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Abbreviations:
ADC = apparent diffusion coefficient
ADT = apparent diffusion tensor
SE = spin echo
TE = echo time

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Diffusion-weighted MR Imaging with Apparent Diffusion Coefficient and Apparent Diffusion Tensor Maps in Cervical Spondylotic Myelopathy[1]

PURPOSE: To evaluate diffusion-weighted magnetic resonance (MR) imaging in patients with cervical spondylosis and/or myelopathy.

MATERIALS AND METHODS: A multishot echo-planar imaging sequence with calculation of apparent diffusion coefficient (ADC) and apparent diffusion tensor (ADT) was applied in 36 patients with symptomatic cervical spondylosis. Diffusion-weighted images read by two neuroradiologists were compared with T2-weighted fast spin-echo images read independently by three neuroradiologists with regard to clinical status (n = 36). MR findings in a selected subgroup of 20 patients whose clinical status was confirmed by electrophysiologic examination also were compared. Sensitivity, specificity, positive predictive value, and negative predictive value of both T2-weighted imaging and diffusion-weighted imaging (ADC and ADT) were calculated and compared.

RESULTS: Patients with myelopathy had abnormal ADC (17 of 21) and ADT (15 of 19) maps with increased ADC and ADT values and decreased anisotropy. For the detection of myelopathy, diffusion-weighted ADC maps had a sensitivity of 80% (17 of 21), while T2-weighted images had a sensitivity of 61% (13 of 21). The negative predictive value was 63% (seven of 11) and 60% (12 of 20) for ADC maps and T2-weighted images, respectively. Conversely, the specificity of diffusion-weighted images (53%; seven of 13) was lower than that of T2-weighted images (92%; 12 of 13). In patients with myelopathy confirmed at electrophysiologic examination, the sensitivity of diffusion-weighted images increased to 92% (12 of 13) and the negative predictive value increased to 75% (three of four), while T2-weighted images had a 53% (seven of 13) sensitivity and a 50% (six of 12) negative predictive value.

CONCLUSION: Diffusion weighting improved the sensitivity of imaging in cervical spondylotic myelopathy.

Cervical spondylosis is a very common degenerative condition of the spine, found in more than 75% of patients after the age of 65. Its most serious complication is myelopathy due to cord compression by bulging or herniated disks and osseous spurs, which occurs in 0.5% of patients (1). Cervical spondylosis is evidenced clinically by neck pain, radiculopathy, and/or myelopathy.

Myelopathy starts with discrete symptoms and evolves for years, with high risks of demyelination, neuronal death, and cavitation in the spinal cord. The most appropriate treatment is surgical decompression, and the earlier the treatment, the more effective (2,3).

Magnetic resonance (MR) imaging with T2 weighting has been reported to have low sensitivity for the detection of cervical myelopathy, with published estimates ranging from

15% to 65% (4–7). Furthermore, the high signal intensity related to cervical myelopathy appears on T2-weighted images only of patients in late clinical stages.

Preliminary data (7–11) have demonstrated the possibility of assessing the spinal cord with diffusion-weighted imaging, an MR imaging technique that evaluates the translation motion of water molecules in vivo (12,13). Spinal cord white-matter tracts are well organized in the craniocaudal direction, so diffusion of water molecules is anisotropically oriented, with a higher apparent diffusion coefficient (ADC) along the fibers than transversely (14–17).

In pathologic brain conditions such as stroke, which require early diagnosis, diffusion imaging provides additional information that conventional techniques do not give. A few studies have demonstrated this new technique's potential for the depiction of pathologic conditions of the spinal cord (7,9,17). The major limitation for diffusion-weighted imaging of the spinal cord in vivo are the artifacts induced by surrounding tissues, including artifacts due to cerebrospinal fluid and carotid and vertebral artery pulsation, and the magnetic susceptibility artifacts caused by bone structures.

Ries et al (18) described a technique for obtaining ADC and apparent diffusion tensor (ADT) measurements in the spinal cord by using a pulsed-field-gradient multishot echo-planar imaging sequence (18). Because pathophysiologic mechanisms in cervical myelopathy are not well depicted by T2-weighted images, the purpose of our study was to evaluate diffusion-weighted images acquired with a multishot echo-planar imaging sequence in patients with clinical symptoms of cervical spondylosis and/or myelopathy.

MATERIALS AND METHODS

Patients

We performed a prospective study of patients referred to our institution (CHU-Pellegrin, Bordeaux, France) between September 1999 and September 2000. The protocol followed ethical rules and was approved by our institutional board, and all patients were informed and gave their consent.

Patient inclusion criteria were *(a)* clinical symptoms of cervical spondylosis (ie, cervical radiculopathy and/or myelopathy) and *(b)* qualitative evidence of cervical canal narrowing on conventional radiographs or computed tomographic (CT) or MR images. Exclusion criteria were *(a)* history of other neurologic disease and/or *(b)* no evidence of cervical canal narrowing on conventional radiographs or CT or MR images. An orthopedic surgeon (J.M.V.) and a rheumatologist (J.D.) selected the patients. A total of 36 patients met our criteria and were included: 22 patients with signs of myelopathy at physical examination, and 14 without clinical myelopathy.

To improve the patient selection based on clinical manifestations, we used the results of electrophysiologic examination (electromyograms and somatosensory evoked potentials) performed in 24 of the 36 patients to select retrospectively a subgroup of patients whose clinical findings were confirmed by electrophysiologic findings. In 20 patients, the electrophysiologic findings were in concordance with clinical findings; 14 patients had myelopathy, and six did not. Patients with discrepancies (four of 24) between clinical and electrophysiologic findings were not included in this subgroup.

All patients underwent MR imaging with the protocol described.

MR Imaging Technique

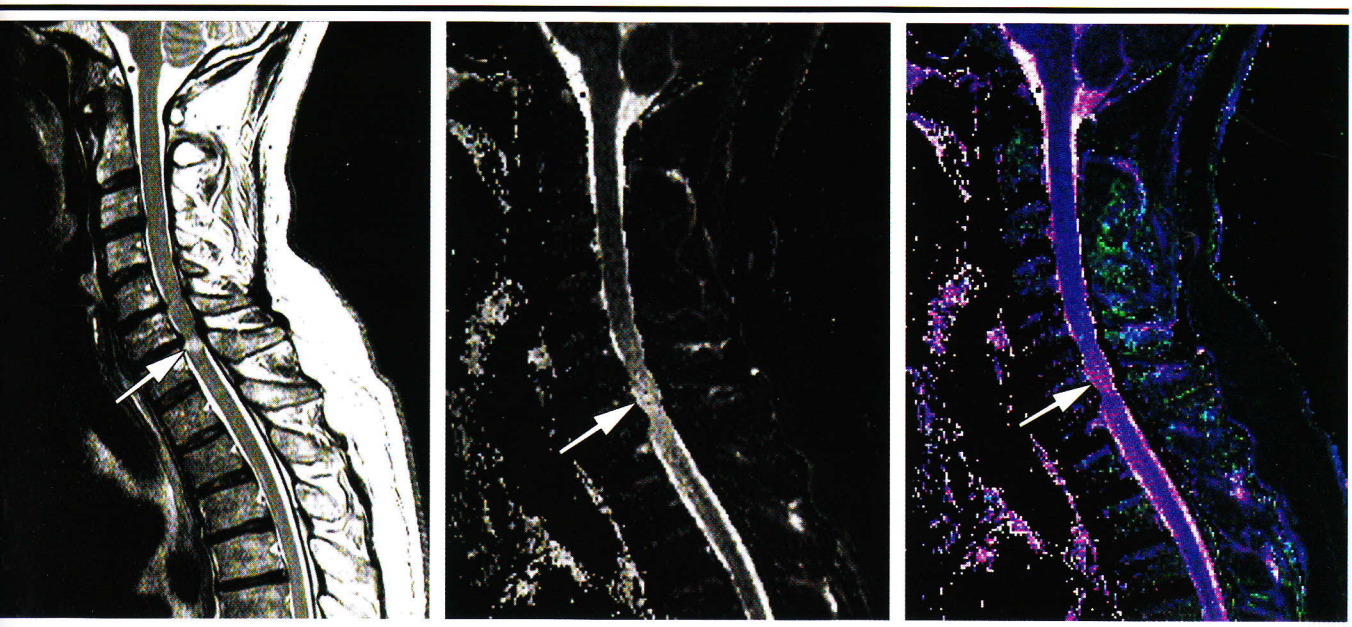
Diffusion imaging was performed on a 1.5-T clinical MR imaging system (Gyroscan NT Intera; Philips Medical Systems, Best, the Netherlands) with actively shielded magnetic field gradients (G maximum, 23 mT/m). The imaging protocol began with the acquisition of a T2-weighted coronal scout image followed by the application of a sagittal diffusion-weighted multishot echo-planar imaging sequence with 13 echoes per excitation, total echo time (TE) of 116 msec (TE for diffusion weighting, 80 msec; TE for echo-planar imaging, 36 msec), image matrix of 256 × 195 pixels, nominal voxel size of 0.9 × 1.17 mm, three sections 5 mm thick, and gap of 1 mm. Two symmetric diffusion-gradient pulses with a combined TE of 80 msec were applied, one before and one after the 180° pulse of a preparatory spin-echo (SE) sequence. To minimize bulk motion effects during diffusion imaging, a navigator echo was acquired and the sequence was triggered at every third R wave by a pulse oximeter. The k space was split into 13 equal sections (13 echoes per excitation, 36-msec echo-planar imaging TE) in the second dimension, each of which was encoded in one of the 13 gradient echoes, in linear order. Diffusion sensitivity was obtained with a pulsed-field-gradient preparatory sequence applied in six different directions and with three b values (b = 0, 300, 600 sec/mm^2). The duration of diffusion-weighted imaging averaged 13 minutes per patient study, based on an average heart rate of 60 beats per minute. The acquisition of ADC alone required around 6 minutes. Patients were asked to breathe very slowly and to avoid moving the head or limbs and swallowing during diffusion-weighted imaging. Subsequently, a sagittal T2-weighted fast SE sequence (field of view, 320 mm; image matrix, 512 × 256; 18 echoes per excitation; repetition time msec/TE msec = 3,000/120; section thickness, 3 mm) was applied for anatomic comparison.

The diffusion data were fitted pixel by pixel to obtain the ADC maps. The data of all six ADC maps were combined to form the ADT. The tensor data were positioned diagonally to obtain eigenvalues and eigenvectors for the analysis of anisotropy and direction of diffusion. More details about the diffusion-weighted imaging sequence are available in the article by Ries et al (18).

Image Analysis

Three neuroradiologists (J.M.C., V.D., and one non-coauthor) who were blinded to the clinical findings independently interpreted the T2-weighted images to determine the presence of signal intensity changes in the spinal cord. Findings on T2-weighted images were considered abnormal when at least two of the neuroradiologists observed increased signal intensity in the spinal cord at the level of spinal canal stenosis.

The diffusion data permitted the mapping of ADC values in three dimensions, the ADC trace, and the ADT. On ADT maps, two informational components are present: color, which indicates the direction of water diffusion (anisotropy), and luminosity, which indicates the magnitude of water diffusion. Anisotropic diffusion of moderate magnitude in the craniocaudal direction was displayed in dark blue. Directional change in diffusion to the anteroposterior direction appeared in red. Directional change to right-left was depicted in green. Isotropic diffusion of high magnitude, such as that of the cerebrospinal fluid, was represented in white. Two neuroradiologists (V.D., A.D.), blinded to the clinical data and to results of T2-weighted fast SE image analysis results, were asked to determine by consensus the presence in the spinal cord of changes in signal intensity and color on the ADC and ADT maps. To ensure this qualitative analysis, ADC and



b. c.

igure 1. MR images of the spine in a 52-year-old man with clinical symptoms of myelopathy. **(a)** Sagittal T2-weighted fast SE image (3,000/120; cho train, 18) shows an area of increased signal intensity (arrow) in the spinal cord at the C6–C7 level. **(b)** ADC map shows increased ADC values rrow) at the level of spinal cord compression (C6–C7) and slightly above and below (light gray–white). **(c)** ADT map shows changes (arrow) in ie diffusion direction. Light red indicates increased luminosity corresponding with increased magnitude, and red indicates change of direction to ie transverse plane.

DT values were calculated offline at a inux workstation by using in-house oftware written in interactive language. DC and ADT values were obtained in egions of interest containing about 100 ixels, which were placed in the center of ie spinal cord to avoid data contamina- on by the surrounding cerebrospinal uid. Standardized regions of interest ere placed at the level of greatest steno- s. Variations in fractional anisotropy of iore than 10% and more than 5% be- ond the standard deviations found in ormal areas of the spinal cord in eight olunteers were considered abnormal for DC and ADT, respectively. Data for iese eight volunteers are given in the rticle by Ries et al (18). The average ADC or all volunteers was 2.58 (SD = 0.21) · 0^{-3} mm^2/sec, and the average fractional nisotropy of the calculated ADT was .83 (SD = 0.11) (18).

tatistical Analysis

MR imaging findings in the 36 patients ere analyzed with regard to the pa- ents' clinical status. Additionally, find- igs were separately analyzed for a sub- roup of 20 patients whose clinical status as confirmed by electrophysiologic ex- mination. For the T2-weighted images, ie κ statistic measure of agreement was alculated for two outcomes and three raters. Sensitivity, specificity, positive predictive value, and negative predictive value of both T2-weighted imaging and diffusion-weighted imaging (ADC and ADT) were calculated and compared.

RESULTS

Analysis of Findings in the Group of 36 Patients

Increased signal intensity was observed on T2-weighted images of the spinal cord in 16 patients. The κ score for the three raters, calculated globally, was 0.77 ($P <$ .001), showing substantial agreement. In interrater comparisons, agreement was almost perfect between raters 1 and 3 (κ = 0.94) and substantial between raters 1 and 2 (κ = 0.72) and between raters 2 and 3 (κ = 0.66).

The calculation of ADC was possible in 34 of 36 patients. ADC could not be calculated in two patients because of poor signal-to-noise ratio and too great a distance between the surface coil and the spinal canal. Among the 34 patients, 21 had clinical myelopathy. Abnormalities on ADC spinal cord maps, confirmed by increased ADC values, were identified at the level of spinal cord compression in 17 patients. Increased signal intensity was depicted on T2-weighted fast SE images of 13 patients. Figure 1 illustrates a case with increased signal intensity on the T2-weighted image and abnormalities on the ADC map. Among the 13 patients with no clinical myelopathy, one had increased signal intensity on T2-weighted fast SE images, and six had increased ADC values. Table 1 indicates the sensitivity, specificity, and positive and negative predictive values for both ADC maps and T2-weighted images.

The calculation of ADT was possible in 32 of 36 patients. Calculation was impossible in the other four patients because of motion artifacts in two, a poor signal-to-noise ratio in the third, and too great a distance between the surface coil and the spinal cord in the fourth. Among the 32 patients, 19 had clinical myelopathy. Abnormal ADT spinal cord maps, confirmed by increased ADT fractional anisotropy values, were found in 15 patients at the level of cord compression (Fig 1). Increased signal intensity was found on T2-weighted fast SE images of 11 patients. Among the 13 patients with no clinical manifestations of myelopathy, one had increased signal intensity on T2-weighted fast SE images, and five had increased ADT fractional anisotropy values. Table 2 indicates the sensitivity, specificity, and positive and negative predictive values of both ADT maps and T2-weighted fast SE images.

Analysis of Findings in the Subgroup of 20 Patients

The calculation of ADC was possible in 19 of the 20 patients. ADC could not be calculated in one patient because of a poor signal-to-noise ratio. Thirteen of 19 patients had symptoms of clinical myelopathy confirmed by abnormal findings at electrophysiologic examination. Abnormal ADC spinal cord maps, confirmed by increased ADC values, were obtained in 12 of these patients at the level of spinal cord compression. Increased signal intensity was found on T2-weighted fast SE images of seven patients. Figure 2 illustrates a case of discrepancy between a T2-weighted image considered normal and an ADC map considered abnormal. Among the six patients with no clinical or electrophysiologic signs of myelopathy, none had a high signal intensity on T2-weighted fast SE images, but three had increased ADC values (Fig 3). Table 3 indicates the sensitivity, specificity, and positive and negative predictive values of both ADC maps and T2-weighted fast SE images.

The calculation of ADT was possible in 17 of the 20 patients. ADT could not be calculated in one patient because of a poor signal-to-noise ratio and in two others because of motion artifacts. Among the 17 patients, 11 had clinical symptoms of myelopathy confirmed by abnormal findings at electrophysiologic examination. Abnormalities found on ADT spinal cord maps of 10 patients at the level of spinal cord compression were confirmed by increased ADT fractional anisotropy values (Fig 2). Increased signal intensity was found on T2-weighted fast SE images of five patients. Among the six patients who had no clinical or electrophysiologic manifestations of myelopathy, none showed increased signal intensity on T2-weighted fast SE images, but three showed increased ADT values (Fig 3). Table 4 indicates the sensitivity, specificity, and positive and negative predictive values of both ADT maps and T2-weighted fast SE images.

TABLE 1
Comparison of T2-weighted Images and ADC Maps for Depicting Cervical Myelopathy in 34 Patients

Image Type	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)
T2-weighted images	61 (13/21)	92 (11/13)	92 (13/14)	60 (12/20)
ADC maps	80 (17/21)	53 (7/13)	73 (17/23)	63 (7/11)

Note.—Data in parentheses are numbers of patients from which percentages were derived.

TABLE 2
Comparison of T2-weighted Images and ADT Maps for Depicting Cervical Myelopathy in 32 Patients

Image Type	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)
T2-weighted images	57 (11/19)	92 (12/13)	91 (11/12)	60 (12/20)
ADT maps	78 (15/19)	61 (8/13)	75 (15/20)	66 (8/12)

Note.—Data in parentheses are numbers of patients from which percentages were derived.

DISCUSSION

Cervical spondylosis is common in the middle-aged and the elderly. Progressive cervical myelopathy is caused by chronic segmental compression of the spinal cord because of spondylotic changes (1,19,20). The mechanism of lesion formation in the spinal cord is not precisely understood, but the initial cause is thought to be an increase in pressure due to continuous or intermittent pinching of the cord, which induces chronic hypoperfusion. Sequential changes such as hypoxia or ischemia may lead to lesion formation (1,21). Early changes include vacuolization of gray matter and white matter (21).

T2-weighted imaging can demonstrate cervical spondylosis accompanied by spinal canal narrowing due to vertebral enlargement and backward bulging of bone spurs and disks at one or more levels (5,22,23). High signal intensity has been observed on T2-weighted images of the spinal cord in 15%–65% of affected patients; this is considered to indicate low sensitivity (4–7).

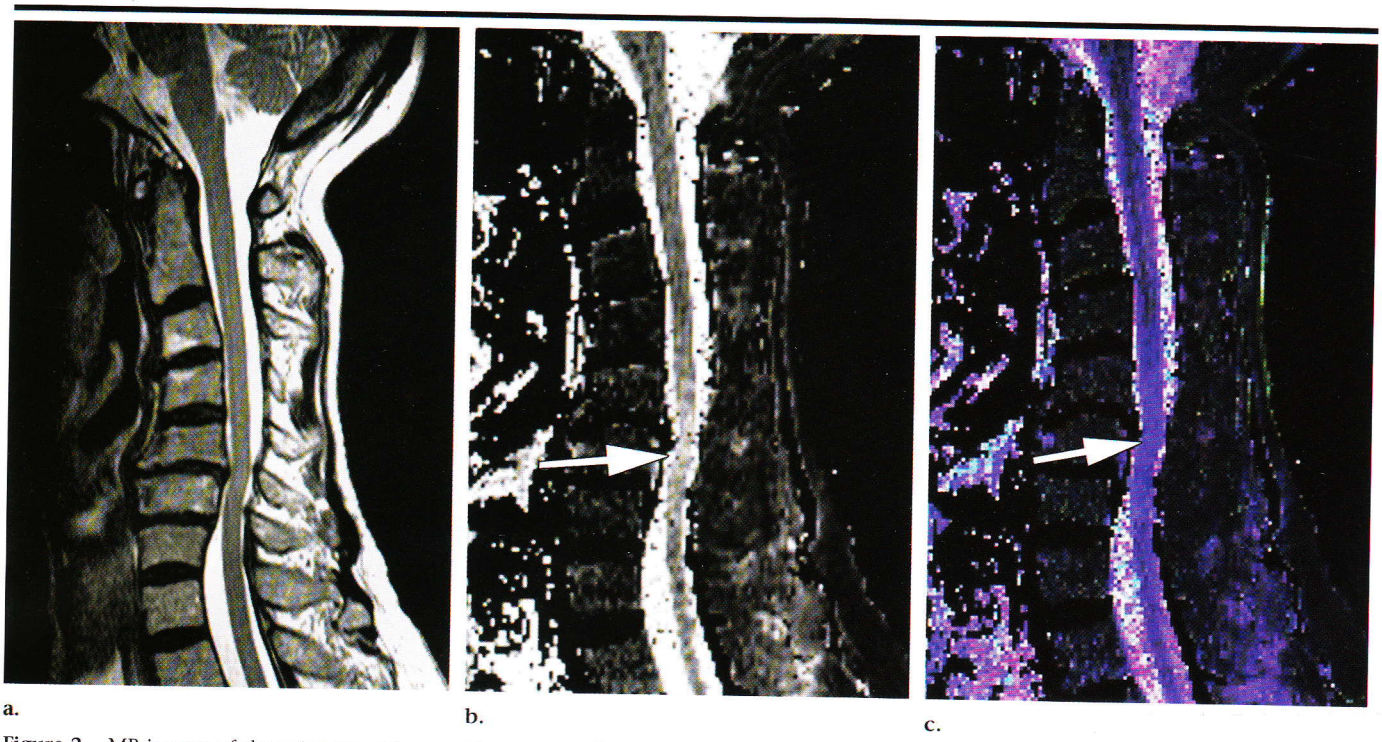
Several diffusion-weighted imaging techniques, including SE, steady-state free precession, and multishot echo-planar imaging, have been proposed to make MR imaging sensitive to water diffusion in the spinal cord (7–10). SE sequences are less vulnerable to the magnetic susceptibility artifacts caused by bone structures; but because total acquisition time with SE sequences is long (11), motion artifacts induced by cerebrospinal fluid flow, carotid and vertebral artery pulsations, or patient motion may affect SE images. Steady-state free precession with a long gradient pulse duration is appropriate for spinal cord imaging because the speed of image acquisition with this technique reduces artifacts caused by patient movement and because the technique is less sensitive to magnetic susceptibility (7,8). Steady-state free precession does not, however, permit the calculation of ADC and ADT.

In this study we used a multishot echo-planar imaging sequence. This sequence has a short acquisition time and is much less vulnerable to magnetic susceptibility than single-shot echo-planar imaging. Calculation of ADC and ADT therefore was possible (18).

The results of our study confirm previous findings by Dousset et al (7) and Castillo et al (8) that diffusion-weighted imaging is more sensitive than T2-weighted imaging in patients with cervical myelopathy. In our study group (n = 36), clinical symptoms of myelopathy assessed by physicians participating in this prospective study were considered the standard with which MR imaging findings were to be compared. Increased ADC values and changes in diffusion flow depicted on ADT maps were found at diffusion-weighted imaging in 17 (80%) of 21 patients and in 15 (78%) of 19 patients, respectively, whereas T2-weighted imaging depicted abnormality in only 13 (61%) of the 21 patients and 11 (57%) of the 19 patients.

In the subgroup of patients selected on the basis of concordance between clinical and electrophysiologic findings, increased ADC values and changes in tensor direction were found at diffusion-weighted imaging in 12 (92%) of 13 patients and 10 (90%) of 11 patients, respectively, whereas T2-weighted imaging depicted abnormality in only seven (53%) of the 13 patients and five (45%) of the 11 patients.

Diffusion weighting increased the sensitivity of MR imaging for the depiction of spinal cord changes in patients with clinical symptoms of cervical spondylotic



a. b. c.

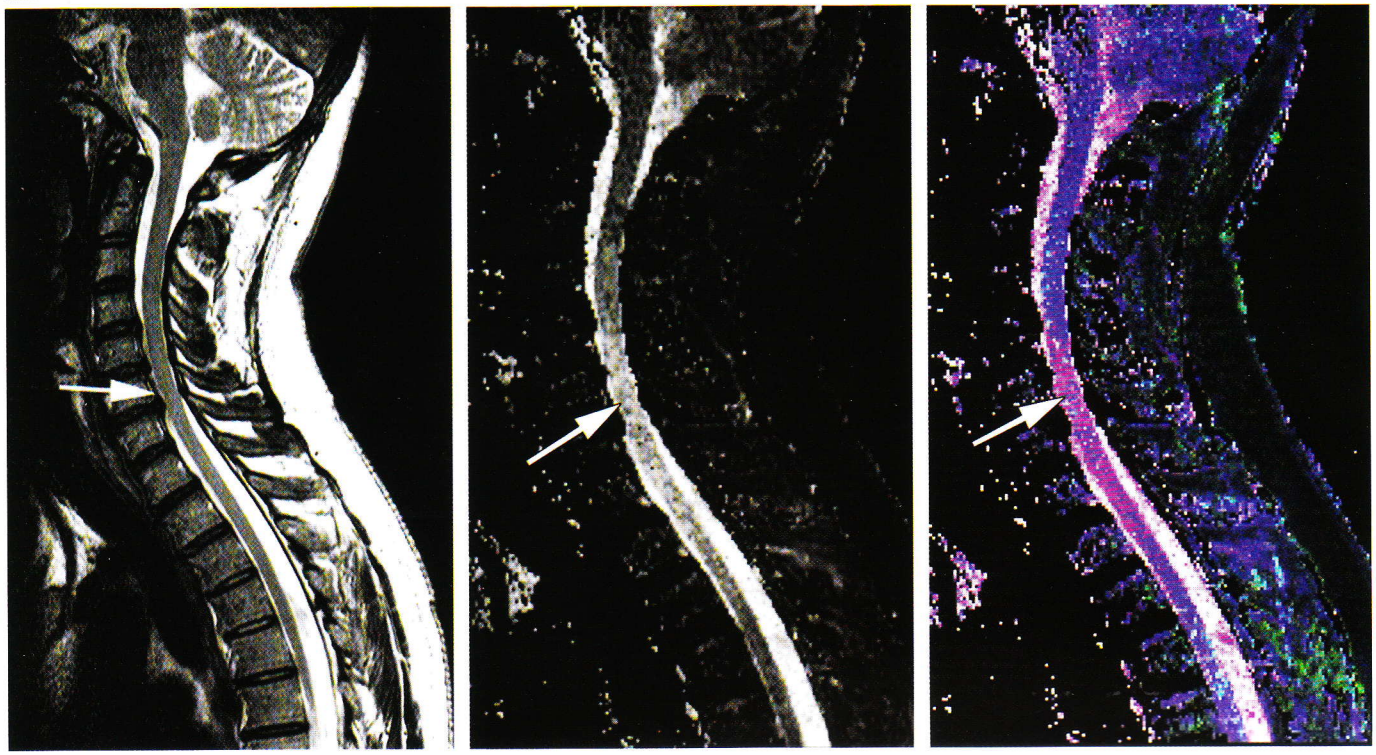
Figure 2. MR images of the spine in a 50-year-old woman with clinical symptoms of myelopathy confirmed at electrophysiologic examination. **(a)** Sagittal T2-weighted fast SE image (3,000/120; echo train, 18) shows spinal cord compression at the C5–C6 level but no increase in signal intensity. **(b)** ADC map shows increased ADC values (arrow) in the spinal cord at C5–C7 (light gray–white). **(c)** ADT map shows changes (arrow) in the diffusion direction at C5–C7 (blue). This case illustrates the improved detection with diffusion imaging in comparison with T2-weighted imaging.

myelopathy. The sensitivity of diffusion-weighted imaging was 90% for patients in whom symptoms of clinical myelopathy were confirmed by electrophysiologic findings. The results were identical with diffusion ADC trace values and tensor values. Although the negative predictive value was comparable in the larger study group between diffusion-weighted images and T2-weighted images, it dramatically improved for diffusion-weighted images in the subgroup of patients whose clinical symptoms were confirmed by electrophysiologic findings, reaching 75%. Conversely, in the subgroup, the negative predictive value dropped to 50% for T2-weighted images.

However, diffusion-weighted imaging, in comparison with T2-weighted imaging, was detrimental to the specificity of diagnosis. The diffusion-weighted image analysis provided specificity between 50% and 60% in the two patient groups. Several facts may explain this low specificity. First, we determined a threshold of abnormality for ADC and ADT values in order to avoid overlap between ADC and ADT variations in the spinal cords of patients and healthy volunteers (18). Increasing this threshold would increase specificity, with a resulting decrease in sensitivity. Further studies may help determine the most accurate threshold. Second, the low specificity may be due to very early modifications in the spinal cord, before any clinical or electrophysiologic manifestations. The false-positive findings on diffusion-weighted images, as illustrated in Figure 3, bring up the question of histologic changes that may modify the diffusion of water molecules at an early stage of the disease, when electrophysiologic and clinical findings are normal.

The pathologic process underlying the high signal intensity seen on T2-weighted images remains imprecise; the increased intensity may be due to water increase in myelomalacia, chronic ischemia, inflammatory edema, and/or cavitation (4–6,19,21–23). The prognostic value of such findings is unclear, as symptoms subside in some patients after surgery but persist or increase in others.

Diffusion-weighted imaging in patients with cervical myelopathy revealed an increase in water diffusion and changes in diffusion direction. At present, we cannot determine which mechanisms produce these abnormalities. It is, however, interesting to note that such abnormalities were not present in the healthy volunteers as described in the article by Ries et al (18) or in the six of 13 patients in our study who had cervical canal stenosis due to radiculopathy alone. These observations permit the exclusion of possible magnetic susceptibility artifacts arising from bone structures. It is likely that diffusion-weighted images show internal changes in the spinal cord. We hypothesize that changes may be located primarily in the interstitial space, in which water molecules may flow rapidly due to the spatial expansion associated with increased internal pressure. Changes in extracellular volume fraction may be the result of functional alterations or morphologic destruction (24–26). An increase in internal pressure may be the result of an increase in pressure around the spinal cord because of cord pinching by bone formations and disks and because of cerebrospinal fluid flow disturbances resulting from the narrowing of the spinal canal. Our hypothesis is supported by other reported observations of water exchanges between the cerebrospinal fluid and the spinal cord interstitial space (27,28). Evidence of rapid fluid flow from the subarachnoid space into the central spinal canal in the rat has been reported by Stoodley et al (27). Observation of intramedullary contrast medium accumulation either following myelogra-



a. b. c.

Figure 3. MR images of the spine in a 40-year-old woman referred for radicular pain who had no clinical symptoms of myelopathy and had negative findings at electrophysiologic examination. (a) Sagittal T2-weighted fast SE image (3,000/120; echo train, 18) shows spinal cord compression (arrow) at the levels of C5–C6 and C6–C7. (b) ADC map shows increased ADC values (arrow) at the level of spinal cord compression and slightly below (light gray–white). (c) ADT map shows changes (arrow) in the diffusion direction (light red).

phy or after intravenous injection of gadolinium in patients with spondylotic myelopathy also contributes to the hypothesis of an enlarged interstitial space (22).

The destruction of cell membranes may result in increased diffusion and water direction changes. Beaulieu et al (24) showed that demyelination in the sciatic nerve of a frog produces loss of anisotropy, with increased flow in the transverse direction.

In a recent article, Yonenobu discussed the surgical option for treating patients with cervical radiculopathy and myelopathy (3). Indeed, the only available treatment is decompressive surgery, which can reduce the risks of permanent disability and progressive myelopathy (29). Since the results of surgical treatment are better in mildly affected patients than in severely affected patients (2,3,20,29), the diagnosis of cervical spondylotic myelopathy must be made as early as possible and with highly sensitive tools. Given the high sensitivity and high negative predictive value of diffusion-weighted imaging, this technique may facilitate decision making and make adequate treatment possible, especially for patients in whom clinical examination reveals discrete symptoms. Negative findings at diffusion-weighted imaging should make surgical treatment questionable; however, consistency between findings at electrophysiologic examination and at

TABLE 3
Comparison of T2-weighted Images and ADC Maps for Depicting Cervical Myelopathy in the Subgroup of 19 Patients with Clinical and Electrophysiologic Findings

Image Type	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)
T2-weighted images	53 (7/13)	100 (6/6)	100 (7/7)	50 (6/12)
ADC maps	92 (12/13)	50 (3/6)	80 (12/15)	75 (3/4)

Note.—Data in parentheses are numbers of patients from which percentages were derived.

TABLE 4
Comparison of T2-weighted Images and ADT Maps for Depicting Cervical Myelopathy in the Subgroup of 17 Patients with Clinical and Electrophysiologic Findings

Image Type	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)
T2-weighted images	45 (5/11)	100 (6/6)	100 (5/5)	50 (6/12)
ADT maps	90 (10/11)	50 (3/6)	76 (10/13)	75 (3/4)

Note.—Data in parentheses are numbers of patients from which percentages were derived.

diffusion-weighted imaging may help direct the physician toward surgical decompression. Further studies will be needed to confirm this view.

In conclusion, diffusion imaging is more sensitive and has a higher negative predictive value than T2-weighted imaging for the early detection of cervical spondylotic myelopathy. In this study, we compared two sequences with defined parameters. It could be of interest to test other diffusion-weighted imaging sequences and T2-weighted sequences. Regarding the latter, different echo trains or TEs might result in improved sensitivity. T2-weighted, short–inversion-time inversion recovery sequences also could be compared with diffusion-weighted sequences (30). Another limitation of this study is the lack of histologic correlation. Further imaging studies of more developed pathologic conditions in animal models or cadavers might provide a better understanding of increased diffusion of water molecules in the chronically compressed spinal cord.

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