Chapter 6

MR Imaging of the Brachial Plexus in Patients with Multifocal Motor Neuropathy

Multifocal motor neuropathy (MMN) is a disorder that clinically simulates lower motor neuron disease (LMND) as both may be characterized by progressive asymmetric weakness of the limbs and muscular atrophy without sensory symptoms.[33,117,122,167,181-183,188,189,213,256,257] However, in MMN electrodiagnostic studies reveal the multifocal motor conduction block that also occurs in chronic inflammatory demyelinating polyradiculoneuropathy (CIDP). This has led to the hypothesis that, like CIDP, MMN is an immune-mediated neuropathy. Improvement of muscle strength following treatment with cyclophosphamide or high-dose intravenous immunoglobulins (IvIg) and the presence of elevated serum anti-GM1 antibodies in many patients with MMN support this hypothesis.[33,117,122,167,181-183,188,189,213,256,257]
MR imaging is useful in examining the normal anatomy and pathology of the brachial plexus.[24,194,200,261,262] MR imaging delineates the brachial plexus due to the inherent contrast differences among the peripheral nerves, the surrounding fat, the related vessels, and the muscles; this makes it suitable for studying peripheral nerve disease of the upper extremities. As symptoms of MMN, LMND and CIDP usually involve the upper extremities, we studied whether MR imaging of the brachial plexus can distinguish MMN from LMND and whether abnormalities resemble those of CIDP. We performed MR imaging scans in patients with MMN and compared them with LMND and CIDP, as well as with normal and a variety of other abnormal controls.

Patients and methods

Patients

Included in the study were nine patients with MMN, five patients with CIDP, and eight patients with LMND. The clinical and MR imaging features of the patients with MMN and CIDP are described in Table 1. The patients with MMN and LMND had a progressive asymmetrical weakness, atrophy, areflexia or hyporeflexia in affected limbs, absence of upper motor neuron features, and no or only minor sensory loss. The patients with MMN had electrophysiologic evidence of motor nerve conduction block (see electrophysiologic studies). All nine patients with MMN

responded to treatment with IvIg as was previously published for patients Nos. 1, 6 and 8.[256,257] All patients with CIDP fulfilled the established research criteria for CIDP[1] of which the definitions for conduction block and temporal dispersion were modified.[125,256]

In the patients with MMN, 12 MR imaging scans were performed of the brachial plexus of the affected sides. The non-affected brachial plexus of patients Nos. 2 and 3 was also scanned. MR imaging scans of patients Nos. 2, 4, 5, 6, 7 and 9 were performed before IvIg treatment was started, while patients Nos. 3 and 8 were scanned after one year, and patient No. 1 after two years of IvIg maintenance treatment. In patient No. 2 the MR imaging scan was repeated after one year of IvIg maintenance treatment. In the patients with CIDP the brachial plexus of both sides was scanned, while in the patients with LMND only the clinically affected sides were scanned. Other controls were 174 patients with clinically suspected brachial plexus pathology of which MR imaging scans were performed between 1992 and 1996.[258,260-262]

Electrophysiologic studies

To detect conduction block or demyelination, the following investigations were done. Motor nerve conduction was measured, on both sides, in the median, ulnar, and deep peroneal nerves using surface electrodes. When no conduction block could be detected the musculocutaneous and tibial nerves were investigated. The compound muscle action potential (CMAP) was recorded from the abductor pollicis brevis, flexor carpi radialis, abductor digiti minimi, biceps brachii, extensor digitorum brevis and abductor hallucis brevis muscles. Stimulation sites were wrist, 5 cm below the elbow, 5 cm above the elbow, axilla, Erb's point, ankle, below the fibular head and popliteal fossa. When stimulation at Erb's point revealed abnormalities, the stimulator was set at maximal output. F waves were recorded after 20 stimuli delivered to the median, ulnar, deep peroneal and tibial nerves at the wrist or ankle. Prior to conduction studies the arms and legs were warmed in water of 37ºC for 30 minutes.[75] For each nerve segment the negative part of the CMAP on proximal stimulation was compared with that on distal stimulation in order to detect definitive conduction block (reduction in CMAP area of at least 50%, irrespective of the amplitude reduction),[203] possible conduction block (reduction in CMAP amplitude of at least 30% for arm nerves or 40% for leg nerves),[4] and increased temporal dispersion (increase in CMAP duration of at least 30%).[125] Evidence of demyelination included: (1) conduction block, (2) increased temporal dispersion, (3) reduction of motor nerve conduction velocity, or increased distal motor latency (DML), or increased minimal F wave latency according to previously described criteria for demyelination,[1] (4) absent F waves. Conduction block was only considered when the CMAP amplitude on distal stimulation exceeded 1 mV. F waves were included only if the DML and motor conduction velocity in the same nerve were not compatible with demyelination. Evidence of demyelination at

common entrapment sites did not count.
Of the nine patients with MMN, all had conduction block (definite in 15 nerve segments of eight patients; possible in 14 nerve segments of six patients). Other evidence of demyelination (i.e., increased temporal dispersion or motor conduction velocity, DML or minimal F wave latency compatible with demyelination) was found in 25 nerves of nine patients.
Of the five patients with CIDP, all had conduction block (definite in seven nerve segments of three patients; possible in 14 nerve segments of five patients). Other evidence of demyelination was found in 19 nerves of five patients.
None of the eight patients with LMND had conduction block. Other evidence of demyelination was found in three nerves of two patients.
Abnormal sensory conduction was found only in the patients with CIDP. Evidence of axonal loss (reduced CMAP amplitude on distal stimulation or abnormalities on concentric needle electromyography) was found in MMN, CIDP and LMND.

MR Imaging

The patients were scanned on a 0.5 Tesla system (Gyroscan T5-II, Philips, Philips Medical Systems, Best, The Netherlands) with the use of a body-wrap-around surface coil or on a 1.5 Tesla system (Gyroscan ACS-NT, Philips, Philips Medical Systems, Best, The Netherlands) with the body coil.
The standard protocol included sagittal T1-weighted spin echo images or a T1-weighted 3D volume acquisition, sagittal proton-density and T2-weighted spin echo images of one side from the spinal cord to the medial side of the humeral head. In the coronal plane thin T1-weighted spin echo images were performed of both sides. An additional coronal fat-suppressed T2-weighted turbo spin echo sequence (TSE STIR) was done in patients Nos. 1, 3, 6, 7, 9, 10, 11, 12, 13 and 14. Gadolinium-DTPA was administered in patients Nos. 1, 2, 5, 11 and 12, and in four patients with LMND.

Results

The MR imaging findings in the patients with MMN were abnormal in four patients (in one patient on both sides, in three patients on one side). MR imaging of patient No. 1 showed pronounced abnormalities of both brachial plexuses (Fig. 1): the right brachial plexus was diffusely swollen and there was an increased signal intensity on the T2-weighted images. No enhancement of the swollen nerves was noted after the intravenous administration of gadolinium-DTPA. The brachial plexus of the less symptomatic left side showed an increased signal intensity of the ventral rami of roots C7 and C8, the trunks, divisions and cords. In patient No. 2 the ventral rami of the roots of the left brachial plexus were slightly swollen, and an increased signal intensity on the T2-weighted images from the ventral rami of the roots through the

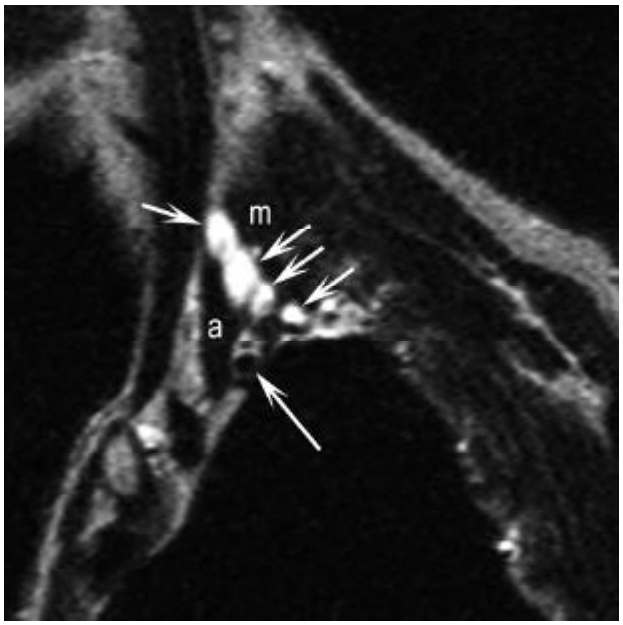

Fig. 1A

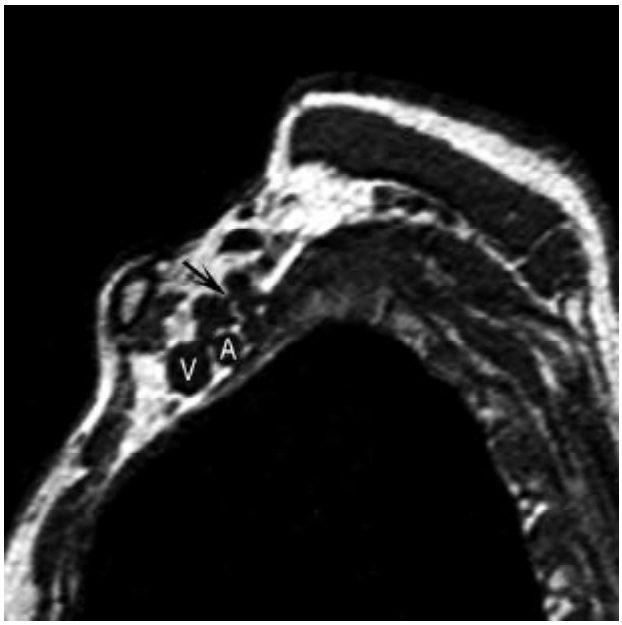

Fig. 1B

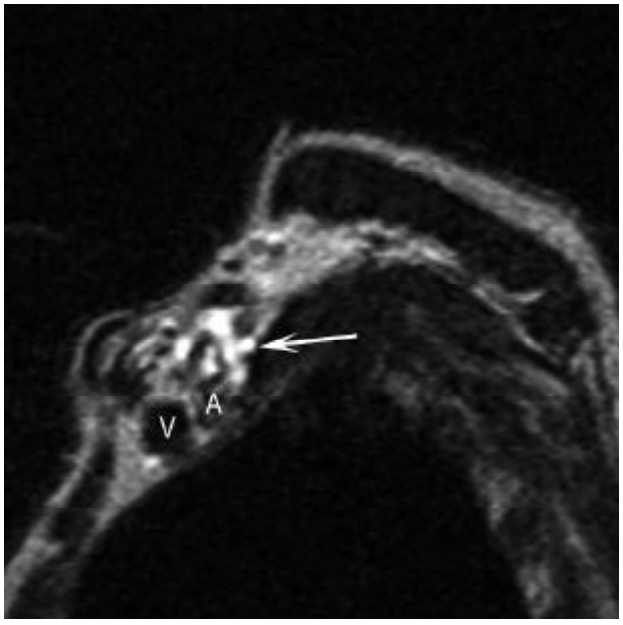

Fig. 1C

Fig. 1. Patient No. 1: MMN.

A. Sagittal T2-weighted image at the level of the right interscalene triangle. The thickened ventral rami of the roots (short arrows) with an increased signal intensity are seen between the anterior (a) and middle (m) scalene muscles. The long arrow points to the subclavian artery.

B. Sagittal T1-weighted image at the level of the divisions shows the thickened right brachial plexus (arrow). A = subclavian artery, V = subclavian vein.

C. Sagittal T2-weighted image at the same level as in **B** demonstrates the increased signal intensity in the thickened brachial plexus. A = subclavian artery, V = subclavian vein.

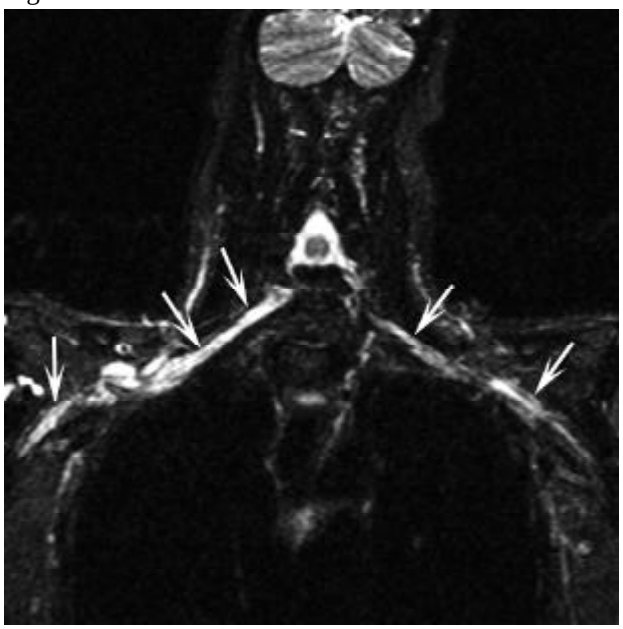

Fig. 1D

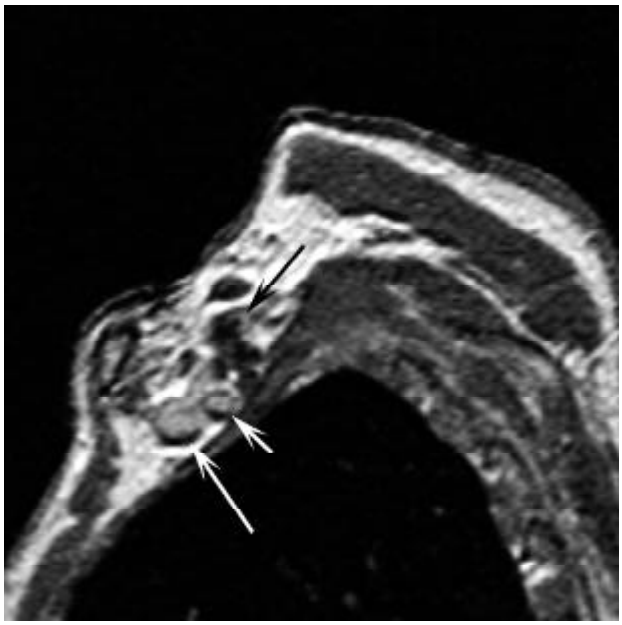

Fig. 1E

origin of the peripheral nerves in the axilla was seen (Fig. 2). There was no enhancement after the administration of gadolinium-DTPA. The right non-symptomatic brachial plexus was scanned for comparison and was unremarkable. After the patient was diagnosed as having MMN, he received IvIg maintenance therapy, which resulted in a nearly complete recovery of muscle strength. Fourteen months after onset of treatment MR imaging was repeated and, despite the beneficial effect of therapy, the MR imaging abnormalities did not show any improvement. Patient No. 3 showed an increased signal intensity on the T2-weighted images in the nerves in the right axilla (Fig. 3). The non-symptomatic left side was normal. Patient No. 4 demonstrated a focal increased signal intensity on the T2-weighted images at the level of the left interscalene triangle where the ventral rami of the roots C5 through Th1 join to form the trunks, and in the peripheral nerves in the left axilla (Fig. 4). In patients Nos. 5, 6, 7, 8 and 9 no abnormalities were detected by MR imaging. Gadolinium-DTPA was given in patient No. 5 and no enhancement was seen.

MR imaging of the patients with CIDP was abnormal in three of the five patients. Patients Nos. 10, 11 and 12 showed an increased signal intensity of both the right and left brachial plexus (Fig. 5). Gadolinium-DTPA was given in patient Nos. 11 and 12 and no enhancement was noted. In contrast with our findings in MMN, the abnormalities on both sides were similar in the CIDP patients.

None of the MR imaging scans of the patients with LMND showed any of the abnormalities found in MMN or CIDP.

In the last four years we have performed MR imaging of the brachial plexus in 174 patients with clinically suspected brachial plexus pathology. No abnormalities were seen in 82 patients. Pathology was found in 92 patients and included trauma (n=30), primary tumors of the brachial plexus (n=6), primary or metastatic tumors near the brachial plexus with or without brachial plexus involvement (n=49), radiation fibrosis (n=4), infection (n=2) and thoracic outlet syndrome (n=1). In this group we found an increased signal intensity of the brachial plexus in two patients with radiation fibrosis and in four patients after trauma.[258,260] The six patients with primary tumors showed an increased signal intensity within the brachial plexus, but this coincided with a well defined mass which enhanced after administration of gadolinium-DTPA.[260-262]

Fig. 1. *Continued.*

D. Coronal TSE STIR image shows the increased signal intensity in both the right and left brachial plexus (arrows). Note that the right brachial plexus is thicker than the left.

E. Sagittal T1-weighted image with gadolinium-DTPA at the level of the divisions shows the thickened brachial plexus (black arrow) which does not enhance (compare to **B**). Note the enhancing subclavian artery (short white arrow) and subclavian vein (long white arrow).

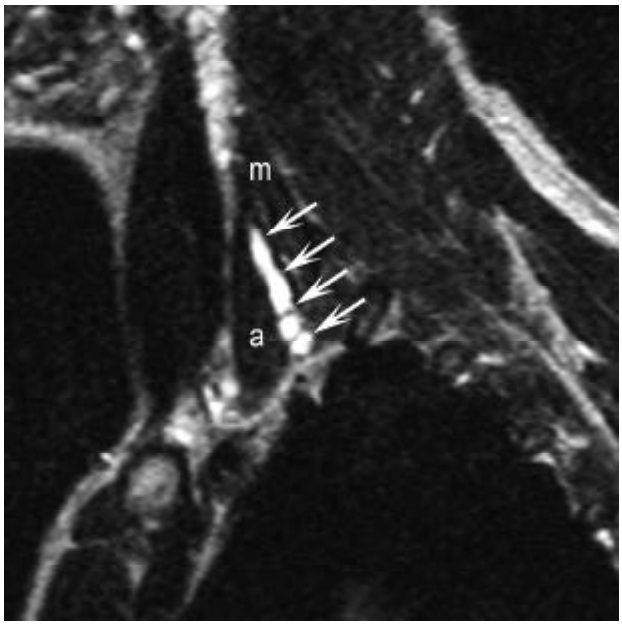

Fig. 2A

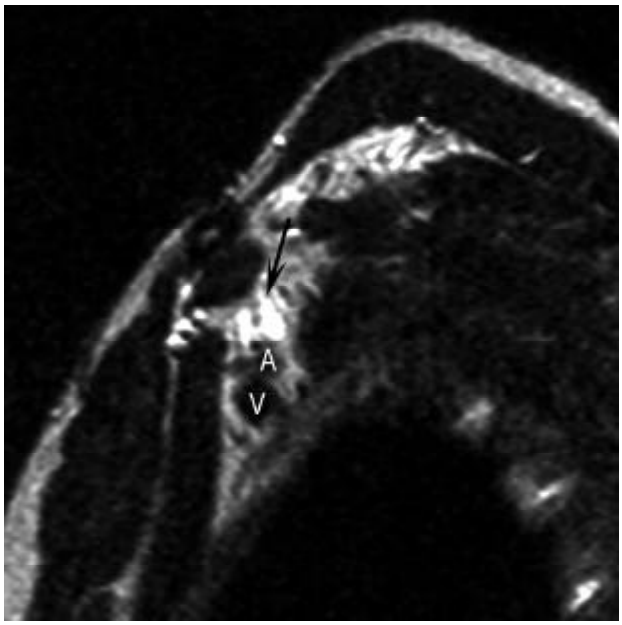

Fig. 2B

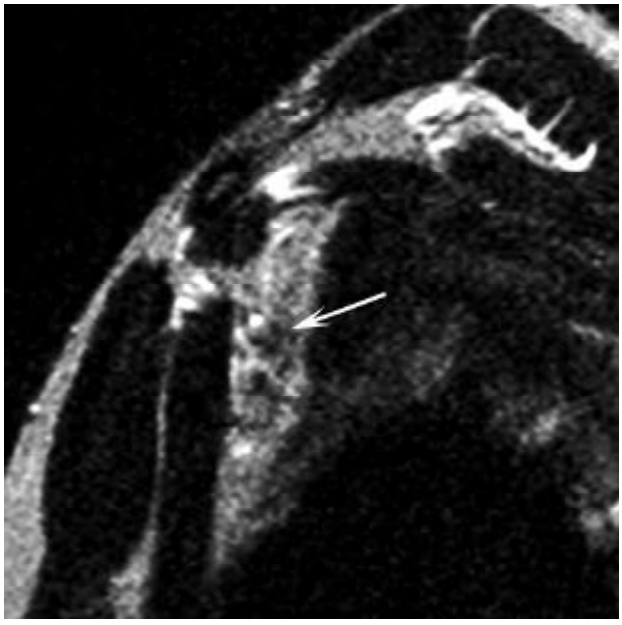

Fig. 2C

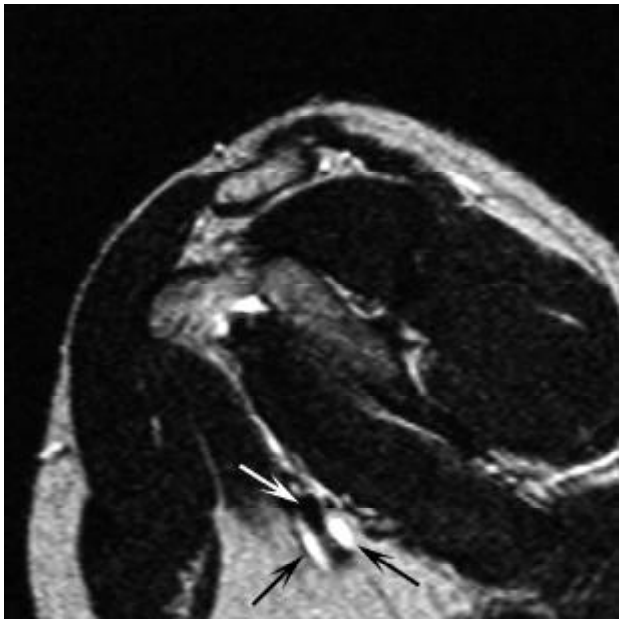

Fig. 2D

Fig. 2. Patient No. 2: MMN.

A. Sagittal T2-weighted image at the level of the left interscalene triangle. The swollen ventral rami of the roots (arrows) with an increased signal intensity are seen between the anterior (a) and middle (m) scalene muscles.

B. Sagittal T2-weighted image shows the increased signal intensity in the cords (arrow) of the left brachial plexus. A = axillary artery, V = axillary vein.

C. Sagittal T2-weighted image of the normal right brachial plexus at the same level as **B** demonstrates the low signal intensity of the cords (arrow).

D. Sagittal T2-weighted image at the level of the left axilla shows the increased signal intensity of the proximal peripheral nerves (black arrows) surrounding the axillary artery (white arrow).

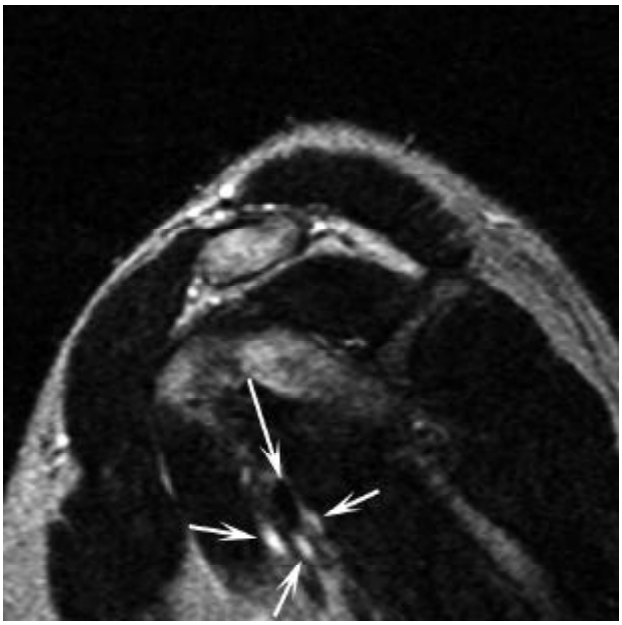

Fig. 3

Fig. 3. Patient No. 3: MMN.
Sagittal T2-weighted image of the right axilla shows the increased signal intensity of the proximal peripheral nerves (short arrows), which was the only abnormality found in this patient. Long arrow points to the axillary artery.

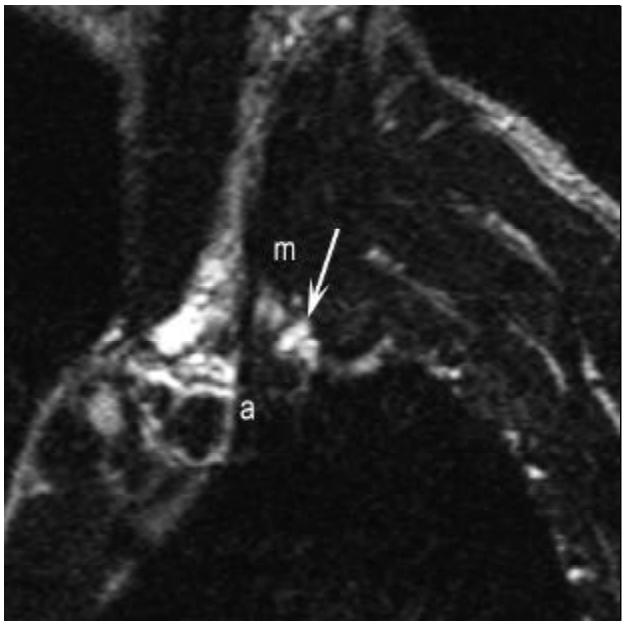

Fig. 4

Fig. 4. Patient No. 4: MMN.
Sagittal T2-weighted image of the left interscalene triangle shows the increased signal intensity of the ventral rami of the roots (arrow), a = anterior scalene muscle, m = middle scalene muscle.

Fig. 5. Patient No. 10: CIDP.

A. Sagittal T2-weighted image of the right interscalene triangle shows an increased signal intensity of the ventral rami of the roots (arrows).

B. Coronal TSE STIR image shows the increased signal intensity of the brachial plexus of both sides (arrows).

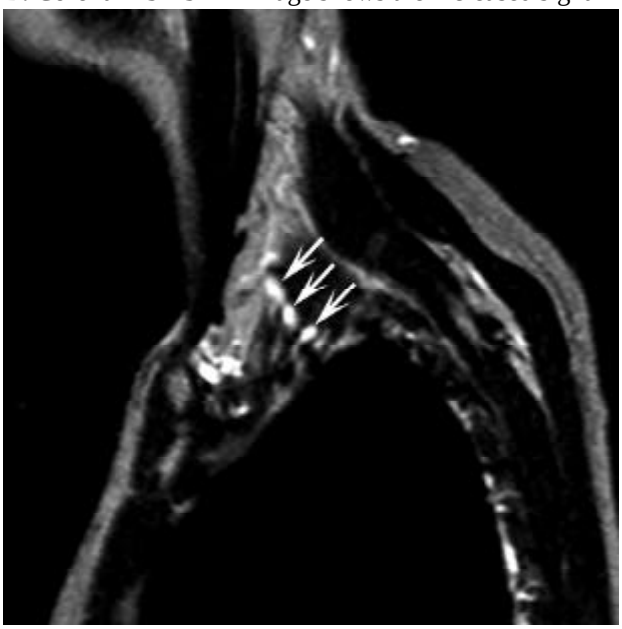

Fig. 5A

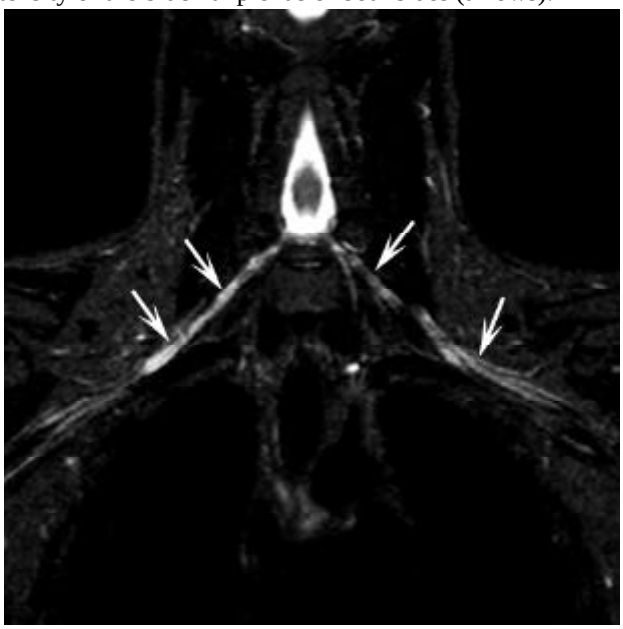

Fig. 5B

Discussion

In the present study we found abnormalities of the brachial plexus in patients with MMN and CIDP by MR imaging. The abnormalities included increased signal intensities of the affected nerves on the T2-weighted images that can be associated with a diffuse nerve swelling. In contrast, MR imaging scans of the clinically non-affected brachial plexus of patients with MMN and of the brachial plexus of patients with LMND were normal. The abnormalities in patients with MMN were similar to those in CIDP. The distribution of the MR imaging abnormalities corresponded with the distribution of symptoms of the patients: asymmetrical in MMN and symmetrical in CIDP.

In MMN and CIDP more than only the brachial plexus is affected, but the brachial plexus is the portion of the peripheral nervous system that can be easily studied with MR imaging, as the brachial plexus can be easily delineated from the surrounding fat, vessels and muscles. The peripheral nerves have the same signal intensity as muscle, which is low to intermediate on both T1- and T2-weighted images.[24,194] As we and other authors have demonstrated, the brachial plexus can have a pathologically increased signal intensity on T2-weighted images in cases of tumor,[194,200,260-262] trauma[114,200,260] or after radiation therapy.[248,258] MR imaging of tumor involvement of the brachial plexus usually demonstrates a more focal increased signal intensity and contrast enhancement. The MR imaging features of brachial plexopathy after radiation therapy, and after trauma, can resemble the abnormalities found with MMN.

The pathological substrate of the swelling of nerves and the increased signal intensity demonstrated by MR imaging of the brachial plexus in our patients with MMN and CIDP is not known. The cause of the MR imaging lesions cannot only be a result of axonal degeneration, as we have not found abnormalities in patients with LMND. The increased signal intensity on T2-weighted images may be due to demyelination, while inflammation and edema might lead to swelling in nerves. In CIDP, neurophysiologic and pathologic studies provide substantial evidence for inflammatory demyelination of peripheral nerves.[1,60]

In MMN, the pathological substrate is less clear than in CIDP, but several studies indicate demyelination of motor nerves. Neuropathologic findings at autopsy in one patient with MMN showed inflammatory demyelination in the motor cranial nerves and motor roots of peripheral nerves.[171] Kaji et al.[108] performed a biopsy a few millimeters distally of a nerve enlargement of the brachial plexus that revealed demyelination, although the pathology of the enlargement itself remained unknown. In another patient with palpable nerves in the supraclavicular region and proximal conduction block, a biopsy from the brachial plexus revealed onion bulb type hypertrophic changes associated with inflammatory cell infiltrates.[26] Another

indication for demyelination in MMN is a study showing mild demyelinating features in sural nerve biopsies of patients with MMN, suggesting that the demyelinating pathophysiology also affects sensory fibers, but to a lesser degree than motor fibers.[47] MR imaging of sciatic nerves of rabbits with experimental demyelination shows an increased signal intensity on T2-weighted images, without signal changes on T1-weighted images.[244] Moreover, MR imaging of the sciatic nerve in a patient with Déjérine-Sottas disease also showed a high signal intensity on T2-weighted images, thought to be due to demyelination and onion bulb formation.[242]

Two case reports by Kaji et al.[108] and Parry[181] described MR imaging of nerves in patients with MMN. Kaji et al.[108] reported MR imaging findings in two patients with MMN. They found a focal enlargement of the median nerve at the site of conduction block with enhancement after the administration of gadolinium-DTPA in one patient. In another patient, a MR imaging scan showed a mass lesion of the brachial plexus. Parry[181] described a high signal intensity on the T2-weighted images and gadolinium-DTPA enhancement of an enlarged upper trunk of the brachial plexus in a patient with MMN. Six reports have described contrast enhancement of swollen lumbosacral roots in patients with CIDP.[20,32,48,53,84,153] One report mentioned that the contrast enhancement disappeared during clinical improvement and reappeared during a relapse.[20] In addition to these studies, we report the MR imaging scans of the brachial plexus in a larger group of nine patients with MMN, of five patients with CIDP, as well as of eight patients with LMND and other controls.

It is important to differentiate MMN from LMND because MMN is a potentially treatable disease. As we found no abnormalities with MR imaging in patients with LMND, MR imaging of the brachial plexus may be useful to distinguish MMN from LMND. In this study we demonstrate that MMN can involve the brachial plexus and that this can be demonstrated with MR imaging, which is important to recognize, regardless of the pathological substrate of the swelling of the nerves and the increased signal intensity.

Table 1

The clinical and MR imaging features of the patients with MMN and CIDP

pt no	m/f	age	duration	distribution weakness	MR imaging
MMN					
1.	m	55	9 y	RA>LA; D>P asymmetric	right brachial plexus diffusely swollen with increased signal intensity, left brachial plexus slightly swollen with increased signal intensity
2.	m	35	3 y	LA; D>P asymmetric	left brachial plexus slightly swollen with increased signal intensity
3.	m	50	7 y	RA,RL; D>P asymmetric	increased signal intensity in the nerves in the right axilla
4.	m	26	4 y	LA,LL,RL; D>P asymmetric	increased signal intensity in the left interscalene triangle and in the nerves in the axilla
5.	m	50	2 y	RA; D>P asymmetric	normal
6.	m	41	11 y	RA,LA,RL,LL; D>P asymmetric	normal
7.	m	34	5 y	RA,LA,LL; D>P asymmetric	normal
8.	f	34	4 y	RA,LL; D>P asymmetric	normal
9.	m	60	2 y	RA,LA,LL; D>P asymmetric	normal
CIDP					
10.	m	26	5 m	RA,LA,RL,LL; D=P symmetric	increased signal intensity of both the right and left brachial plexus
11.	m	48	8 m	RA,LA,RL,LL; P>D symmetric	increased signal intensity of both the right and left brachial plexus
12.	m	66	5 m	RA, LA, RL, LL; D=P symmetric	increased signal intensity of both the right and left brachial plexus
13.	m	22	6 m	RA,LA,RL,LL; D=P symmetric	normal
14.	f	61	8 m	RA,LA,RL,LL; D>P symmetric	normal

pt no = patient number; m = male; f = female; y = years, m = months, LA = left arm; RA = right arm; LL = left leg; RL = right leg; D = distal; P = proximal