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Lumbar Herniated Disk Disease and Canal Stenosis:
Prospective Evaluation by Surface Coil MR, CT, and Myelography

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Sixty patients with suspected lumbar herniated disk and/or canal stenosis were studied prospectively with surface coil MRI, CT, and/or myelography, and the results were compared with the surgically confirmed abnormality. Forty-eight patients had lumbar surgery at 62 levels. There were no negative explorations. Thirty-nine patients had a myelogram and CT. Thirty of the CTs were performed following the injection of metrizamide for myelography. Nine patients had a CT without intrathecal contrast material 1 to several days before the myelogram. Six patients had myelography only, and three patients had CT only. All studies were evaluated for the location and type of disease in a forced choice fashion. Independent of the surgically correlated levels, there was 86.8% agreement between the MR and CT studies in all patients at 151 levels and 87.2% agreement between MR and myelography at 218 levels. At the operative levels, there was 82.6% agreement between MR and surgical findings for both type and location of disease; 83% agreement between CT and surgical findings; and 71.8% agreement between myelography and surgical findings. There was 92.5% agreement when MR and CT were used jointly, and 89.4% agreement when CT and myelography were used jointly. The results of this study indicate that a technically adequate MR examination was equivalent to CT and myelography in the diagnosis of lumbar canal stenosis and herniated disk disease. CT and MR can be complementary studies, and surface coil MR can be viewed as an alternative to myelography.

Previous experience has indicated that MR can identify lumbar canal stenosis and herniated nucleus pulposus. However, current experience shows that with conventional body coil imaging, MR cannot be considered equivalent to CT and/or myelography for the evaluation of small or lateral disk herniations, neural foraminal disease, and canal stenosis. The reasons most often cited for this are the slice thickness and spatial resolution of MR and its inability to discriminate cortical bone from soft tissue [1–6]. It has been suggested by us and others that the introduction of surface coil imaging, which provides an improved signal-to-noise ratio over a limited distance, might obviate these disadvantages by trading off the increased signal-to-noise for thinner slices and thus a smaller voxel element with a concomitant improvement in spatial resolution. This could then provide an MR examination that would be equivalent to CT or myelography [4, 7, 8].

To test this hypothesis we undertook a prospective study on a group of patients who were presumed to have herniated disk, lumbar canal stenosis, or both. We compared the results of surface coil MR with CT and/or myelography without reference to either the clinical information or other imaging observations. These findings were then compared with the surgically confirmed pathology for an objective measure of accuracy.

Materials and Methods

Sixty patients were admitted to this study between September 1984 and February 1985. The patients were referred for enrollment in the study on the basis of their clinical history and

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a physical exam that indicated a strong probability of herniated disk or lumbar canal stenosis, with the likelihood they would require surgery. Patients with a known diagnosis and/or a prior imaging study—for example, CT and/or myelography—were excluded. All patients who entered the study were scheduled for an MR and either a CT, myelogram, or both. Although most patients had a myelogram followed by high-resolution CT, in some, the number and sequence of examinations were determined by patients' convenience, clinical preference, and financial considerations. All exams were completed within 1 week. In most cases, MR was the first examination, followed by myelography and then CT. Forty-eight patients aged 19–73 years (mean, 46) had lumbar surgery at 62 levels. There were no negative explorations.

In the operated group, all 48 patients had an MR and at least one other study (CT and/or myelography). Thirty-nine patients had a myelogram and CT. Thirty of the CTs were performed after the patient was injected with metrizamide for myelography at delays of 2 to 6 hr. Nine patients had CT 1 to several days before the myelogram, without an injection of intrathecal contrast. Six patients had myelography only, and three patients had CT only.

CT was performed on either a Delta 2060 or Pickerview 1200 synerview unit with a 120–130 kV and 400–800 mAs. Lateral scout images were obtained in all patients for alignment of the sections. Sections of 5 mm were obtained through at least the L5 and L4 levels, and the L3 level if indicated.

Myelography was performed after the installation of 8–14 ml of 190 mg/dl metrizamide in the lumbar subarachnoid space. Routine anteroposterior, lateral, and oblique films were obtained with the side of interest in the dependent position.

The MR examinations were performed on a 0.6 T superconductive unit (Teslacon-Technicare, Solon, OH) using a prototype surface coil. The surface coil was circular, 12 cm in diameter, and composed of ⅝-in. copper tubing. It served as a receiver only; a 50-cm body coil served as the radiofrequency transmitter.

The MR study involved four separate acquisitions. First, patient position and coil placement were determined with a single coronal image with the X-gradient turned off for orientation. The remaining acquisitions were obtained with a 4-mm slice thickness, 1-mm gap, and four averages. The first of these was a 32-msec echo time (TE)/0.5 sec repetition time (TR) sagittal study consisting of 10 sections obtained in 4.4 min. The second was a 90-msec TE/2-sec TR sagittal study with 12 sections obtained in 18 min. The last was a transverse 32-msec TE/2-sec TR study with 12 sections obtained in 18 min through the suspected level(s) of abnormality, with the angle of acquisition adjusted, if necessary, for true transverse images through the disk space. The matrix size for all studies was 128 × 256.

When the study was complete, copies of the examination were collected for subsequent, independent interpretation with only the hospital number for identification. The MR, CT, and myelographic examinations were interpreted by three of us, without access to the patients' names, clinical information, or results of other imaging studies. All studies were evaluated via a forced-choice method for the location and type of disease(s) and for compression of the spinal nerve(s) or thecal sac. An attempt was made to determine if the abnormality was caused by a herniated disk or by canal stenosis from bony or soft-tissue compression. The two major types of stenosis, central and lateral, including both foraminal and lateral recess stenosis, were grouped under the broad heading of spinal stenosis. The abnormalities in the last category were grouped under the broad heading of spinal stenosis.

Other observations noted were the presence or absence of arachnoiditis, signal changes within the vertebral body, and whether the herniated disk appeared to be protruding or whether it seemed to be a free fragment.

The three separate MR acquisitions were interpreted in the following manner. First, the sagittal T1-weighted short TE/TR images were evaluated for disk-space height; canal compression; presence and configuration of epidural fat and nerve root in the neural foramina in the parasagittal plane; disk position and configuration; vertebral body signal; and upper lumbar neural canal, including the conus (Figs. 1A and 1B). The signal intensity of the disk and adjacent vertebral endplates were evaluated on the T2-weighted sagittal image (long TE/TR) (Fig. 1C). In addition, the CSF–extradural interface was examined for the presence or absence of herniated disk and canal stenosis. The axial images, which produced the highest signal intensity, were evaluated for the disk, thecal sac, and canal contour as well as for the nerve roots within the epidural fat (Fig. 1D).

The MR and CT criteria for herniation were similar. Briefly stated, they involved identifying a focal extention of the disk margin beyond the vertebral margin, with resulting epidural-fat, nerve-root, or thecal-sac displacement. On myelography, the changes sought were a sharp wedge- or tent-shaped indentation of the anterior or lateral aspect of the thecal sac and/or nerve root sleeve.

Criteria for lumbar stenosis on MR or CT were (1) a distortion or paucity of epidural fat either in the neural foramina, lateral recess, or posteriorly between the ligamentum flavum, and (2) a diminution in the overall size of the neural foramina, neural canal, and /or thecal sac. An attempt was made to determine the contribution of hypertrophied facet joints and bony overgrowth as well as hypertrophy of the ligamentum flavum.

The surgical operative findings were then reviewed and included on a general demographic form with the patient's name, age, gender, and clinical data. Subsequently, a computer match was made with the imaging studies at the operative levels.

Results

Tables 1 and 2 list the agreement and disagreement, respectively, among MR, CT, and myelography with the surgical findings. A match was also made with the combined results of MR and CT, and of CT and myelography. In this last grouping, if one of the diagnostic tests was confirmed at surgery, it was rated as an agreement.

Independent of the surgically correlated levels, there was an 86.8% agreement between the MR and CT findings in all patients (operated or not) at 151 levels. The agreement with myelography at 218 levels was 87.2%. The difference in the number of levels reflects the visualization of the L1 through L3 levels by MR and myelography, areas not routinely examined by CT.

At the operative levels, there was an 82.3% agreement between MR and surgical findings for both type and location of disease; an 83% agreement between CT and surgical findings, and a 71.4% agreement between myelography and surgical findings. When the operated levels were broken down into those studied with plain CT and those studied with metrizamide CT, the agreement with surgical findings was 91% (11 of 12) and 81% (33 of 41), respectively. There was a 92.5% agreement when MR and CT were used jointly, and an 89.4% agreement when CT and myelography were used jointly. All disks shown to be normal by MR were also shown to be normal on both CT and myelography.

For the 11 cases in which there was disagreement between the MR and surgical findings, the breakdown was as follows. In four patients the MR diagnosis was that of a herniated disk

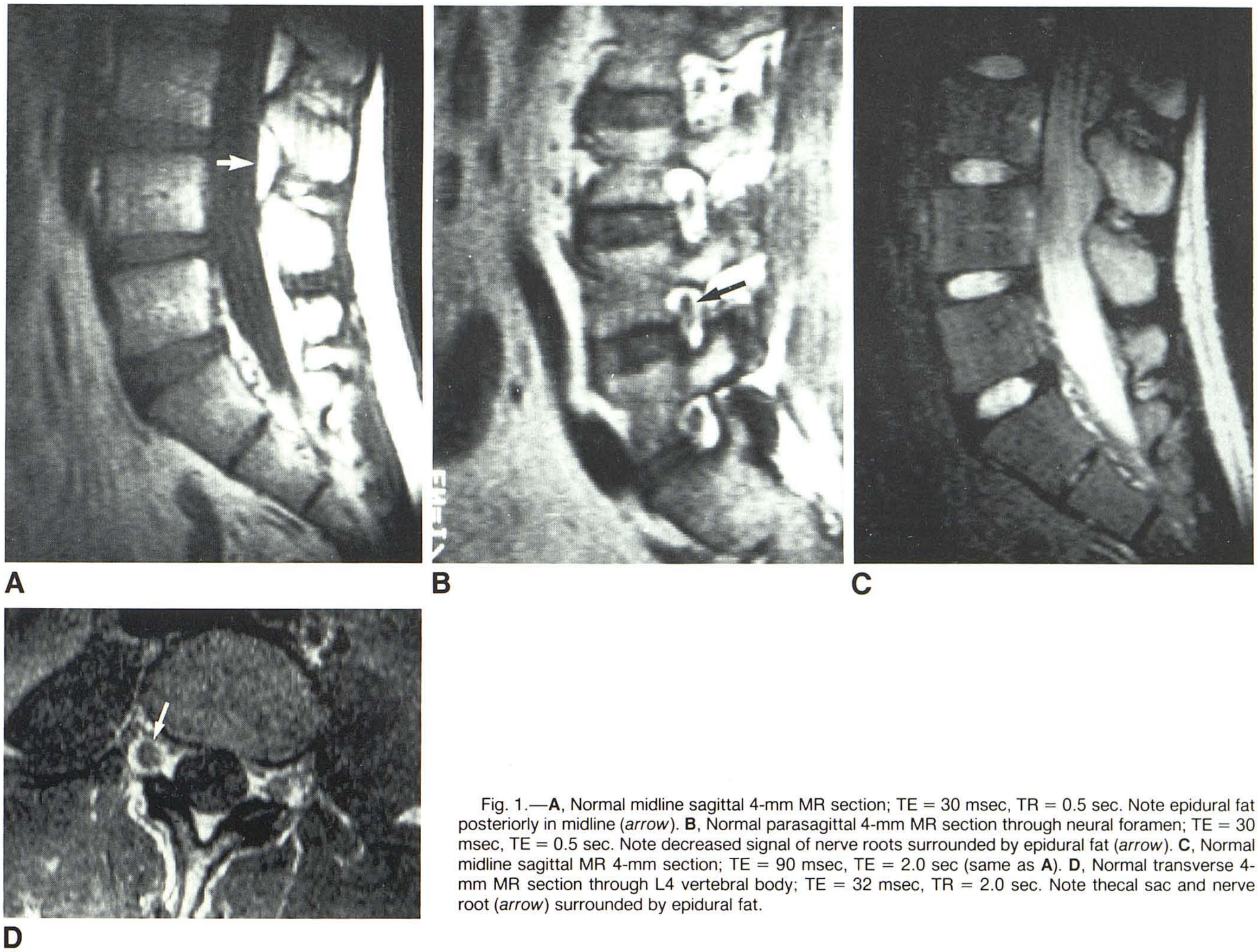


Fig. 1.—**A**, Normal midline sagittal 4-mm MR section; TE = 30 msec, TR = 0.5 sec. Note epidural fat posteriorly in midline (*arrow*). **B**, Normal parasagittal 4-mm MR section through neural foramen; TE = 30 msec, TE = 0.5 sec. Note decreased signal of nerve roots surrounded by epidural fat (*arrow*). **C**, Normal midline sagittal MR 4-mm section; TE = 90 msec, TE = 2.0 sec (same as **A**). **D**, Normal transverse 4-mm MR section through L4 vertebral body; TE = 32 msec, TR = 2.0 sec. Note thecal sac and nerve root (*arrow*) surrounded by epidural fat.

TABLE 1: **Lumbar Surgical Findings and Imaging Results: Agreement by Location and Disease Type**

	Surgical Findings/MR	Surgical Findings/CT	Surgical Findings/ Myelography	Surgical Findings/MR & CT	Surgical Findings/CT & Myelography
No. of levels	62/62	53/53	56/56	53/53	47/47
Herniation	32/28	29/25	32/27	29/26	28/26
Stenosis	30/23	24/19	24/13	24/23	19/16
% Agreement	82	83	71	92	89

TABLE 2: **Lumbar Surgical Findings and Imaging Results: Disagreement by Location and Disease Type**

Imaging/Surgical Findings	MR	CT	Myelography
Herniation/Stenosis	4	2	3
Stenosis/Herniation	1	3	3
No disease/Stenosis	3	3	8
No disease/Herniation	0	1	2
Herniation and stenosis/Herniation only	3	0	0
Total	11	9	16

and the surgical findings were those of canal stenosis. In one case, MR diagnosed stenosis of the neural foramina, but surgery demonstrated a lateral disk. In three cases, there was narrowing of the lateral recesses noted at surgery, while the MR was interpreted as normal at these levels. In three cases, MR was read as disk herniation with stenosis posteriorly, while surgery demonstrated only a herniated disk.

Of the total of 28 surgically confirmed herniated disks, MR predicted a free fragment in six. This was surgically confirmed in four patients.

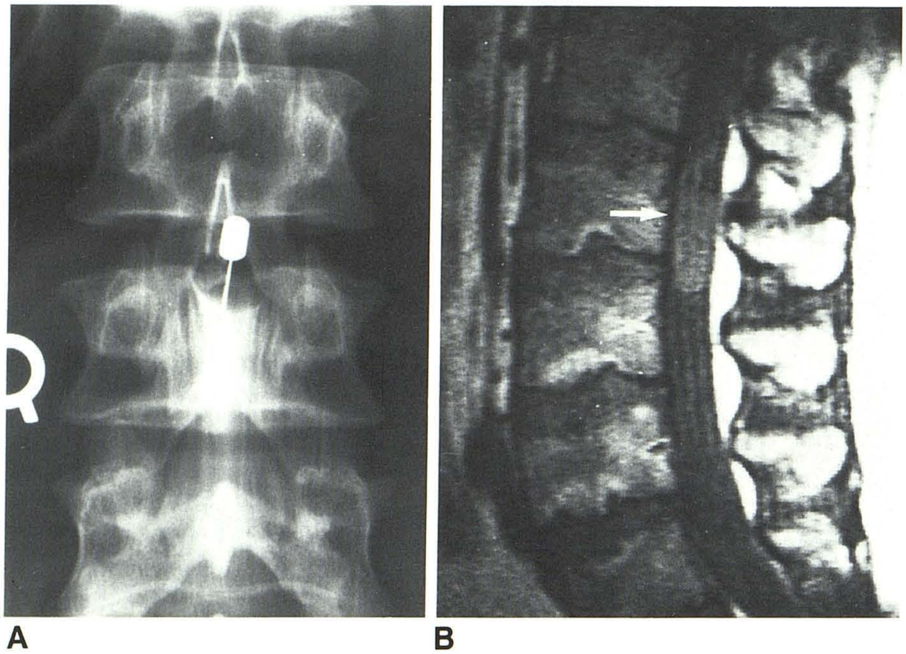


Fig. 2.—32-year-old man with L5 radiculopathy. **A**, Anteroposterior radiograph of lumbar spine at L3 level after installation of metrizamide into thecal sac. Note intradural filling defect at level of needle. CT without metrizamide performed before this study was normal to level of L3 pedicles. **B**, Sagittal 4-mm MR section (TE = 30 msec, TR = 0.5 sec) showed intradural mass of intermediate signal intensity at L2 and L2–L3 levels (*arrow*). An ependymoma was identified at surgery.

Disagreements between the CT and surgical findings were similar to those found between MR and surgery. Exceptions were that CT misdiagnosed two cases of lateral stenosis and one herniated disk, which were accurately identified by MR. Three cases identified by MR as herniation and stenosis were accurately diagnosed by CT as herniation only.

The disagreements between myelographic and surgical findings occurred at 16 levels; eight of these were at the L5–S1 levels. The remaining eight cases were those in which myelography failed to show lateral stenosis, which was identified at the time of surgery.

In the 12 patients studied but not operated on, one had metastatic disease identified by MR where there was diminished signal intensity on the T1-weighted images of the involved vertebral bodies. Bony changes were not noted on either CT or myelography. One patient had an ependymoma at the L2–L3 level identified by both MR and myelography but not by CT, because it was above the level of the study (the patient had an L5 radiculopathy clinically) (Fig. 2). Two patients had arachnoiditis identified by myelography but not by MR. Two patients had lumbar canal stenosis, and one had a disk herniation identified by MR and/or CT and myelography, but all three chose conservative management. Five patients had normal MRs and normal CTs and/or myelographic studies.

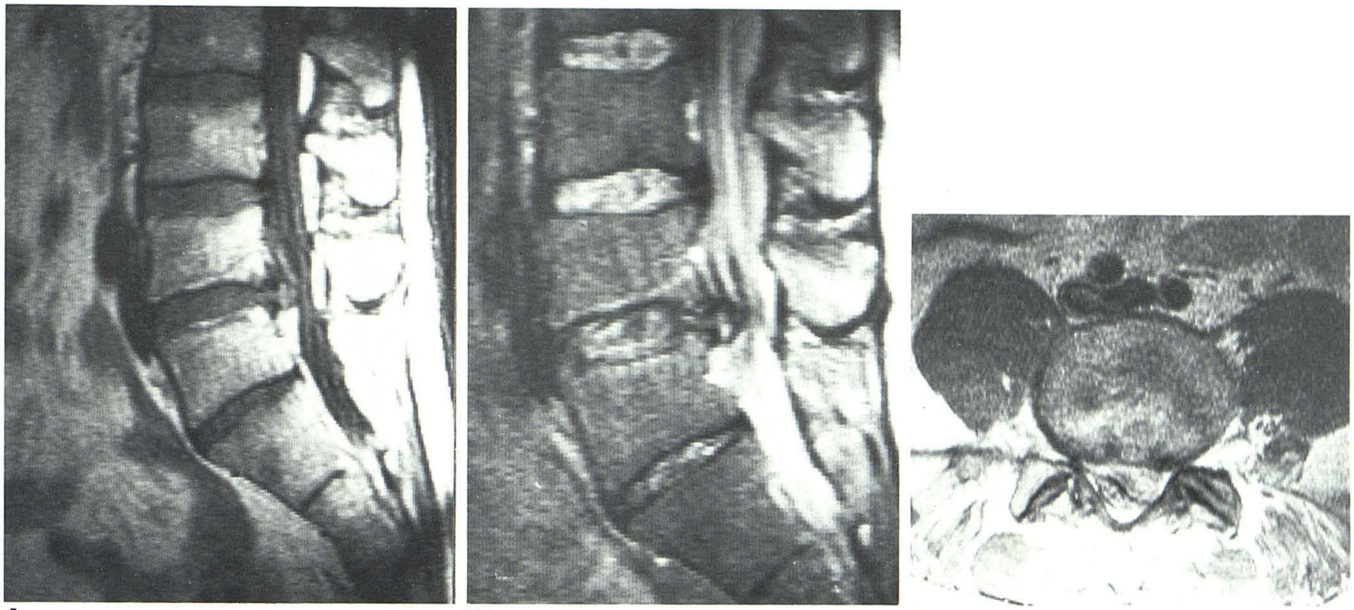
Discussion

In this study, surface coil MR was as accurate as CT and slightly more accurate than myelography in evaluating lumbar disk disease and canal stenosis. The combined results of MR and CT were as accurate as those of CT and myelography.

The accuracy of MR in this study can be ascribed to the use of a surface coil, which produces an improved signal-to-noise ratio and allows the use of a smaller imaging voxel element. The coil itself is not responsible for the thinner sections that are usually achieved with a stronger imaging gradient. Rather, the surface coil allows the signal-to-noise in the smaller voxel elements to remain adequate for imaging. In addition, it serves to reduce the patient-generated noise and is not as affected by artifacts from respiratory motion and blood flow.

The contour of herniation of the intervertebral disk was characteristic in the majority of cases. An angular protrusion of the disk with sharp (rather than rounded) margins was the rule in most cases on both the transverse and sagittal images (Fig. 3). Lateral herniations of the intervertebral disks could be identified by distortion of this epidural fat on parasagittal images (Fig. 4) but were better seen on transverse images. On the more T2-weighted sagittal images (90-msec TE/2-sec TR) there is a relative increase in the signal of the central portion of the normal disk. In cases of disk degeneration this central region demonstrates a decreased signal intensity. Thus, suspected levels of abnormality related to disk degeneration could be identified on the sagittal images and were helpful in directing the transverse examination. All levels of herniation identified were associated with a decreased signal intensity of the disk on the sagittal 90-msec TE/2-sec TR images relative to normal disks and adjacent CSF.

The transverse 30-msec TE/2-sec TR images produced the highest signal of the three techniques, and the long TR allowed a sufficient number of slices at 4 mm to cover three



A B C

Fig. 3.—28-year-old woman with left L4 radiculopathy. **A** and **B**, Sagittal midline 4-mm MR sections; TE = 30 msec, TR = 0.5 sec, and TE = 90 msec, TR = 2.0 sec. There is a "pinched off" herniated appearance of L4 disk with an increased signal intensity of herniated segment when compared with remainder of intervertebral disk. **C**, Transverse 4-mm MR section (TE = 32 msec, TR = 2.0 sec) through L4 disk. There is a large disk herniation, with herniated fragment showing slightly higher signal than remaining disk. At surgery, a large free fragment was identified.

disk spaces. There was excellent demonstration of the epidural fat and nerve roots in the neural foramina laterally, and the overall dimensions of the lateral recesses and neural foramina could be consistently and accurately assessed. The posterior and lateral configurations of the disk (Fig. 5) were seen best with this pulse sequence and it was the most accurate for demonstrating lateral disk herniation and imaging of the neural foramina (Fig. 6).

There were five cases in which the signal intensity of the herniated disk segment remained higher than the CSF on the axial images (30-msec TE/2-sec TR). In two of these, free fragments were identified at surgery (Fig. 3).

These three pulse sequences were also complementary in the evaluation of canal stenosis (Fig. 7). The T1-weighted image was useful in evaluating the size and contour of the neural canal, foramen, and thecal sac as well as the location of the conus medullaris, which can be obscured by the relatively increased signal intensity of the CSF on longer TE and TR images. However, cortical bone and surrounding fibrous or ligamentous structures are manifested by a decreased signal intensity on this pulse sequence, and may be difficult to separate.

The more T2-weighted sagittal images allowed an accurate assessment of the extradural–CSF interface and overall canal dimensions, and were particularly accurate for identifying anterior and/or posterior extradural defects in cases of canal stenosis.

The techniques in this study were kept constant to reduce variability from patient to patient; and although this approach provided satisfactory results, there is certainly room for further study of various pulse sequences and other technical factors. For instance, in work done subsequent to this study it has become apparent that certain modifications of the exam technique can produce equivalent, and in some cases improved, accuracy. This would include a multislice-multiecho technique in the sagittal plane that allows a 30- and 90-msec TE to be acquired simultaneously with a 2-sec TR. This produces a high-signal sagittal image as well as a heavily T2-weighted image without increasing the exam time. Experience at 1T suggests the transverse images can be acquired with a shorter TR (e.g., 0.5 sec), which produces an adequate signal for anatomic evaluation in much less time. This allows multiple separate acquisitions with the appropriate angle for the various disk levels without increasing the overall exam time. With this pulse sequence technique the lumbar nerve roots can be identified within the thecal sac on the transverse images by the higher signal intensity from the surrounding CSF.

In comparing the results of surface coil MR with high-resolution CT and water-soluble myelography, certain recognizable advantages and disadvantages of the various studies became apparent. Despite the accuracy of high-resolution CT and plain-film myelography [with studies showing from 72–97% agreement with surgical findings (9–15)], recognizable problems exist, and in many clinical situations these modalities are used together.

Myelography still involves considerable radiation and the need for intrathecal contrast medium, and, despite reasonably acceptable side effects with nonionic agents, is still an invasive procedure and in most situations is performed only on hospitalized patients. The diagnostic accuracy of myelography is questionable in cases of far lateral disease and at the L5–S1 level, where the epidural space may be large. MR, on

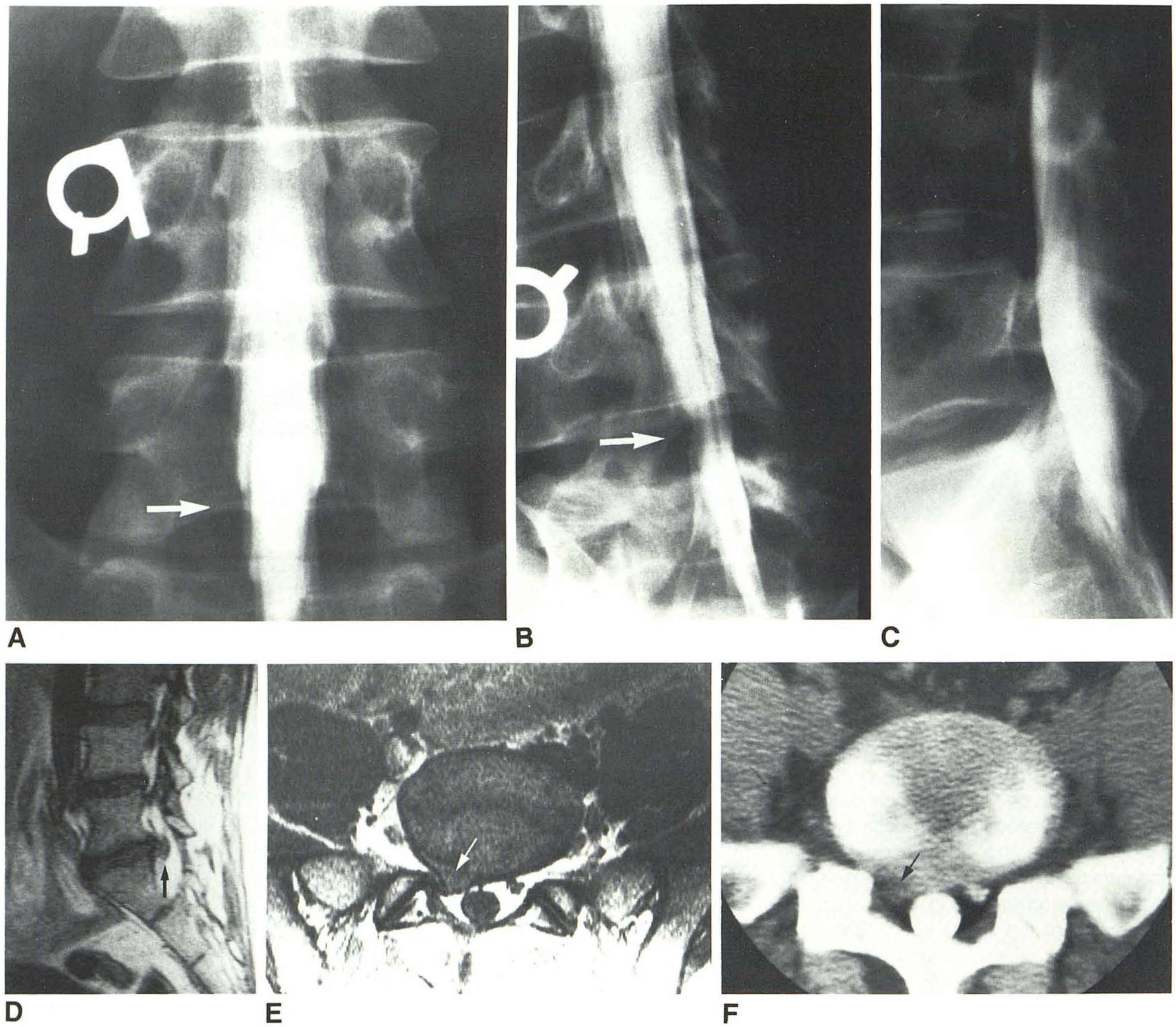


Fig. 4.—40-year-old woman with right S1 radiculopathy. **A, B,** and **C**, Anteroposterior lateral and oblique radiographs of lumbar spine from metrizamide myelogram. There is a subtle extradural defect involving right S1 nerve root on anteroposterior and oblique radiographs (*arrows*) and a mildly increased anterior extradural space at L5–S1 level on lateral radiograph. **D**, Parasagittal 4-mm MR section (TE = 30 msec, TR = 0.5 sec) 1 cm off midline. There is posterior lateral herniation of L5 disk indenting the epidural fat (*arrow*). **E**, Transverse 4-mm MR section (TE = 30 msec, TR = 2.0 sec) angled to L5 disk. Note right posterior lateral herniation of L5 disk (*arrow*). **F**, Transverse 5-mm high-resolution CT section through L5 disk showing right posterior lateral herniation of L5 disk similar to MR study (*arrow*).

the other hand, requries no intrathecal contrast agent or ionizing radiation, and, in this study, was as accurate or more so than myelography for lateral disease and at the L5–S1 level. However, at present, myelography still has some advantages in certain situations. In this study there were two cases in which myelography was more sensitive to changes of arachnoiditis than was either MR or CT. And while surface coil MR can examine the entire lumbar canal, the potential exists for the entire spinal axis to be studied in a shorter period of time with myelography.

At our institution, CT is usually performed only to the L3 level. Moreover, owing to time and radiation considerations, it may be impractical to examine the entire lumbar canal with an appropriate slice thickness and spatial resolution. Transverse imaging is the rule; reformatting and secondary reconstruction, while sometimes helpful, result in a corresponding loss of spatial and contrast resolution. Appropriate scan angles are needed for the intervertebral disks and this may be difficult at the L5–S1 level because of limitation in gantry angulation. With MR, the entire lumbar canal, including the

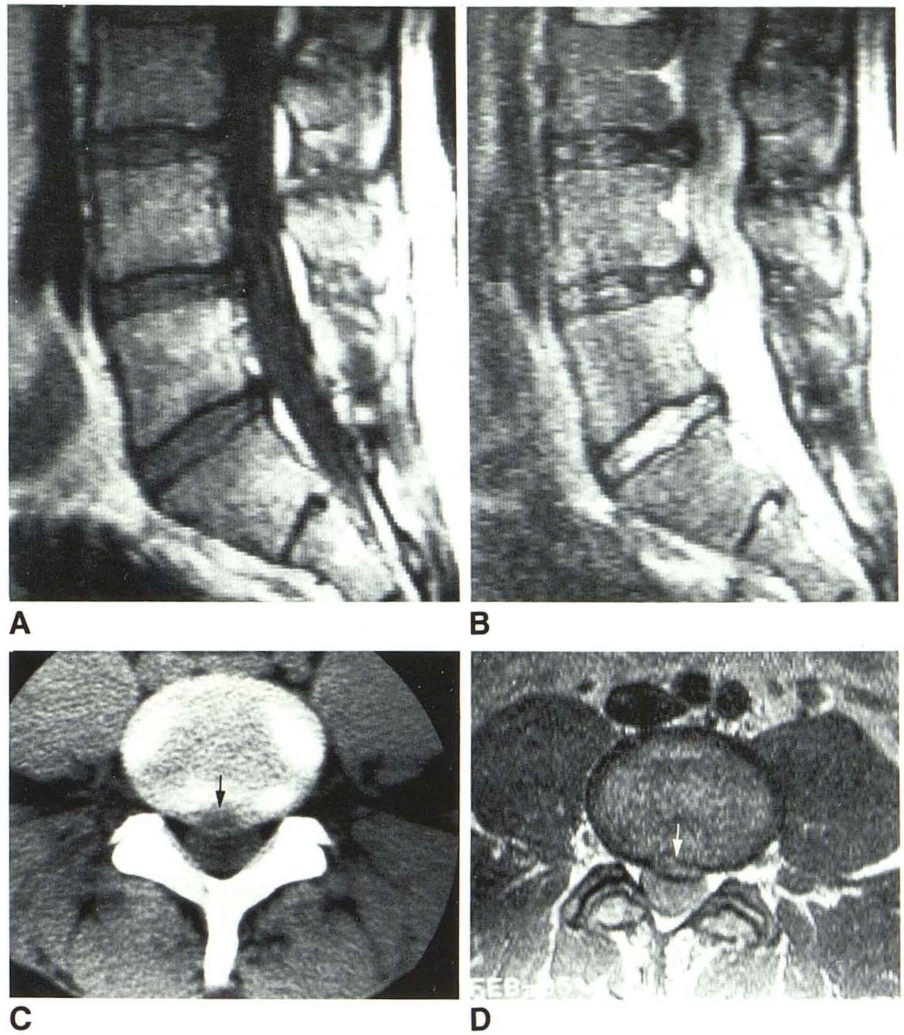


Fig. 5.—**A** and **B**, Sagittal midline 4-mm MR section (TE = 30 msec, TR = 0.5 sec, and TE = 90 msec, TR = 2.0 sec) through lumbar spine. There is a decrease signal of L3 and L4 disks and, to a lesser extent, of L5 disk on TE = 90 msec, TR = 2.0 sec image. There is mild posterior protrusion of disk at L3 and L4 levels. **C**, High-resolution CT and **D**, transverse 4-mm MR section (TE = 32 msec, TR = 2.0 sec) through the L4 disk. On high-resolution CT image, there is a smooth central protrusion of L4 disk (*arrow*). On MR image, there is protrusion of L4 disk with sharp margins suggestive of herniation (*arrow*). Herniation was confirmed at surgery. Similar angulations of disk margin were also noted at L3, but surgery was performed only at L4 level.

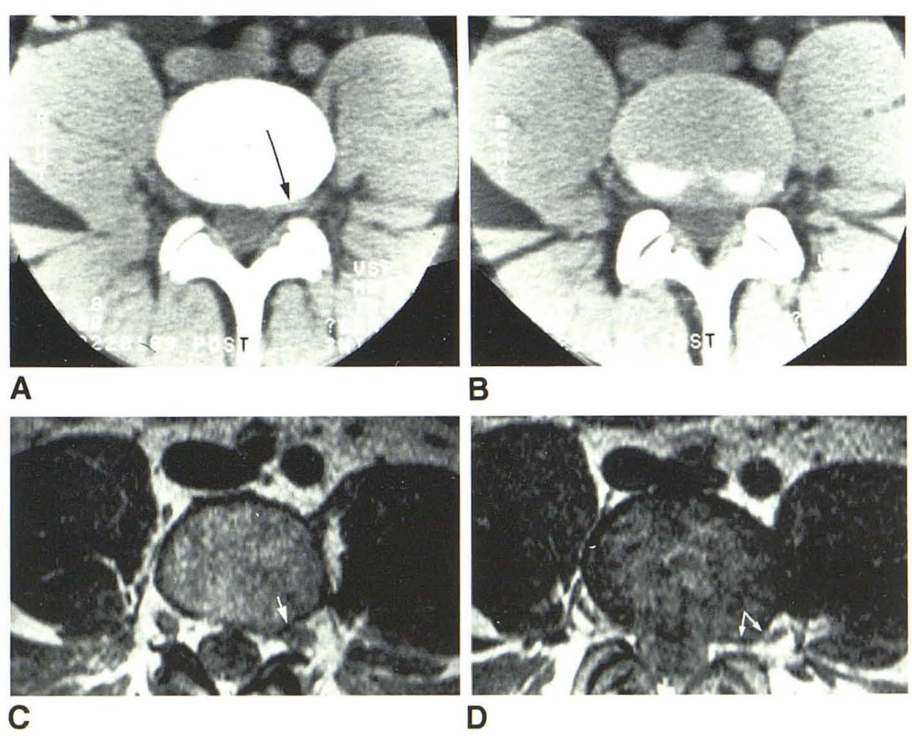


Fig. 6.—**A** and **B**, Contiguous 5-mm transverse high-resolution CT images through lower L4 vertebral body and disk level. There is paucity of epidural fat laterally on left as well as mild prominence of L4 disk on left (*arrow*). **C** and **D**, Contiguous transverse MR images (TE = 30 msec, TR = 2.0 sec) through same levels as **A** and **B.** Note reduction of epidural fat and narrowing of neural foramina surrounding L4 nerve root (*arrow*). There is acute angulation of margins of L4 disk laterally on left (*arrows*) that was found to represent a lateral disk herniation at surgery. Note decreased signal of disk in **D** when compared with **C**, which is partially through vertebral body.

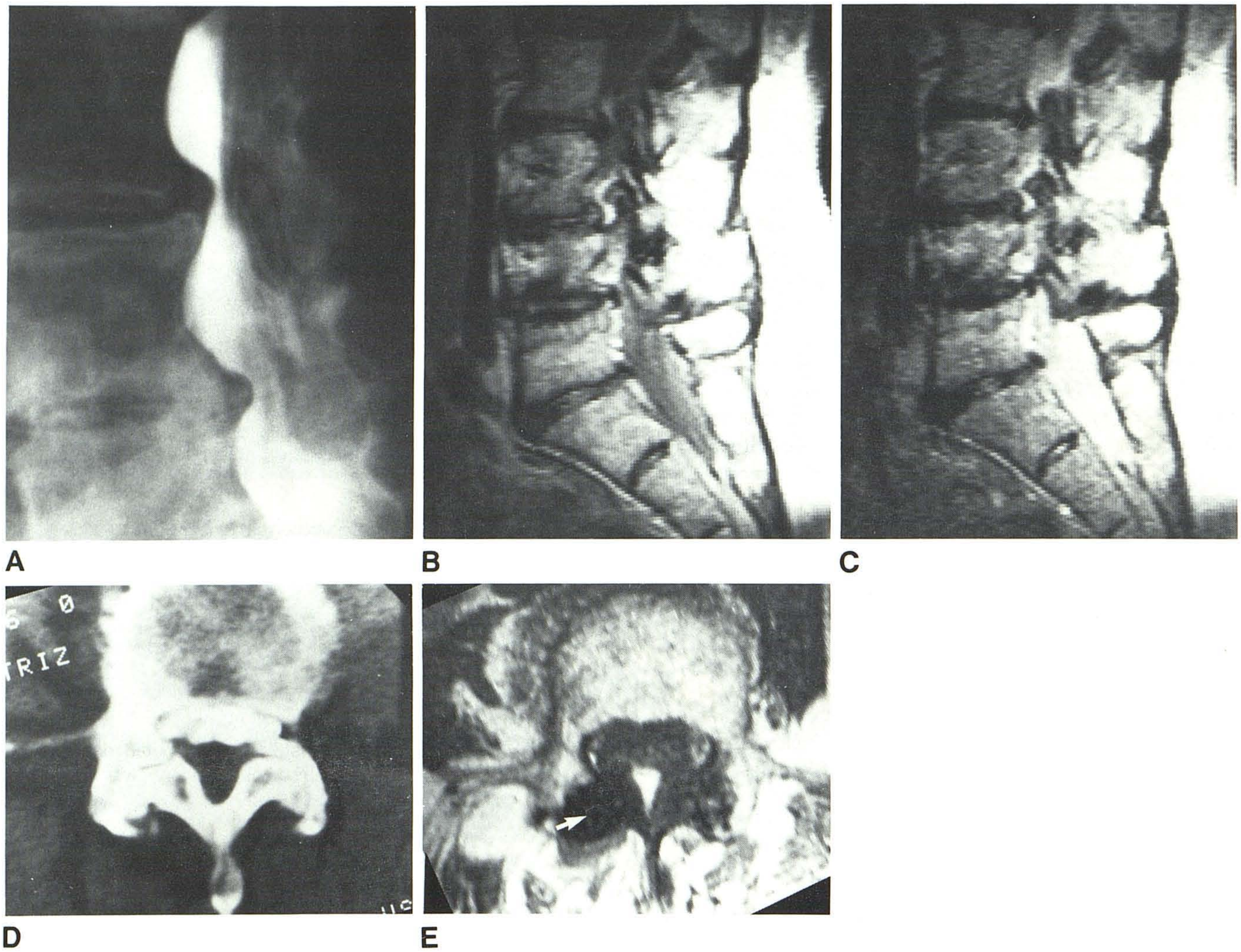


Fig. 7.—62-year-old man with pseudoclaudication consistent with lumbar canal stenosis. **A**, Lateral view on metrizamide myelogram. Anterior extradural defects are noted at L3, L4, and L5 levels. **B**, Sagittal midline 4-mm MR section (TE = 32 msec, TR = 0.5 sec) showing marked canal stenosis from both anterior and posterior extradural elements. There is minimal scoliosis at L3 and L4. **C**, Sagittal midline 4-mm MR section (TE = 90 msec, TE = 2.0 sec) again showing marked canal stenosis, further emphasizing major contribution from posterior elements, proven at surgery. All visible disk levels show a decreased signal, presumably secondary to degeneration. **D**, High-resolution CT after metrizamide myelogram at L4 level. There is marked compression of thecal sac from hypertrophic bony changes involving facet joints and posterior elements. **E**, Transverse MR image (TE = 30 msec, TR = 2.0 sec) through same level as **C**. Compression of thecal sac is similar to that in high-resolution CT. Epidural fat is well seen, but signal from ligamentum flavum and posterior bony elements is confluent. Note decreased signal intensity within bony changes in right facet joint, which is seen in certain cases of degenerative disease (*arrow*).

region of the conus, may be examined in the sagittal plane without prolonging the exam time. Images can be obtained in any plane and at any angle off the primary orthogonal planes. On the other hand, unlike CT, the angle of acquisition of MR is set for an entire acquisition and is not as flexible in terms of changing disk levels.

Although every effort was made to eliminate bias in this study, certain potential flaws became apparent. First, although herniated disks were treated in a precise fashion, the treatment of spinal stenosis as a broad category was advantageous to MR. In order to facilitate statistical analysis we chose to treat stenosis in a more global manner. We felt this was appropriate because of the diffuse and multilevel nature of the process and because the surgical approach in the lumbar region is usually more encompassing, entailing a bilateral laminectomy at more than one level.

Second, while the surgical appraisal of herniation was precise, that of stenosis was often more general in the operative description; yet it must be assumed to be correct because it cannot be tested. This can produce problems in the analysis, and it must be assumed that at least one false surgical diagnosis was probably made. This is illustrated by one of the 11 patients for whom there was disagreement between the operative findings and those of MR, CT, and myelography. The surgical diagnosis was that of bony facet overgrowth. Postoperatively, there was no improvement in this patient, and a subsequent MR study again identified what appeared to be a herniated L5 disk with the surgical changes predominately at the L4 level. Another problem, noted by Haughton et al. [11], is that a nuclear fragment lodged behind the posterior longitudinal ligament, which may be diagnosed correctly as a herniated disk by CT and MR, may appear as a bulging anulus (which would be assumed to be secondary to a spondylitic process in conjunction with other spondylitic changes) and thus might be categorized as stenosis at the time of surgery.

A final criticism would be our grouping of all CTs together, those performed with metrizamide (30 of 42) and those performed without it (12 of 42). We chose to do this to simplify the analysis. It has been suggested by some that metrizamide CT is superior to plain CT [10, 16]; but similar accuracy, especially with herniated disk disease, has been reported with plain CT [11, 17]. In this study the results showed a slightly greater agreement of surgery with plain CT, but the numbers are too small to draw any meaningful conclusion. It is further understood that metrizamide CT, while an invasive test, can potentially provide a more accurate delineation of the thecal sac and the evaluation of intradural and intramedullary lesions.

Despite these limitations, the results of this study indicate that a technically adequate MR examination was equivalent to CT and myelography in diagnosing lumbar canal stenosis and herniated disk disease. In this study, there was still significant disagreement, ranging from 17–29%, with the surgical findings when any of the three techniques was used alone. This disagreement was most apparent in cases of lumbar stenosis. Thus, in both herniated disk disease and lumbar canal stenosis, a combination of studies may be indicated for preoperative evaluation. In such cases, CT and MR can be complementary studies and MR can be viewed as an alternative to myelography.

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