Magnetic Resonance Neurography for Cervical Radiculopathy: A Preliminary Report

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MAGNETIC RESONANCE NEUROGRAPHY was used to directly image cervical spinal nerves in patients with clinical and radiographic evidence of cervical radiculopathy. A magnetic resonance imaging phased-array coil system was used to obtain high-resolution coronal T1-weighted spin echo, coronal/axial T2-weighted fast spin echo with fat saturation, and coronal/axial fast short tau inversion recovery weighted images of the cervical spine and spinal nerves. Three patients with neck and upper extremity pain and one asymptomatic volunteer were studied. The T2-weighted and the fast short tau inversion recovery images demonstrated markedly increased signal in the proximal portion of the affected spinal nerves. In two patients, contrast-to-noise measurements of the affected spinal nerves showed a markedly increased intensity compared with that of the noninvolved spinal nerves. Our findings demonstrate that phased-array coils used in conjunction with magnetic resonance neurography sequences can detect signal abnormalities within compressed cervical spinal nerves in patients with corresponding radicular symptoms and findings. This technique may prove to be helpful in evaluating patients with multilevel disc and/or spondylotic disease of the cervical spine. (Neurosurgery 38:488–492, 1996)

Key words: Cervical, Magnetic resonance imaging, Neurography, Radiculopathy, Spine

Current spinal imaging techniques demonstrate degenerative disc disease and spondylosis of the cervical spine in both symptomatic and asymptomatic patients (1). Conventional magnetic resonance imaging (MRI) has been reported to disclose cervical disc disease in 20% of asymptomatic patients (3). Some patients with cervical radiculopathy exhibit radiographic abnormalities at multiple levels, the significance of which is often questioned. Therefore, the clinical significance of radiographic lesions in a patient with cervical radiculopathy requires correlation of the physical examination and electrodiagnostic studies with radiographic studies.

To directly image symptomatic spinal nerve roots in patients with cervical radiculopathy, we used magnetic resonance neurography (MRN) techniques. Similar techniques have been successful in demonstrating increased signal abnormalities in both traumatized and compressed peripheral nerves (4, 5). Our goal was to determine whether MRN could detect signal changes in cervical spinal nerves subjected to compression from either a disc or an osteophyte.

PATIENTS AND METHODS

Three patients with radiographic evidence of herniated cervical discs on MRI and symptoms of cervical radiculopathy were selected for MRN studies. One asymptomatic volunteer underwent a MRN examination for comparison. All images were obtained on a 1.5-T magnetic resonance scanner (Signa; General Electric, Milwaukee, WI). Imaging sequences included coronal T1-weighted conventional spin echo (TR, 700 ms; TE, 20 ms) sequences and T2-weighted fast spin echo (TR, 5000 ms; TE, 90–100 ms) sequences in the coronal and axial

planes. In addition, axial and coronal fast spin echo multiplanar short tau inversion recovery (FMPIR) sequences were used (TR, 5000 ms; TE, 52 ms; TI, 160 ms) in Patients 1 and 2. Custom-designed phased-array surface coils developed to image the brachial plexus were used. The improved signal-to-noise ratio of these coils allowed high spatial resolution studies using a 512 matrix. The C5 through C8 spinal nerves were bilaterally imaged.

Image analysis was both quantitatively and qualitatively performed. In Patients 1, 2, and 4, quantitative analysis of spinal nerve signal intensity was performed on the axial images. A small region of interest (ROI) was placed over the spinal nerve roots at the medial border of the scalene muscles on the axial FMPIR images (*Fig. 1*). An additional ROI was placed within the adjacent middle scalene muscles, bilaterally. The standard deviation (*SD*) of noise was measured from a ROI placed in the air along the neck. A contrast-to-noise ratio (CNR) was calculated from the signal intensities (*S*) in each of these ROIs as follows: $CNR = (S_{nerve} - S_{scalene})/(SD_{noise})$.

The calculated CNR for both the left (*L*) and right (*R*) roots were compared for each level by arbitrary subtraction of the CNR of the left root from the right root, and is expressed as CNR (*R* − *L*). If the roots are symmetrically isointense, which should be expected in a normal patient, this difference should be zero. A positive difference would indicate a hyperintense right root, and a negative difference would indicate a hyperintense left root.

RESULTS

Table 1 outlines the calculated CNR results for two patients and a control patient. The CNR for each level is listed, as is the difference. In the control patient, CNR (*R* − *L*) was <1.0. This finding was also noted in the two symptomatic patients except for in the C6 levels. In both patients, the CNR (*R* − *L*) was markedly increased, indicating abnormally hyperintense right C6 roots. The case histories for the two patients are further described.

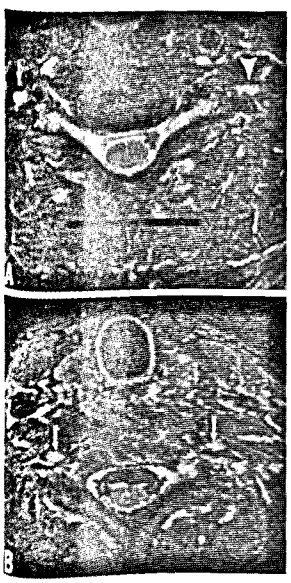

FIGURE 1. *A*, axial FMPIR image from Patient 1 illustrating the difference in signals between the right and left C6 spinal nerves. There is a higher signal in the right C6 spinal nerve (*arrow*) than in the left C6 spinal nerve (*arrowhead*). *B*, axial FMPIR from the control volunteer (Patient 4). The signal intensity is nearly identical in both the left and right C6 spinal nerves (*arrows*).

TABLE 1. Contrast-to-Noise Ratio Values[a]

Patient No.	CNR Nerve (R)	CNR Nerve (L)	CNR (R−L)
Patient 1			
C5	16.5	15.6	0.9
C6	27.1	12.1	15.0
C7	7.9	8.0	−0.1
Patient 2			
C5	4.1	4.0	0.1
C6	12.9	5.0	7.9
C7	7.3	7.6	−0.3
Patient 4 (control)			
C5	10.9	11.0	−0.1
C6	5.9	6.5	−0.6
C7	5.9	5.3	0.6

[a] **CNR, contrast-to-noise ratio; R, right; L, left.**

Patient 1

A 50-year-old man presented with a 2-year history of neck pain and shooting pain radiating in a C6 distribution down the right arm. Physical examination was remarkable for trace weakness of his right biceps muscle. His reflexes were normal throughout his upper extremities. Electrical studies, including electromyography (EMG) and dermatomal somatosensory evoked potentials, were normal. Conventional MRI showed a large disc bulge at C5–C6, which was more prominent on the right side. MRN of the cervical spinal nerves revealed increased signal exclusively located in the right C6 spinal nerve (*Fig. 2A*) when compared with the contralateral C6 nerve. Quantitative analysis of the axial FMPIR images confirmed the increased signal intensity of the right C6 spinal nerve, as described above (*Table 1*).

Patient 2

A 45-year-old man presented with a 1-year history of shooting pains in the neck and right upper extremity. He described tingling and numbness in the right C6 dermatome. On physical examination, he had Grade 4+/5 weakness in the right biceps and brachioradialis muscles, a diminished right biceps reflex, and a normal sensory examination. The result of the EMG was normal, but nerve conduction studies showed increased latencies consistent with a neurapraxic injury of the right C6 spinal nerve. Conventional MRI revealed a disc bulge and an osteophyte at the C5–C6 level. MRN of the cervical spinal nerves revealed increased signal in the right C6 spinal nerve (*Fig. 2B*) when compared with the contralateral C6 nerve, a finding confirmed by quantitative analysis (*Table 1*).

Patient 3

A 54-year-old man presented with a 4-week history of paraspinal muscle spasm in the neck and sharp pain radiating down the right arm into the dorsum of the right hand. On physical examination, he had

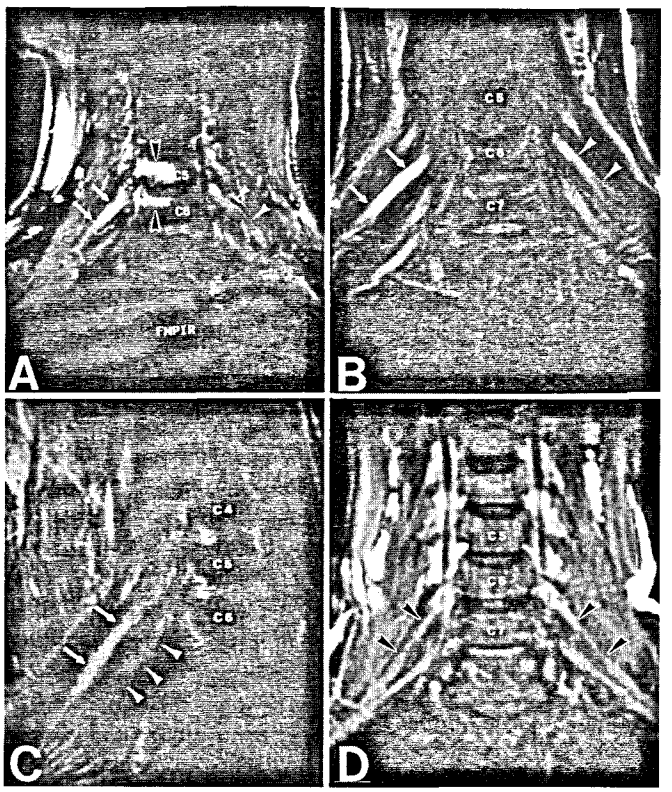

FIGURE 2. *A*, coronal FMPIR image from Patient 1. Note the markedly higher signal in the right C6 spinal nerve (*arrows*) when compared with the left (*white arrowheads*). Also note the degenerative reactive marrow changes in the C5 and C6 vertebral bodies (*black arrowheads*). *B*, coronal FMPIR image from Patient 2. Again note the higher signal in the right C6 nerve (*arrows*) when compared with the asymptomatic left C6 spinal nerve (*arrowheads*). *C*, coronal T2-weighted fast spin echo image from Patient 3. The right spinal nerves are visible in this image, which shows higher signal in the C5 nerve (*arrows*), corresponding to the EMG results, than in the adjacent C6 nerve (*arrowheads*). *D*, coronal FMPIR from an asymptomatic volunteer (Patient 4). No differences in signal intensity are identified when comparing the right and left C6 spinal nerves (*arrowheads*).

Grade 4/5 weakness in his right deltoid, biceps, and triceps muscles, with diminished sensation to light touch and pinprick in the right C5 and C6 dermatomes. EMG showed denervation changes and nerve conduction abnormalities, consistent with an axonotmetic injury of the right C5 spinal nerve. Computed tomography (CT)/myelography revealed multiple ventral compressions throughout the cervical spinal canal, most prominent at C4–C5 and C5–C6. Conventional MRI studies of the cervical spine revealed osteophytes and bulging discs at C4–C5 and C5–C6. MRN of the cervical spinal nerves showed the right C5 spinal nerve to have higher signal intensity than the adjacent C6 and C7 nerves (*Fig. 2C*). Quantitative analysis could not be performed, because the patient was unable to tolerate the axial FMPIR study.

Patient 4 (control)

A 38-year-old female volunteer underwent conventional MRI and MRN with the phased-array coil. She had never complained of neck pain or spasm and denied ever having experienced any radiculopathic upper extremity pain or weakness. Conventional MRI showed no evidence of cervical disc degeneration or spondylosis. The axial and coronal FMPIR sequences (*Figs. 1B* and *2D*) showed all cervical spinal nerves from C5 to C8 to have similar signal intensity. CNRs of the spinal nerves (*Table 1*) confirmed nearly identical signal intensities on the two sides.

DISCUSSION

These clinical cases demonstrate our initial attempts at directly imaging the spinal nerves in patients with cervical radiculopathy. The cases of Patients 1 and 2 illustrate increased signal in the affected spinal nerve with the use of the FMPIR sequences, and the case of Patient 3 shows the increased spinal nerve signal on the T2-weighted fast spin echo sequences. The increased signal in the nerves was present for 2 to 3 cm distal to the point of compression. In addition, these cases illustrate that increased signal intensity in the symptomatic spinal nerves is present even when the results of the electrodiagnostic studies are normal (Patient 1). Similar increases in signal intensity are present in neurapraxic (Patient 2) and axonotmetic (Patient 3) grades of injury. Quantification of the spinal nerve signal using CNR measurements allowed for direct comparison of the symptomatic spinal nerve with the contralateral asymptomatic spinal nerve. Comparison of the nerve signals at different levels (*Table 1*) shows that the signal intensities in the right and left cervical nerves are nearly identical at the asymptomatic levels and at all levels in the control patient (Patient 4). However, comparison of the C6 spinal nerves of Patients 1 and 2 shows the signal to be much higher in the symptomatic root. In the patient with multilevel disc herniations and osteophytes on conventional magnetic resonance images, MRN confirmed the level of abnormality (Patient 3).

The diagnosis and treatment of cervical radiculopathy depends on the careful correlation of clinical history, physical examination, electrodiagnostic studies, and radiographic images. MRI reveals many of the lesions that can cause cervical radiculopathy, including herniated nucleus pulposus (HNP) and osteophytes. In a series of 40 patients surgically confirmed to have cervical radiculopathy, 84% of the HNPs were accurately shown on preoperative MRI and, overall, 92% of compressive lesions were identified (21). Modic et al. (12) compared MRI, CT/myelography, and myelography alone in the diagnosis of lesions causing cervical radiculopathy. MRI predicted 74% of surgically confirmed lesions, CT/myelography predicted 85%, and myelography alone predicted 67%. When MRI was used in conjunction with CT/myelography, the sensitivity of the techniques was 90% (12). Gradient-echo sequences and three-dimensional MRI techniques provide better images of the cervical foramina and have further increased the sensitivity of MRI techniques (1, 16, 19).

However, radiographic studies of the cervical spine may yield normal images in a symptomatic patient or may show a herniated disc in an asymptomatic person. Clearly, the incidence of degenerative changes of the disc and spondylosis within the cervical spine increases with age (3, 6, 8). For example, plain radiographs of the cervical spine showed ab-

normalities in 75% of both symptomatic and asymptomatic patients in the 7th decade of life (6). Hitselberger and Witten (8) found that 21% of asymptomatic patients studied by posterior fossa myelography had defects in the contrast column in the cervical region. Wiesel et al. (20) reported the incidence of lumbar spine abnormalities shown on CT in a series of 52 asymptomatic volunteers. Overall, 35% of patients had evidence of lumbar spinal disease (HNP, facet degeneration, or foraminal stenosis), with the total increasing to 50% in those patients older than 40 years.

MRI of the cervical and lumbar spine has also shown a large number of false-positive results in asymptomatic patients (2, 3, 10). Boden et al. (3) found that 19% of 63 asymptomatic volunteers had either a HNP, a disc bulge, or foraminal stenosis in the cervical spine. The number of abnormal studies increased to 28% in the group of volunteers older than 40 years. If the authors included narrowing or degenerative changes within the discs and osteophytes in the criteria for abnormal scan results, then 60% of the study population older than 40 years exhibited MRI abnormalities. Similar results for the lumbar spine have recently been published in which only 36% of asymptomatic subjects had normal-appearing discs at all levels from L1–L2 to L5–S1 (10). Thus, although MRI, CT, and myelography have high levels of sensitivity in detecting degenerative disease of the spine, all of these imaging modalities yield a significant number of false-positive results in the asymptomatic population and may disclose a misleading abnormality in the symptomatic patient.

Techniques that directly image the affected spinal nerves would be useful in patients with multilevel disc disease shown on conventional radiographic imaging techniques, when clinical symptoms are not confined to a single dermatomal distribution, or with ambiguous results shown on electrodiagnostic and conventional imaging studies. MRI is useful in the diagnosis and evaluation of traumatic, compressive, and inflammatory lesions of peripheral and cranial nerves (4, 5, 7, 11, 13–15, 17). Using special fast spin echo sequences and fat suppression in conjunction with phased-array coils, Filler et al. (5) and Howe et al. (9) reported on MRN techniques to image peripheral nerves with greater resolution and conspicuousness. Similar sequences have been used in conjunction with wrist coils to image the median nerve in patients with carpal tunnel syndrome in which the compressed nerves appear bright on T2-weighted and short tau inversion recovery imaging sequences (4). In a series of 36 patients, there was excellent correlation with electrodiagnostic studies (4). In addition, the study showed that decompression of the affected median nerve could result in normalization of the signal. Short tau inversion recovery images have shown similar signal increases in the optic nerve in patients with optic nerve injury (18).

Our goal was to adapt MRN to directly image the affected cervical spinal nerves in patients with cervical radiculopathy symptoms and findings. Using the fast spin echo and FMPIR sequences in conjunction with a custom-designed brachial plexus coil, symptomatic spinal nerves demonstrated increased signal intensity when compared with both adjacent ipsilateral and contralateral spinal nerves. These changes extended several centimeters distal to the point of compression and were observed even in patients with normal electrodiagnostic findings. By using the axial FMPIR images, we were able to quantify the signal changes in the affected spinal nerves. Further work in much larger series of both symptomatic and asymptomatic populations will be necessary to analyze the sensitivity and specificity of this technique. However, these cases illustrate the potential for MRN to directly image signal changes in compressed spinal nerves in patients with cervical radiculopathy.

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COMMENTS

Our ability to evaluate the functional status of the nervous system has been exponentially increasing in recent years. As recently as several decades ago, we were only able to assess function by neurological examination. Subsequently, electrophysiological techniques, such as electroencephalography, electromyography, evoked potential, spinal cord and brain stem monitoring, and electrodiagnostic peripheral nerve studies, have allowed us to further our understanding of impairments of central and peripheral nervous system function. Recently, techniques for the functional evaluation of the brain have been expanded to include functional magnetic resonance imaging, magnetoencephalography, and magnetic source imaging. These latter techniques allow clinicians not only to objectively assess neurological impairment but also to assess the presence and anatomic origin within the central nervous system of eloquent function, such as speech, motor function, and sensory function. Although motor or sensory impairment, as well as electrodiagnostic findings, may be suggestive of a surgical lesion related to cervical nerve root compression, the ability to predict response to surgery is still somewhat deficient.

Dailey et al. have developed and used a technique that may indeed help us acquire additional "functional" information about nerve root injury or injury to the peripheral nervous system. With their technique, we may be able to precisely localize the anatomic level of involvement (correlation with clinical symptoms), provide functional and physiological information about the effects of nerve root compression, and perhaps demonstrate the lack of significant involvement in questionable cases. This may decrease the potential for unnecessary surgery.

The adaptation of previously reported techniques by Dailey et al. to cervical spine disease is indeed intriguing and worthy of further work. Although the results are clearly preliminary, further refinement of this technology may help us to more precisely and accurately select patients for surgical procedures. I am sure that future information from larger patient series will be illuminating.

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The technique for magnetic resonance neurography to help specify the diagnosis of cervical radiculopathy is an interesting idea with probable potential. Cervical phased-array coils may provide the diagnostic strength that we currently do not have. Dailey et al. present an interesting technique. We occasionally face difficult decisions when patient history and examination are of limited benefit in determining which of the multiple potential cervical nerve roots are symptomatic. Electromyography/nerve conduction velocity evaluation has been of limited value in these circumstances. The data presented in this article are quite limited but are nonetheless interesting. As this technology develops, it will be interesting to more rigorously evaluate this potential diagnostic technique.

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The authors alert us to a diagnostic study that might help in some patients. However, in the first two patients that the authors describe, this study was unwarranted because the history, examination, and the conventional magnetic resonance imaging were nicely correlated. However, in Patient 3, a diagnostic test, the magnetic resonance neurography, was of obvious help.

It would have been of interest for the authors to speculate about why the changes were present. Is this increase in signal seen in the affected roots, edema, or possibly even inflammation? Why are the changes seen not at the site of compression but distal to the point of compression?

In conclusion, the authors add a diagnostic technique that will help in a few perplexing cases but should not be routinely used. Simple and more direct diagnostic tests are available. I also agree with the authors that this work is indeed preliminary and that further work in a larger series of both symptomatic and asymptomatic populations will be necessary to analyze the sensitivity and specificity of this technique.

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