MAGNETIC RESONANCE IMAGING OF THE CERVICAL AND THORACIC SPINE AND THE SPINAL CORD

A Study Using a 0.3 T Vertical Magnetic Field

ELNA-MARIE LARSSON

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Title and subtitle

Magnetic Resonance Imaging of the Cervical and Thoracic Spine and the Spinal Cord. A Study Using a 0.3 T Vertical Magnetic Field

Magnetic resonance imaging (MR), using a 0.3 T resistive scanner with an iron core and a vertical magnetic field, was evaluated in patients with different diseases affecting the cervical and thoracic spine and the spinal cord. The results indicate that MR is well suited as the procedure of choice for emergency examination of patients with spinal cord symptoms, for examination of patients with suspected spinal multiple sclerosis and for pre-operative evaluation of patients with rheumatoid arthritis with neurological symptoms emanating from the cranio-cervical junction. In patients with cervical radiculopathy and/or myelopathy, caused by spondylosis or disk herniation, MR was found to be equivalent with myelography and CT myelography but MR has several practical advantages. MR at 0.3 T using a vertical magnetic field provided information comparable to that reported from examinations performed with superconducting MR scanners.

In order to optimize the MR examinations of the spine, the signal characteristics of different coils available when using a vertical magnetic field were determined by phantom studies. Recommendations for optimal coil selection for different levels of the cervical and thoracic spine are given. In addition, the paramagnetic contrast medium gadolinium-DTPA was administered intravenously to patients with suspected spinal multiple sclerosis. Enhancement of clinically active lesions in the cervical spinal cord was observed. Serial MR examinations with gadolinium-DTPA showed that a decrease in enhancement could be correlated with decrease in clinical symptoms and signs.

Key words Magnetic resonance imaging, spine, spinal cord, spinal nerve roots, multiple sclerosis, rheumatoid arthritis, spinal stenosis, intervertebral disk displacement, techniques, gadolinium-DTPA.

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The development of new techniques has rapidly changed the algorithms for the radiological evaluation of spinal diseases during the last two decades. New procedures provide diagnostic information that could not be obtained previously.

Conventional radiography

Conventional radiography has been, and still is, the basic method for the morphological evaluation of the spine. It provides information about vertebral dislocation and pathological changes in the vertebrae and can also indirectly reveal abnormalities in the intervertebral disks.

Myelography

With the advent of myelography in 1921, with the injection of contrast medium into the subarachnoid space, pathological changes within the spinal canal and the neural foramina could be demonstrated (76). A great advantage of myelography is the possibility of investigating the entire spinal canal in one examination. However, myelography still has several disadvantages. The spinal cord and nerve roots above or below a complete block cannot be visualized unless a new spinal puncture with injection of contrast medium is carried out above or below the block. The method is invasive with potential complications related to the spinal puncture as well as to the toxicity of the contrast medium, although serious complications, such as convulsions, have not been reported with the new water-soluble nonionic contrast medium iohexol (78). The examination is uncomfortable for the patient and hospitalization is usually required, at least following cervical and thoracic myelography.

CT and CT myelography

Computed tomography (CT), introduced for examination of the brain in 1972 (27), was, with the advent of whole-body scanners in 1975 also utilized for examination of the spine (10). CT displays the anatomy and structural abnormalities of the osseous spine with good image quality. In addition, the paraspinal soft tissues, which are difficult or impossible to demonstrate by conventional radiography and myelography, can be demonstrated by CT. In the lumbar spine, the dural sac and the extradural contents of the spinal canal are delineated on CT without the use of contrast medium because of the abundant epidural fat in this region (22, 53). In the cervical and thoracic spine, however, intrathecal contrast medium is required for accurate assessment of the contents of the spinal canal on CT because the canal is smaller and the anterior epidural space contains little fat (9, 53, 79, 91).

CT myelography has been reported to provide additional information compared with myelography, including better differential characterization of bone vs. soft tissue lesions and direct demonstration of cord size and foraminal narrowing. CT myelography also permits evaluation of regions distal to a severe narrowing or myelographic block (2, 8, 35). It has, however, been reported that either myelography or CT myelography alone is sufficient for preoperative evaluation of more than [illegible] per cent of patients with cervical radiculopathy or myelopathy (82). In the same study it was suggested that both examinations should be performed when one method alone fails to define the aetiology of the clinical neurological symptoms and signs. Delayed CT following myelography or CT myelography can reveal syringomyelia (3) or cystic necrosis and cavitation (30) in the spinal cord. Like myelography, CT myelography is an invasive procedure with potential complications, but it can be performed on outpatients (62). A major disadvantage of the method is that it provides only axial images. Reconstruction in sagittal or other planes can be made, but to display the longitudinal dimensions of the cervical or thoracic spinal cord contiguous thin slices covering a large region must be acquired. This requires a high radiation dose and long scanning time (91). The same information is obtained with just two or three films in myelography. In the lumbar spine, the selection of levels for CT scanning can be based on clinical symptoms and signs of nerve-root involvement whereas the clinical symptomatology from the cervical spine is insufficiently reliable to ascertain the levels of nerve-root involvement (59). Accordingly, the choice of levels for CT myelography of the cervical or thoracic spine is best guided by preceding myelography (91).

Magnetic resonance imaging (MR)

The first MR image of the human body (the thorax) was published in 1977 (7). Images of the head and abdomen were demonstrated in 1978 but prototype clinical imaging trials were not initiated until 1980 (15, 27, 44).

MR is a nonionizing technique capable of producing tomographic images. Unlike CT, however, MR can provide images directly in any plane and MR provides better soft tissue contrast than any hitherto employed radiological technique (15). The method is noninvasive and can be performed on outpatients. Three types of magnets with different magnetic field strengths are presently available for clinical MR imaging: resistive with an air-core (0.02–0.2 T) or with an iron-core (0.3–0.4 T), permanent (0.3 T) and superconducting (0.2–2.0 T) (43). The signal-to-noise ratio (SNR) increases with increasing field strength (80). The introduction of surface coils provided a substantial improvement in the SNR in all types of magnets (1, 25, 41, 88). The long imaging time is a disadvantage but with new techniques, e.g. using pulse sequences with a reduced flip angle and gradient refocused echo, the imaging time may be reduced (13, 14, 26).

MR is vulnerable to image degradation from various types of patient motion that occur during the relatively protracted acquisition time of the pulse sequence (43). Physiological motion, especially that related to cardiac activity, respiration and peristalsis of the alimentary tract, gives rise to artifacts on MR images of the chest and abdomen. The absence of these types of physiological motion is an advantage in brain and spine imaging, although thoracic spine images may be affected by artifacts caused by the cardiac activity. The oscillatory pulsation of the cerebrospinal fluid (CSF) may, however, degrade the spine image quality, most prominent in sequences acquired with long repetition times (TR) (23, 69, 70). Several techniques for the reduction of motion-induced artifacts have been applied with varying degrees of success (12, 23, 43, 71).

In clinical trials, MR has proved particularly efficacious for the evaluation of suspected neurological disease (43). Currently, imaging of the spine is the second most commonly performed MR examination following studies of the brain (29). Body coil imaging of the spine did not provide adequate spatial resolution for the detection of small lesions and, with the exception of cervical myelopathy, most investigators believed that myelography, CT and CT myelography remained more efficacious in examining the spine (29, 55). By 1986, surface coils were more readily available, as were thin-section imaging techniques, and MR was beginning to be considered a modality competitive with myelography and CT myelography, even for the evaluation of extradural disease (29). The ability to obtain sagittal and coronal images of the spine, as in myelography, and in addition axial images, as in CT and CT myelography, is a great advantage of MR. However, using surface coils, the field of view is limited, so if a long segment of the spinal column is to be examined, consecutive series of images must be obtained. The external morphology of the spinal cord is delineated by MR as well as by myelography and CT myelography, but MR is the only modality that provides a direct image of intramedullary lesions. In addition, MR is sensitive in the detection of extramedullary disease in the spinal canal, in the vertebral bodies and in the paravertebral soft tissues (21, 29, 43, 55). However, since cortical bone emits no signal in MR, cortical bony abnormalities are difficult to define and cortical bone cannot be distinguished from adjacent ligaments (29, 43).

The intravenous injection of paramagnetic contrast media, such as gadolinium-diethylene triamine pentaacetic acid (Gd-DTPA), has recently been reported to improve the detection and delineation of intramedullary and intradural extramedullary tumours (84, 86, 87). Gd-DTPA has also proved useful for the differentiation of recurrent lumbar disk herniation from postoperative extradural fibrosis (28). As with iodinated contrast enhancement, Gd-DTPA enhancement is related to the breakdown of the blood-brain barrier or to increased tissue perfusion. The definite role of paramagnetic contrast media in MR imaging of the spine has not yet been determined.

The question of optimal magnetic field strength has not been resolved. Superconducting magnets have the advantage of great stability and achieving high field strengths to provide the best possible SNR (15). On the other hand, superconducting magnets are expensive and also have a high maintenance cost because a continual supply of liquid helium and nitrogen is required for cooling (80). These magnets have a horizontal magnetic field oriented along the long axis of the magnet and the patient. The presence of a strong magnetic field oriented in this way results in environmental problems, including the risk of bringing ferromagnetic metallic objects into the scanning room and difficulties in using emergency and life-supporting equipment in the room (43, 80). Chemical shift artifacts at interfaces between well-hydrated structures and fat, e.g. at the margins of the vertebral bodies, disturb the interpretation of high field strength images but are negligible at lower field strengths (43). Flow-induced artifacts may be less pronounced at low field strengths than at high field strengths, since flow-induced phase shifts are proportional to the magnetic field gradient strength (23) and an MR unit with low magnetic field strength generally utilizes lower gradient strengths than a MR unit with a high field strength (80).

A resistive magnet with an iron core and a vertical magnetic field has several advantages despite the lower SNR resulting from the lower field strength. The magnet is cheaper than the superconducting magnets and the maintenance cost is lower than that for both superconducting magnets and resistive magnets with an air core as the electric power consumption is reduced when an iron core is used (60). The magnet can be installed, without magnetic shielding, adjacent to other examination rooms in the department of radiology since the stray field of the magnet is reduced by the iron core (60). This location of the MR scanner allows increased efficiency and facilitates emergency MR examinations of patients who have first undergone other studies in the department, e.g. conventional radiography of the spine or chest radiography. The vertical magnetic field has a smaller effect than a horizontal field on surrounding equipment in the MR examination room. The vertical field also allows utilization of solenoidal surface coils of different sizes wrapped around the neck or the torso. Such coils give a high SNR from the whole tissue volume surrounded by the coil without the decrease in SNR from deep structures, which is inevitable when a planar surface coil is used (41). Interest has been drawn to the problem of constructing planar surface coils with improved depth performance, and recently it has been shown that by using a Helmholtz double-coil design, with the anatomic region of interest centred between two planar surface coils, a more uniform SNR may also be obtained with a horizontal magnetic field (64).

MR imaging is contra-indicated in patients with pacemakers and ferromagnetic intracranial aneurysm clips (43). In a small number of patients MR examination can not be performed because of claustrophobia.

Most published MR investigations of the spine have been performed with superconducting magnets operating at field strengths between 0.35 and 1.5 T. No systematic evaluation has been made of MR of the spine using a resistive magnet with an iron core and a vertical magnetic field of intermediate strength. This type of MR unit has, as mentioned above, several practical and economical advantages.

The aims of the present investigation were:

1) To evaluate the efficacy of a 0.3 T resistive MR unit with a vertical magnetic field in the diagnosis of diseases affecting the cervical and thoracic spine and the spinal cord.

2) To determine the signal characteristics of the conventional head coil and body coil as well as different solenoidal surface coils by phantom studies in order to optimize the coil selection for cervical and thoracic spine imaging.

3) To evaluate the role of the paramagnetic contrast medium Gd-DTPA in MR imaging of suspected spinal multiple sclerosis.

MATERIALS, METHODS AND RESULTS

Method for MR examinations

All MR examinations were performed using a resistive scanner with an iron core and a vertical magnetic field operating at 0.3 T (Fonar β-3000 M). In this system, the built-in body coil is used as transmitter. The body coil, the head coil or a surface coil is used as receiver. The surface coil is wrapped around the neck or the torso. Several surface coils with different diameters are available. Most examinations were performed using surface coils but in some cases the head coil or the body coil was used as receiver. Multi-slice images were obtained using a 256 x 256 matrix interpolated to a 512 x 512 display matrix. The phase-encoding gradient was always aligned along the axis of the spine for sagittal images in order to direct motion artifacts, caused by pulsatile CSF and blood flow, away from the region of interest (23). Because of this, cardiac gating, which prolongs imaging time, was not considered necessary. Spin-echo pulse sequences were used in all investigations. The repetition times (TR), echo times (TE), and pixel size used for the spine images are given in Table 1. Five excitations were performed at TR=300 ms, three excitations at TR=500 ms and one excitation at TR=2000 ms. The slice thickness was 5.0 mm with a 2.1 mm interslice gap. Sagittal images were always obtained first. The midline sagittal slice was then used as a scout image for positioning and angulation of axial or coronal images.

In the text below, short TR/TE pulse sequences are defined as pulse sequences with TR=300–500 ms and TE=16–28 ms, and long TR/TE pulse sequences as sequences with TR=2000 ms and TE=56–84 ms.

Emergency magnetic resonance examination of patients with spinal cord symptoms (36)

Materials and methods

Eighteen patients (2–81 years old, mean age 43 years) with spinal cord symptoms of sudden or relatively sudden onset were examined with MR. Solenoidal surface coils were used in all except three cases where a head coil or body coil was used. All patients had a sagittal short TR/TE scan and most of them also had a sagittal long TR/TE scan. Additional axial or coronal short TR/TE images were obtained in some cases. Four of the patients were mechanically ventilated during the MR examination. Conventional radiographs of the spine had been obtained in 15 patients and in five patients an iohexol myelography was performed before or after the MR examination. In all patients the preliminary clinical diagnosis was known when the MR images were evaluated and in three cases the results of myelography were also known. The MR diagnosis was verified by histopathologic examination in seven patients and was confirmed by observing the clinical course of the disease and by performing one or two additional MR examinations in eight patients. In three patients the MR diagnosis was supported solely by observation of the clinical course of the disease.

Results

The results of the MR examinations and the histopathological findings are summarized in Table 2.

The cranial and caudal extent of the epidural tumours could be clearly defined and the degree of spinal cord compression could be assessed. Paraspinal tumour tissue was well demonstrated on sagittal images but the lateral portions of the tumour were more exactly delineated on axial or coronal scans. The paraspinal lymphoma and neuroblastoma were found to extend through the intervertebral foramina to the epidural space. Intravertebral tumour tissue had low signal intensity in contrast to the high signal intensity of normal bone marrow on short TR/TE images. The intramedullary tumour appeared cystic with a low signal intensity in the rostral and caudal part and intermediate signal intensity in the middle on short TR/TE images. This was interpreted as being a cystic tumour with high protein content in the middle part, whereas a rather soft solid tumour with rostral and caudal cystic components was revealed at surgery.

In the patient with disk space infection, increased signal intensity was seen on long TR/TE images in the disk as well as in epidural and paravertebral soft tissue components, which were interpreted as abscesses. Staphylococcus aureus was cultured from the patient's blood and from puncture material from the paraspinal abscess. Only small remnants of the abscesses were seen on MR following treatment with antibiotics for one month. The patients with myelitis exhibited local enlargement of the cervical cord on short TR/TE images accompanied by increased signal intensity within the cord on long TR/TE images. On subsequent MR examinations, cord atrophy had developed in one of the patients and the width of the spinal cord had returned to normal in the other.

The spontaneous epidural haematoma had high signal intensity on short TR/TE images in both patients (Fig. 1), and in one of them the haematoma exhibited a low signal surrounded by a high signal on long TR/TE images. Spontaneous resorption of both haematomas had taken place when follow-up MR examinations were performed after four and 12 weeks, respectively.

The patients with disk herniations exhibited a low signal intensity indentation on the anterior subarachnoid space and the cord on short as well as long TR/TE images. As no osteophytes were visible on conventional radiographs and both patients gave a history of relatively sudden onset of symptoms, the aetiology of the indentations was consid-

Table 1

Spine imaging parameters used in the different investigations

Investigation	TR/TE (ms/ms)	Pixel size (mm)
Emergency MR examination of patients with spinal cord symptoms (36)	500/28 2 000/56	1.0–1.2 1.0–1.2
Myelopathy patients studied with MR for multiple sclerosis plaques (57)	500/28 2 000/56	1.0 1.0
Pre- and postoperative MR imaging of the cranio-cervical junction in rheumatoid arthritis (38)	300/16 or 500/28 2 000/56	1.0 1.0 1.0
Comparison of myelography, CT myelography and MR imaging in cervical spondylosis and disk herniation: pre- and postoperative findings (39)	300/16 or 500/28 2 000/56	0.8–1.0 0.8–1.0 0.8–1.0
Coil selection for MR imaging of the cervical and thoracic spine using a vertical magnetic field (40)	500/16	1.0–1.4
Gd-DTPA enhancement in MR of suspected spinal multiple sclerosis (37)	300/16 or 500/16 2 000/84	1.0 1.0 1.0

Table 2

Results of emergency MR in 18 patients with spinal cord symptoms. Histopathological findings in 7 of the patients

MR diagnosis (histopathological findings)	No. of patients
Epidural tumour with cord compression and intra- and paravertebral tumour growth (1 myeloma, 1 metastasis from prostatic carcinoma and 1 from Ewing sarcoma, 1 non-Hodgkin lymphoma, 1 neuroblastoma)	5
Intramedullary cystic tumour (cystic and solid astrocytoma)	1
Diskitis with epidural and paraspinal abscesses and cord compression	1
Cervical myelitis	2
Epidural haematoma (spontaneous) with cord compression	2
Disk herniation (1 cervical, 1 thoracic) with cord compression	2
Fractures with cord compression and contusion	2
Osteophytes and bulging disk with cord contusion after trauma without fracture or dislocation	2
Normal except for disk degeneration	1

Fig. 1

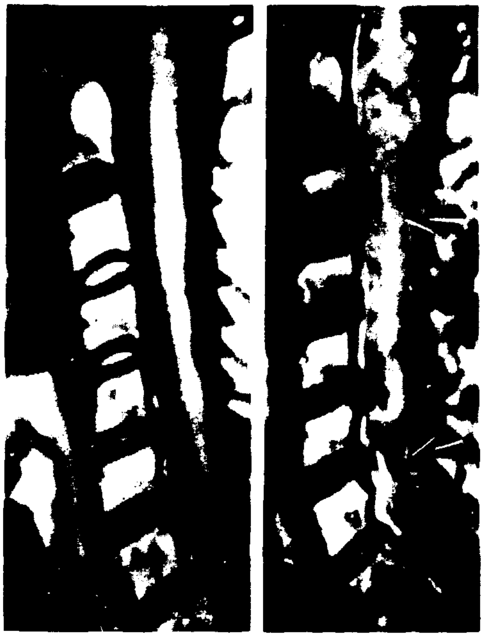

Fig. 2a Fig. 2b

Fig. 1. Spontaneous epidural haematoma (→) with spinal cord compression. Sagittal short TR/TE (500/28) image.

Fig. 2. Suspected spinal multiple sclerosis.

Sagittal short TR/TE (500/28) image (a) shows slight general atrophy of cervical spinal cord.

Long TR/TE (2000/56) image (b) reveals oblong high signal intensity lesion (→) with small transverse diameter.

[(a) and (b) reprinted from (57), with permission]

ered to be disk herniation. This was confirmed in both cases by surgery.

In the trauma patients with fractures, cord compression caused by bony elements protruding into the spinal canal was visualized on short TR/TE images. In addition, increased signal intensity within the cord could be seen on long TR/TE images. In two patients without fracture or dislocation of the bony elements, but with clinical signs of cord injury, long TR/TE images revealed lesions with high signal intensity within the cord. One of these patients had a bulging disk and osteophytes at the level of the cord injury and the other had osteophytes at the level below the area of high signal intensity. On follow-up examination of the latter patient there was no signal abnormality in the cord and the patient had recovered almost completely.

The patient with normal MR also had a normal myelogram and he recovered without treatment. A diagnosis that could explain his symptoms was not assigned.

Myelopathy patients studied with magnetic resonance for multiple sclerosis plaques (57)

Materials and methods

Table 3 summarizes data on seven patients with myelopathy and a clinical suspicion of demyelinating disease. None of them had a definite multiple sclerosis diagnosis, since they had no clinical evidence of lesions in any other part of the central nervous system (73). Cases 1–4 were studied with MR 1–5 months after the onset of their latest attack of myelopathy. All of them had residual symptoms emanating from the cervical spinal cord at the time of the MR examination. Cases 5–7 had a chronic progressive course of the myelopathy. The CSF was examined for oligoclonal bands and IgG/albumin ratio, and visual evoked potentials were recorded in all patients. MR of the cervical spine was performed using a solenoidal surface coil wrapped around the neck and MR of the brain was performed using the head coil. All patients underwent sagittal short, as well as long, TR/TE scans of the cervical spine and an axial long TR/TE scan of the brain. In case 2 a second MR examination was performed four months after the first one.

Results

The laboratory results and the MR findings are described in Tables 3 and 4. The lesions in the cord had high signal intensity on long TR/TE images but could not be seen on short TR/TE images. The cranio-caudal extent of the cervical cord lesions differed as indicated in Table 4. The lesions had an oblong configuration (Fig. 2). The lesions described as large in Table 4 involved a large cross-section of the cord, while the lesions of intermediate and small size had a smaller transverse diameter (Fig. 2).

Table 3

Clinical data and MR findings in 7 patients with suspected spinal multiple sclerosis

Case No.	Sex and age	Duration of disease at MR	Clinical course	Intrathecal IgG synthesis	Visual evoked potentials	MR cervical spinal cord	MR brain
1	M 33	5 months	1 attack	+	–	+	–
2	F 21	2 months	1 attack*	+	+	+	+
3	F 27	2 years	2 attacks	–	+	–	+
4	F 43	2 years	6 attacks	+	+	+	–
5	M 43	20 years	Attacks → progressive	+	+	+	+
6	F 48	8 years	Progressive	+	+	+	–
7	M 60	15 years	Progressive	+	+	+	–

* A second attack (optic neuritis) occurred one month after the MR examination (three months after the first attack).
– = normal.
+ = pathological.

Table 4

MR findings in 7 patients with suspected spinal multiple sclerosis

Case No.	MR cervical spinal cord		MR brain
	Short TR/TE images	Long TR/TE images	
1	Local athrophy at level C4–C5	Large plaque at C4–C5	Normal
2	I. Slight local enlargement of the cord at C4	Large plaque at C4	Multiple plaques
	II. Normal (4 months later)	Plaque at C4 slightly smaller than before. New small plaque at T1	
3	Normal	Normal	Multiple plaques, also in the mesencephalon
4	Slight general atrophy of cervical cord	Plaques of intermediate size at C3–T1	One small lesion of doubtful significance
5	General atrophy of cervical cord, less pronounced at C3–5	Plaque of intermediate size at C3–6	Multiple plaques, also in the cerebellum
6	Local atrophy at C3	Plaque of intermediate size at C2–3	Normal
7	Local atrophy at C3	Small plaque at C3	Normal

Pre- and postoperative MR imaging of the cranio-cervical junction in rheumatoid arthritis (38)

Materials and methods

Ten patients (50–79 years old, mean age 67 years) with chronic rheumatoid arthritis with atlanto-axial subluxation were examined with conventional radiography and MR of the cervical spine before and, on average, six months after posterior occipitocervical fusion (4). The conventional radiographs included flexion-extension lateral views. MR was performed using a head coil with low centring. Sagittal short and long TR/TE images were obtained with the head in the neutral position. The pre-odontoid space was measured on conventional radiographs and on MR images from the lower posterior border of the anterior arch of the atlas to the nearest part of the odontoid process; a value exceeding 3 mm was regarded as horizontal atlanto-axial subluxation (63). The presence of vertical atlanto-axial subluxation was assessed (63). When peri-odontoid soft tissue, pannus, was seen on MR it surrounded the odontoid process. The portion of the pannus bulging posteriorly into the spinal canal was measured. Because the posterior border of the odontoid pro-

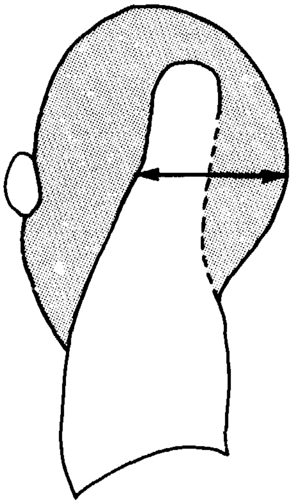

Fig. 3. Sagittal schematic drawing of anterior arch of atlas and odontoid process surrouded by pannus. → indicates measured sagittal diameter of odontoid process and intraspinal pannus behind it.

[Reprinted from (38), with permission]

a b

Fig. 4. Rheumatoid arthritis involving the cranio-cervical junction.

Pre-operative sagittal short TR/TE (500/28) image (a) shows pannus surrounding odontoid process. Compression of upper cervical cord is caused by horizontal atlanto-axial subluxation and pannus.

Short TR/TE (300/16) image (b) after posterior occipito-cervical fusion shows that horizontal atlanto-axial subluxation and pannus have decreased. There is no remaining cord compression. Artifacts from surgical fixation material are confined to posterior part of the neck.

[(a) and (b) reprinted from (38), with permission]

Table 5

Pre- and postoperative horizontal atlanto-axial mobility on conventional radiographs compared with size of pannus on MR images in 10 patients with rheumatoid arthritis

Case No.	Sagittal measurement (mm)			
	Atlanto-axial mobility (pre-odontoid space in flexion-extension on conventional radiographs		Odontoid process + posterior pannus on MR images	
	Preop.	Postop.	Preop.	Postop.
1	2 (18–16)	0 (12–12)	11	10
2	0 (2–2)*	0 (2–[illegible]	–	–
3	7 (10–3)	0 ([illegible]	12	10
4	5 (12–7)	0 (12–12)	11	9
5	12 (12–0)	4 (9–5)	16	10
6	7 (11–4)	0 (11–11)	10	7
7	5 (10–5)	0 (2–2)	11	9
8	3 (11–8)	0 (6–6)	13	9
9	5 (12–7)	0 (6–6)	16	10
10	9 (12–3)	0 (5–5)	16	9

* This patient had severe vertical atlanto-axial subluxation, no pannus was present.

cess was often difficult to identify on MR due to erosion, the largest sagittal diameter was measured from the anterior border of the odontoid process to the posterior border of the pannus (Fig. 3).

Results

Peri-odontoid pannus formation was revealed by MR pre-operatively in nine patients, all with mobile horizontal atlanto-axial subluxation (Table 5) (Fig. 4 A). The signal intensity of the pannus was equal to or slightly lower than that of the spinal cord on short TR/TE images and equal to or higher than that of the cord on long TR/TE images. Compression of the medulla and/or upper cervical cord, due to subluxation and peri-odontoid pannus bulging into the spinal canal, was seen in seven patients (Fig 4 A). Increased signal intensity within the medulla or spinal cord at the level of compression was seen pre-operatively on long TR/TE images in three patients, all with myelopathy. In two patients, this region could not be evaluated on long TR/TE images because of poor image quality. After stabilizing surgery the peri-odontoid pannus had decreased in size in all patients with pre-operative pannus (Table 5, Fig 4 B). Postoperatively, three patients had some remaining compression of the medulla and/or cord secondary to immobile subluxation, while the pannus posterior to the odontoid process had disappeared. Artifacts caused by the surgical fixation material (stainless steel wires and pins) were confined to the posterior part of the neck on short TR/TE images and did not interfere with the evaluation of the peri-odontoid region and the anterior part of the medulla/cervical cord (Fig. 4B). On long TR/TE images, the artifacts were larger and usually reached at least the anterior border of the cord. Consequently, signal abnormalities in the cord could not be evaluated postoperatively with MR.

Comparison of myelography, CT myelography and MR imaging in cervical spondylosis and disk herniation: pre- and postoperative findings (39)

Materials and methods

Twenty-six patients (30–70 years old, mean age 52 years) with cervical radiculopathy and/or myelopathy, caused by spondylosis or disk herniation, were examined with myelography, CT myelography and MR. Fourteen of the patients were operated upon and 11 of these agreed to undergo postoperative MR and CT examinations.

Conventional radiographs of the cervical spine had been obtained within a year prior to myelography in all patients and were also obtained postoperatively.

Myelography was performed with the patient in the prone position after instillation of 10–12 ml iohexol (240 mg I/ml) into the subarachnoid space via lumbar puncture. At the end of the examination a lateral image was obtained in the supine position.

CT myelography in the supine position was performed 1–4 hours after myelography. Angled axial 2 mm thick slices (except in four patients where 4 or 5 mm slice thicknesses were used) were obtained through the level(s) with the most severe narrowing of the spinal canal on the myelogram. A total of 32 levels were examined in the 26 patients. Postoperative CT was performed without contrast medium through the levels where surgery had been performed.

MR was performed using a solenoidal surface coil. Twenty patients were examined with MR within four days following myelography and six patients within three months. Sagittal and axial short TR/TE images and sagittal long TR/TE images were obtained in all patients preoperatively and in 11 patients postoperatively. In nine patients, an axial long TR/TE sequence was performed in addition, pre-operatively. The axial slices, angled parallel to the disk space, were obtained at the levels of the most severe pathological findings seen on the sagittal scans. When MR was performed it was known which levels had previously been selected for CT myelography.

Different types of surgery were performed within four months following the MR examination in 14 patients. The postoperative MR and CT examinations were performed 6–9 weeks after surgery in seven patients and 4 1/2–9 months after surgery in four patients.

The patients' medical records and surgical reports were reviewed. The side and degree, but not the level, of radiculopathy and the degree of myelopathy were assessed. The surgical findings were categorized as osteophytes and/or disk. The degree of postoperative improvement was also estimated.

The myelograms, CT myelograms and MR examinations were reviewed separately, each together with conventional radiographs, without knowledge of the clinical history, the results of the two other radiological examinations or the surgical findings. Pre-operative CT or MR images were available when the corresponding postoperative examination was evaluated. The degree of narrowing of the spinal canal, caused by osteophytes and/or disk and soft tissue, was evaluated at the 32 levels with maximal stenosis. The presence of anteroposterior vertebral dislocation, nerve root sheath deformity, and on MR also signal abnormalities in the spinal cord, were assessed. Correlation between clinical radiculopathy and radiological root sheath deformity was considered probable when clinical and radiological findings were ipsilateral or when clinical symptoms were bilateral and radiological findings were unilateral and vice versa.

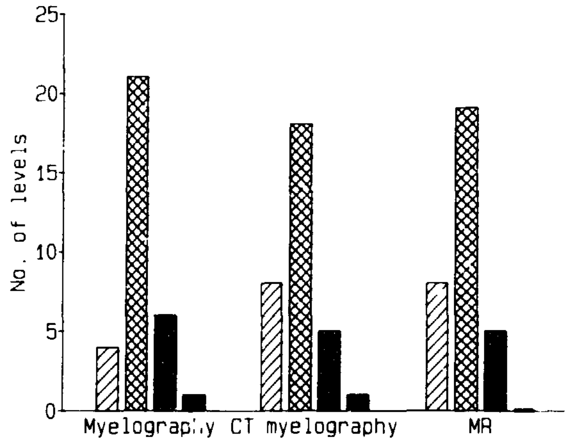

Fig. 5. Degrees of narrowing of anterior subarachnoid space and compression of cord at 32 levels (26 patients).

- mild narrowing
- moderate narrowing
- severe narrowing with cord compression
- impossible to evaluate

Results

The degree of narrowing of the anterior subarachnoid space and compression of the cord as assessed on myelography, CT myelography and MR are shown in Fig. 5. When reviewing the protocols for each level, five levels showed more pronounced narrowing on myelography than on CT myelography and/or MR. In the patients with moderate narrowing, the indentation on the subarachnoid space was usually more pronounced on myelography in the prone position than on CT myelography and MR.

Five levels exhibited narrowing which appeared to be caused solely by disk herniation according to all three methods (Fig. 6). At three of these levels, surgery revealed disk herniation and at two levels, disk herniation combined with osteophytes.

Anteroposterior vertebral dislocation caused by degenerative changes was seen on both myelography and MR at two levels, and on myelography alone at three additional levels. The prone and supine lateral myelograms revealed various degrees of mobility between the vertebrae at the levels of dislocation in all five cases.

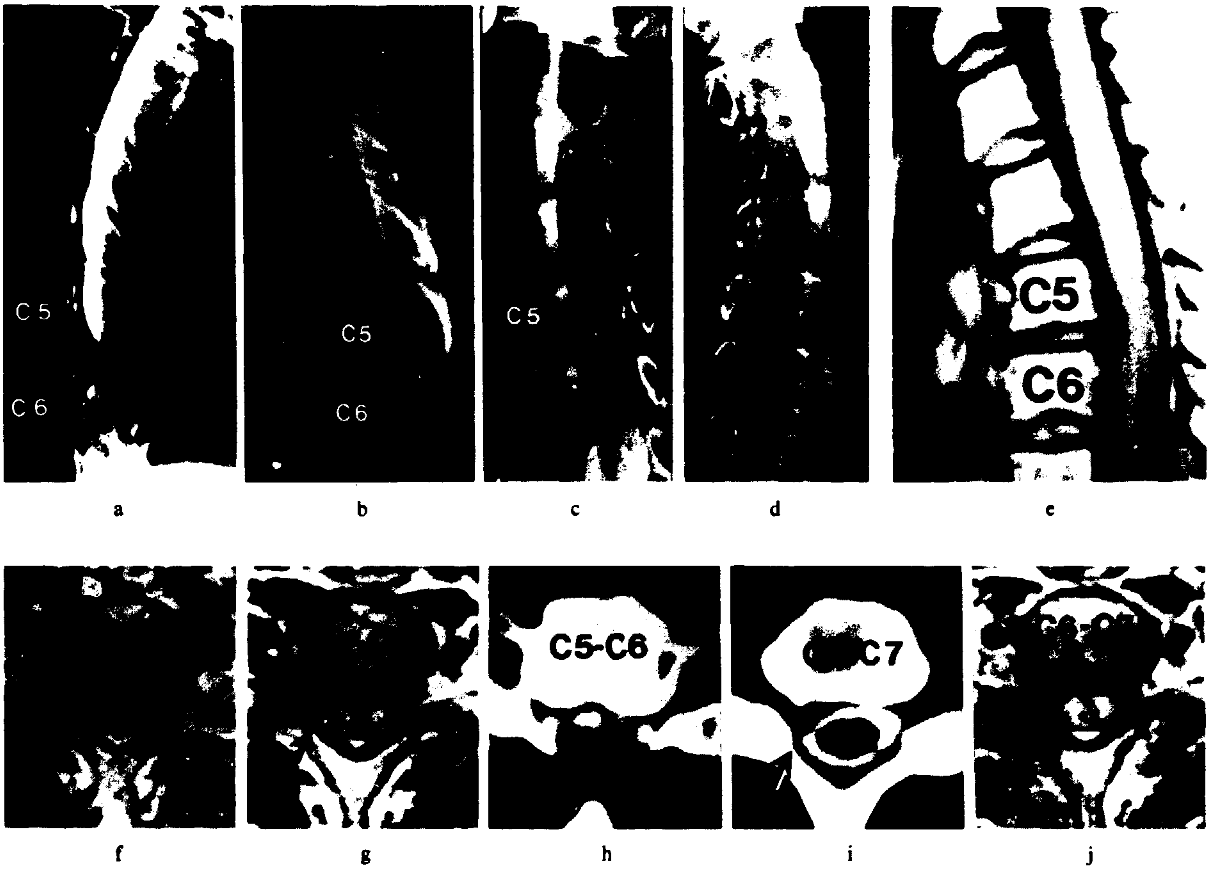

Fig. 6. Patient with bilateral radiculopathy, most pronounced on the right side, and slight myelopathy. Posterolateral diskectomy (soft disk) was performed at C6–C7 which resulted in slight decrease in clinical symptoms. Surgery will later be performed at C5–C6.

Myelography with lateral prone (a), lateral supine (b), and oblique views (c, d) shows severe narrowing with bilateral nerve root sheath deformity and slight compression of the cord at C5–C6 and moderate narrowing with right-sided nerve root sheath deformity at C6–C7. The narrowing at C5–C6 is caused mainly by osteophytes, the narrowing at C6–C7 is attributed to disk herniation (no osteophytes at this level on conventional radiographs). The narrowing at C5–C6 appears more pronounced in the prone than in the supine position.

Sagittal (e) and axial (f,g) short TR/TE (500/28) MR images and CT myelography (h, i) confirm the myelographic findings. The right-sided nerve root sheath deformity at C6–C7 (→) is apparent on axial MR as well as on CT myelography.

Axial short TR/TE (500/28) image (j) at C6–C7 eight weeks after surgery shows some remaining impingement on the anterior subarachnoid space with discrete right-sided nerve root sheath deformity (→, compare g). The remaining impingement is probably caused by postoperative tissue swelling.

The evaluation of nerve root sheath deformity using the three methods is summarized in Fig. 7. Bilateral deformities were seen more often on myelography than with the other two methods. The evaluation of each level is presented in Table 6.

Correlation between clinical radiculopathy and nerve root sheath deformity seen on myelography was considered probable in 19/24 patients (79 %), on CT myelography in 19/25 patients (76 %) and on MR in 20/26 patients (77 %).

Eight patients had myelopathy, and in four of these severe narrowing of the spinal canal with compression of the cord was revealed by all three methods (Fig. 6). One of these patients also exhibited increased signal intensity in the cord on long TR/TE images. No compression of the cord was seen in the remaining four patients. However, two of them had a narrow spinal canal and anteroposterior vertebral dislocation with instability and the third showed an increased signal in the cord on long TR/TE images for unknown reasons. The fourth patient showed no correlation between clinical and radiological findings with any modality regarding radiculopathy or myelopathy.

Postoperative MR and CT examinations showed normalization of the width of the subarachnoid space in two patients. These patients had no remaining symptoms. Some remaining impingement on the subarachnoid space was seen on MR in nine patients (Fig. 6). The degree of clinical improvement could generally be correlated with the radiological improvement. The remaining protrusions consisted of osteophytes in three patients, osteophytes

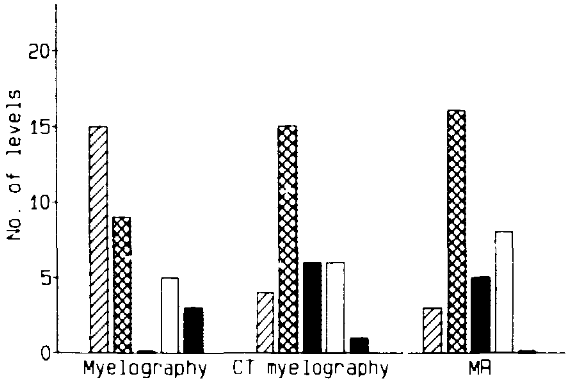

Fig. 7. Nerve root sheath deformity at 32 levels (26 patients).

- bilateral deformity
- right-sided deformity
- left-sided deformity
- no deformity
- impossible to evaluate

Table 6

Cervical spondylosis and disk herniation. Evaluation of nerve root sheath deformity at 32 levels (26 patients) on myelography, CT myelography (CTM) and MR. Definition of agreement and disagreement between methods

Agreement (A to D)	
A. Identical evaluation by all three methods	11 levels
B. Myelography: bilateral deformity, CTM and MR: unilateral deformity on same side	7 levels
C. Either myelography or CTM not possible to evaluate, identical evaluation by MR and the evaluable method	4 levels
D. Myelography: discrete unilateral deformity, CTM and MR: no deformity	2 levels
Disagreement (E to F)	
E. Myelography: no deformity, CTM and MR: unilateral deformity on same side	2 levels
F. Myelography: bilateral deformity, CTM and MR: various differences between evaluations	6 levels

Table 7

Summary of the coils used, number of scans and field of view in the studies of signal characteristics of different coils

Study	Coil	No. of scans	FOV (cm)
Small tube phantom	Head	3	35
	Surface 15 cm	3	35
Large tube phantom	Body	3	35
	Surface 30 cm	3	35
Small tube phantom			
Images centred 0.0 cm from coil centre	Surface 15 cm	2	35
Images centred 3.5 cm from coil centre	Surface 15 cm	3	35
Images centred 7.0 cm from coil centre	Surface 15 cm	2	35
Images centred 10.5 cm from coil centre	Surface 15 cm	2	35
Alderson phantom	Head	3	25.6
Cranio-cervical junction	Surface 15 cm	2	25.6
Cervico-thoracic junction	Surface 15 cm	3	30
	Surface 30 cm	3	30
	Body	3	30
Normal volunteer	Head	1	25.6
Cranio-cervical junction	Surface 15 cm	1	25.6
Cervico-thoracic junction	Surface 15 cm	1	30
	Surface 30 cm	1	30
	Body	1	30

combined with soft tissue in four patients and solely soft tissue in two patients. The osteophytes were usually unilateral. The nature of the remaining protrusions was difficult to determine with MR alone. CT was useful in providing information about the size and side localization of the bony components of these protrusions.

Coil selection for MR imaging of the cervical and thoracic spine using a vertical magnetic field (40)

Materials and methods

Imaging of the cranio-cervical junction can be performed using a conventional head coil or a solenoidal surface coil (15 cm diameter), wrapped around the neck. The latter coil is also used for examination of the cervical spine. Thoracic spine imaging can be performed using the body coil or a solenoidal surface coil (30 cm diameter), wrapped around the chest

In the first part of the study, two different tube phantoms filled with non-doped water were used to obtain information about intrinsic coil sensitivity (Table 7). The effects on the SNR of centring the images at various distances from the centre of a surface coil were also investigated (Table 7).

In the second part of the study, a human-like plastic phantom (Remcal/Alderson, Humanoid Systems Inc.,

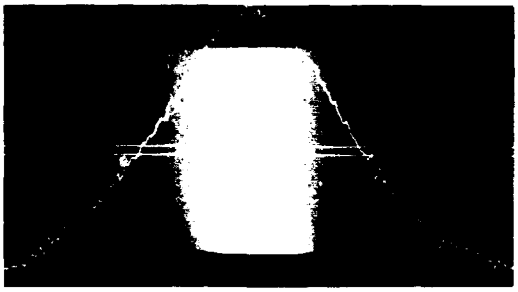

Fig. 8. MR image of small tube phantom, obtained using 15 cm surface coil, with signal intensity profile.

Carson, USA) was used to simulate clinical imaging. The phantom had the shape of a human head, neck and chest and was filled with non-doped water. The cranio-cervical junction was studied using the head coil (placed as caudally as possible) and the 15 cm surface coil (Table 7). The cervico-thoracic junction was studied using the 15 cm surface coil, the 30 cm surface coil and the body coil (Table 7).

Sagittal short TR/TE images of the tube phantoms and the Alderson phantom were obtained according to the protocols given in Table 7. Measurements of signal intensity were performed on the centre slice of each scan. As a measure of SNR, signal-to-background ratios were calculated for each scan by dividing the signal intensity values along a profile through the phantom (Fig. 8) by the average of two background values measured in the right and left margins of each image.

In the third part of the study, two healthy volunteers were examined using the same coils and parameters as those used in the Alderson phantom scans (Table 7).

Results

The SNR curves for the 15 cm surface coil and for the head coil, obtained in the small tube phantom are shown in Fig. 9. The corresponding SNR curves for the 30 cm surface coil and for the body coil obtained in the large tube phantom are shown in Fig. 10. When the images were centred at an increasing distance from the centre of a surface coil, the SNR decreased at the centre of the surface coil and in the direction from the transmitter coil but did not change in the direction towards the transmitter coil.

The Alderson phantom study of the cranio-cervical junction showed that the 15 cm surface coil gave a higher SNR than the head coil up to a distance of approximately 9 cm cranial to the centre of the surface coil. The corresponding study of the cervico-thoracic junction showed that the 15 cm surface coil had a higher SNR than the body coil up to a distance of approximately 13 cm caudal to the centre of the surface coil. The 30 cm surface coil had a higher SNR than the body coil up to a distance of approximately 2 cm cranial to the centre of the surface coil. In a region between the two surface coils the body coil had higher SNR than any of the surface coils.

In the images of the normal volunteers the cranio-cervical junction was best depicted when using the head coil and the levels T4–T6 were best depicted when using the body coil. The surface coils provided better images of the remaining parts of the cervical and thoracic spine.

Gadolinium enhancement in MR imaging of suspected spinal multiple sclerosis (37)

Materials and methods

Five patients with oblong, high signal intensity lesions in the cervical spinal cord on long TR/TE MR images (Fig. 11 A) and a clinical suspiction of demyelinating disease were examined with MR before and after intravenous injection of Gd-DTPA. Clinical and laboratory data on the patients are summarized in Table 8. None of the patients had been assigned a definite multiple sclerosis diagnosis as all had isolated myelopathy. Sagittal images of the cervical spine were obtained using a solenoidal surface coil. Gd-DTPA was administered intravenously at a dose of 0.1 mmol/kg body weight. Imaging protocols consisted of short TR/TE images before and 10, 45 and 60 minutes, and in one case also 24 hours, after the patient had received Gd-DTPA. Long TR/TE images were obtained before and 30 minutes after Gd-DTPA. In two patients with contrast enhancement in the primary MR examination (cases 1 and 2), MR examinations before and after Gd-DTPA were repeated 3 months later. In case 1, a second follow-up examination was performed 5 1/2 months after the first MR examination. Axial long TR/TE images of the brain without contrast medium were obtained using a head coil.

The patients underwent neurological examinations prior to and following the MR examinations. Cases 1 and 2 were categorized to be clinically active and cases 3–5 clinically stable at the time of the primary MR examination.

Results

Clinically active patients: The short TR/TE images revealed local enlargement of the cervical cord at the level of the lesion, seen on long TR/TE images, in case 1 (Figs 11 A and B) while the cord had normal configuration in case 2. Contrast enhancement of the lesion was observed on short TR/TE images in both patients. The enhancement was best seen on images obtained 45 and 60 minutes after Gd-DTPA injection (Figs 12 B and C). A discrete enhancement was already present 10 minutes after injection (Fig. 12 A). No remaining enhancement was visible after 24 hours (case 1). A slight enhancement was also discerned on long TR/TE images 30 minutes after Gd-DTPA injection.

In case 1, the enlargement of the cord had decreased and the contrast enhancement appeared less intense three

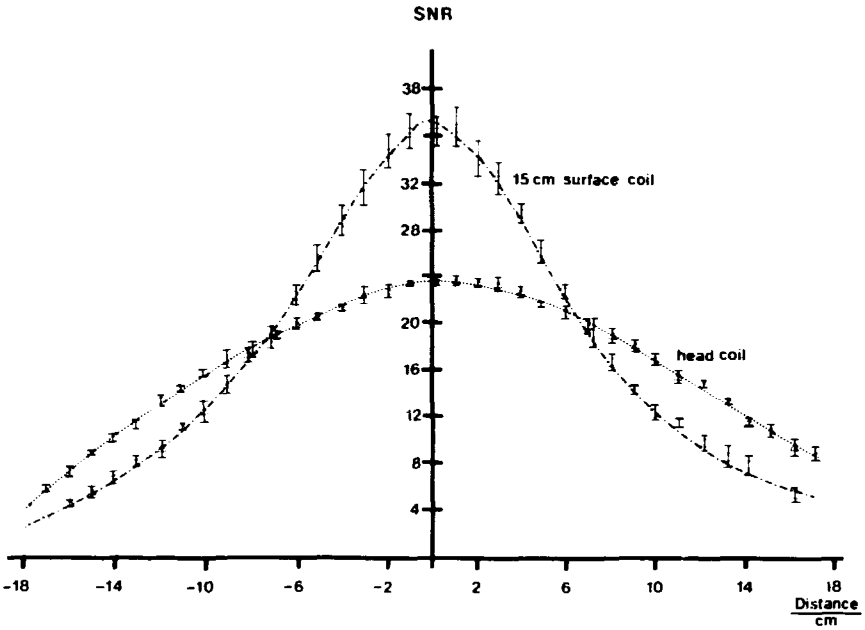

Fig. 9. SNR curves for 15 cm surface coil and for head coil, obtained along a 6 mm single intensity profile through the centre of a tube phantom. The origin of the horizontal axis was placed at the point of SNR maximum.

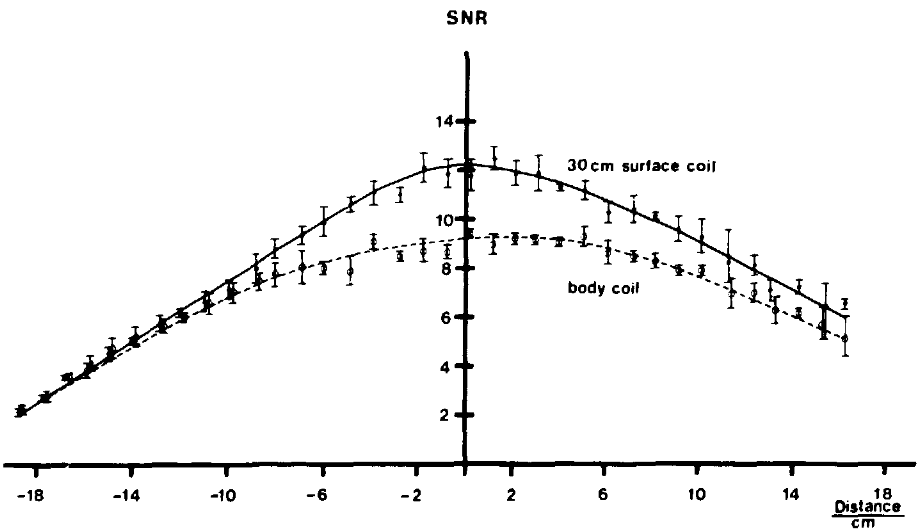

Fig. 10. SNR curves as in Fig. 9, but for 30 cm surface coil and body coil.

months later. At an MR examination 5 1/2 months after the first one, the width of the cord was normal and no contrast enhancement could be observed in this patient. In case 2 the contrast enhancement had disappeared completely after 3 months. The lesions could not be identified on long TR/TE images without Gd-DTPA after 3 and 5 1/2 months in the two patients. The decrease in contrast enhancement could be correlated with a decrease in clinical signs and symptoms of cervical myelopathy in both patients.

MR of the brain showed one small high signal intensity lesion in case 1 and was normal in case 2.

Clinically stable patients: Short TR/TE images revealed local or general atrophy of the cervical cord in cases 4 and 5 in whom the duration of the disease was long (Table 8). In case 3, with a shorter duration of disease (Table 8), the cord had normal width. No Gd-DTPA enhancement was observed in these three patients.

Two of the patients had multiple asymptomatic high

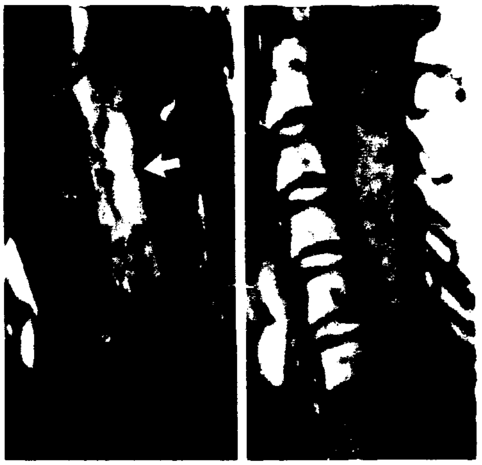

Fig. 11a Fig. 11b

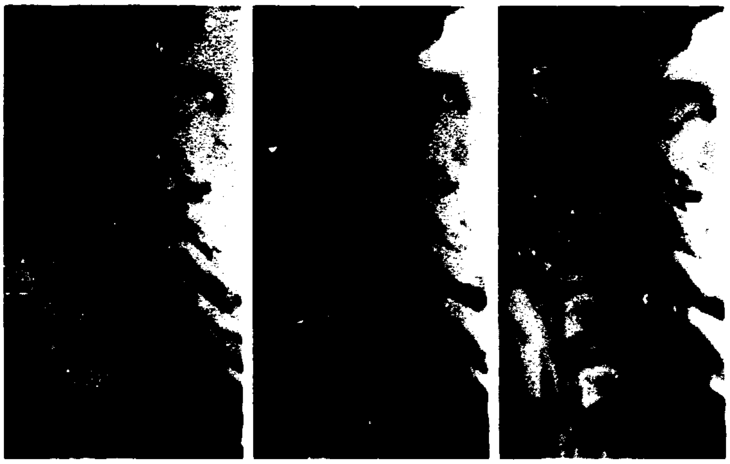

Fig. 12a Fig. 12b Fig. 12c

Fig. 11. Suspected spinal multiple sclerosis. Patient with clinically active cervical myelopathy.

Sagittal long TR/TE (2000/84) image (a) shows oblong lesion with high signal intensity (→) in the cord at C3–C4.

Short TR/TE (300/16) image (b) before Gd-DTPA reveals local enlargement of the cord at the level of the lesion.

[(a) and (b) reprinted from (37) with permission.]

Fig. 12. Same patient as in Fig. 11. Short TR/TE (300/16) images obtained 10 min. (a), 45 min. (b), and 60 min. (c) after intravenous injection of Gd-DTPA. Delayed contrast enhancement (→) is demonstrated, best seen 45 and 60 min. after Gd-DTPA. A slight enhancement (→) can be detected after 10 min.

[(a)–(c) reprinted from (37) with permission.]

Table 8

Clinical and laboratory data on 5 patients with suspected spinal multiple sclerosis

Case No.	Sex and age	Duration of disease at first MR	Clinical course	Intrathecal IgG synthesis	Visual evoked potentials
1	F 43	1 month	1 attack	+	+
2	M 40	1.5 months	1 attack	−	+
3	F 44	4 months	1 attack	+	−
4	F 49	9 years	Progressive	+	+
5	M 44	21 years	Attacks → progressive	+	+

+ = pathological.
− = normal.

signal intensity lesions, compatible with multiple sclerosis plaques, in the brain on long TR/TE images, while MR of the brain was normal in the third patient.

No adverse reactions to intravenous administration of Gd-DTPA were observed.

DISCUSSION

Evaluation of different diseases of the cervical and thoracic spine and spinal cord using a 0.3 T MR scanner with a vertical magnetic field

Emergency magnetic resonance examination of patients with spinal cord symptoms (36)

Emergency examination of the spine and spinal cord is often warranted in patients who have experienced a gradual onset of neurological dysfunction followed by sudden deterioration. Accordingly, an emergency examination is needed not only in patients with acute trauma or spinal diseases with sudden onset, but also in patients with abscesses or tumours that have become large enough to cause severe spinal cord symptoms requiring urgent surgical decompression. Myelography has been the method of choice for evaluation of the spinal cord in these situations. The results of the present study indicate that MR has the potential to replace myelography in the emergency examination of patients with spinal cord symptoms.

MR has previously been used as an emergency examination only in a limited number of patients (34, 47), mainly because of difficulties encountered in securing images in critically ill patients requiring life supporting equipment. Because MR scanners with an iron core and a vertical magnetic field have a low stray field (60), different types of emergency equipment can be accommodated and used in the scanning room. Thus, mechanical ventilation of patients with respiratory failure, as well as during anaesthesia, is possible using ventilators that are not specially adapted for use in a magnetic environment. In addition, the scanner has a wide opening, which facilitates supervision of, and communication with, the patient.

MR has obvious advantages over myelography in the emergency situation MR is noninvasive and the spine and spinal cord can be examined from any angle without moving the patient. This facilitates the examination of severely injured patients and patients with severe pain.

In tumour cases, involvement of the vertebrae, the spinal canal and also the paraspinal tissue can be accurately delineated with MR (24, 55, 77, 81). The extent of an intramedullary tumour (including oedema) can be better defined with MR than with myelography, because the signal intensity of the tumour differs from that of the cord (46, 55). It may, however, as in one of the patients in the present study, be difficult to differentiate between an intramedullary protein-containing cystic tumour and a solid tumour as the signal characteristics are very similar (17).

Epidural and/or paraspinal abscess complicating disk space infection can be distinguished from tumour with MR due to the associated increased signal intensity in the infected disk on long TR/TE images (54, 65). Intramedullary infection (myelitis) exhibits increased signal intensity within the spinal cord on long TR/TE images and swelling of the cord is usually seen on short TR/TE images.

The diagnosis of spontaneous epidural haematoma can be made with MR alone because of the characteristic signal intensity of the haematoma (Fig. 1) (68).

Disk herniation may be difficult to differentiate from osteophytes on MR because of the variable signal intensity encountered in herniated disks, as well as the partial volume averaging of adjacent structures (56). However, the combination of conventional radiographs and MR is usually sufficient for this differentiation.

In trauma patients, the spatial relationship of fracture fragments to the neural canal can be demonstrated with MR as well as with CT. In addition, compression of the cord by bone fragments can be demonstrated with MR (47, 49). Extramedullary haematoma and intramedullary lesions, such as contusion and haematoma, can also be revealed (34). The degree to which the spinal cord is affected is of importance when the need for surgical intervention is assessed. Even if surgery is not performed, comparison of the appearance of the spinal cord at the time of injury and at subsequent MR examinations may give important clues as to the eventual outcome (20). Fractures and dislocations of the lower cervical and upper thoracic vertebrae are often difficult to depict on conventional radiographs and may be overlooked, especially in patients with injuries at several levels of the spine. Such lesions are detected on MR without difficulty and MR can, in addition, reveal which part of the spinal cord is most severely injured, which is useful in the planning of treatment. In cervical spondylosis, contusion of the cervical cord may follow trauma without fracture or dislocation, as in two of the patients in the present study. Such lesions are difficult to detect by any radiological method other than MR.

Thus, MR is capable of detecting and defining the extent of intraspinal and paraspinal lesions. In some cases, the nature of the lesion can be inferred from specific signal characteristics, as in epidural or intramedullary haematoma. In most instances, however, the diagnosis is made from the findings at MR taking the clinical symptoms and signs into account. MR can in the emergency situation rule out causes of cord affection which need immediate surgical intervention. In conservatively treated patients with an equivocal initial diagnosis, follow-up MR examinations can easily be performed to establish the correct diagnosis.

In the emergency MR examination of patients with spinal cord symptoms, a sagittal short TR/TE sequence should be performed first. This gives excellent anatomic information and is usually adequate for the detection and evaluation of epidural tumour and haematoma. Axial short TR/TE images should also be obtained in patients with disk herniation. Occasionally, axial and/or coronal short TR/TE images are needed for the exact delineation of other lesions, such as tumours with paraspinal extension where emergency surgery or radiation therapy is planned. Sagittal long TR/TE images are usually necessary for accurate evaluation of myelitis, intramedullary tumour, diskitis, abscess and spinal cord contusion. In the thoracic spine it may be difficult to exactly determine the level of a lesion on MR images obtained with a surface coil because of the limited field of view. In most cases, this problem can be overcome by comparing the sagittal MR image with the conventional radiograph of the thoracic spine. If this is impossible, a fast sagittal body coil scan, including the lesion and either the upper cervical region or the lumbosacral region, should be performed as a supplement.

Suspected spinal multiple sclerosis (57)

MR is not required for confirmation when a definite diagnosis of multiple sclerosis has been made on clinical grounds. Clinically, a dissemination of the lesions in space and in time is included in the diagnostic criteria of multiple sclerosis (73). The spinal form of multiple sclerosis, with predominating symptoms from the spinal cord, is probably the most common variety of the disease (48). Before dissemination has occurred, which may take many years, other diagnoses must be considered. In patients with isolated myelopathy and a clinical suspicion of demyelinating disease, MR is useful for demonstration of asymptomatic lesions in the brain lending further support to the diagnosis of multiple sclerosis, as in three of the seven patients in the present study. One of these patients developed an optic neuritis one month after the MR examination, clinically converting the diagnosis to definite multiple sclerosis. Other reports have similarly described patients with isolated spinal cord symptoms where MR revealed clinically silent plaques in the brain (11, 51). In myelopathy patients with a normal MR scan of the brain, an MR examination of the spinal cord can provide support for the diagnosis of multiple sclerosis if oblong high signal intensity lesions are detected on long TR/TE images, especially if they are associated with local or general atrophy of the cord on short TR/TE images, as in four of the patients in the present study. In addition, other potential causes of myelopathy, such as spinal cord compression, can be excluded (51). Accordingly, patients with isolated myelopathy, involving the cervical spinal cord, and clinical suspicion of demyelinating disease, should be examined with long and short TR/TE MR scans of the cervical spine and an axial long TR/TE scan of the brain.

The oblong configuration of the spinal cord lesions may be explained by the selective breakdown of the blood-brain barrier of longitudinal spinal cord veins, resulting in the diffusion of anti-myelin antibodies and the formation of progressing plaques with longitudinal extension (42, 45). It should be emphasized that the high signal intensity lesions on long TR/TE images are not specific for multiple sclerosis, but can also be caused by e.g. cord contusion, intramedullary tumour or ischaemia (11). However, the clinical history and symptoms, together with CSF analysis and visual evoked potential recording, may be helpful in equivocal cases. In an acute phase of demyelinating disease, the cervical cord may show local swelling at the level of the lesion, as in one of the patients in the present investigation. This finding may also be consistent with intramedullary tumour, which, however, is less probable if MR of the brain reveals multiple concomitant plaques. A follow-up MR examination showing normalization of the width of the cord also argues against a tumour diagnosis. The patients with a short duration of disease in the present investigation had intramedullary lesions with a larger transverse diameter than the patients with long duration of the disease. The large diameter of the lesion as well as the above mentioned local swelling may be secondary to oedema accompanying acute lesions (51).

Rheumatoid arthritis involving the cranio-cervical junction (38)

Compression of the medulla and upper cervical cord in patients with severe chronic rheumatoid arthritis is caused not only by atlanto-axial subluxation but frequently also by pannus, as shown in the present investigation. Before the introduction of MR such pannus formation could be indirectly demonstrated by myelography, which may be very difficult to perform in patients with rheumatoid arthritis who have joint deformities and pain. CT myelography with sagittal reconstruction has recently been the preferred technique, as it depicts bony as well as soft tissue abnormalities better than conventional radiography and myelography (83). MR provides better delineation of the pannus than previously used methods because of its superior contrast discrimination (5, 61, 92), and imaging can be performed in any plane without moving the patient. In addition, MR can reveal intramedullary lesions with high signal intensity on long TR/TE images. Such lesions, seen in three patients with myelopathy in the present study, may represent oedema and ischaemic changes caused by compression of the cord (50).

Cord compression would probably have been a more frequent finding if MR had been performed in flexion. However, MR in flexion is difficult to perform and might induce neurologic symptoms in patients with pronounced atlanto-axial instability. In the present investigation, the maximal narrowing of the spinal canal was inferred from conventional radiographs in flexion, demonstrating vertebral subluxation, combined with MR in the neutral position, showing the extent of pannus posterior to the odontoid process. As the morphological information is most important in these patients, sagittal short TR/TE images should be sufficient.

The pannus surrounding the odontoid process consists of proliferative inflammatory granulation tissue derived from the synovia in the small joints and bursae adjacent to the odontoid process. However, fibrous components are probably present within the pannus, since the signal intensity in pure inflammatory tissue should be higher on long TR/TE images than was noted in most patients in the present study. Post-mortem examinations support this assumption (50). It has been suggested that mechanical dysfunction and instability in the cranio-cervical junction may cause formation of fibrous granulation tissue and hypertrophy of connective tissue elements as the abnormal response to chronic stress and friction (85). Accordingly, rheumatoid peri-odontoid inflammatory granulation tissue may increase in size due to hypertrophy of fibrous elements when atlanto-axial instability has occurred. The postoperative reduction of pannus in the present study seems to be the result of the atlanto-axial immobility achieved by the surgical posterior fusion.

Postoperative short TR/TE images are useful despite artifacts from the surgical fixation material since these artifacts are confined to the posterior part of the neck. Postoperative MR is valuable in patients with residual or new neurological symptoms.

Cervical spondylosis and disk herniation (39)

In patients presenting with cervical radiculopathy and/or myelopathy, the radiological evaluation is of utmost importance in establishing the extent and location of disease if surgery is being considered. Surgery is performed only when the radiological findings explain the clinical symptoms and signs.

The comparison of the three radiological methods in the present study did not reveal any significant diagnostic superiority of myelography, CT myelography or MR regarding the evaluation of site and degree of narrowing of the spinal canal, correlation between clinical radiculopathy and radiological root sheath deformity and between clinical myelopathy and radiological cord compression. In previous reports, MR has been considered ideal for the evaluation of patients with myelopathy (29, 46) whereas CT myelography has been found to be more accurate in the evaluation of patients with radiculopathy (32, 56).

The narrowing of the spinal canal often appeared somewhat more pronounced at myelography, with images obtained in the prone position with forced extension of the neck, than with CT myelography and MR. However, all indentations on the anterior subarachnoid space seen on myelography at the 32 evaluated levels were also evident on CT myelography and MR. In agreement with other reports it was found to be more difficult to distinguish bone from soft tissue with MR than with CT myelography in the present investigation (29, 55, 56). However, the combination of MR and conventional radiographs gave sufficient information for this differentiation. Considering surgery, the choice of operative approach is based more on the degree of stenosis, the degree of lateralization and the number of levels involved than on the aetiology of the stenosis (82).

Neither myelography, CT myelography nor MR imaging is as accurate in the evaluation of radiculopathy in the cervical spine as in the lumbar region (21). The smaller neural foramina in the cervical spine and the lack of epidural fat have limited attempts to achieve completely reliable results, despite improvements in imaging techniques (21). The more frequent observation of bilateral root sheath deformities on myelography than on CT myelography and MR in the present investigation (Fig. 7) is probably due to the accentuation of protrusions in the prone position. The accuracy of MR will probably improve with the reduction of the interslice gap (from 2.1 mm to 0.5 mm with our equipment) because this allows a better evaluation of the nerve root sheaths on axial slices.

In the present study, postoperative MR revealed the site and degree of remaining indentation on the subarachnoid space and on the spinal cord. As in previous reports (55, 66) the precise aetiology of the remaining protrusions could not be determined. CT without contrast medium is useful as a complement to provide information on the contribution of remaining osteophytes or, after anterior fusion, potential encroachment of the bone graft on the anterior subarachnoid space. MR examination in the immediate postoperative period is probably of limited value because extensive soft tissue changes, related to the surgical procedure, may render the interpretation difficult, as has been described in the lumbar spine (67).

According to the results of the present investigation, a single examination using myelography, CT myelography (if possible, preceded by a lateral myelogram for selection of levels) or MR is sufficient for the radiological pre-operative evaluation of most patients with cervical radiculopathy and/or myelopathy. Because MR has several practical advantages, it is well suited as the primary imaging modality, together with conventional radiographs. In most patients, sagittal and axial short TR/TE images are sufficient. In patients with myelopathy long TR/TE images are useful for the detection of signal abnormalities in the spinal cord. Postoperative MR is useful in patients with persisting or new symptoms.

Coil selection (40)

Surface coils are essential for accurate MR evaluation of the spine as they dramatically improve the image quality by increasing the SNR (21, 25, 55). Knowledge of the signal characteristics and the limitations of the different coils is a prerequisite for selecting the optimal coil for a specific level of the spine.

The studies using tube phantoms showed that the 15 cm surface coil for the neck gives a markedly higher SNR than the head coil at the centre of the coil, but the SNR of the surface coil decreases faster cephalad and caudad than that of the head coil (Fig. 9). These results indicate that the 15 cm surface coil is to be preferred when it is possible to place its centre at the level of interest. Similarly, the 30 cm surface coil should be selected rather than the body coil for imaging of the thoracic spine (Fig. 10).

Sometimes, the centre of a solenoidal surface coil cannot be placed at the level of interest for anatomical reasons, e.g., at the cranio-cervical and cervico-thoracic junctions. If a surface coil is used for such a level, the coil should be placed as close as possible to the level of interest. It is not advisable to centre the images at some distance from the surface coil centre towards the level of interest, because then the SNR decreases in a large portion of the image and does not increase at any level. The images should instead be centred at or relatively close to the centre of the surface coil leaving the level of interest at some distance from the centre of the image. If the level of interest is situated outside the selected FOV another coil, that can be placed closer to the level of interest, e.g. the body coil, must be chosen. The body coil or the head coil are also to be preferred when they provide a higher SNR than the surface coil at such a level because they, unlike the surface coil, can be placed at the level of interest.

The results of the Alderson phantom study of the cranio-cervical junction, confirmed by the images of the normal volunteer, indicate that the head coil should be used for examination of the cranio-cervical junction, while the 15 cm surface coil is preferred for the remaining part of the cervical spine. The head coil should be placed as caudally as possible. This use of the head coil in our MR equipment is usually optimal for imaging of the cranio-cervical junction in patients with rheumatoid arthritis, when the odontoid process, peri-odontoid pannus and their effect on the medulla and upper cervical cord are to be evaluated (38, 61).

The results of the Alderson phantom study of the cervico-thoracic junction, confirmed by the normal volunteer images, suggest that the body coil should be used for examination of the thoracic spine at the level of the shoulders, usually corresponding to the levels of the thoracic vertebrae 4-6. The 15 cm surface coil is to be preferred cranial to this region and the 30 cm surface coil caudal to it.

The value of gadolinium-DTPA in MR imaging of suspected spinal multiple sclerosis (37)

Acute demyelinating lesions are indistinguishable from older, chronic lesions on long TR/TE MR images (19, 33). In the present investigation, delayed Gd-DTPA enhancement of suspected demyelinating lesions in the cervical cord was seen on short TR/TE images in two patients with active disease (Fig. 12), while no enhancement was noted in three patients with clinically stable disease. In patients with definite or suspected multiple sclerosis a correlation has previously been described between recent clinical exacerbation of the disease and contrast enhancement of lesions in the brain seen on CT (75, 90) as well as on MR (16, 18, 19). Recently, suspected Gd-DTPA enhancement of a clinically active lesion in the cervical cord has been reported using MR on a patient with definite multiple sclerosis (86) and extensive enhancement has been demonstrated in the cervical cord in another patient with an acute spinal relapse of multiple sclerosis (52). The inflammatory process of an active demyelinating lesion is associated with a transient breakdown of the blood-brain barrier, which is responsible for the contrast enhancement (19, 75). MR imaging with Gd-DTPA has been reported to be more sensitive than CT with large doses of iodinated contrast medium in identifying abnormalities of the blood-brain barrier in patients with multiple sclerosis (19).

Gd-DTPA enhancement of multiple sclerosis plaques in the brain has been reported to be observed on short TR/TE images obtained only 3 minutes after contrast injection in most cases, whereas a few lesions were better seen on delayed (55 min.) images (19). Enhancement of intracranial and intraspinal tumours is usually most marked immediately after injection of contrast medium (6, 74, 86, 87, 89) but delayed scans have been reported to show a further increase in signal intensity in some tumours, especially small ones (72, 89). It is presumed that demyelinating lesions produce a minor blood-brain barrier disruption compared with the disruption associated with malignant tumours (90). An increased dose of iodinated contrast medium and a delay before scanning allow a larger amount of contrast medium to leak from the intravascular to the interstitial space, thereby improving the detection of demyelinating lesions in the brain on CT (75, 90). The same mechanism is probably responsible for the increase in signal intensity on the delayed MR scans of the spinal cord compared with the early post-injection scans in the present study. If delayed scans had not been performed, the discrete contrast enhancement 10 minutes after Gd-DTPA would probably have been interpreted as equivocal. Accordingly, delayed scans are recommended after Gd-DTPA in patients with suspected demyelinating lesions if no enhancement is seen on early post injection scans.

A decrease in Gd-DTPA enhancement of the lesions in the spinal cord on follow-up MR examinations accompanied a decrease in clinical symptoms and signs in the two patients with active disease in the present study. The evolution of acute Gd-DTPA-enhancing cerebral demyelinating lesions to inactive nonenhancing lesions over time has previously been demonstrated on MR of a dog with experimental allergic encephalomyelitis (33). In a recent report, serial Gd-DTPA-enhanced MR of the brain was performed in seven patients with acute relapse of multiple sclerosis (52). On the second scan (3-5 weeks after the first scan), persisting enhancement was seen in only 12/54 lesions which showed enhancement on the first scan in that investigation. No lesion showed persisting enhancement on the third scan (after 6 months). In the present investigation, one of the patients showed a slight persisting enhancement in the cervical cord three months after the first MR examination but no enhancement was seen after 5 1/2 months. Presumably, the duration of the contrast enhancement is variable, in analogy with the variable course of the disease in different patients.

In patients with isolated myelopathy, MR without contrast medium can lend support to the diagnosis of multiple sclerosis by revealing dissemination in space as mentioned above. In addition, Gd-DTPA-enhanced MR may, in the future, be used as indirect support of dissemination in time when contrast-enhancing active lesions and non-enhancing inactive lesions are observed in the same examination. This requires, however, further studies of the enhancement pattern of demyelinating lesions and a development of the technique in order to reliably detect enhancement of all active lesions.

Another potential use of MR in demyelinating disease is to monitor the disease activity in therapeutic trials (31, 58). It has been reported that the development of new cerebral lesions visible on MR is much higher than the rate of development of clinical relapses (58). Serial Gd-DTPA-enhanced MR may be of additional value in evaluating the effects of treatment as Gd-DTPA is a marker of the blood-brain barrier impairment which occurs in new plaques (52).

General remarks

It would be valuable to make a direct comparison of MR examinations at different field strengths by examining the same patients in different MR scanners, which has so far not been possible. However, the observations made in the present investigation are in accordance with those in the literature mostly obtained with superconducting MR scanners. MR imaging at 0.3 T, using a vertical magnetic field, evidently provides comparable information. The lower SNR obtained using the relatively low field is well compensated for by the ease in performing emergency examinations, the availability of solenoidal surface coils, less pronounced artifacts and low maintenance cost.

Conclusions

1) MR at 0.3 T with a vertical magnetic field can replace myelography in the emergency evaluation of patients with spinal cord symptoms. Because MR has several advantages, it is well suited as the procedure of choice following conventional radiography in these patients.

MR should be the preferred radiological modality in patients with isolated myelopathy and clinical suspicion of demyelinating disease.

MR, combined with conventional radiographs in flexion and extension, provides adequate information for the pre-operative evaluation of patients with rheumatoid arthritis with neurological symptoms emanating from the cranio-cervical junction.

MR, together with conventional radiographs, can replace myelography and/or CT myelography as the primary imaging modality for the pre-operative evaluation of patients with cervical radiculopathy and/or myelopathy caused by spondylosis or disk herniation.

2) When using a 0.3 T MR scanner with a vertical magnetic field the head coil should be used for imaging of the cranio-cervical junction, while the 15 cm solenoidal surface coil should be selected for imaging of the remaining part of the cervical spine and the upper thoracic spine. The body coil is superior for the thoracic region at the level of the shoulders (T4-T6) but the 30 cm solenoidal surface coil is to be preferred for the more caudal part of the thoracic spine.

3) The paramagnetic contrast medium Gd-DTPA may be useful in MR imaging of suspected demyelinating lesions in the cervical cord in the detection of enhancement of active lesions. Serial MR examination with Gd-DTPA may be used to monitor disease activity.

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