagnosis of idiopathic ATM or SCI. The diagnosis of idiopathic ATM was established by one neurologist, using the criteria of the Transverse Myelitis Consortium Group (8, 10-13). The diagnosis of SCI was established by one neurologist and one spine radiologist, with the clinical course and follow up response after treatment (7, 14-16). Patients with disc herniation at the same level as the high intramedullary signal intensity on T2WI were also excluded. Ultimately, 13 patients (M : F = 8 : 5; mean age, 39.5 years; range, 29-50 years) with idiopathic ATM, and seven patients (M : F = 2 : 5; mean age, 58 years; range, 48-75 years) with SCI were included in this study. Four patients were also included in the idiopathic ATM from a previous study about diffusion tensor images (17). In the ATM group, seven patients initially presented with the disease and six patients had been previously diagnosed with ATM. Of the six, four patients had relapsed symptoms, while the other two patients were in symptom-free periods. None of the patients with ATM had a definite cause for their disease. All seven patients in the SCI group had been initially attacked, presenting with acute spinal dysfunction. Six patients had an unremarkable medical history; without history of stroke or hypertension. In one patient, SCI had occurred as a complication after a bronchial artery embolization.

For the diagnosis of ATM, cerebrospinal tapping was performed in all cases. Among the 13 patients with ATM, CSF pleocytosis was detected in only three patients. For the other 12 patients, the CSF revealed no sign of inflammation. According to the criteria of the Transverse Myelitis Consortium Group, these 12 patients were classified as "possible ATM".

DWI Techniques

A 1.5-T MR scanner (Gyroscan Intera, Philips Healthcare, Las Vegas, NV, USA) was used for DWI. Head and neck coils were applied to all subjects. DWI with ADC maps were added to conventional sequences, including T1, T2 weighted images and contrast enhanced T1 weighted images of the axial and sagittal planes. Sensitivity encoding (SENSE) single-shot echo-planar imaging with a pulse sequence and SENSE factor of 2 was used for the sagittal DWI in the cervical spinal cord with a b-value of 900 s/mm^2; 15 diffusion gradient directions, five excitations, and a 4-mm slice thickness. The diffusion gradient strength was 30 mT/m, the foldover direction was anteroposterior, and the fat shift direction was posterior. The TR/TE was 7,000/100 msec, with a matrix of 112 × 128; the field of view of 224 × 224 mm, and a 4-mm slice thickness.

Image Analysis

Two radiologists; one an experienced spine radiologist and the other a resident doctor, evaluated the DWIs and ADC maps in consensus. They also evaluated T2-sagittal images, focusing on the extent of signal changes. The extent of the lesions was measured using the height of the vertebral body as

the unit of measurement. The patients having different DWI or ADC map signal characters were compared in terms of the extent of the T2-high signal.

RESULTS

Table 1 summarizes the MR findings. Most of the patients (11 of 13, 85%) with ATM did not show restricted diffusion on ADC maps (Fig. 1). Only two of the 13 patients (15%) with idiopathic ATM showed restricted or increased diffusion on ADC maps. A patient showed restricted diffusion, while the other showed increased diffusion on the ADC map.

Among the 11 idiopathic ATM patients with iso signal intensity on ADC, a high signal intensity on DWI was observed in eight patients (8/11, 72%), which can be regarded as a T2 shine-through effect due to high signal intensity on the T2 weighted sequence. The other three patients with idiopathic ATM showed iso-signal intensity on both the DWI and the ADC map.

The restricted or increased diffusion on ADC maps tend to appear in ATM patients who have larger intramedullary T2-high signal lesions. All three patients with idiopathic ATM and an iso-signal on both the DWI and the ADC map had less than one spine segment involved. The extent of the signal change was two spine segments for patients with restricted diffusion (Fig. 2), and four spine segments in one patient with increased diffusion (Fig. 3). In the case with increased ADC signal, the DWI signal was isointense. The isointense signal on DWI was derived from the summation of low signal intensity according to increased diffusion and high signal intensity from the T2 shine-through effect.

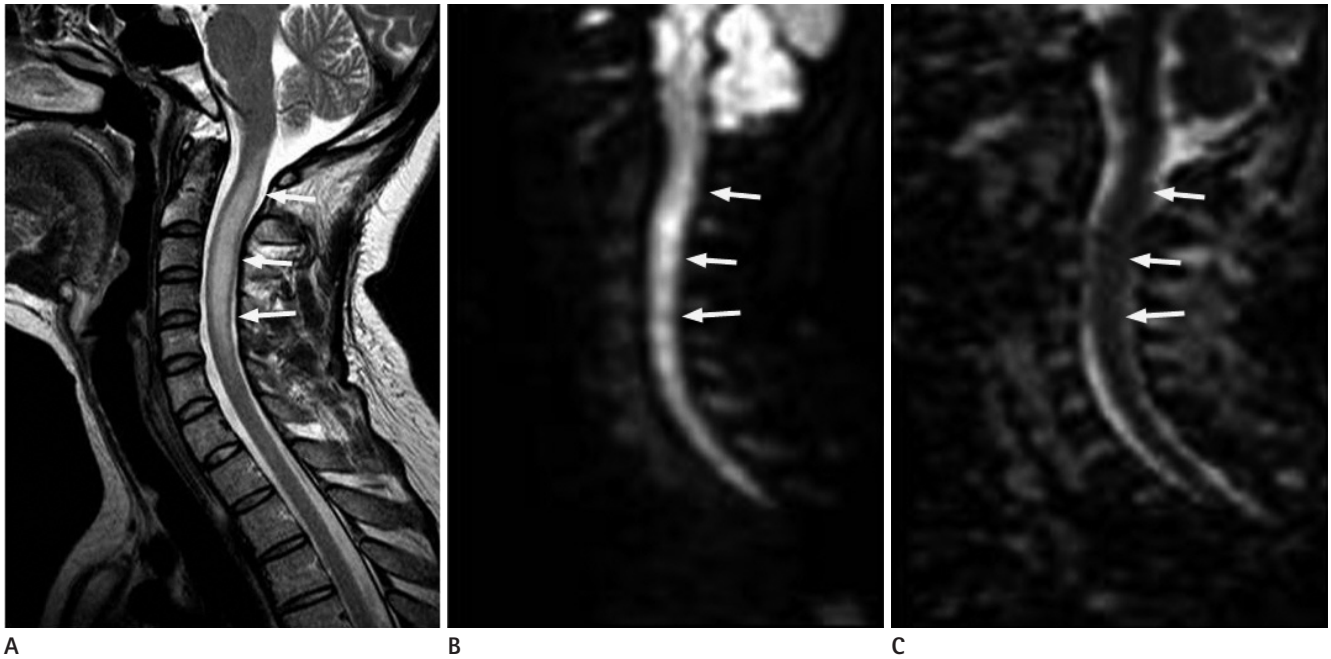
The extent of signal change in the 8 patients with a T2 shine-through effect were 2.7 spine segments on average (range 1-7). The mean length of the lesion in patients without diffusion restriction was about two vertebral body heights.

Among the seven patients with SCI, five showed restricted diffusion (Fig. 4). The other two patients had iso-signal inten-

Table 1. Signal Changes on Diffusion Weighted Images (DWI) and Apparent Diffusion Coefficient Map on MRI

	DWI ↑, ADC – DWI –, ADC –	DWI ↑, ADC ↓	DWI –, ADC ↑
ATM (*n* = 19)	16 (85%)	2 (10%)	1 (5%)
SCI (*n* = 7)	2 (29%)	5 (71%)	0 (0%)

Note.—ATM = acute transverse myelitis, SCI = acute spinal cord infarct, DWI = diffusion weighted images, ADC = apparent diffusion coefficient map, ADC- = iso-signal intensity on ADC, ADC ↑ = high signal intensity on ADC, ADC ↓ = low signal intensity on ADC



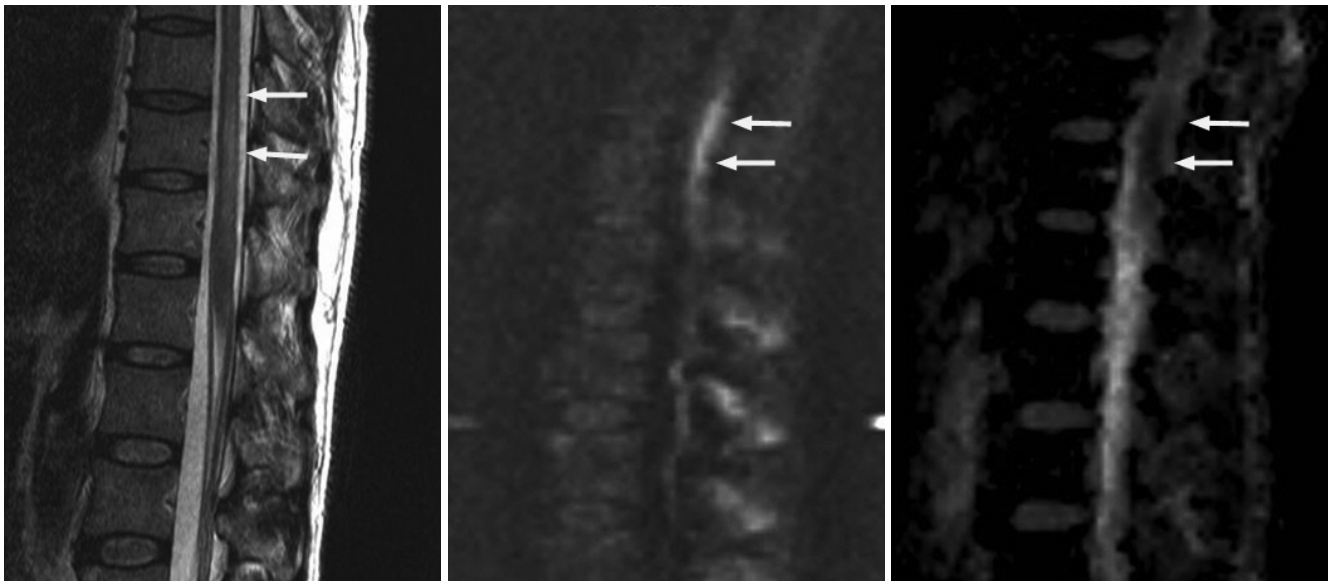
A B C

Fig. 1. A 32-year-old woman with acute transverse myelitis.
A. Sagittal T2 weighted image shows intramedullary high signal intensity with cord swelling from level C1 to C6 (arrows).
B, C. Diffusion weighted image and apparent diffusion coefficient map demonstrate no abnormal signal change (arrows).

sity on the ADC map. The five patients with SCI showed restricted diffusion irrespective of the extent of the signal change (five, four, three, one spine segment, and diffuse involvement from thoracic level to the conus). In the two patients without restricted diffusion, the extent of the involved lesion was 4 and 1 spine segment in each patient.

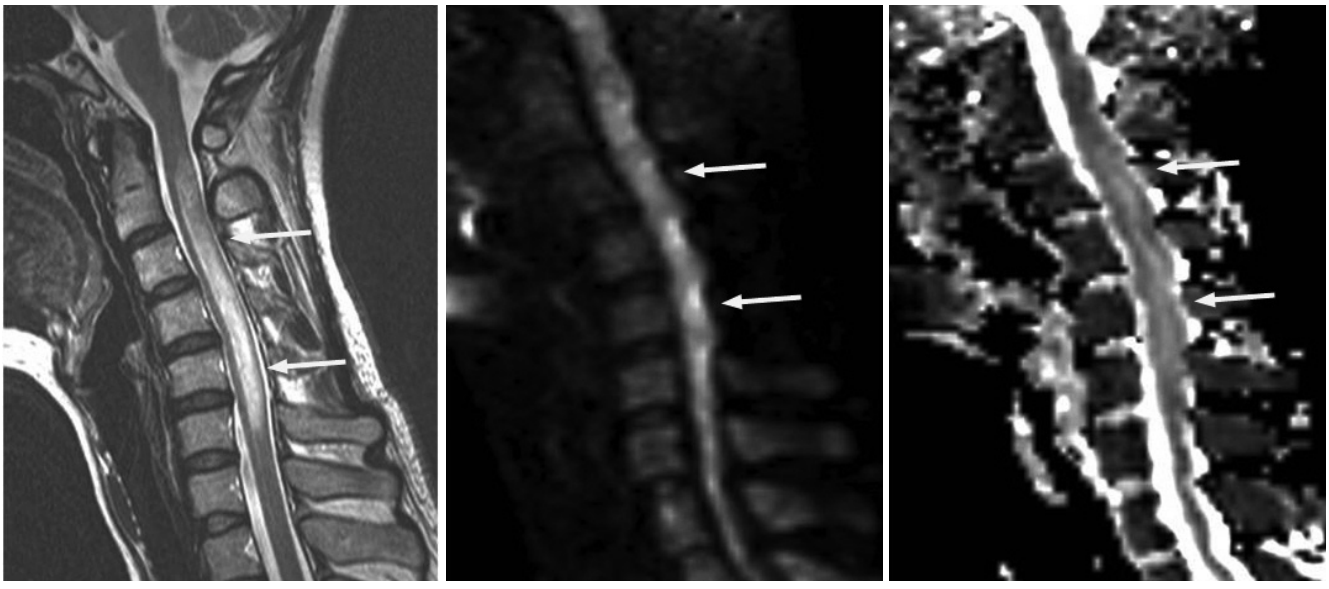
DISCUSSION

ATM is characterized by acute or subacute onset spinal



A B C

Fig. 2. A 49-year-old man with acute transverse myelitis.
A. Sagittal T2 weighted image shows intramedullary high signal intensity lesion from level T8 to T11 (arrows).
B, C. Diffusion weighted image **(B)** and apparent diffusion coefficient map **(C)** illustrate focal diffusion restriction in a cord lesion on a T2 weighted image (arrows).



A B C

Fig. 3. A 29-year-old woman with acute transverse myelitis. MRI taken 5 days after onset of symptoms.
A. Sagittal T2 weighted image shows intramedullary high signal intensity with cord swelling from level C2 to C6 (arrows).
B. Diffusion weighted image shows iso-signal intensity, probably due to a summation effect of T2 shine-through effect and increased diffusion (arrows).
C. Apparent diffusion coefficient map demonstrates high signal intensity, which implies increased diffusion (arrows).

cord dysfunction involving both the anterior and posterior spinal cord (10). Clinical findings include motor, sensory, and autonomic symptoms. ATM is a rare disorder with an incidence of one to four new cases per million per year (18). ATM affects all ages, with bimodal peaks between ages of 10 and 19 years and 30 to 39 years. No gender or familial predisposition has been reported (19).

ATM can be classified into idiopathic ATM and disease-associated ATM. Disease-associated ATM can be diagnosed if a patient is predisposed to having an inflammatory disease (i.e., multiple sclerosis, systemic lupus erythmatosus, Sjogren syndrome, Behcet disease, or sarcoidosis) (20). ATM can be the presenting features of demyelinating disease such as neuromyelitis optica or multiple sclerosis. In ATM patients, 75% to 90% have monophasic disease, while 20% of patients have recurrent episodes. Patients with multifocal lesions in the spinal cord, concurrent lesions in the brain, oligoclonal bands in the CSF, or serum auto-antibodies, are at greater risk of recurrence (19). The diagnosis of idiopathic ATM can be made by the criteria proposed by the Transverse Myelitis Consortium Working Group. According to these criteria, a diagnosis of ATM requires evidence of inflammation. The presence of inflammation is determined only by MRI and CSF analysis. Therefore, the low sensitivity and specificity of CSF study limits these criteria. Consequently, cases that satisfy all criteria except evidence of inflammation in CSF studies are labeled as "possible ATM" (10).

SCI is a severe neurological condition with a poor prognosis, resulting in paraplegia in 33% of patients (9). No established treatment for spinal cord infarction exists, but anticoagulation with heparin and aspirin appears to improve outcome (21-23). The usefulness of DWI in spinal cord infarction has been demonstrated in several papers (3, 4, 9, 24-26). Thurnher and Bammer (9) reported six cases of spinal cord infarction that demonstrated diffusion restriction and they were previously reviewed in published reports. In a majority of patients with spinal cord infarction, signal abnormalities were noted in both T2 weighted images and diffusion weighted images.

The differentiation of ATM from SCI is important for several reasons. First, the therapeutic strategy is different for each disease. Initial treatment should include anticoagulation and steroid therapy until a definitive diagnosis is made. Further, both anticoagulation and steroid therapy has a considerable risk of dangerous complications. Therefore, diagnosis should be made as soon as possible. Second, the diagnostic

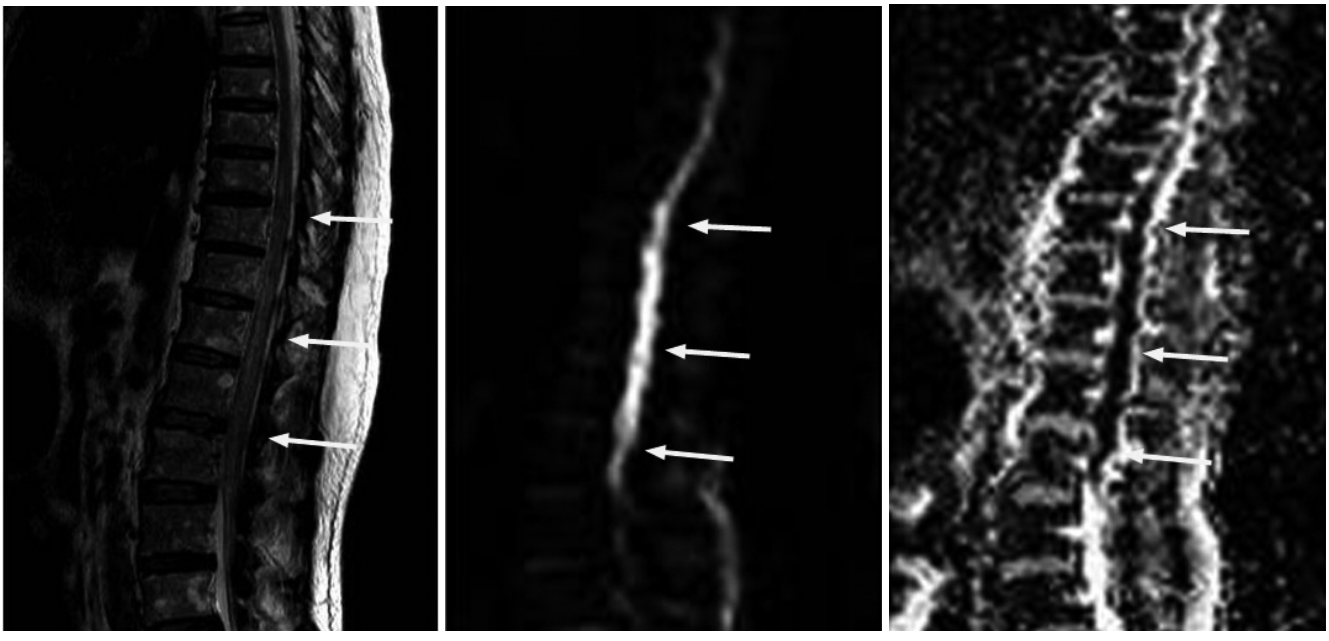


Fig. 4. A 75-year-old woman with a spinal cord infarction.
A. Sagittal T2 weighted image illustrates diffuse intramedullary high signal intensity with cord swelling from level T8 to conus (arrows).
B, C. Diffusion weighted image and apparent diffusion coefficient map demonstrate diffusion restriction in the affected level (arrows).

plan is different for each disease. After exclusion of vascular myelopathy, additive studies (i.e., brain MR, orbit MR) should be undertaken in ATM patients to test for the possibility of multiple sclerosis or neuromyelitis optica. Lastly, the prognosis of ATM is very different from that of SCI.

This study was designed to demonstrate diffusion characteristics of ATM, with an assumption that the diffusion characteristics would help in differentiating ATM and SCI. In most cases of ATM, diffusion restriction was not identified. In contrast, diffusion restriction was noted in most SCI cases, consistent with previous reports (3, 4, 9, 24-26). In two patients with a relatively larger extent of ATM involvement, abnormal signal intensity was noted on ADC. In a patient, the ADC signal was increased, which implied increased diffusion. Renoux et al. (27) also observed increased ADC and fractional anisotropy in two multiple sclerosis patients. They explained that the increased ADC may be due to modifications of the extracellular compartments caused, for example, by intracellular edema with inflow of the extracellular space or by cellular infiltration by inflammatory cells.

According to our results, DWI with an ADC map can give useful information for differentiating ATM and SCI. However, in patients with long segmental cord lesions, changes in the ADC map can be demonstrated. In patients with very small (less than one spine segment) cord lesions, the changes in DWI can be missed due to the low spatial resolution of DWI.

Our study has some limitations. First, the number of patients was small in both the ATM and SCI groups since these are both rare disorders. Second, the duration between the onset of symptoms and the date of MRI was not unified in the ATM group. The duration varied from a few hours to one month. The temporal changes in signal on diffusion-weighted images could have been a compounding factor in this study. Therefore, further study is needed that is focused on signal changes of ATM on DWI with time courses. Lastly, the spatial resolution was low because axial images of DWI and ADC were not available. In conclusion idiopathic ATM usually does not demonstrate restricted diffusion, which can be a clue for differentiating it from SCI. However, idiopathic ATM would rarely show a diffusion change with larger segment involvement.

REFERENCES

1. Holder CA, Muthupillai R, Mukundan S Jr, Eastwood JD, Hudgins PA. Diffusion-weighted MR imaging of the normal human spinal cord in vivo. *AJNR Am J Neuroradiol* 2000;21:1799-1806
2. Bammer R, Fazekas F, Augustin M, Simbrunner J, Strasser-Fuchs S, Seifert T, et al. Diffusion-weighted MR imaging of the spinal cord. *AJNR Am J Neuroradiol* 2000;21:587-591
3. Loher TJ, Bassetti CL, Lövblad KO, Stepper FP, Sturzenegger M, Kiefer C, et al. Diffusion-weighted MRI in acute spinal cord ischaemia. *Neuroradiology* 2003;45:557-561
4. Küker W, Weller M, Klose U, Krapf H, Dichgans J, Nägele T. Diffusion-weighted MRI of spinal cord infarction--high resolution imaging and time course of diffusion abnormality. *J Neurol* 2004;251:818-824
5. Barker GJ. Diffusion-weighted imaging of the spinal cord and optic nerve. *J Neurol Sci* 2001;186 Suppl 1:S45-S49
6. Clark CA, Barker GJ, Tofts PS. Magnetic resonance diffusion imaging of the human cervical spinal cord in vivo. *Magn Reson Med* 1999;41:1269-1273
7. Nedeltchev K, Loher TJ, Stepper F, Arnold M, Schroth G, Mattle HP, et al. Long-term outcome of acute spinal cord ischemia syndrome. *Stroke* 2004;35:560-565
8. Brinar VV, Habek M, Brinar M, Malojcić B, Boban M. The differential diagnosis of acute transverse myelitis. *Clin Neurol Neurosurg* 2006;108:278-283
9. Thurnher MM, Bammer R. Diffusion-weighted MR imaging (DWI) in spinal cord ischemia. *Neuroradiology* 2006;48:795-801
10. Román GC. Proposed diagnostic criteria and nosology of acute transverse myelitis. *Neurology* 2003;60:730-731; author reply 730-731
11. de Seze J, Lanctin C, Lebrun C, Malikova I, Papeix C, Wiertlewski S, et al. Idiopathic acute transverse myelitis: application of the recent diagnostic criteria. *Neurology* 2005;65:1950-1953
12. Jacob A, Weinshenker BG. An approach to the diagnosis of acute transverse myelitis. *Semin Neurol* 2008;28:105-120
13. Krishnan C, Kaplin AI, Deshpande DM, Pardo CA, Kerr DA. Transverse Myelitis: pathogenesis, diagnosis and treat-

ment. *Front Biosci* 2004;9:1483-1499
14. Masson C, Pruvo JP, Meder JF, Cordonnier C, Touzé E, De La Sayette V, et al. Spinal cord infarction: clinical and magnetic resonance imaging findings and short term outcome. *J Neurol Neurosurg Psychiatry* 2004;75:1431-1435
15. Pathak M, Kim RC, Pribram H. Spinal cord infarction following vertebral angiography: clinical and pathological findings. *J Spinal Cord Med* 2000;23:92-95
16. Weidauer S, Nichtweiss M, Lanfermann H, Zanella FE. Spinal cord infarction: MR imaging and clinical features in 16 cases. *Neuroradiology* 2002;44:851-857
17. Lee JW, Park KS, Kim JH, Choi JY, Hong SH, Park SH, et al. Diffusion tensor imaging in idiopathic acute transverse myelitis. *AJR Am J Roentgenol* 2008;191:W52-W57
18. Bhat A, Naguwa S, Cheema G, Gershwin ME. The epidemiology of transverse myelitis. *Autoimmun Rev* 2010;9: A395-A399
19. Kaplin AI, Krishnan C, Deshpande DM, Pardo CA, Kerr DA. Diagnosis and management of acute myelopathies. *Neurologist* 2005;11:2-18
20. Krishnan C, Kaplin AI, Pardo CA, Kerr DA, Keswani SC. Demyelinating disorders: update on transverse myelitis. *Curr Neurol Neurosci Rep* 2006;6:236-243
21. Ramelli GP, Wyttenbach R, von der Weid N, Ozdoba C. Anterior spinal artery syndrome in an adolescent with protein S deficiency. *J Child Neurol* 2001;16:134-135
22. Lewis DW, Packer RJ, Raney B, Rak IW, Belasco J, Lange B. Incidence, presentation, and outcome of spinal cord disease in children with systemic cancer. *Pediatrics* 1986;78: 438-443
23. Young G, Krohn KA, Packer RJ. Prothrombin G20210A mutation in a child with spinal cord infarction. *J Pediatr* 1999; 134:777-779
24. Beslow LA, Ichord RN, Zimmerman RA, Smith SE, Licht DJ. Role of diffusion MRI in diagnosis of spinal cord infarction in children. *Neuropediatrics* 2008;39:188-191
25. Fujikawa A, Tsuchiya K, Koppera P, Aoki C, Hachiya J. Case report: spinal cord infarction demonstrated on diffusion-weighted MR imaging with a single-shot fast spin-echo sequence. *J Comput Assist Tomogr* 2003;27:415-419
26. Shinoyama M, Takahashi T, Shimizu H, Tominaga T, Suzuki M. Spinal cord infarction demonstrated by diffusion-weighted magnetic resonance imaging. *J Clin Neurosci* 2005;12:466-468
27. Renoux J, Facon D, Fillard P, Huynh I, Lasjaunias P, Ducreux D. MR diffusion tensor imaging and fiber tracking in inflammatory diseases of the spinal cord. *AJNR Am J Neuroradiol* 2006;27:1947-1951

특발성 급성 횡단성 척수염과 급성 척수 경색의 감별에 있어서의 확산 강조 MR 영상의 의의[1]

김여군[1] · 이준우[1] · 김재형[1] · 강흥식[1] · 박경석[2]

목적: 특발성 급성 횡단성 척수염과 급성 척수 경색의 확산 강조 MR 소견을 비교한다.

대상과 방법: 2006년 2월부터 2009년 4월까지 급성 척수기능이상을 보인 환자들에서 확산 강조 영상과 확산 계수 지도를 획득하였다. 연구 포함 기준은 1) 최종 임상 진단에서 특발성 급성 횡단성 척수염이나 급성 척수 경색으로 진단된 환자이며 2) T2강조영상에서 척수내 고신호강도 병변이 있는 경우로 하였다. 최종적으로 13명의 특발성 급성 횡단성 척수염과 7명의 급성 척수 경색 환자가 포함되었다. 두 명의 영상의학과 의사가 확산 강조 영상과 확산 계수 지도를 평가하였고, 시상면의 T2 강조영상에서 척수병변의 범위를 측정하였다.

결과: 13명의 특발성 급성 횡단성 척수염 환자 중 11예(85%)는 확산영상에서 이상신호를 보이지 않았다. 1예는 확산 제한을 보였고, 1예에서는 확산계수가 증가되었다. 확산영상에서 이상 소견을 보인 2예는 척추체의 길이 기준으로 2개 이상의 넓은 범위를 침범하는 경우였다. 7명의 급성 척수 경색 환자 중 5예(71%)에서 확산 제한을 보였다. 척추체의 길이 기준으로 척수 경색 환자의 침범 범위는 1개에서 5개 이상으로 다양하였다.

결론: 특발성 급성 횡단성 척수염은 대부분 확산영상에서 확산 제한을 보이지 않으며, 이 소견은 급성 척수 경색과의 감별에 도움을 줄 수 있다. 그러나 넓은 범위를 침범한 특발성 급성 횡단성 척수염에서는 확산 제한을 보일 수 있다.

분당서울대학교병원 [1]영상의학과, [2]신경과