MAGNETIC RESONANCE IMAGING OF SPINAL TUMORS

A study using a 0.3 T vertical magnetic field

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Title and subtitle
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Abstract
A total of 168 patients with spinal tumors were evaluated with MRI (0.3 T scanner, vertical magnetic field). The study shows that MRI is a sensitive method for demonstration of spinal tumors. MRI also provides a possibility to separate different histological types of tumors based on their morphology and signal characteristics. *INTRAMEDULLARY TUMORS* (25 cases): Ependymomas (6 cases) and astrocytomas (7 cases) were most common. Ependymomas have a more irregular signal pattern than astrocytomas. Astrocytomas are more common in the upper spine and are more often completely cystic. Contrast enhancement is important for separation of cyst, edema and solid tumor. *INTRADURAL EXTRAMEDULLARY TUMORS* (31 cases): Neuromas (14 cases) and meningeomas (11 cases) were most common. Neuromas always had markedly increased signal intensity on T2-weighted images. Meningeomas were only hyperintense occasionally. Neuromas were more inhomogeneous than meningeomas on T1-weighted images. Contrast enhancement is valuable for delineation of small tumors. *EXTRADURAL TUMORS* (91 cases): 76 patients had metastases, 7 primary spinal tumors and 8 multiple myelomas. T1-weighted images are almost always superior to other sequences because tumor invasion in the fatty bone marrow is seen as a low signal area in contrast to the high signal from the fat. *SPINAL LYMPHOMAS* (14 cases): May be divided into vertebral, paraspinal and epidural tumors. Most cases have all locations. Typically, spinal lymphoma often involves the paravertebral lymph nodes with invasion of adjacent vertebrae and extension through the intervertebral foramen to the intraspinal compartment. *SPINAL NEUROFIBROMATOSIS* (7 cases): Most patients had multiple, often bilateral neurofibromas. One patient had a meningeoma and one spinal dysplasia with meningoceles. MRI is superior to other modalities for evaluation of the full extent of the disease. The coronal view is often valuable because of the arrangement of the tumors. In addition to providing diagnosis, MRI is of great value in treatment follow-up.

Key words
MRI, Spinal tumors, Intramedullary tumors, Intradural extramedullary tumors, Epidural tumors

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MAGNETIC RESONANCE IMAGING OF SPINAL TUMORS

A study using a 0.3 T vertical magnetic field

MING HUA LI

Lund 1992

To my wife, Juping,
my little daughter, Lili
and my home city, Shanghai

CONTENTS

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals.

I. MR imaging of spinal intramedullary tumors.
Acta Radiologica 32 (1991), 505.

II. MR imaging of intradural extramedullary tumors.
Acta Radiologica 33 (1992), 207.

III. MRI of spinal extradural tumors at 0.3 T.
Submitted to Neuroradiology.

IV. MR imaging of spinal lymphoma at 0.3 T.
Acta Radiologica 33 (1992), 338.

V. MR imaging of spinal neurofibromatosis.
Acta Radiologica 32 (1991), 279.

ABSTRACT

A total of 168 patients with spinal tumors were evaluated with magnetic resonance (MR) imaging, using a 0.3 T resistive scanner with an iron core and a vertical magnetic field. The study shows that MR is an extremely sensitive imaging method for the demonstration of spinal tumors. MR also provides the possibility of distinguishing different histological types of spinal tumors based on their morphological appearance and signal characteristics.

Intramedullary tumors (25 cases): Ependymomas (6 cases) and astrocytomas (7 cases) were the most common tumors. Ependymomas have a more irregular signal pattern than astrocytomas. Astrocytomas are more common in the upper spine and are more often completely cystic. Contrast enhancement is very important for the separation of cysts, edemas and solid tumors in the evaluation of intramedullary tumors.

Intradural extramedullary tumors (31 cases): Neuromas (14 cases) and meningeomas (11 cases) were the most common tumors. All neuromas showed markedly increased signal intensity on T2-weighted images. Meningeomas were only hyperintense occasionally. Neuromas were more inhomogeneous than meningeomas in T1-weighted images. Contrast enhancement is valuable for the delineation of small intradural extramedullary tumors.

Extradural tumors (91 cases): Seventy-six patients had metastases, 7 primary spinal tumors and 8 multiple myelomas. T1-weighted images are

almost always superior to other sequences as tumor invasion in the fatty bone marrow is seen as a low-signal area in contrast to the high signal from normal bone marrow.

Spinal lymphomas (14 cases): May be divided into vertebral, paraspinal and epidural tumors. Most patients have tumors in all locations. Typically, spinal lymphoma often involves the paravertebral lymph nodes with invasion of adjacent vertebrae and extension through the intervertebral foramen to the intraspinal compartment.

Spinal neurofibromatosis (7 cases): Most patients had multiple, often bilateral neurofibromas. One patient had a meningeoma and another one had spinal dysplasia with meningoceles. MR is superior to other modalities for the evaluation of the full extent of the disease. The coronal view is often valuable due to the arrangement of the tumors.

MRI does not only give the diagnosis but is also of great value in treatment follow-up.

KEY WORDS

MRI, Spinal Tumors, Intramedullary Tumors, Intradural Extramedullary Tumors, Epidural Tumors

INTRODUCTION

Spinal tumors may arise from the neural tissue, the meninges, the bone or surrounding soft tissue, or embryonal rests or as a result of derangement of embryogenesis, or they may spread from other tumors (CNS or non-CNS origin) to the spine. Traditionally, tumors arising in the spinal cord are termed intramedullary, a tumor originating outside the spinal cord but inside the dural compartment is termed intradural extramedullary, whereas those outside the dura are termed extradural (46). Patients with spinal tumors frequently presented a formidable diagnostic challenge with older techniques (76). However, with the development of new imaging techniques, the reliability of the preoperative diagnosis of spinal tumors has rapidly increased.

Myelography has long been the diagnostic mainstay in the evaluation of the spinal cord and nerve roots from the foramen magnum to the sacrum. Visualization of the negative shadow margins of the cord and its coverings as well as direct assessment of the integrity of the bony canal frequently enabled radiologists to classify mass lesions as intramedullary, extramedullary intradural, and extradural tumors. However, myelography cannot visualize the full extent of the lesions when there are multiple areas of myelographic blockage unless a new spinal puncture with injection of contrast medium is carried out above or below the blockage (33). Myelography is also difficult to perform when wishing to evaluate the entire spinal canal in a very ill patient and cannot detect spinal metastases which have not yet encroached upon the subarachnoid space, nor is demonstration of paravertebral tumor extension

possible. The method is invasive with potential complications related to the spinal puncture, as well as to the toxicity of the contrast medium (68).

Computed tomography (CT) of the spine has been employed as an imaging modality for spinal, intraspinal, and paraspinal neoplasms for 15 years (4, 28, 54). CT displays the anatomy of the osseous spine and adjacent soft tissue with remarkable clarity. CT can outline the full extent of spinal tumors which have extradural, bony and paraspinal involvement. The content of the spinal canal can also be shown in great detail following the introduction of intrathecal contrast medium. Therefore, CT-myelography usually clearly differentiates epidural from intradural lesions. Moreover, intramedullary masses can usually be distinguished from intradural extramedullary lesions (23). CT-myelography or delayed CT following myelography can reveal cystic necrosis and cavitation in the tumor (11, 35), however, CT-myelography is also an invasive procedure. CT provides only axial images which makes it difficult to cover the complete spine (33).

MR is an imaging technique capable of producing images without ionizing radiation. Like CT, MR provides computer-generated images comprised of pixels of a specific intensity. The pixel intensity in CT is based on the X-ray attenuation coefficient, which in turn depends on the electron density, whereas the pixel intensity in MR is a complex function of proton density, T1 and T2 relaxation times and flow (12).

Many early reports documenting the usefulness of MR in the spine commented on its ability to image the spine and the spinal cord in multiple planes and thus accurately pinpoint neoplastic disease (13, 21, 31-32, 34, 38, 49-51, 56). Additionally, MR not only characterizes lesions based on morphology and location with respect to the cord and surrounding structures, but also according to signal intensity characteristics that reflect tissue T1, T2, and spin-density as well as paramagnetic effects and motion. The subsequent implementation of surface coil technology, cardiac gating, gradient refocusing, and the use of paramagnetic contrast agents have done much to increase the sensitivity and specificity of MR in the diagnosis of spinal disease (6, 16, 26-27, 30, 39, 40, 62, 65, 72, 76).

Most published MR investigations of spinal tumors have been performed with superconducting magnets at field strengths between 0.35 and 1.5 T. This study was performed with a resistive magnet with an iron core and a vertical magnetic field of intermediate strength.

The aims of the present investigation were to evaluate:

1. The capability of a 0.3 T resistive MR unit with a vertical magnetic field in the diagnosis of spinal tumors.

2. The capability of a 0.3 T resistive MR unit with a vertical magnetic field in the differential diagnosis of various histological types of spinal tumors.

3. The MR appearance of spinal neurofibromatosis and lymphoma.

SUBJECTS, METHODS AND RESULTS

In a study of all patients with spinal diseases examined by MR during the period from June 1986 to November 1989 at Lund University Hospital, 168 patients were found to have spinal tumors (Table 1).

All MR examinations were performed using a resistive scanner with an iron core and a vertical field operating at 0.3 T (Fonar ß-3000 M). In this system, the built-in body coil is used as transmitter. Most examinations were performed using solenoidal surface coils as receivers which were wrapped around the neck or the torso. In some cases, the head coil or the body coil was used. 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. Spin-echo pulse sequences were used in all investigations and gradient-echo pulse sequences were used in a few investigations in addition. Sagittal images were obtained first in all investigations and the mid-line sagittal slice was then used as a scout image for positioning and angulation of axial or coronal images. In the text below, T1-weighted images are defined as pulse sequences with TR = 300-500 ms and TE = 16-30 ms, and T2-weighted images as pulse sequences with TR = 1500-2000 ms and TE = 56-84 ms. Five excitations were performed at TR=300 ms, three excitations at TR=500 ms and one excitation at TR=2000 ms. Gadolinium diethylene-triamine-penta-acetic acid (Gd-DTPA) (0.1 mmol/kg body weight) was used for the enhancement of T1-weighted

images in 8 cases. The slice thickness was 5.0 to 7.1 mm with a 0.5 to 2.1 mm interslice gap.

MR IMAGING OF SPINAL INTRAMEDULLARY TUMORS (I)

Twenty-five patients (7-78 years old, mean age 39.5 years, male/female = 16/9) with intramedullary tumors were examined with MR. Solenoidal surface coils were used in all examinations. Sagittal T1-weighted images were obtained in all patients and in the majority also sagittal T2-weighted images. Axial and coronal scans were obtained in some cases. Gd-DTPA was used for the enhancement of T1-weighted images in 6 patients.

Eighteen patients underwent surgery with opening of the dura after MR examination and histopathological diagnosis from the tumors was available. One patient underwent laminectomy and a needle biopsy from the tumor. Two patients underwent laminectomy only. In these 3 patients histopathological diagnosis was not obtained. In 4 patients no surgery was performed. In 3 of them the nature of the tumors was considered to be medulloblastoma because of previous surgery for histopathologically proven medulloblastoma in the posterior fossa. In one patient the tumor was considered to be a metastasis because of histologically proven lung cancer (Table 2).

The tumors caused an expansion of the cord in the area of lesion in all patients and often involved several vertebral levels. The distribution of

location of astrocytomas and ependymomas is presented in Table 3 and the signal pattern in Table 4. In 2 patients with astrocytoma surgically proven as exclusive cystic degeneration, one showed homogeneous slight hyperintensity relative to the cord in T1-weighted images and homogeneous marked hyperintensity in T2-weighted images. The other one showed a uniformly decreased signal like that of CSF in T1-weighted images. A heterogeneous signal pattern was observed with ependymoma on T1-weighted imagesin all 6 patients. One had areas with increased signal in combination with areas isointense to the cord indicating the presence of blood. There were 3 ependymomas with surgically proven partial intratumor cyst formation. One of them showed a central low signal with irregular borders and 2 showed a heterogeneous signal pattern only in T1-weighted images. In T2-weighted images 2 cases showed homogeneous hyperintensity relative to the cord and one showed inhomogeneous hyperintensity. One of them had a marked enhancement of a partially exophytic tumor nodule with a surrounding unenhanced cyst which was well demonstrated in T1-weighted images after injection of intravenous Gd-DTPA.

Two patients with histopathological diagnosis of glioma showed inhomogeneous signals with iso- and hyperintensity relative to the cord in T1-weighted images and homogeneous hyperintensity in T2-weighted images. One of the MR investigations was performed after contrast injection. No enhancement in the area of the tumor was noted which suggested completely cystic degeneration. In 3 unspecified tumors, one showed an inhomogeneous signal with iso- and hypointensity relative to the cord, one an inhomogeneous signal with iso- and hyperintensity which suggested intratumor bleeding, probably secondary to previous needle biopsy, and the

other one a homogeneous isointense signal on T1-weighted images. In T2-weighted images, all 3 showed homogeneous hyperintense signals. In two of the patients MR was performed after injection of a contrast medium. One showed partial enhancement of the tumor and the other one showed no enhancement in the area of the lesion.

In three patients with previously pathologically proven cranial medulloblastoma their disease had spread to the spinal canal and cord. One cervical cord involvement extended from the fourth ventricle medulloblastoma, down through an expanded cervical cord which showed inhomogeneous iso- and hyperintensity in T2-weighted images. Two cases with CSF pathways spread showed ill-defined CSF space and irregular surface of the cord, respectively in T1-weighted images. The pattern of irregular surface of the cord was demonstrated more clearly in T1-weighted images after injection of intravenous Gd-DTPA in one case.

One conus melanoma showed a slightly hyperintense signal relative to the cord in T1-weighted images, which was surgically and histologically confirmed as a melanotic melanoma with intratumor hemorrhage. One cervical cord metastasis from a bronchial carcinoma showed an enlarged cord with homogeneous isointensity relative to the cord in T1-weighted images and hyperintensity in T2-weighted images.

In one patient, an intramedullary neurinoma was found at the C2 level at surgery. This tumor had an inhomogeneous appearence in both T1- and T2-weighted images. Following injection of intravenous Gd-DTPA a tumor

nodule became markedly enhanced , whereas the surrounding tissue was unenhanced, consistent with edema. In one patient with a conus teratoma the signal pattern was mixed with areas of both high and low signal intensity relative to the cord in T1- and T2-weighted images. The finding was consistent with a tumor containing fat and calcification, which was confirmed at surgery.

MR IMAGING OF INTRADURAL EXTRAMEDULLARY TUMORS (II)

Thirty-one patients with intradural extramedullary tumors (10-82 years old, mean 49 years, male/female=12/19) were examined with MR. Solenoidal surface coils were used for all examinations. All patients were examined with T1-weighted images and 20 with T2-weighted images in addition. Sagittal views were obtained for all patients, axial in 17, coronal in 11 and oblique in one. In one patient T1-weighted images were obtained after intravenous injection of Gd-DTPA. Iohexol myelography had been performed before the MR examination in 13 patients. Two neuroradiologists retrospectively reviewed all tumors with regard to clinical history, surgical and pathological records, and MR findings. A third neuroradiologist without knowledge of the clinical history or myelography findings then evaluated MR images and made a diagnosis for each tumor respectively.

MR imaging accurately determined the location of the tumors in all 31 patients. This was best demonstrated with T1-weighted images. In 10 of the 13 patients who had undergone myelography the localization of the

tumor was correctly determined on the myelogram. One of them was misinterpreted as an extradural lesion which was corrected after MR examination. In the remaining 2 cases the lesions were missed because the amount of contrast at the level of interest was insufficient. According to the third neuroradiologist's evaluation, the MR diagnosis was in agreement with the histological diagnosis in 23/31 tumors (74%).

In all 11 patients with meningeoma (28-82 years old, mean 62 years, male/female = 2/9) the tumors had a broad base towards the dura and compression or displacement of the cord. Nine patients had widening of the subarachnoid space above and below the tumors and 5 showed outward compression of the epidural fat adjacent to the lesions. Two meningeomas had epidural extension, one of which mainly involved the epidural space. In this patient compression of the cord without widening of the subarachnoid space above and below the tumor was found. The location and signal pattern of the tumors are shown in Table 5 and 6. One case examined with T1-weighted images after injection of intravenous Gd-DTPA showed marked enhancement of the tumor. Intratumor calcification found in 3 meningeomas at surgery was not demonstrated on MR images. A low signal band between the tumor and the compressed cord was demonstrated on T1-weighted images in 4 patients.

In 14 patients with neuroma (10-79 years old, mean 50 years, male/female = 7/7), 7 tumors had a broad base towards the dura. Compression or displacement of the spinal cord or cauda equina was demonstrated in 12 patients. Ten patients had widening of the subarachnoid space above and

below the tumors and 7 showed outward displacement of the epidural fat. Two neurinomas and one neurofibroma had an epidural extension through the intervertebral foramen with a "dumb-bell" shape. The location and signal pattern are given in Table 5 and 6. A low-signal intensity band between the tumor and the compressed cord was demonstrated on T1-weighted images in 6 patients.

Three metastases (one from a uterus cancer, one from an intracranial astrocytoma and one from a melanoma of unknown origin), 2 lipomas and one ependymoma were found in the intradural space in this study. All 6 patients had compression or displacement of the cord or cauda equina. Five patients had widening of the subarachnoid space above and below the tumors and 3 showed outward displacement of the epidural fat. A broad base towards the dura was noted in 5 tumors. In the metastases the signal was isointense relative to the cord in T1-weighted images. One ependymoma showed homogeneous isointensity relative to the cord on T1-weighted images and marked hyperintensity on T2-weighted images. The signal intensity of two lipomas was consistent with fat in both T1- and T2-weighted images.

MRI OF SPINAL EXTRADURAL TUMORS AT 0.3 TESLA (III)

Ninety-one patients (12-83 years old, mean 60 years, male/female = 53/38) with epidural tumors were examined with MR. Solenoidal surface coils were used in most cases and in a few the head or body coil. Sagittal T1-weighted images were taken for all patients, axial images for 38 and coronal for 10 patients. For 22 patients T2-weighted images were

also collected and 3 patients were examined with a gradient echo sequence (GE) with 10^0 and 60^0 flip angles, and TE of 12 ms and TR of 300 ms. Seventy-five patients underwent one examination, 11 had two and 5 underwent three or more.

Of the 91 patients, 49 had a histological diagnosis from the spinal lesion and in 42 the diagnosis was based on the history and histology of a primary tumor elsewhere in the body. The distribution of primary tumors is shown in Table 7. Seventy-six patients had metastases, 7 had primary spinal tumors and 8 had multiple myelomas. Standard anteriorposterior and lateral radiography of the spine was performed for 83 patients. The conventional films showed involvement of vertebral bone in 77 patients. In 52 the lesions were lytic, 13 were sclerotic (11 prostate cancer, one lung cancer and one uterus cancer) and 12 had a mixed pattern with both lytic and sclerotic components. In 6 patients (2 sarcomas, one melanoma, 2 multiple myelomas and one lung cancer) the conventional radiography was equivocal. Of 17 patients examined with myelography, 6 had a myelographic blockage at the level of the lesion and 11 had compression of the dura. Twenty-four patients were examined with CT which showed vertebral bone destruction.

All 91 patients showed destruction of vertebral bone with either bone marrow or both marrow and cortex engagement in MR imaging. Fifty-one patients showed involvement of multiple areas at different levels. Fifty-six patients had vertebral body compression at multiple (36 cases) or single (20 cases) levels. Sixteen patients demonstrated bulging of the vertebral body with compression of the subarachnoid space and 67

patients had an extradural mass with compression and displacement of the cord. There was no correlation between the degree of intraspinal involvement and the extent of vertebral lesion. In the remaining 8 patients the lesion was located in the vertebral bone without encroachment on the spinal canal. Sixty patients had a paravertebral soft tissue mass.

The signal patterns of the vertebral tumors is shown in Table 8. The signal intensity was low relative to normal bone marrow in T1-weighted images in the majority of cases and in 22 patients examined with both T1- and T2-weighted images, T1-weighted images provided the best information in 18 patients, T2-weighted images in one patient and in 3 patients the information was equally good. The signal from the epidural mass was usually isointense relative to the cord in T1-weighted images and higher than the cord in T2-weighted images. In 21 patients with spinal metastases from prostate cancer, 14 showed a markedly decreased signal relative to the bone marrow in T1-weighted images, and 2 of them showed inhomogeneous low- and isointense signals and one showed a markedly decreased signal relative to bone marrow in T2-weighted images. In these patients, 11 had sclerotic lesions in the affected vertebra on the conventional radiographs. Two patients with upper cervical vertebral melanoma showed a marked heterogeneous signal in T1-weighted images. One of two lesions involving the odontoid process showed a markedly decreased signal relative to bone marrow in T2-weighted images. Three of 8 patients with multiple myelomas had an inhomogeneous signal pattern with combined diffuse, low intensity and focal lower intensity in T1-weighted images. In 3 patients who were examined with GE sequences, the lesions

were shown to have a very high signal and were clearly visualized. The lesions corresponded to low-signal areas in T1-weighted images.

MR IMAGING OF SPINAL LYMPHOMAS (IV)

Fourteen patients (31-78 years old, mean 58 years, male/female = 7/7) with spinal lymphomas were examined with MR imaging. There were 10 non-Hodgkin lymphomas (NHL), 2 Hodgkin's disease (HD) and 2 unclassified lymphomas. Thirteen patients had previous history of extra-spinal lymphoma. Solenoidal surface coils of appropriate diameter were used in 11 patients and the body coil in 3 patients. T1-weighted images were obtained for all patients and T2-weighted images for 5 patients. Sagittal views were obtained in all patients, axial in 10 and coronal in 6. Ten patients underwent one examination, 3 had two two examinations, and one underwent three examinations. Two patients underwent repeated MR examinations after radiotherapy. Nine underwent conventional radiography, 4 had myelography and 4 radioisotope bone scan studies.

INTRASPINAL LYMPHOMA: In 2 patients with NHL the lesions were located entirely in the epidural space without paravertebral or vertebral involvement. The lesions had a long extension in the lumbar and thoracic spine, respectively. In 8 patients with paravertebral and vertebral lymphoma, epidural extension was also present. All these 10 patients had an epidural mass with compression of the cord or the cauda equina which was well demonstrated on MR. Signal intensity was similar to that of the cord in 9 patients and higher than that of the cord in one patient in

T1-weighted images. In 3 patients examined with T2-weighted images the lymphoma was hyperintense relative to the cord. Myelography showed epidural lesions in 3 patients.

VERTEBRAL LYMPHOMA: In 3 patients the lymphoma involved only the vertebrae. Four patients had predominantly vertebral lesions, while para- and intraspinal involvement was slight. Five patients with mainly paraspinal involvement also had vertebral destruction which was located either in the margin of the vertebral body close to the paravertebral lesions or in the area of the intervertebral foramen. The signal from the diseased vertebrae was low relative to marrow on T1-weighted images. In 4 patients the lesions showed an inhomogeneous signal pattern with diffusely decreased intensity and superimposed focal areas of even lower signal intensity in some vertebral bodies. In T2-weighted images (3 cases), 2 patients demonstrated inhomogeneous iso- and hyperintensity relative to marrow and one showed homogeneous isointensity. In 8 patients examined with conventional radiography, 6 exhibited lytic changes and 2 were equivocal.

PARASPINAL LYMPHOMA: Five lymphomas mainly involved the paraspinal soft tissue. Two of them involved multiple areas and 2 showed enlargement of lymph nodes in the posterior mediastinum and the retroperitoneum. All patients had vertebral involvement and 4 had intraspinal involvement through the intervertebral foramina. The paraspinal lesions were hypo- or isointense relative to surrounding muscle tissue in T1-weighted images and hyperintense in T2-weighted images.

Repeated MR examination of 2 patients following radiation therapy showed complete resolution of the epidural mass in the lumbo-sacral segment in one patient and partial disappearance of the paravertebral mass in the thoracic segment in the second patient.

MR IMAGING OF SPINAL NEUROFIBROMATOSIS (V)

Seven patients (16-40 years old, mean 27.8 years, male/female = 4/3) with neurofibromatosis (NF) were examined with MR. Solenoidal surface coils were used in all patients. All investigations included a sagittal and coronal T1-weighted image, for 6 patients coronal T2-weighted images, for 2 sagittal T2-weighted images and for 4 axial T1-weighted images. In one patient T1-weighted images after injection of intravenous Gd-DTPA were obtained. Three patients underwent one examination, 2 three examinations, one four examinations, and one five examinations. Conventional radiography was performed in 5 patients. Myelography and CT-myelography were performed in 4 patients. The diagnosis of NF had been established by histopathological examination in 5 patients before MR examination and in 2 after.

Paraspinal lesions were demonstrated in MR imaging in 6 patients. Coronal T2-weighted images were especially valuable for disclosing paraspinal lesions. Four patients had bilateral involvement along the axis of the spine and 2 unilateral involvement at multiple levels. Five patients had multiple intraspinal lesions. The intraspinal lesions were most often located laterally in the spinal canal at levels corresponding

to the nerve roots, frequently causing compression and displacement of the cord. Some lesions had an extension through the neural foramen to the paraspinal region causing so called "dumb-bell" tumors with enlarged neural foramen. In one patient, multiple paraspinal tumors were found along nerves in the lumbar sacral plexus creating a plexiform pattern of tumors. Two patients had bilateral acoustic neuromas and multiple intracranial meningeomas consistent with NF type II. In most patients the relation between the tumors and the surrounding normal structures was well visualized in T1-weighted images. The signal pattern was iso- or of low intensity relative to the cord in T1-weighted images. The margins of the lesions were well demonstrated and well defined in relation to surrounding structures in T2-weighted images in which the tumors were hyperintense. Most lesions were homogeneous in both T1- and T2-weighted images. In 3 patients some lesions had a central area of decreased signal in T2-weighted images. In one patient with bony dysplasia and meningoceles the signal intensity in the meningoceles paralleled that of CSF on both T1- and T2-weighted images. T1-weighted images with injection of intravenous Gd-DTPA were obtained in one patient showing a marked enhancement of the lesions.

In 3 patients also examined with myelography and CT, MR was found to be superior because it showed more lesions and visualized especially paraspinal lesions better. In the patient with meningoceles, CT initially misinterpreted the lesion as neurofibromas, while MR and myelography clearly showed the true nature of the lesions. In one patient, myelography visualized a small tumor that was not seen on an unenhanced MR examination.

DISCUSSION

INTRAMEDULLARY TUMORS (I)

Ependymomas and astrocytomas are the two main histological types of intramedullary tumors occurring in the spine (7). Typically, these tumors grow infiltratively along the longitudinal axis of the cord and they usually exhibit reactive edema in the adjacent parenchyma, which accounts for the indistinct tumor margin on MR images. In general, the signal intensity of both ependymomas and astrocytomas is low or isointense relative to the cord in T1-weighted images, and high in T2-weighted images. Intratumor small foci of necrosis, encased native vessels and tumor vascularity cause inhomogeneous low-intensity and isointensity signals relative to the cord in T1-weighted images, but still homogeneous hyperintensity in T2-weighted images. If they are accompanied by intratumor hemorrhage, hemosiderin deposition or calcification, the signal pattern will be heterogeneous in both T1- and T2-weighted images (3, 67, 71, 82). This phenomenon was more frequent in ependymomas in our study. It seems to be reasonable to believe that the connective tissue stroma in ependymomas which is intensively vascular can cause intratumor hemorrhage (7), especially in myxopapillar ependymoma.

The association of intratumor cavitation with ependymomas and astrocytomas is wellknown. The pathogenesis of cyst formation and liquefaction in tumors is considered by some to be caused by degeneration and necrosis within the neoplasm (69, 83). The preoperative demonstration of intratumor cysts is a most relevant MR finding which influences surgical

technique. Intratumor focal necrosis might only be visualized as areas with inhomogeneous signal in T1- and T2-weighted images. Cystic degeneration with tumoral nodules is best demonstrated in T1-weighted images before and after injection of intravenous Gd-DTPA. A completely cystic tumor involving a long segment of the cord will have a uniform signal pattern in MR images, as was most common in astrocytoma in this study. If the signal intensity is similar to that of CSF, it may be confused with syringomyelia. In exclusively cystic tumors the residual tumor wall appears as a hyperintensity rim in T2-weighted images. However, this can also be seen around a syrinx and this is thought to represent gliosis caused by a non-neoplastic reaction secondary to the chronic pulsations of the cyst fluid (69, 74). Cysts containing different elements might produce a complex MR appearance which makes recognition of the cyst difficult (36, 63, 69). For example, high-protein or blood elements in cysts may lead to a homogeneous highintensity signal in T1-weighted images, but the lack of enhancement in post-contrast MR scans will be very helpful for the recognition of cysts.

The cervical and thoracic cord are the most frequent sites of intramedullary metastasis from non CNS origin and the most common primary tumors are lung and breast carcinoma (25, 59). One of two intramedullary metastases from non CNS-origin in this study was from a lung cancer. This tumor involved a large portion of the cervical and thoracic cord. The MR appearance of metastasis might be similar to primary intramedullary neoplasms, however, the clinical history is usually helpful in the correct diagnosis. In the second case with melanoma, a localized expansion of the lower thoracic cord with a hyperintense signal relative to

the cord in T1-weighted images was found. This signal pattern is similar to that of intracerebral melanoma which is thought to be caused by the paramagnetic products of hemorrhage, as well as the paramagnetic stable free radicals known to exist within melanin (3, 82).

Intracranial neoplasms, especially medulloblastomas, frequently spread through the CSF pathways to the spinal subarachnoid space, which might lead to direct invasion of the surface of the cord and nerve roots (48, 84). In this study, two intracranial medulloblastomas had spread via CSF pathways. They had a different appearence with an ill-defined contour of the cord, obliteration of the subarachnoid space or irregular surface and tumor nodules on the cord and nerve roots in T1-weighted images. The injection of intravenous Gd-DTPA facilitates the demonstration of the pathologic changes mentioned above in T1-weighted images (42, 60).

Several hypotheses concerning the origin of intramedullary neurinoma have been proposed (17, 64): they may originate from the perivascular nerve endings, or from aberrant fibers or ectopia of Schwann cells within the spinal cord, or from the differentiation of mesenchymal cells into Schwann cells, or they may start at the origin of nerve roots. One case in this study was pathologically proven to be an intramedullary neurinoma from the left posterior nerve root at C2 level. The area of the lesion showed an extensively expanded cord with an inhomogeneous signal pattern on both T1- and T2-weighted images. Following Gd-DTPA, a marked enhancement of the well-demarcated tumor was found, and the surrounding could be interpreted as edema. The marked enhancement can be

explained by the hypervascularity and the lack of blood-brain (cord) barrier in neurinoma.

The most common site of origin of CNS teratoma is in the pineal region and it may be found rarely in the subdural space of the spine (52, 78). Intramedullary teratoma is extremely rare. As elsewhere in the body, intramedullary teratoma is composed of a mixture of well-differentiated tissue of adult type and organoid pattern derived from all three germinal layers. This histological feature is responsible for the characteristic heterogeneous signal on MR imaging. Fatty components with markedly increased signal intensity and calcified areas with a low signal will be well demonstrated on both T1- and T2-weighted images.

INTRADURAL EXTRAMEDULLARY TUMORS (II)

The compartmentalization of a process is important in that it considerably narrows the differential diagnosis of a spinal tumor. MR imaging can accurately determine the intradural extramedullary location of the tumors. Identification of compression or displacement of the cord or cauda equina allows a diagnosis of extramedullary lesion on MR imaging as well as in myelography and CT-myelography. Only the demonstration of the wide subarachnoid space above and below the lesion or the outward compression of the epidural fat can establish the diagnosis of intradural extramedullary lesion. This anatomic distortion was well depicted in T1-weighted images due to the good contrast between CSF and the surrounding structures. In order to localize the tumor accurately, sagittal and axial views shculd be performed routinely. Sometimes, coronal or

oblique images are valuable. Both meningeomas and neuromas may involve epidural space and extend via the intervertebral foramen to the paraspinal area in which the typical signs of the intradural tumor mentioned above might be missing. One of our meningeomas mainly involved the epidural space at several levels and had a left paraspinal extension which is difficult to distinguish from metastasis (80).

Delineation of tumors depends on the spatial resolution of the scan and the contrast with respect to adjacent structures. In general, MR imaging is less sensitive to intradural extramedullary tumors than other spinal tumors (73), unless intravenous contrast medium is injected. However, with high-quality MR imaging and optimal plane selection, the diagnosis of intradural extramedullary tumors can readily be made. Meningeomas often have a broad base towards the dura, but this sign is not useful in a larger tumor which always has a broad contact with the dura. A low signal band between the tumor and the compressed cord in T1-weighted images represents in part a tumor capsule and CSF "entrapment" (10, 47, 86). The identification of this phenomenon is useful for the location of an intradural extramedullary tumor but not for histological classification.

The signal intensity of neuromas and meningeomas is slightly lower than or equal to that of the cord in T1-weighted images and higher than that of the cord in T2-weighted images (44, 58). In our study, neuromas often showed lower signal intensity in T1-weighted images and higher signal intensity in T2-weighted images than meningeomas. This may suggest that

neuromas have a higher water content than meningeomas (9, 86). Meningeomas have a more homogeneous appearance than neuromas in both T1- and T2-weighted images (66). The tendency towards cystic degeneration and necrosis in neuromas is greater than in meningeomas. This pathologic change is probably responsible for the heterogeneous signal in both T1- and T2-weighted images in some neuromas (20). A pathologic feature of meningeomas, namely calcification, is poorly detected by MR imaging unless a calcification is dense causing a decreased signal (47, 86). Slight erosion of the cortical bone is also difficult to demonstrate by MR imaging. Lipomas in the intradural space are uncommon (19). It is not difficult to make an accurate diagnosis based on hyperintensity in both T1- and T2-weighted images. A solitary metastasis is easily confused with other tumors in this area without a history of primary tumor. In this study, one lumbar ependymoma had a slight hypointense signal in T1-weighted images and marked hyperintensity in T2-weighted images, as seen in neuromas. It is assumed that it is the clear cytoplasm of the ependymal cells that gives rise to the high signal intensity in T2-weighted images (79).

EXTRADURAL TUMORS INCLUDING LYMPHOMAS (III, IV)

Most spinal metastases begin in the vertebral bone marrow, and MR imaging is capable of detecting bone marrow metastasis (5, 18, 57). Vertebral bone metastasis can sometimes be demonstrated by MR despite equivocal or negative studies with other procedures (5). In this study, there were six patients with equivocal conventional radiography, despite vertebral bone metastases with intraspinal soft tissue masses well

demonstrated with MR imaging. Avrahami et al. assumed that early malignant infiltration of the bone marrow may lead to metabolic biochemical changes in the bone marrow, rather than destructive or other structural changes (5). MR is more reliable than conventional radiography and even CT for the demonstration of early malignant infiltration of bone marrow (57).

The identification of multiple areas of involvement is extremely important in the decision regarding whether surgery or radiotherapy should be used and for appropriate mapping of radiation ports (70). MR allows the entire spine to be imaged directly in the sagittal or coronal plane, which makes it possible to detect widely separated metastatic lesions. In this study, MR imaging showed involvement of multiple areas at different levels in 51 patients. Myelography or CT myelography are usually unsatisfactory for evaluation of multiple involvement as multiple metastases are either strictly osseous and produce no subarachnoid space compression or, more important, because some of them are located between two areas of myelographic blockage.

Demonstration of paravertebral involvement is another advantage of MR which is especially useful in the evaluation of the full extent of spinal lymphoma due to its special growth pattern. MR can well demonstrate a paravertebral mass with extension through the intervertebral foramen to the epidural space in lymphoma (33, 77, 85). Coronal and axial views at selected levels will best demonstrate paravertebral involvement.

MR imaging also plays a prominent role in follow-up studies of vertebral tumors. In this study two patients with lymphoma showed complete and partial resolution of the intraspinal content and paravertebral mass, respectively, at repeated MR examinations after radiotherapy.

The signal pattern of metastatic vertebral bone, is in general, homogeneous and of hypointensity relative to bone marrow in T1-weighted images and iso- or slight hyperintensity on T2-weighted images. Our study shows that T1-weighted images provide the best information in the majority of cases and in only one of 22 cases were T2-weighted images superior. In some patients, however, the signal may be heterogeneous on both T1- and T2-weighted images. We believe this is a result of several factors: metastatic infiltration with incomplete replacement of marrow; partially sclerotic metastasis; uneven growth of metastatic lesions and miscellaneous elements (hemorrhage, calcification, etc.) within the metastatic lesions.

In general, MR findings in spinal metastases lack characteristics allowing a diferential diagnosis between various types of primary tumors. In this study, however, 14 of 21 patients with carcinoma of the prostate had metastatic lesions of the vertebral bone which gave a more decreased signal than other tumors on T1-weighted images. In one patient a decreased signal was also seen on T2-weighted images. This MR finding was related to sclerotic metastasis according to conventional radiography (75). In four of eight patients with multiple myeloma, the signal intensity of the vertebral lesions was heterogeneous with a diffusely low

signal and small foci of lower signal strength in T1-weighted images, which may be suggestive for the diagnosis of some multiple myelomas (5).

Spinal lymphomas commonly involve the paravertebral lymph nodes with invasion of adjacent vertebrae and extension through the intervertebral foramen to the epidural space (33, 77, 85). They may also infiltrate the vertebral bone marrow (43, 57), or epidural space alone. MR imaging is an optimal modality for the demonstration of the full extent of the lesions described above. The signal of bony lesions is typically decreased in intensity relative to marrow in T1-weighted images. In some patients, the diseased vertebral bodies gave a diffusely decreased signal with superimposed focal areas of even lower signal which might be explained by focal nodules of lymphoma (57). In two patients, spinal involvement was only seen in the epidural space extending over several vertebral levels. The mechanisms for the initial occurrence of lymphoma in the epidural space is under debate (53), but we believe that these two patients represent initial blood-borne involvement of the epidural space in the spine. In one case the epidural mass was hyperintense relative to the cord in T1-weighted images, which made it easy to confuse with a hematoma, however, the clinical history may be helpful for the differential diagnosis.

SPINAL NEUROFIBROMATOSIS (V)

Neurofibromatosis (NF) has recently been divided into two types according to the location of the genetic defect (8, 45, 55, 61, 81). In NF 1 the

defect is located in chromosome 17 and in NF 2 in chromosome 22. NF 1 was previously known as Von Recklinghausen's disease or peripheral NF with a 0.025% incidence. NF 2 was previously known as bilateral acoustic NF or central NF with a 0.002 % incidence. Aoki et al suggested that cranial NF 1 was primarily a disease of nerves and astrocytes and that NF 2 was a disease of the coverings of the central nervous system (2). It seems reasonable to regard two of our cases as NF 2 and the remaining five cases as NF 1 on the basis of recently established criteria by the NIH Consensus Development Conference (2, 55).

Frequently, spinal NF involves both intra- and paraspinal areas, and sometimes extends along nerve roots towards peripheral nerves. Many of the spinal manifestations of NF can be evaluated using conventional radiography and myelography (15, 37). However, besides its inability to demonstrate paraspinal tumors, myelography cannot show lesions in cases with myelographic blockage at two levels or more. CT is capable of demonstrating paraspinal lesions and, if contrast medium is introduced intra- thecally, also intraspinal pathology. However, the same limitations as for myelography remain in cases of myelographic blockage. CT is also impractical because it is difficult to cover the entire spine. MR is an ideal technique for the evaluation of both intra- and paraspinal tumors (15, 41). T1-weighted images are most valuable for demonstrating anatomic information, especially the relation between tumors and cord. Sagittal plane images may display NF involvement in the longitudinal extent of the spine, while the coronal plane is best for displaying paraspinal lesions and peripheral nerve lesions. The axial plane is helpful

for defining tumor extent at selected levels. T2-weighted images were especially valuable for the demonstration of paraspinal tumors because their high signal relative to surrounding muscles makes them easy to detect.

The signal of lesions was equal to or somewhat lower than that of the cord and equal to or slightly higher than that of surrounding muscles in T1-weighted images. In T2-weighted images the signal intensity was markedly increased relative to the cord and muscle. This is consistent with findings reported by other authors (15, 41). The majority of lesions were homogeneous except when accompanying intratumor necrosis was found. However, some lesions may contain areas in the center with decreased intensity in T2-weighted images. Based on pathological observations, it has been suggested that the central areas of decreased signal are due to condensations of relatively cellular fibrous tissue or the contribution of collageneous elements which cause a rapid decay of signal intensity at the center of some lesions (1, 15, 29).

NF 1 is associated with bony dysplasia and meningoceles, which was seen in one of our cases. In this case, the initial interpretation was neurofibromas after CT examination which, however, was changed to the correct diagnosis after having performed MR and myelography. The low signal similar to that from CSF in T1-weighted images rules out a solid tumor and confirms the diagnosis of a meningocele.

THE VALUE OF Gd-DTPA IN MR IMAGING OF SPINAL TUMORS

Gd-DTPA is a stable paramagnetic MR imaging contrast agent which has demonstrated its usefulness in a number of clinical situations in the central nervous system (9, 14, 16, 24, 73). Its contrast effect depends on both an adequate vascular delivery and a blood-brain (cord) barrier defect of sufficient size to allow its accumulation in the extravascular space. Bydder et. al were the first to report MR enhancement of spinal cord tumors with Gd-DTPA (16). More recently, others have shown improved detection of intramedullary tumors in the spine with Gd-DTPA (22).

In the first part of the period during which the MR examinations in this study were performed, Gd-DTPA was not registered in Sweden and therefore contrast enhancement could not be used. Only 8 patients (6 intramedullary tumors, one intradural extramedullary tumor and one epidural tumor) were examined with T1-weighted images after injection of intravenous Gd-DTPA in this study (Table 9). However, some comments can be made despite the limited number of patients examined with contrast enhancement. T1-weighted images with intravenous injection of Gd-DTPA were extremely useful in the evaluation of the intramedullary tumors with a mixed pattern of solid tumor and cavities. In our study an intramedullary neurinoma was separated from surrounding edema in post-contrast MR which was impossible to determine in the pre-contrast MR. Gd-DTPA has also been reported to be extremely helpful in the visualization of leptomeningeal tumor spread in the spine (42, 60, 74). In this study, one case with a drop metastasis to the spinal subarachnoid space had an irregular surface of the cervical and thoracic cord on T1-weighted images, which was

enhanced after injection of intravenous Gd-DTPA, so that enhancing tumor nodules on the surface of the cord could be separated from the cord.

Intradural extramedullary tumors are best shown in T1-weighted images after intravenous injection of Gd-DTPA because the signal difference between the tumor and surrounding CSF will increase (73). In our study, an equivocal T1-weighted image was obtained from one patient with a small neurinoma. After the injection of intravenous Gd-DTPA, the lesion was clearly delineated. However, large tumors are usually easy to detect and delineate also without contrast enhancement.

Gd-DTPA enhancement may be of benefit in the detection of neoplasms of the epidural space in some cases, but it is unlikely to be routinely used in the evaluation of extradural tumors in the spine (75). As a matter of fact, vertebral engagement of metastases might be hidden by contrast agents as the signal difference between normal bone marrow and metastases in T1-weighted images will decrease after injection of contrast agents.

CONCLUSIONS

Based on the results of the present investigation of the role of MR with a magnetic field of 0.3 T in the diagnosis of spinal tumors, the following conclusions can be drawn:

- MR is the most sensitive procedure for the demonstration of intramedullary tumors and accompanying cysts, necrosis and hemorrhage.

Although typing of certain tumors is sometimes difficult with MR, some MR findings are characteristic for various histological types of intramedullary tumors (I).

- MR can not only provide all information about intradural extramedullary tumors given by myelography and CT-myelography but may also directly demonstrate the tumor and its relation to the surrounding structures. Taking into account the morphologic changes, location and signal pattern in MR imaging, combined with the age and sex of the patient, MR can provide the possibility of distinguishing between neuromas and meningeomas in most cases (II).

- MR can evaluate the total extent of spinal metastatic lesions and demonstrates well intraspinal impingement with compression of subarachnoid space and the cord. MR, together with conventional radiography, should be the primary imaging modality for evaluation of patients with known or suspected spinal metastatic disease at the onset of neurologic symptoms or severe bone pain or both. The full demonstration of special growth patterns in some diseases (lymphoma and neurofibromatosis) is helpful in making an accurate diagnosis. In addition, MR is also very helpful for follow-up studies in extradural tumors (III, IV, V).

- The paramagnetic contrast medium, Gd-DTPA, is useful in MR imaging of spinal tumors, especially in intramedullary and intradural extramedullary tumors. T1-weighted images with intravenous injection of Gd-DTPA are particulary helpful for identifying solid

tumors and cavities, for separating the tumor from the surrounding edema, for delineating the active area of the tumor, for delineating smaller tumors and for demonstrating leptomeningeal metastasis of the spinal cord (I, II, IV).

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Table 1. Diagnosis and location of spinal tumors in 168 patients examined by MR

	intra-medulllary	intradural extra-medullary	extradural	neurofibro-matosis
ependymoma	6	1		
astrocytoma	7			
meningeoma		11		
neuroma	1	14		
metastasis	2	2	76	
medulloblastoma	1			
drop metastasis	2	1		
myeloma			8	
teratoma	1			
lipoma		2		
glioma	2			
unspecified tumor	3			
lymphoma			14	
neurofibro-matosis				7*
primary spinal tumor			7	
Total	25	31	105	7

*Multiple neurofibromas 5 patients, multiple neurofibromas and one meningeoma 1 patient, bone dysplasia 1 patient.

Table 2. Histological diagnosis in 25 patients with intramedullary tumors

astrocytoma	7 (8)*
ependymoma	6 (7)*
glioma	2
unspecified tumor	3 (only laminectomy)
medulloblastoma	3 (histological diagnosis from intracranial tumors)
metastasis	2 (1 case with histological diagnosis from primary tumor)
neurinoma	1
teratoma	1

* 7 patients with 8 astrocytomas and 6 patients with 7 ependymomas

Table 3. Location of astrocytomas and ependymomas*

	astrocytomas (n=8)	ependymomas (n=7)
cervical	2	1
cervical-thoracic	4	1
thoracic	1	1
thoracic-lumbar	1	3
lumbo-sacral		1

* 7 patients with 8 astrocytomas and 6 patients with 7 ependymomas

Table 4. Signal intensity of astrocytomas and ependymomas in MR

signal relative to cord		astrocytomas T1-W (n=7)	astrocytomas T2-W (n=4)	ependymomas T1-W (n=6)	ependymomas T2-W (n=6)
homogeneous	low	1			
	iso	2			
	high	1	4		3
inhomogeneous	iso- and low	3		5	
	iso- and high			1	3

Table 5. Location of meningeomas and neuromas

	meningeomas (n=11)	neuromas (n=14)
cervical	3	6
thoracic	8	5
lumbo-sacral		3

Table 6. Signal intensity of meningeomas and neuromas in MR

signal relative to cord		meningeomas T1-W (n=11)	meningeomas T2-W (n=6)	neuromas T1-W (n=14)	neuromas T2-W (n=11)
homo-geneous	low	1		1	
	iso	10	3	8	
	high		1		7
	marked high				4
inhomo-geneous	iso- and low			5	
	iso- and high		2		

Table 7. Distribution of primary tumors in 91 patients with extradural tumors

prostate	21
breast	14
kidney	12
bladder	4
lung cancer	6
sarcoma	5
melanoma	3
thyroid	2
pancreas	1
anus	1
epipharynx	1
colon	1
unknown	5
multiple myeloma	8
primary spinal tumor	7
Total	91

Table 8. Signal intensity of diseased vertebral bone in MR in 91 patients with extradural tumor

signal relative to bone marrow		T1-weighted (n=91)	T2-weighted (n=22)
homogeneous	low	61	1
	iso		8
	high		6
inhomogeneous	iso- and low	30	2
	iso- and high		5

Table 9. Presentation of 8 patients with MR after contrast injection.

case/age/sex No.	histological diagnosis	enhancement
Intramedullary tumors:		
1/44/M	ependymoma gr. II (partially cystic formation)	+ (tumor nodule)
2/26/F	medulloblastoma (CSF pathway spread)	+ (superficial and nodular tumors)
3/67/F	neurinoma	+ (entire tumor)
4/51/F	glioma (post-operation cystic formation)	-
5/73/F	unspecified tumor	+ (tumor nodule)
6/75/F	unspecified tumor	-
Intradural tumor:		
7/18/F	neurinoma	+ (entire tumor)
Extradural tumor:		
8/67/F	meningeoma (post-operative remaining tumor)	+ (entire tumor)

+, enhancement; -, no enhancement.