AJNR

Gadolinium-DTPA-Enhanced MR Imaging of Spinal Neoplasms: Preliminary Investigation and Comparison with Unenhanced Spin-Echo and STIR Sequences

Gary K. Stimac, Bruce A. Porter, Dana O. Olson, Rebecca Gerlach and Monique Genton

AJNR Am J Neuroradiol 1988, 9 (5) 839-846
http://www.ajnr.org/content/9/5/839

Gadolinium-DTPA-Enhanced MR Imaging of Spinal Neoplasms:
Preliminary Investigation and Comparison with Unenhanced Spin-Echo and STIR Sequences

Gary K. Stimac[1,2]
Bruce A. Porter[1]
Dana O. Olson[1]
Rebecca Gerlach[2]
Monique Genton[1]

Unenhanced T1- and T2-weighted spin-echo, short inversion time inversion recovery (STIR), and gadolinium-DTPA (Gd-DTPA)-enhanced spin-echo and STIR imaging techniques were used in 20 patients as part of a multicenter study to assess the safety and efficacy of Gd-DTPA in spinal imaging. Five patients had normal MR scans. Of those with lesions, both Gd-DTPA-enhanced T1-weighted spin-echo and unenhanced STIR scans improved detection and evaluation of spinal tumors over conventional spin-echo methods, particularly T2-weighted spin echo, by providing higher tissue contrast in shorter imaging times. The Gd-DTPA-enhanced T1-weighted spin-echo scans were most helpful in evaluating intradural tumors, whereas STIR sequences were most effective for extradural tumors and bone metastases. In most cases, Gd-DTPA-enhanced T1-weighted spin-echo scans best delineated tumor margins, and the enhancement was helpful in suggesting a cellular or active nature of the lesions. In some cases, the enhancement resulted in a more homogeneous and thus less abnormal-appearing marrow in vertebrae involved by tumor; therefore, a precontrast T1-weighted spin-echo scan is necessary in all patients who are to be studied with Gd-DTPA.

A combined approach that uses T1-weighted spin-echo, Gd-DTPA-enhanced T1-weighted spin-echo, and STIR images currently appears optimal for MR imaging of spinal neoplasms. T2-weighted spin-echo images add information only in occasional cases.

Gadolinium-DTPA (Gd-DTPA) is an effective contrast agent for MR imaging of brain lesions [1–4]. This is due in part to the blood-brain barrier, which allows enhancement of tumor and other lesions that disrupt this barrier without enhancing the surrounding normal brain. Because Gd-DTPA is distributed throughout the interstitial spaces of tissues outside the brain and spinal cord, MR studies were undertaken to determine whether clinically useful enhancement of tumors in or near the spine would occur.

Various MR sequences have been used to evaluate spinal tumors. Most investigators advocate a combination of T1-weighted spin-echo and T2-weighted spin-echo sequences [5], but short inversion time inversion recovery (STIR) sequences also have been used [6]. We previously used T1-weighted spin-echo techniques to evaluate patients with bone-marrow malignancies [7, 8] and recently used a combination of STIR and T1-weighted spin-echo techniques in more than 400 patients with spinal marrow and brain disease [9, 10]. In the present study, we extended our experience with T1-weighted spin echo and STIR in the evaluation of spinal disease by evaluating the effects of Gd-DTPA.

We obtained T1- and T2-weighted spin-echo and STIR images before and after administration of Gd-DTPA in a multicenter trial to assess the safety and efficacy of Gd-DTPA in spinal MR. The objectives were to determine whether Gd-DTPA improved detection and delineation of spinal tumors, to assess the relative contribution of STIR, and to develop an improved MR protocol for imaging spinal tumors.

This article appears in the September/October 1988 issue of *AJNR* and the December 1988 issue of *AJR*.

Received December 28, 1987; accepted after revision March 29, 1988.

This work was supported by funds from Berlex Laboratories, Inc., and the Biomedical Research Support Program, University of Washington.

[1] First Hill Diagnostic Imaging Center, 1001 Boylston Ave., Seattle, WA 98104. Address reprint requests to G. K. Stimac.

[2] Department of Radiology, SB–05, University of Washington, Seattle, WA 98195.

***AJNR* 9:839–846, September/October 1988**
0195–6108/88/0905–0839

Subjects and Methods

Patients were chosen according to the protocol for the multicenter Gd-DTPA drug study under institutional review board approval. Most had known or strongly suspected spinal tumor, as demonstrated by other imaging tests or by prior biopsy. The patients with known primary tumors were thought to have metastatic spinal disease on clinical grounds. Of 20 patients examined, seven had metastatic tumor (prostate, three; breast, two; and colon and lung, one each), four had infiltrative marrow tumor (myeloma, three; lymphoma, one), and four had primary tumors. Two of the latter group had intrathecal ependymomas, one had a giant cell tumor of the sacrum, and one patient with neurofibromatosis had multiple tumors including two meningiomas and four neural tissue tumors. Five patients had normal MR scans. Clinical and surgical follow-up was obtained up to 9 months after examination.

All images were obtained on a 0.15-T MR system.* Each patient underwent a precontrast series of sequences consisting of sagittal STIR, 1400/100/36/2,4 (TR/TI/TE/excitations), with a 256 × 128 matrix; T1-weighted spin echo, 600/22/4 (TR/TE/excitations), with a 256 × 256 matrix; T2-weighted spin echo, 2000/60/2, with a 256 × 256 matrix; and axial T1-weighted spin echo, 600/22/4, with a 256 × 128 matrix. After IV injection of Gd-DTPA (0.1 mmol/kg) the sequences were repeated with the addition of a delayed sagittal T1-weighted spin-echo sequence 1 hr after injection.

Scans were reviewed subjectively by two radiologists to determine for each imaging sequence (1) the relative tissue contrast of tumor as compared with surrounding structures, (2) the distinctness of margins, and (3) whether the detection of the lesion was improved or diminished by the contrast enhancement. Also noted was the detection of additional tumor or adenopathy. Each sequence was evaluated with respect to its usefulness in making the overall diagnosis, in an attempt to determine the best series of sequences for evaluating and/or screening patients with possible spinal tumor.

* Picker International, Cleveland, OH.

Results

The interpretation of our results depends on an understanding of the appearance of normal bone marrow on low-field T1-weighted spin-echo and STIR images. At a field strength of 0.15 T, spinal marrow is reliably and readily imaged with T1-weighted spin-echo techniques because the marrow fat provides a nearly homogeneous, high-intensity signal (see the normal upper and lower vertebral bodies of Fig. 1A). Tumor, because of its long T1, is easily detected as a low-intensity defect in the marrow. Radiation therapy results in replacement of red marrow by yellow marrow and consequent uniformly increased signal, as shown on the nontumor areas of the middle vertebral bodies in Figure 1A.

Gd-DTPA enhancement, because it shortens T1, shows tumor as increased intensity on T1-weighted spin-echo scans (Fig. 1B). The effects of Gd-DTPA on T2-weighted spin-echo and STIR images are, in general, less pronounced and are discussed below.

STIR suppresses the signal from fat and shows the normal vertebral bodies as low intensity (Fig. 1C). Tumor has high intensity and is easily detected against the low-intensity surroundings but not when it is adjacent to the high-intensity intervertebral disks and the CSF. Irradiated marrow has a lower intensity than normal marrow on STIR (Fig. 1C).

Unenhanced and Gd-DTPA-enhanced T1-weighted spin-echo scans and unenhanced STIR scans provided high tissue contrast in short imaging times and were effective in detecting spinal tumors. The relative effectiveness of each sequence depended on tumor type and location. Table 1 describes the regions of clinical spinal involvement and additional abnormalities identified. Table 2 lists the subjective comparison for each imaging sequence (T1- and T2-weighted spin echo and STIR) of (1) the relative tissue contrast of tumor as compared

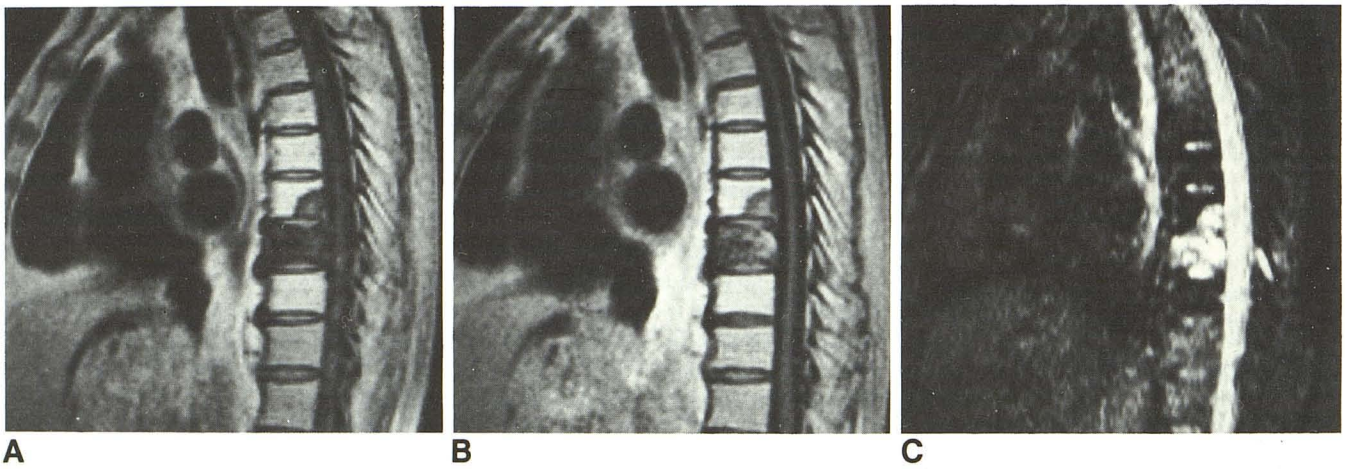

Fig. 1.—Case 3. Blastic prostate carcinoma metastases to T7 and T8.

***A*, Precontrast T1-weighted spin-echo image, 600/22, shows tumor replacement of marrow at T7 and T8 resulting in low-intensity appearance. Remaining marrow of T7 and that of T5, T6, and T9 shows radiation therapy-induced yellow marrow conversion. Tumor was easily detected but compression of thecal sac was difficult to assess owing to low intensity of both tumor and CSF.**

***B*, After Gd-DTPA, an identical T1-weighted spin-echo sequence shows partial enhancement of tumor and better delineation of its posterior margins.**

***C*, Unenhanced short TI inversion recovery image, 1400/100/36. Note high contrast between tumor and irradiated marrow of vertebral bodies. Margin between tumor and ventral thecal sac is evident, showing that ventral thecal sac was not indented.**

TABLE 1: Locations of Clinical Lesions and Additional Abnormalities

Case No.	Lesion	Clinical Lesions	Additional Findings
Metastases:			
1	Prostate	L5, T7	Adenopathy; malignant ascites
2	Prostate	L2, S1	L3–L5 diffuse marrow involvement
3	Prostate	T7, T8	Postoperative fluid
4	Colon	L3	Presacral mass
5	Lung	T6	Primary lung carcinoma
6	Breast	T7, L5	None
7	Breast	T7	L1–L5 metastases
Marrow tumors:			
8	Myeloma	L4, S1	T1–S2 involvement
9	Myeloma	T2	Two additional spine lesions
10	Myeloma	T10	Two rib lesions
11	Lymphoma	Entire spine	Periaortic lymphadenopathy
Primary tumors:			
12	Ependy-moma	Thecal sac, L3–S2	Surgical changes
13	Ependy-moma	C6–T4	None
14	Giant cell	S1, S2	Marrow radiation; cyst
15	Neurofibroma	L4, C1	Three additional schwannomas

TABLE 2: Effectiveness of MR Imaging Techniques in Lesion Identification

Disease: Case No.	Contrast Between Tumor and Surrounding Tissue	Definition of Tumor Margins	Tumor Masking by Gd-DTPA[a]
Prostate:			
1	IR, Gd, T1, T2	Gd, T1, T2, IR	+1
2	T1, IR, Gd, T2	Gd = T1, IR = T2	+1
3	IR = T1, Gd, T2	Gd, T1, IR, T2	+1
Colon:			
4	IR, T1, Gd, T2	Gd, T1, IR, T2	+1
Lung:			
5	T1, IR, T2, Gd	Gd, T1, T2, IR	+2
Breast:			
6	IR, T1 = Gd, T2	IR, T1 = Gd, T2	None
7	IR, T1, T2, Gd	T1, T2, Gd, IR	+1
Myeloma:			
8	IR, T1, T2, Gd	T1, IR, T2, Gd	+3
9	IR, T1, Gd, T2	IR, T1, Gd, T2	+1
10 (rib)	IR, Gd, T1, T2	Gd, T1, IR, T2	None
Lymphoma:			
11	IR, T1, Gd, T2	T1, IR, Gd, T2	+2
Ependymoma:			
12	Gd, IR, T2Gd, T2, T1	Gd, T1, T2, IR	None
13	GdD, T2Gd, Gd, T2, T1, IR	Gd, T2Gd, T2, IR, T1	None
Giant cell tumor:			
14	IR, T2, Gd, T1	Gd = T2, IR , T1	+1
Schwannoma:			
15 (left IAC)	Gd, T1, IR = T2	Gd, T1, IR = T2	None
15 (right IAC)	Gd, T1, T2, IR	Gd, T1, T2, IR	None
15 (right neck)	T2Gd = IR, Gd, T2, T1	T2Gd = IR, Gd, T2, T1	None
Meningioma:			
15 (C1)	Gd, T1, T2, IR	Gd, T1, T2, IR	None
Neurofibroma:			
15 (lumbar)	IR, Gd, T2, T1	IR, Gd, T2, T1	None

Note.—Imaging studies are listed in the order of the most to the least effective. Sequences not listed were less effective. IR = precontrast short inversion time inversion recovery; Gd = Gd-DTPA–enhanced T1-weighted spin echo; T1 = unenhanced T1-weighted spin echo; T2 = unenhanced T2-weighted spin echo; T2Gd = Gd-DTPA–enhanced T2-weighted spin echo; GdD = delayed Gd-DTPA–enhanced T1-weighted spin echo; IAC = internal auditory canal.

[a] Tumor masking was detected only on unenhanced T1-weighted spin-echo images. +1 = minimal enhancement; +2 = definitely enhanced but distinguishable as abnormal; 3+ = enhanced to appear similar to adjacent structure.

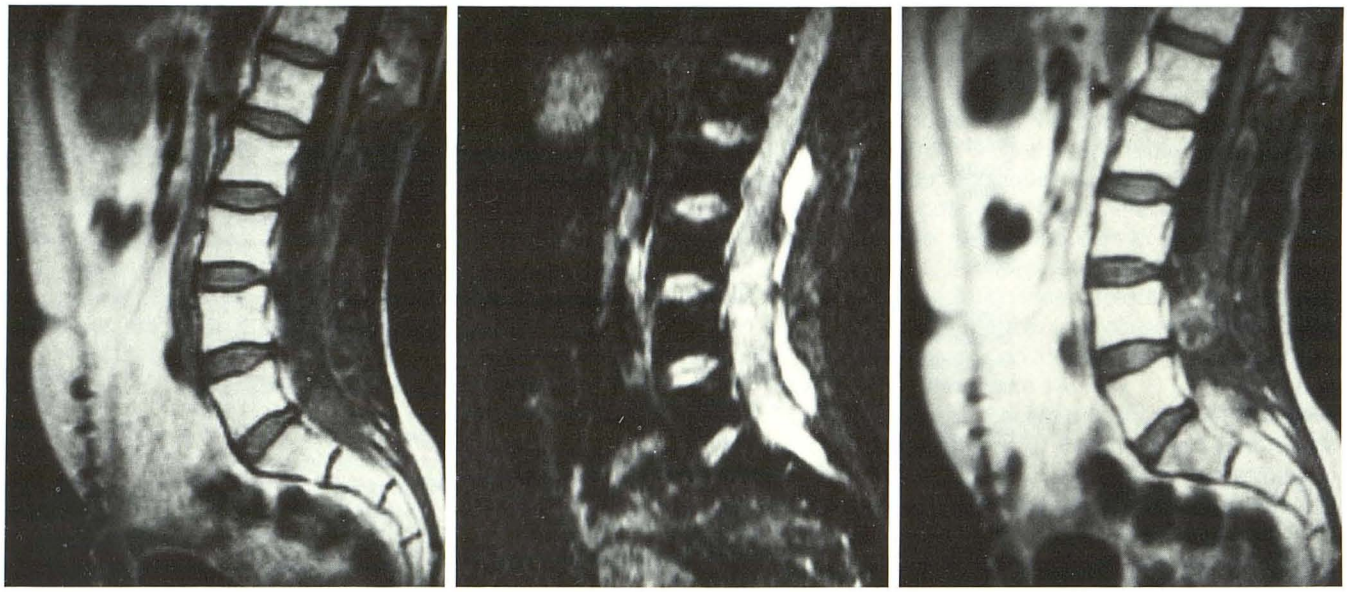

Fig. 2.—Case 12. Recurrent intradural ependymoma extending from L3 to S2.

A, Precontrast T1-weighted spin-echo scan, 600/22, reveals wide laminectomy from previous surgery. Soft tissue fills thecal sac from L3–L4 through S2.

B, Short TI inversion recovery image, 1400/100/36, shows enlargement of thecal sac and several areas of increased intensity within. Mass is not clearly defined because CSF and mass are of similar high intensity.

C, Delayed postcontrast T1-weighted spin-echo scan, 600/22, shows focal enhancement at L4 and at S1–S2. Remaining areas of intrathecal material do not enhance more than other tissues. Because there was only mild progression of symptoms and surgery would be difficult in this previously resected and irradiated area, surgical proof is not yet available.

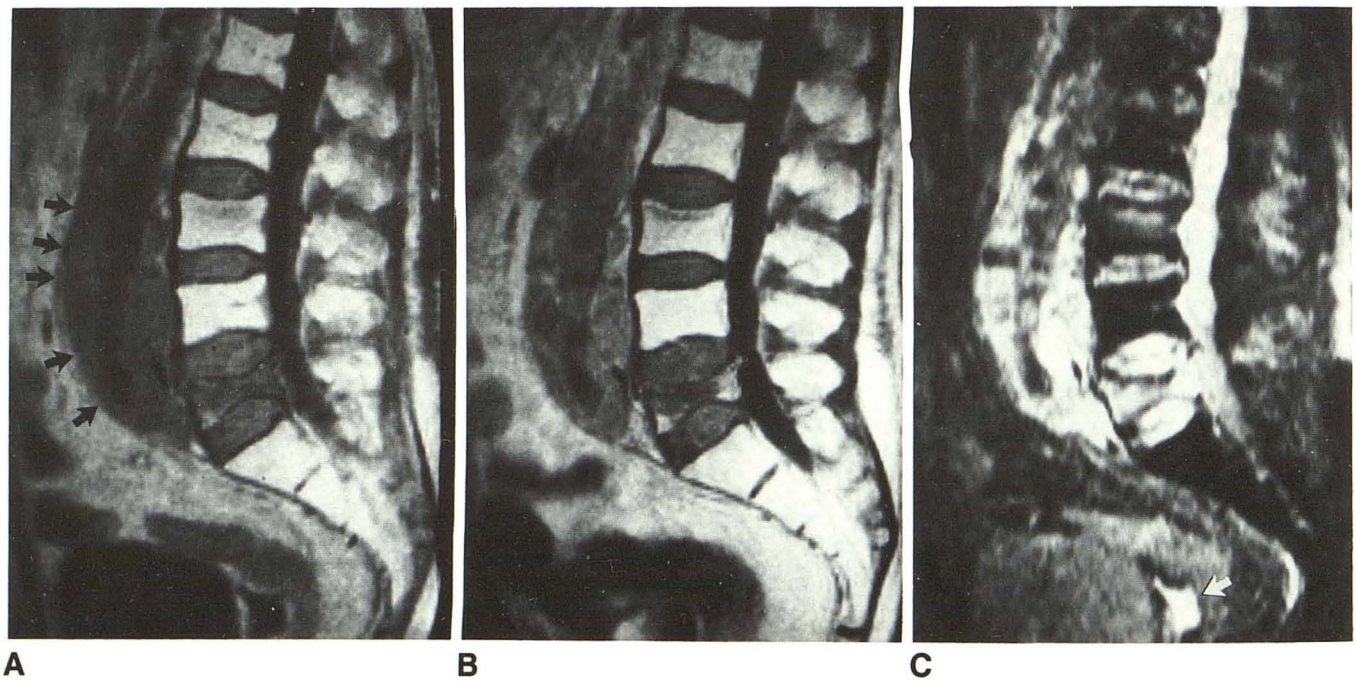

Fig. 3.—Case 1. Prostate carcinoma metastases to L5 and T7.

A, Precontrast T1-weighted spin-echo scan, 600/22, shows L5 marrow replacement and compression. Ventral compression of thecal sac is not easily seen because involved vertebral body is of similar intensity to CSF. Extensive periaortic adenopathy is also identified (*arrows*).

B, Post–Gd-DTPA T1-weighted spin-echo scan, 600/22, shows partial enhancement of L5, clearly delineating infiltrated bone from CSF. Enhancement of periaortic adenopathy is evident.

C, Precontrast short TI inversion-recovery image, 1400/100/36, easily shows collapsed vertebral body, but discrimination from CSF is poor. Periaortic adenopathy has very high tissue contrast with respect to surrounding fat. Also, ascites (*arrow*) is posterior to bladder.

with surrounding tissues, (2) the distinctness of tumor margins, and (3) the degree to which Gd-DTPA enhanced the tumor to an intensity similar to that of adjacent tissues or normal marrow. In general, STIR produced the highest contrast between tumor and surrounding structures (Fig. 1), except for tumors within or adjacent to the CSF. T1-weighted spin-echo scans also were highly effective in detecting lesions within the bone. Tumor within the thecal sac or adjacent CSF was best seen on Gd-DTPA-enhanced scans (Fig. 2).

Tumor margins were usually best shown by the Gd-DTPA-enhanced scans (Fig. 3). Only the Gd-DTPA scans were capable of showing enhancement suggesting a vascularized character of the tumor, but in our study this enhancement was not specific for active tumor. For example, in two patients with myeloma (cases 9 and 10), in two patients with prostate carcinoma (cases 2 and 3), and in one patient with breast carcinoma metastasis (case 7), the lesions were quiescent (as evidenced by lack of clinical progression) and showed mild enhancement. In the patient with giant cell tumor (case 14), there was dense enhancement in the involved sacral bodies and the surrounding soft-tissue mass (Fig. 4). The composition of this mass in the site of previous resection and radiation of a giant cell tumor is not known because the patient had few and stable clinical symptoms, and biopsy was not indicated. A follow-up scan at 9 months showed no interval change. The best explanation for this latter case is quiescent cellular material; the high intensity on STIR argues against scar tissue or fibrosis because both of these are normally of low intensity on STIR.

In 10 of the 15 cases, the administration of Gd-DTPA caused less tissue contrast between the tumor and surrounding tissues by enhancing the tumor toward the intensity of marrow fat, abdominal fat, or other paraspinous structures. However, this was considered to be minimal (+1) in seven of these 10 cases. Only in one myeloma patient (case 8, Fig. 5) was the marrow tumor completely obscured (+3). The potential for masking was highest for infiltrative spinal marrow tumor (three of four cases). Some degree of obscuration (+1

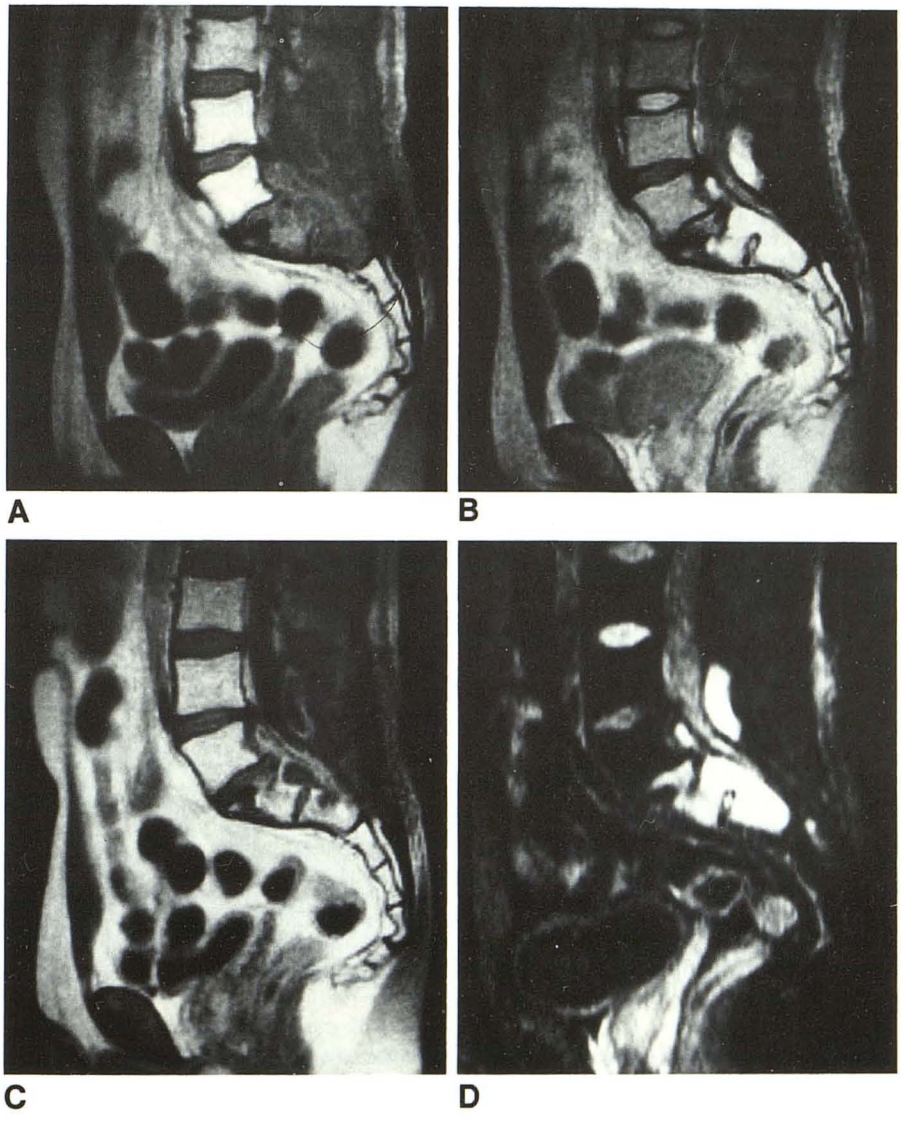

Fig. 4.—Case 14. Resected and irradiated giant cell tumor of sacrum.

***A*, Precontrast T1-weighted spin-echo scan, 600/22, shows involvement of S1, S2, and adjacent thecal sac by soft-tissue mass. Previous laminectomy is evident.**

***B*, Precontrast T2-weighted spin-echo scan, 2000/60, reveals sacral lesion plus high-intensity area posterior to thecal sac.**

***C*, Post-Gd-DTPA T1-weighted spin-echo scan, 600/22, shows enhancement of most of sacral lesion with nonenhancing central areas. Note clear delineation of margins of lesion dorsal to thecal sac.**

***D*, Postcontrast short TI inversion recovery scan, 1400/100/36, depicts sacral lesion and complex dorsal fluid collection with very high tissue contrast. Because symptoms did not progress, no surgery was performed. Follow-up scan 9 months later showed no change, suggesting quiescent tumor or posttherapy tissue with high water content. Appearance on short TI inversion recovery scan is not compatible with typical scar tissue, which is low intensity on this sequence. Lesion dorsal to spine presumably represents postsurgical complex fluid collection. Urine in bladder is low intensity due to T1 and T2 shortening, making bladder wall visible.**

or +2) occurred in most of the spinal metastases (six of seven cases) and was only seen on T1-weighted spin-echo scans. Little if any enhancement of the spinal lesions occurred on T2-weighted spin-echo and STIR scans.

The additional findings (see Table 1) were demonstrated most effectively on precontrast T1-weighted spin-echo and STIR and on postcontrast T1-weighted spin-echo scans. Enhanced T1-weighted spin-echo and unenhanced STIR images were complementary in screening the patient with neurofibromatosis; STIR was best for extradural lesions (Fig. 6) and enhanced T1-weighted spin-echo scans were best for intradural lesions. Postcontrast T2-weighted spin-echo scans

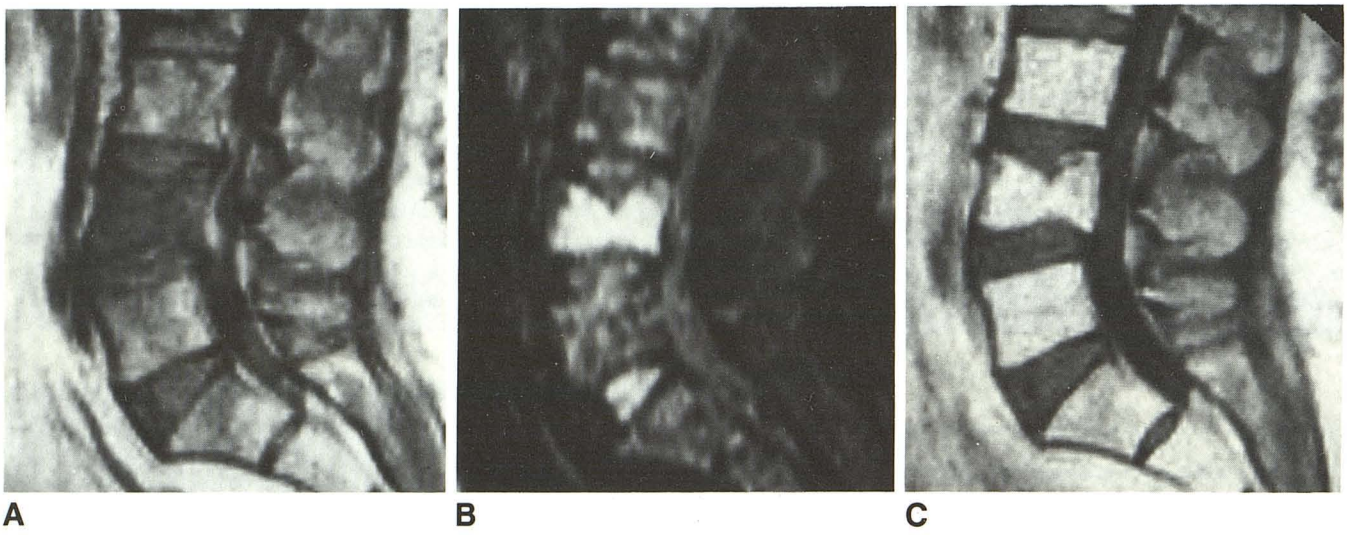

Fig. 5.—Case 8. Myeloma.
***A*, Precontrast T1-weighted spin-echo image, 600/22, shows inhomogeneous low intensity of marrow of multiple vertebral bodies, most severe at L4 with resultant compression.**
***B*, Precontrast short TI inversion recovery image, 1400/100/36, reveals multiple areas of abnormality, especially at L4. Such high intensity was seen from T1 to S2, indicating involvement of most of spine.**
***C*, Post-Gd-DTPA T1-weighted spin-echo scan, 600/22, shows diffuse enhancement of all vertebral bodies and nearly normal appearance of marrow, obscuring underlying disease.**

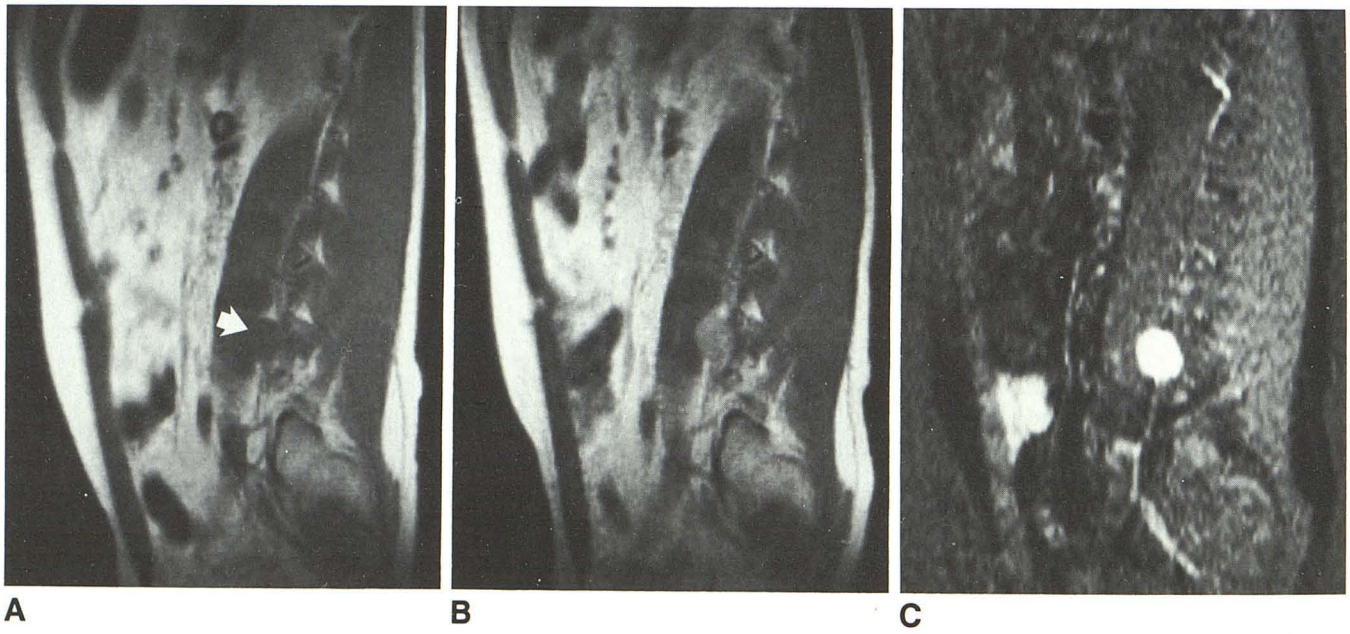

Fig. 6.—Case 15. Patient with neurofibromatosis screened for additional spinal lesions before surgery.
***A*, Precontrast T1-weighted spin-echo scan, 600/22. To left of neural foramina is rounded soft-tissue abnormality (*arrow*), seen only in retrospect.**
***B*, Post-Gd-DTPA T1-weighted spin-echo image, 600/22, shows enhancement of lesion.**
***C*, Short TI inversion recovery image clearly demonstrates neuroma against low-intensity background of muscle and suppressed fat.**

were of limited use but were helpful in the diagnosis of one of the ependymomas (case 13) and of a schwannoma of the neck (case 15). Adenopathy was best seen on precontrast STIR and T1-weighted spin-echo scans because, after contrast administration, lymph nodes had an intensity similar to abdominal fat and enhancing interstitial tissue (case 1, Fig. 3).

Two patients experienced transient warmth at the injection site. None of the patients had any long-term adverse effects.

Discussion

Contrast enhancement depends on both blood flow to the lesion and uptake of the contrast material. The ability to detect the lesion further depends on the enhancement of the lesion and on the relative enhancement of adjacent structures as shown on the particular MR sequence. Because gadolinium shortens both T1 and T2, it affects T1- and T2-weighted spin-echo and STIR images. However, the greatest enhancement is seen on T1-weighted spin-echo images. This also has been the experience of other investigators.

The Gd-DTPA scans showed intense enhancement of two lesions but only mild diffuse enhancement of the others. All 19 lesions enhanced to some degree. The enhancement or lack thereof was considered helpful in metastatic tumors, diffuse marrow malignancies, and primary tumor for both identification and characterization. In two cases of treated myeloma, two of prostate metastases, and one of breast metastases, the enhancement was detectable only by computerized signal-intensity measurements, presumably reflecting inactive or effectively treated disease with low cellularity and/or vascularity. Lack of uptake on radionuclide bone scans in myeloma and in quiescent metastatic lesions after successful radiation or chemotherapy is well known [11]. This may also occur in Gd-DTPA-enhanced scans. The delayed T1-weighted spin-echo scans showed a gradual change in the enhancement, resulting in a more diffuse appearance of the enhanced lesions; the delayed scan was considered helpful in only one case (case 13). On T2-weighted spin-echo and STIR scans, both T1 and T2 effects occur and the enhancement depends on the relative contribution of these effects. Positive enhancement (i.e., higher intensity) on T2-weighted spin-echo scans was seen in a few cases, notably the ependymomas and one of the schwannomas, but was usually minimal. STIR also showed no or minimal change from precontrast scans of the spinal abnormalities. However, negative enhancement occurred in the urine within the bladder, a finding that may eventually assist in evaluating bladder-wall neoplasms (Fig. 4C).

Because of the dissimilar appearance of tumor and marrow on unenhanced T1-weighted spin-echo and STIR scans, these sequences were expected to be best in identifying marrow tumor. Tumor within or adjacent to CSF was best shown on the Gd-DTPA-enhanced T1-weighted spin-echo scans as anticipated. We found the STIR sequence showed the highest contrast between tumor and surrounding structures for lesions outside the thecal sac and not adjacent to CSF, because tumor was seen as high intensity and the signal of paraspinous and marrow fat was suppressed. Unenhanced T1-weighted spin-echo scans easily showed lesions within the bone marrow as low intensity compared with the normal high-intensity marrow; they were much less sensitive in demonstrating lesions elsewhere because of low soft-tissue contrast. This parallels our previous experience in imaging spinal tumors [7, 8]. Gd-DTPA enhanced the marrow tumors only slightly and, in the case of diffuse marrow disease, often masked the lesions. However, because the enhancement sharpened the tumor margins, particularly in areas adjacent to low-intensity anulus or CSF, it complemented the precontrast images.

Lesions within the canal (and the schwannomas) were identified more easily with Gd-DTPA-enhanced T1-weighted spin-echo scans because the enhanced lesions were adjacent to the low-intensity CSF. In addition, these lesions may enhance more than tumor infiltration of the marrow does. This superiority of Gd-DTPA-enhanced T1-weighted spin-echo scans over other methods for demonstrating intrathecal lesions has been shown by others [12]. In three patients (cases 12, 13, and 15), postcontrast T2-weighted spin-echo imaging provided high tissue contrast.

Delineation of tumor margins depends on the spatial resolution of the scan and the contrast with respect to adjacent structures. Gd-DTPA-enhanced T1-weighted spin-echo or, in some cases, unenhanced T1-weighted spin-echo scans showed the best delineation of the margins of lesions. The margins of intrathecal tumor were best defined on enhanced T1-weighted spin echo. Similarly, the margins of tumor confined to the bone but adjacent to the low-intensity CSF, anulus, and paraspinous ligaments were best seen on the enhanced T1-weighted spin-echo scans. Despite the 128 × 256 matrix used on the STIR sequences to shorten imaging time, margins were occasionally shown best on STIR because of the very high tissue contrast.

Because the marrow is normally of high intensity on T1-weighted spin-echo scans, Gd-DTPA enhancement can make marrow tumor more difficult to detect. When partial obscuration occurred, the delayed scans showed a more diffuse effect, making the lesion even more difficult to identify. Such lesions will not be missed, provided a precontrast T1-weighted spin-echo scan is also obtained. The even higher sensitivity of STIR images also effectively eliminates the possibility of missing macroscopic marrow involvement by tumor. When contrast-induced lesion masking occurs, the identification of the tumor margins against the thecal sac or other structures complements findings on precontrast T1-weighted spin-echo or STIR images.

Various sequences were helpful in evaluating additional tumor or adenopathy. The effectiveness of a particular sequence was largely dependent on whether the additional lesion was within the bone or surrounded by fat, in which case T1-weighted spin-echo or STIR images were best; or whether the lesion was in the intrathecal or extraspinal soft tissues, in which case either Gd-DTPA-enhanced T1-weighted spin-echo or precontrast STIR scans were most effective. Adenopathy enhanced diffusely on T1-weighted spin-echo scans, but this made the abnormality more difficult to distinguish from normal fat.

In this preliminary study, intrathecal and primary solid tu-

mors were best imaged by a combination of unenhanced and enhanced T1-weighted spin-echo scans. Metastases to bone and diffuse marrow involvement by myeloma and lymphoma were most effectively identified and characterized on unenhanced T1-weighted spin-echo and unenhanced STIR images. Lesions surrounded by CSF were best detected with Gd-DTPA-enhanced T1-weighted spin echo. While other results may be obtained by imaging at different field strengths, we believe our general conclusions will be supported by larger investigations. We suggest the most effective imaging sequences for imaging spinal neoplasms are a combination of unenhanced T1-weighted spin echo, unenhanced STIR, and enhanced T1-weighted spin echo; T2-weighted spin-echo images may be of occasional use and should be included as indicated.

ACKNOWLEDGMENTS

We thank the First Hill Diagnostic Imaging Center for imaging and research support and the physicians at the Tumor Institute of Seattle, Pacific Medical Center, and Providence Medical Center for patient referrals and clinical follow-up.

REFERENCES

1. Kilgore DP, Breger RK, Daniels DL, Pojunas KW, Williams AL, Haughton VM. Cranial tissues: normal MR appearance after intravenous injection of Gd-DTPA. *Radiology* **1986**;160:757–761
2. Carr DH, Brown J, Bydder GM, et al. Intravenous chelated gadolinium as a contrast agent in NRM imaging of cerebral tumours. *Lancet* **1984**;1:484–486
3. Felix R, Schorner W, Laniado M, et al. Brain tumors: MR imaging with gadolinium-DTPA. *Radiology* **1985**;156:681–688
4. Niendorf HP, Laniado M, Semmler W, Schorner W, Felix R. Dose administration of gadolinium-DTPA in MR imaging of intracranial tumors. *AJNR* **1987**;8:803–815
5. Smoker WRK, Godersky JC, Knutzon RK, Keyes WD, Norman D, Bergman W. The role of MR imaging in evaluating metastatic spinal disease. *AJNR* **1987**;8:901–908
6. Bydder GM, Young IR. MR imaging: clinical use of the inversion recovery sequence. *J Comput Assist Tomogr* **1985**;9:659–675
7. Olson DO, Shields AF, Scheurich CJ, Porter BA, Moss AA. Magnetic resonance imaging of the bone marrow in patients with leukemia, aplastic anemia, and lymphoma. *Invest Radiol* **1986**;21:540–546
8. Porter BA, Shields AF, Olson DO. Magnetic resonance imaging of bone marrow disorders. *Radiol Clin North Am* **1986**;24:269–289
9. Porter BA, Olson DO, Stimac GK, Shields AF, Nelson SJ. STIR imaging of marrow malignancies. In: *Proceedings of the annual meeting Soc Magn Reson Med*, Vol. 1, New York City, August **1987**:146
10. Stimac GK, Olson DO, Porter BA, Genton M, Gerlach R. STIR imaging of the brain: comparison with spin-echo technique. Presented at the annual meeting of the American Society of Neuroradiology, New York City, May **1987**
11. Thrall JH, Ellis BI. Skeletal metastases in diagnostic imaging of bone disease. *Radiol Clin North Am* **1987**;25:1155–1168
12. Sze G, Abramson A, Krol G, et al. Gd-DTPA in the evaluation of leptomeningeal tumor spread in the spine. In: *Proceedings of the annual meeting Soc Magn Reson Med*, Vol. 1, New York City, August **1987**:6