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Magnetic Resonance Imaging of the Lumbar Spine with CT Correlation

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The results of magnetic resonance (MR) imaging and computed tomography (CT) in 18 patients with known degenerative disk disease of the lumbar spine were compared. In 60 intervertebral disk levels studied, there were 17 disks with degeneration and disk bulge, and 15 herniated disks. Final diagnoses were based on several factors, with surgical confirmation in five patients. There was good correlation between the two methods at 51 of the 60 levels studied. However, there were major discrepancies in interpretation at nine intervertebral disk levels. These included three false-positve MR imaging interpretations of a herniated disk and one false-negative herniated disk on MR imaging. MR imaging detected one case of disk herniation that was missed prospectively on CT. There were also four presumed degenerated disks seen on MR scans that appeared normal on CT. The conus medullaris was imaged in 16 of 18 patients. The sagittal view proved best for demonstrating both disk abnormality and the conus medullaris. The transaxial view was sometimes helpful in localizing a disk herniation, but partial-volume averaging in the 7-mm slice thickness limited its usefulness. There were five disk herniations that could not be accurately localized on the MR scan. MR imaging proved more sensitive than CT in detecting early disk disease, which appeared as decreased signal intensity within the disk. In three postoperative cases, MR imaging was better able to distinguish between recurrent disk herniation and postoperative scar formation. CT, on the other hand, was more specific in distinguishing herniated disk from disk bulge and proved far superior to MR imaging in localizing disk herniation. CT remains the preferred method for evaluation of lumbar spine degenerative disk disease. However, MR imaging is useful in clinical evaluation of lumbar disk disease as a complementary procedure. It may be valuable in postoperative patients and in equivocal cases where CT cannot differentiate between a small disk herniation and an asymmetric disk bulge. MR imaging should prove useful also in evaluating patients with suspected lesions of the conus medullaris or the lumbar subarachnoid space. Further advances in MR imaging technology involving thinner sections, imaging coils with better signal-to-noise ratio, and elimination of the interslice gap on the multislice technique can be expected to improve the utility of MR imaging in the lumbar spine.

Computed tomography (CT) has proven to be a sensitive, accurate, and efficient noninvasive method for evaluating degenerative disease of the lumbar spine. In addition to abnormal intervertebral disks, associated degenerative changes of the lumbar spine, including spinal stenosis and facet joint disease, are well demonstrated with this technique. However, there are limitations to the use of CT in lumbar spine evaluation. These include the fact that only a small area of the spine is evaluated: The routine study depicts the spine from above the L3–L4 intervertebral disk space to just below the L5–S1 intervertebral disk space. Moreover, high-resolution scans are obtained only in the transaxial projection. Although many surgeons prefer to view the spine in sagittal or coronal projections for preoperative planning, the computer-reformatted CT images in these planes provide limited resolution. Finally, the conus medullaris and lower thoracic spinal cord are not evaluated by CT, since this area is not included in the scanning field. Even when this area is scanned, CT without intrathecal metrizamide does not depict the spinal

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cord and the spinal canal adequately. Thus, intraaxial or intradural extraaxial abnormalities usually are not detectable on CT examinations performed without intrathecal metrizamide.

Magnetic resonance (MR) imaging has the potential to overcome all of these limitations. Although there have been several reports illustrating the ability of MR imaging to detect intervertebral disk disease [1–4], the sensitivity and accuracy of MR imaging as compared with CT in lumbar spine evaluation is unproven at this time. For this reason, we undertook a study correlating CT and MR imaging results in a series of patients with known lumbar spine degenerative disk disease.

Materials and Methods

The major objective of this study was to determine the accuracy of MR imaging for identifying and characterizing abnormalities of the lumbar intervertebral disk. CT and MR imaging studies were interpreted independently and the results were tabulated. In patients whose CT scan showed unequivocal characteristic findings of disk herniation or disk bulge, this study was presumed to be correct. However, since only five of 18 patients had direct surgical correlation, other criteria were used to establish the final diagnosis in cases in which there was a discrepancy between CT and MR findings and the CT findings were equivocal. In these cases, the diagnosis was based on a number of factors including the clinical presentation, retrospective review of the CT and MR studies, and the clinical response to chemolytic therapy if this was performed.

The 18 patients in the series were selected on the basis of abnormal CT findings at one or more intervertebral disk levels. CT was performed using a GE 8800 or 9800 CT scanner. Routine technique for the lumbar spine consisted of transaxial scanning from just above the L3–L4 intervertebral disk space to just below the L5–S1 disk space. Slice thickness on the GE 8800 scanner was 5 mm with overlapping scans obtained at 3-mm intervals. Scanning time was 9.6 sec at 400 mA. With the GE 9800, contiguous axial slices were obtained using a 3-mm collimator and 4-sec scanning time at 140 mA. No gantry tilt was used routinely, and sagittal and coronal reformatting of the axial images was done in all patients. Angled CT sections through a disk space were obtained only in selected cases to clarify questionable or equivocal findings on the routine study. In three patients, additional levels (L1–L2 and L2–L3) were evaluated by CT because the clinical presentation raised concern about possible abnormalities involving those areas. The CT criteria used for diagnosis of disk herniation and disk bulge were those described by Williams et al. [5] and by Haughton and Williams [6].

MR imaging was performed using a Diasonics MT/S system with a superconducting magnet operating at a field strength of 0.35 T. The details of this system have been described [7, 8]. The protocol included spin-echo (SE) sequences in a sagittal projection providing a field of view about 40 cm long. With proper positioning (i.e., centering about 4 cm above the umbilicus), the lower thoracic region to the end of the sacrum is imaged routinely. In all but one patient, images were obtained using two different pulse repetition times (TR): a short TR of 500 msec, resulting in an image with T1-weighted contrast; and a longer TR of 1500 or 2000 msec, resulting in an image with T2-weighted contrast. Echo delay times (TE) were 28 and 56 msec with each sequence. Multislice technique was used with a slice thickness of 7 mm and a 3-mm gap between adjacent slices. Imaging time varied from 4.5 min for the short-TR and 12.5–17 min for the longer-TR sequences. When a disk protrusion was seen on the sagittal images, a transaxial view was obtained using a TR of 1500 or 2000 msec. In three cases, patients underwent additional pulse sequences in the coronal projection. Total study time, including patient positioning and tuning of the MR imaging unit, ranged from about 45 to 90 min, according to the number of views obtained and the number of pulse sequences performed.

In order to interpret and correlate the MR imaging studies with the CT scans, prospective working criteria were devised for characterizing normal and abnormal intervertebral disks as demonstrated on the MR images. Disk herniation was defined as protrusion of disk material (with the same or similar MR signal as the involved intervertebral disk) beyond the posterior margin of the adjacent vertebral bodies (fig. 1). We called this the "toothpaste sign" of disk protrusion. Disk bulge was defined as posterior displacement of the disk anulus beyond the margins of the vertebral bodies. This is manifested by indentation of the epidural fat and/or thecal sac at the disk margin by a protruding structure with markedly diminished or absent MR signal (fig. 2). In our working criteria, disk bulge did not contain signal intensity similar to that of the intervertebral disk material. No attempt was made to distinguish among bulging anulus, osteophytic spur, and calcified posterior longitudinal ligament, all of which may have a similar appearance with diminished signal on MR imaging. Although these criteria were used for prospective analysis of the MR imaging studies presented here, retrospective review and correlation of our results prompted subsequent modification of the criteria, as explained in the Discussion.

Results

In the 18 patients included in this study, a total of 60 intervertebral disk levels were directly correlated with CT and MR imaging. The sagittal projection was the single most valuable view for defining disk pathology by MR imaging, since the entire lumbar spine was viewed on a single sagittal image, enabling direct comparison of the signal intensities of the individual lumbar intervertebral disks. The spinal canal and the conus medullaris also could be evaluated on this view (fig. 3).

The normal intervertebral disk was best depicted using a T2-weighted imaging sequence. The normal disk was seen as a relatively high-signal-intensity structure on the 28-msec-TE image, the anulus and the nucleus pulposus were usually indistinguishable. A lower-intensity, horizontally-oriented cleft was visible within the normal disk. The 56-msec-TE image often demonstrated the nucleus pulposus as an ill-defined zone of higher signal intensity (i.e., longer T2 relaxation time) surrounded by the more peripheral anulus (fig. 3). It has been suggested [1, 3, 9] that decreased signal intensity of an intervertebral disk space indicates degenerative changes and dehydration within a disk, and we assumed this to be the case in our studies.

The short-TR sagittal image of 500 msec proved to be the most reliable for viewing the conus medullaris. This pulse sequence provided an image with T1-weighted contrast, in which the cerebrospinal fluid (CSF) (with a long T1 relaxation time) appeared as black and the lower thoracic spinal cord and conus medullaris as higher signal intensity. The conus medullaris was clearly depicted in 16 of the 18 patients. The two failures to depict the conus occurred early in our series and were due to operator-dependent technique limitations: In one patient, the 500-msec-TR image was not obtained; in the other case, we inadvertently centered too low, and the region of the conus medullaris was not included on the image.

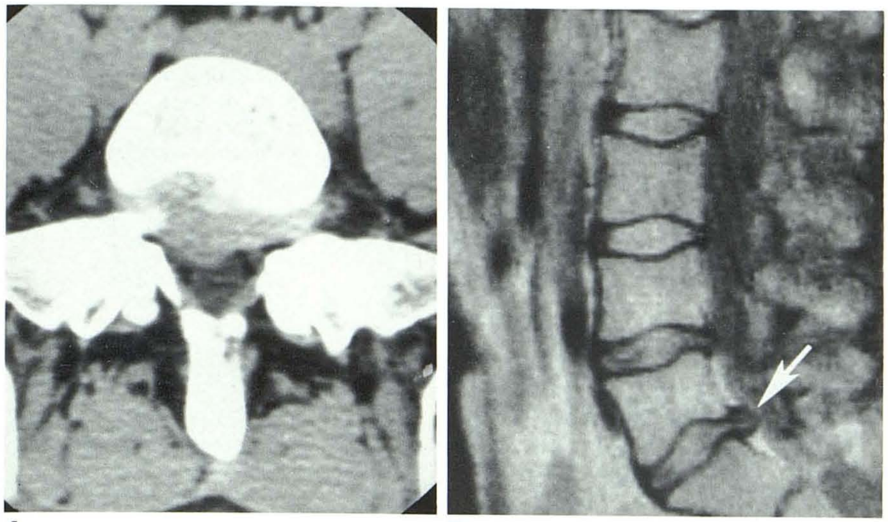


Fig. 1.—**A**, Transaxial CT scan at L5–S1 level. Typical appearance of posterolateral disk herniation on right side. **B**, Sagittal MR image (SE scan, TR 1500 msec, TE 28 msec). Degeneration at L4–L5 and L5–S1 levels as evidenced by diminished signal intensity; herniation of disk material at L5–S1 level. In addition to displacement of ventral epidural fat at this level, there is protrusion of disk material beyond posterior margins of vertebral body (*arrow*)—the "toothpaste sign" of disk herniation.

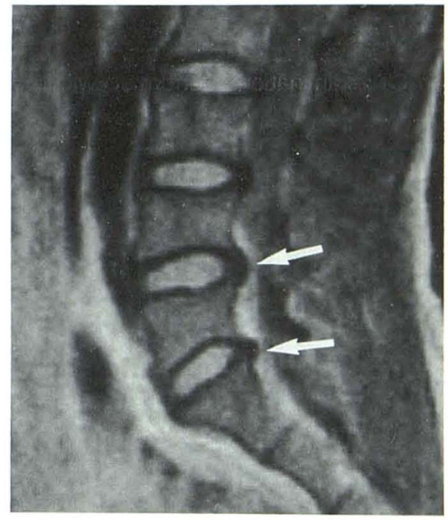


Fig. 2.—Sagittal MR image (SE scan, TR 1500 msec, TE 28 msec). Prominent disk bulges at L4–L5 and L5–S1 levels (*arrows*) and moderate bulge at L3–L4 level. Diminished signal from bulging anulus and ligaments; no protrusion of material with signal similar to that of intervertebral disk. Ventral epidural fat (which has high signal intensity) is indented by bulging anuli at lower two levels.

Images in the sagittal projection using a long TR of 1500 or 2000 msec proved best for evaluation of disk disease. The T2-weighted contrast showed presumed degenerative changes within the disk as shortened T2 relaxation time or decreased signal intensity, which was most evident on the 56-msec-TE image. Also, the degenerated disk had a more homogeneous appearance; in our series, definition of structure within the abnormal disk space was often lost. The central cleft usually was not visible and the anulus and nucleus pulposus usually could not be differentiated in degenerated disks. The decreased signal intensity often was not demonstrated on images obtained using the 500-msec TR.

Herniated disk material was best demonstrated on the long-TR, short-TE (28-msec) image. The herniated fragment was either poorly seen or not seen on the 56-msec-TE image of the long-TR sequence as well as with either the 28- or 56-msec TE using the shorter (500-msec) TR sequence. In addition, the longer-TR images provided a better signal-to-noise (S/N) ratio than did the short-TR sequence, resulting in more precise delineation of fine structural detail. Posterior disk herniation and disk bulge were easily definable on the sagittal images, and even a laterally-placed disk herniation within a neural foramen was detected using this view. Extruded disk fragments were identified in three cases (fig. 4) as herniated disk material that extended superiad or inferiad from the disk space but maintained a connection with the central disk material. There was one case of a presumed sequestered disk herniation with no apparent connection between the herniated disk fragment and the central disk material.

One limitation of the sagittal view was its inability to accurately localize a disk herniation. Thus, it was impossible not only to distinguish a central from a posterolateral herniation but also, in most cases, to distinguish between a right or a left posterolateral herniation. In order to overcome this limitation, in those patients who had a herniated disk demonstrated on the sagittal view, a transaxial image was also obtained. The transaxial images helped to localize and determine the side of a disk herniation in 10 cases (fig. 5), but in five additional cases, MR imaging failed to identify the side of herniation.

Coronal views were obtained in three patients and did not add any useful information. Because of the normal lordotic curvature of the lumbar spine, the spinal canal was visualized in short, discontinuous segments; consequently, we found this view to be the least useful.

A summary of the CT and MR imaging findings is given in table 1. Retrospective comparison of the CT and MR findings showed there was good correlation between CT and MR imaging interpretations at 51 (85%) of the 60 disk levels studied. There were major discrepancies in interpretation at nine disk levels (15%), detailed in table 2. These included three cases of false-positive diagnosis of herniated disk on MR imaging, which had the classic appearance of degenerative disk bulge on the corresponding CT scans. In retrospect, the correct diagnosis should have been suspected from the MR image, since there was protrusion of disk material not only along the posterior aspect of the vertebral body but also along its anterior aspect (fig. 6).

There was one missed diagnosis of a herniated disk on MR

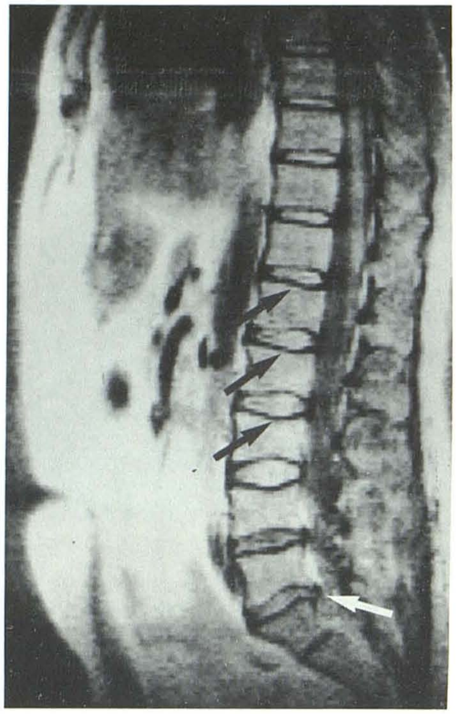


Fig. 3.—Nonmagnified sagittal MR image (SE scan, TR 1500 msec, TE 28 msec) of lower thoracic and entire lumbar spine shows full (40-cm) field of view obtained on routine MR study. Degenerative changes with diminished signal intensity at L4–L5 and L5–S1 levels; herniation manifested by posterior protrusion of disk material at L5–S1 level (*white arrow*). Conus medullaris is well demonstrated, as are normal intervertebral disks within upper portion of lumbar spine; their slightly higher signal intensity centrally is believed to represent normal nucleus pulposus (*black arrows*), better seen on 56-msec-TE image (not illustrated here).

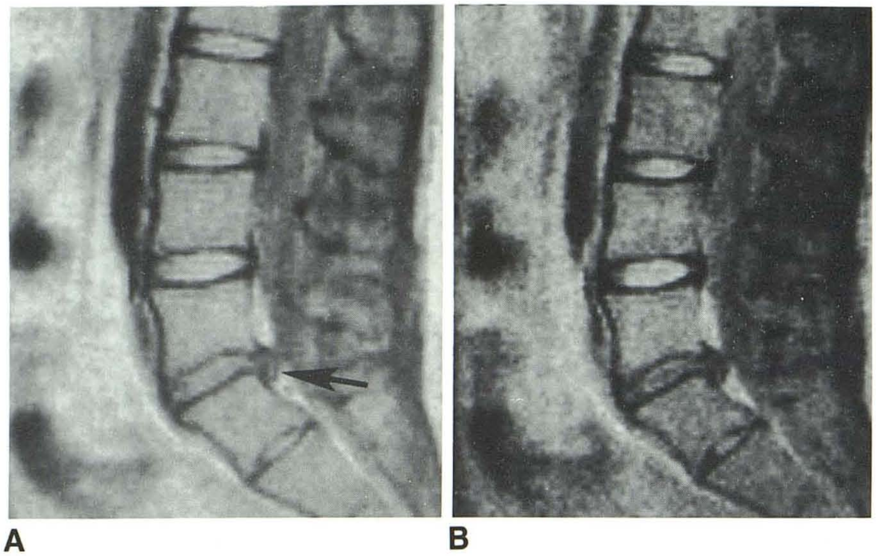


Fig. 4.—**A**, MR image (SE scan, TR 1500 msec, TE 28 msec) showing inferior displacement of extruded disk fragment that extends inferior to disk space and posterior to body of S1 (*arrow*). Patient has transitional S1 vertebra. Slight decrease in signal at degenerated L5–S1 disk. **B**, Delayed (56-msec-TE) SE image shows further decrease in signal intensity of degenerated L5–S1 disk in comparison with normal disk signals at higher levels. Although second SE image shows decreased signal intensity better, lost signal within disk makes visualization of herniated fragment much more difficult. In some cases, herniated fragment cannot be seen on long-TE image and may be mistaken for a disk bulge if this image is viewed in isolation.

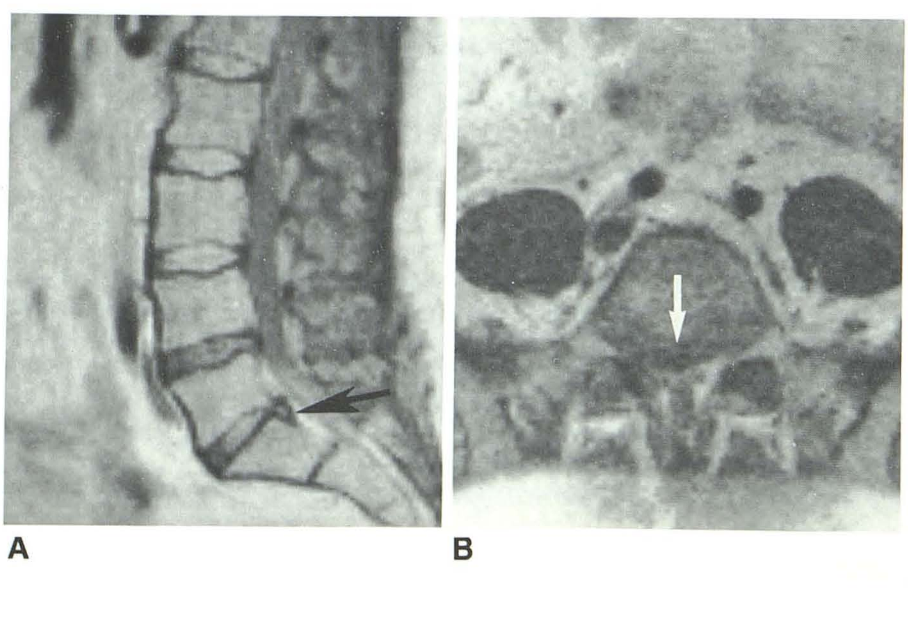


Fig. 5.—**A**, Sagittal MR image (SE scan, TR 2000 msec, TE 28 msec) showing extruded disk fragment that is displaced inferiad, posterior to body of S1 (*arrow*). **B**, Transaxial view shows asymmetry of epidural fat and its displacement and obliteration posterolaterally on right side. Disk herniation (*arrow*) is seen as area of diminished signal intensity on transaxial view, probably because of partial-volume effects together with contrast of herniated disk material against epidural fat (which is of relatively higher signal intensity).

TABLE 1: **Summary of CT and MR Imaging Findings and Final Diagnoses**

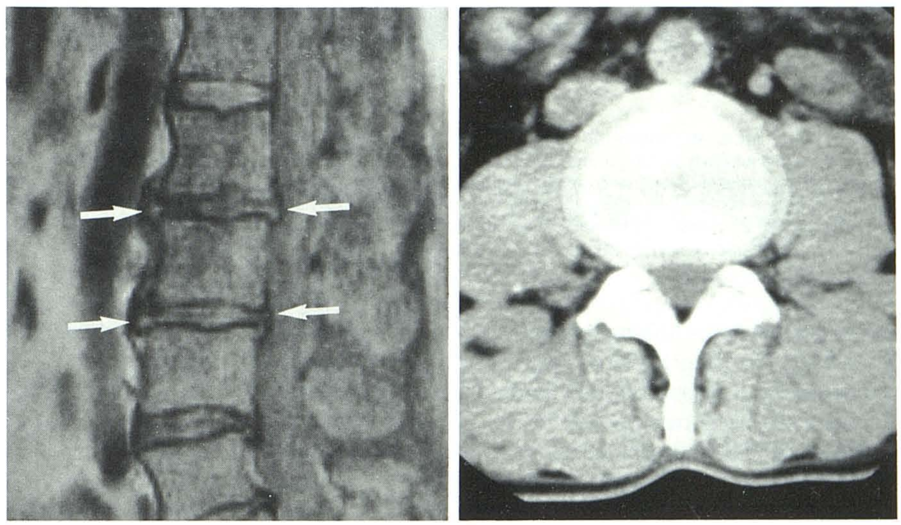
	Imaging Findings		Final Diagnosis*
	CT	MR	
Normal disk	27	23	23
Disk bulge without herniation	17	15	17
Herniated disk	14	17	15
Degenerative disk without bulge	1	4	4
Other†	1	1	1
Total	60	60	60

Note.—Imaging studies included 60 lumbar intervertebral disk levels in 18 patients.
* Final diagnoses were based on several factors, with surgical confirmation in five patients.
† Postoperative scar tissue.

TABLE 2: **Summary of Discrepancies between CT and MR Imaging Findings at Nine Disk Levels**

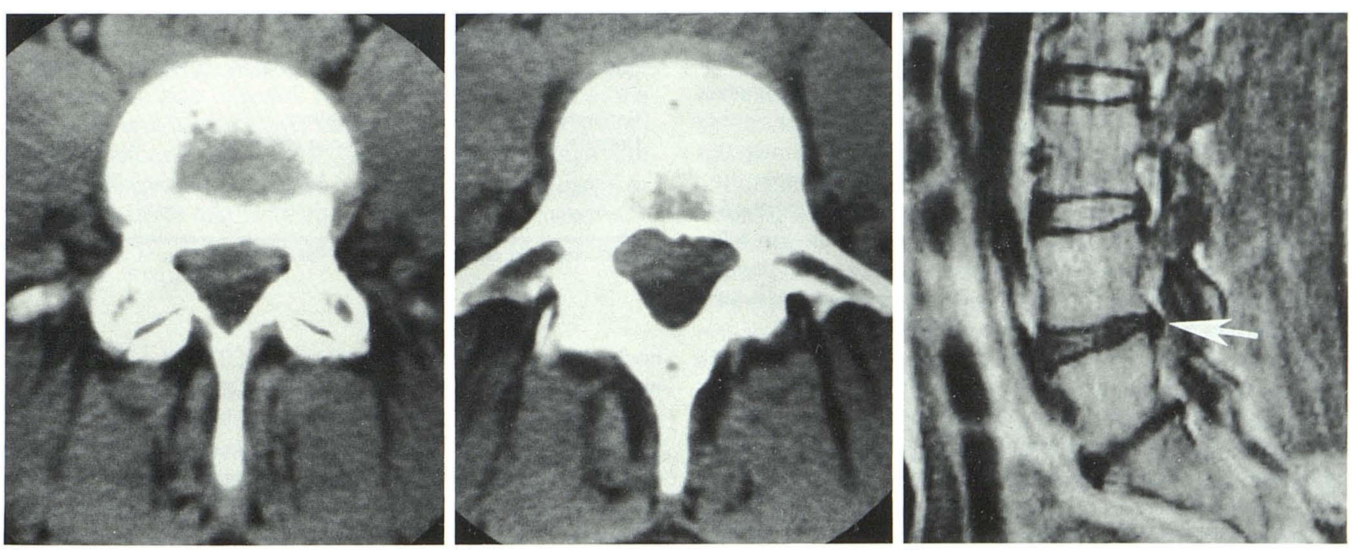
Discrepancy	No. of Levels
False-positive MR imaging finding for herniated disk	3
False-negative MR imaging finding for herniated disk	1
False-negative CT finding for herniated disk	1
Degenerated disk on MR imaging with normal CT scan	4

Note.—Imaging studies included 60 lumbar intervertebral disk levels in 18 patients.



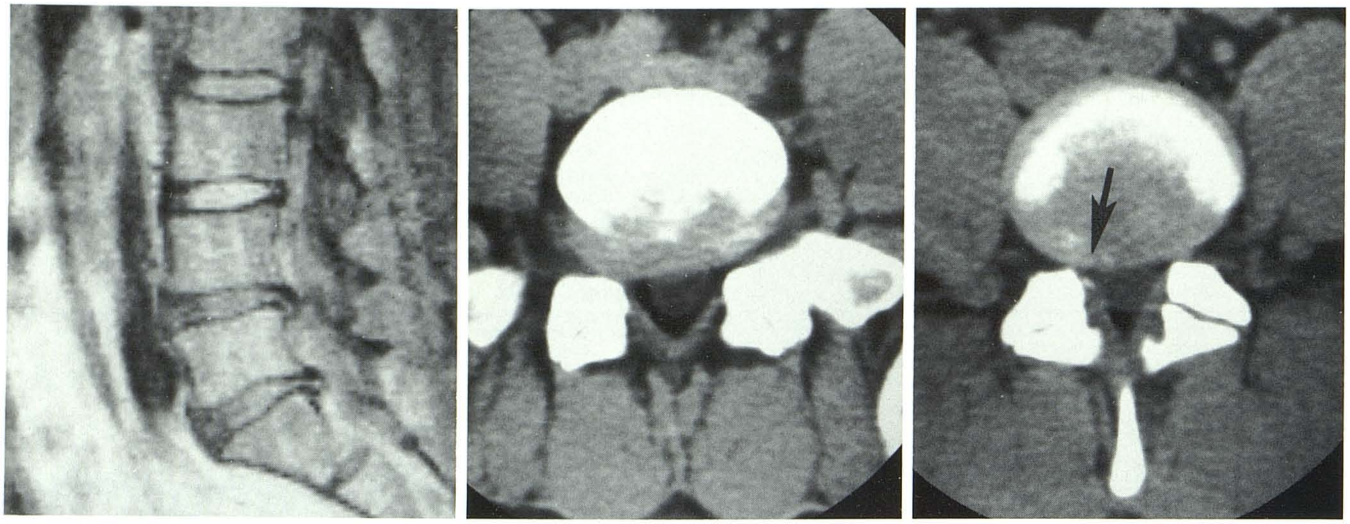
A B

Fig. 6.—**A**, Sagittal MR image (SE scan, TR 2000 msec, TE 28 msec) showing posterior protrusion of disk material at all levels from L2–L3 to L5–S1. L4–L5 and L5–S1 had confirmed posterior disk herniations. Although L2–L3 and L3–L4 levels were initially interpreted as disk herniations on MR image, correlation with CT scan revealed typical disk bulges. In retrospect, there is anterior as well as posterior protrusion of disk material at both of these levels (*arrows*). **B**, Transaxial CT scan at L3–L4 level shows classic appearance of concentric disk bulge. L2–L3 level showed similar appearance on CT.



A B C

Fig. 7.—**A**, Transaxial CT scan at L4–L5 level showing prominent central disk herniation. Scan at level of L5 lateral recess (**B**) shows extruded fragment extending into right lateral recess. **C**, Sagittal MR image (SE scan, TR 2000 msec, TE 28 msec) shows degenerative changes with diminished signal at both L4–L5 and L5–S1 levels. Prominent disk bulge (seen as area of diminished signal intensity) at L4–L5 level (*arrow*), but no herniated disk fragment nor inferior extrusion of disk material behind body of L5 is seen. This was sole false-negative MR interpretation of disk herniation in our series.



A B C

Fig. 8.—**A**, Sagittal MR image (SE scan, TR 1500 msec, TE 28 msec). Diminished signal intensity at L4–L5 and L5–S1 levels indicates degenerative changes. There is posterior protrusion of disk material at both of these levels; L4–L5 level shows some inferior extrusion of herniated disk. **B**, Transaxial CT scan at L5–S1 level reveals posterolateral disk herniation on right side. Scan at L4–L5 level (**C**) was initially interpreted as showing only mild disk bulge. In retrospect, there is asymmetry posterolaterally on right side (*arrow*) with obliteration of epidural fat in this region, correlating well with disk herniation at L4–L5 as seen on MR image (**A**). (Note similarity in CT appearance of this disk herniation with L5–S1 disk herniation shown in **B**.)

imaging, in which the MR image showed only the appearance of a bulging disk (fig. 7) whereas the CT scan showed a large disk herniation with an extruded fragment extending into the lateral recess. We have no definitive explanation for this misdiagnosis, although partial-volume effects and the 3-mm gap between adjacent slices may have led to the false-negative appearance of the MR image.

Prospective evaluation of the CT studies resulted in misinterpretation of a herniated disk as a small bulge, which was diagnosed correctly as a disk herniation on the MR image (fig. 8). Retrospective review of the CT scan showed an asymmetric bulge corresponding to the disk herniation seen on the MR image.

At four disk levels, CT showed normal-appearing intervertebral disks whereas MR imaging showed diminished signal due to a shortened T2 relaxation time. This was presumed to represent dehydration and degenerative changes within the disks [1, 3, 9]. Two of these patients had symptoms referable to the levels with degenerative signal changes on the MR images, and they also had abnormal discograms at these levels. The other two patients were asymptomatic at the involved levels and did not undergo discography.

The cases in which a herniated disk was detected by MR imaging but the herniation could not be precisely localized were not counted as discrepancies or errors in interpretation, because the correct diagnosis was made. We considered these as cases in which CT added significant useful information. Similarly, the cases of recurrent disk herniation identified by MR imaging were not considered discrepancies since, even though the CT scans were equivocal, the correct diagnosis was included in the differential diagnosis of the CT interpretation.

A comparative summary of the amount and type of diagnostic information obtained from the CT and MR imaging studies, respectively, is given in table 3. Although this type of evaluation is somewhat subjective in nature, we believe the comparison is valid. The two methods yielded equal diagnostic information at 42 (70%) of the 60 intervertebral disk levels studied, whereas CT provided more or better information at 10 levels (17%). In addition to the disk herniation that was missed on MR imaging and the three disk bulges misinterpreted as disk herniation on the MR studies, there were five cases in which MR imaging correctly diagnosed a disk herniation but failed to localize the side of the herniated fragment.

TABLE 3: **Comparative Summary of Diagnostic Information Obtained from CT vs. MR Imaging**

	No. of Levels
CT and MR imaging yielded equal infomation	42
CT yielded additional information:	
Localized side of herniation	5
Identified disk bulge misinterpreted as herniation on MR imaging	3
Identified disk herniation missed on MR imaging	1
Identified postoperative interbody fusion and fibrosis	1
Subtotal	10
MR imaging yielded additional information:	
Identified disk herniation missed on CT	1
Differentiated recurrent disk herniation from postoperative scar tissue	2
Estimated true size of disk herniation	1
Detected disk degeneration in case with normal CT scan	4
Subtotal	8
Total	60

Note.—Imaging studies included 60 lumbar intervertebral disk levels in 18 patients.

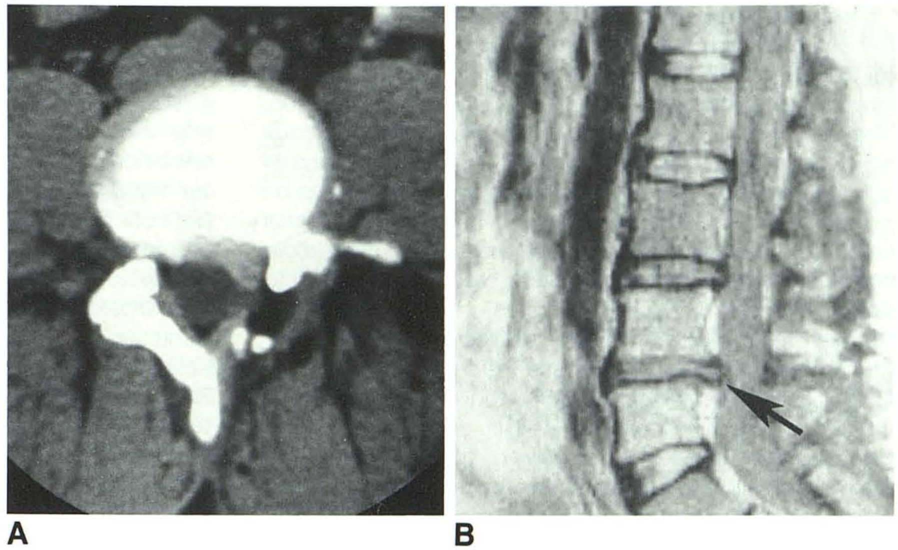


Fig. 9.—**A**, Transaxial CT scan reveals postoperative laminotomy on left side and increased density in epidural space along left side. Although possibility of recurrent disk herniation was suggested, changes seen on CT could not be clearly differentiated from postoperative fibrosis. **B**, MR image (SE scan, TR 2000 msec, TE 28 msec) unequivocally shows recurrent disk herniation (*arrow*) protruding posterior to vertebral bodies and displacing epidural fat. Degenerative signal changes within L3–L4 and L4–L5 intervertebral disks; mild bulge at L3–L4 level.

CT in these cases precisely localized the herniation. Finally, there was one case involving postoperative studies in a patient who had undergone a posterior laminectomy and posterior interbody fusion. This patient had extensive vertebral-body sclerosis around the interbody fusion and widespread scarring in the spinal canal. Although both CT and MR imaging showed the postoperative changes, the CT scan was easier to interpret and better defined the nature of the morphologic changes; the MR image alone provided a confusing picture.

MR imaging provided more or better information than CT at eight disk levels (13%). One disk herniation was missed on CT but correctly diagnosed on the MR image. In two postoperative cases, we were unable to differentiate clearly between scar formation and recurrent disk herniation on the CT studies. MR imaging in each case unequivocally showed a recurrent disk herniation (fig. 9), which was subsequently proved at surgery. In another case, the MR image better estimated the size of a disk herniation. In this instance, the size of the disk herniation was overestimated on the CT scan because deformity and swelling of the underlying nerve root was misinterpreted as part of the herniated disk. Finally, at four levels, disks that were interpreted as normal on the CT scans showed signal changes indicating disk degeneration on the MR images.

Discussion

MR imaging offers several advantages over CT for evaluation of the lumbar spine. The entire lumbar spine is included in a single sagittal view and the lower thoracic spinal cord, conus, and lumbar subarachnoid space are imaged routinely. Furthermore, the superb contrast resolution of MR imaging provides excellent potential for evaluation of intraspinal pathology such as neurofibromas or meningomas without intrathecal injection of metrizamide and without ionizing radiation [3, 10].

We attempted to determine the sensitivity and accuracy of MR imaging as compared with CT of the lumbar spine for detection of intervertebral disk pathology. CT was used as the basis for comparison for several reasons. First, CT has been shown to be very accurate in evaluation of the nonoperated back [11–13]. Second, although direct anatomic correlation through autopsy or surgery would have been welcome, it proved impractical, since autopsy material is extremely rare in this patient population and only five of the 18 patients in our series have undergone surgery. The rest of the patients were treated either conservatively or by injection with chymopapain. It should be noted that in all five patients who subsequently underwent surgery, there was accurate correlation between the surgical findings and the CT and MR imaging interpretations.

We did not attempt to evaluate MR imaging for all forms of lumbar spine degenerative disease, but emphasized the diagnosis of lumbar disk disease and differentiaton of disk herniation, disk bulge, and normal intervertebral disk. We did not evaluate the ability of MR imaging to define osteophytic spurs, degenerative lumbar facet joint disease, or spinal stenosis.

Decreased T2 relaxation time was seen at several disk levels in which no bulge or herniation was present. This was presumed to represent early degenerative changes within the involved disk that had not yet progressed sufficiently to be manifested by disk-space collapse, annular bulge, or herniation. Several Schmorl nodes were seen at various intervertebral disk levels and, although these represent herniation of disk material into the vertebral end-plates, these disks usually were *not* associated with an abnormal decrease in MR signal as was seen with all of the posterior disk herniations. When decreased signal was present at intervertebral levels with Schmorl nodes, there were other associated abnormalities such as disk bulge or posterior disk herniation. Thus, the mere presence of an end-plate herniation does not seem to correlate with disk degeneration per se, and the exact etiology and pathophysiology of this type of herniation remains unclear.

It has been suggested that the shortened T2 relaxation time is due to desiccation within the degenerating intervertebral disk [9]. However, complex biochemical changes occur within degenerating disks [14–17]. In addition to dehydration, there is an increase in collagen within the nucleus pulposus and a decrease in the mucopolysaccharide content and in chondroitin sulfate. The effects of these complex changes on the MR signal and the direction and magnitude of signal change contributed by each of these processes (which occur simultaneously) is not known. Further research is needed to clarify the important factors in this area.

In interpreting our MR imaging studies prospectively, criteria for herniated nucleus pulposus were established on the basis of known pathologic changes and experience gained from CT. These held up quite well in detecting abnormal disks. However, subsequent review of the MR studies revealed three disk levels characterized by posterior protrusion of disk material with signal that was isointense with the involved disk, but in which the corresponding CT scans showed the classic findings of degenerative concentric disk bulge. In these cases, protrusion of disk material was also present *anterior* to the vertebral body on the sagittal MR image. Thus, in some cases of degenerative disk bulge, the MR image shows nearly equal anterior and posterior protrusion of disk material. Therefore, our criteria for disk bulge should be modified to include these findings. Similarly, our criteria for disk herniation must be modified to restrict the diagnosis to cases showing protrusion of *isointense* disk material that is entirely or predominantly posterior or posterolateral. Use of the modified criteria would have allowed more accurate interpretation of these cases. However, there still remains the possibility of concurrent disk herniation and a bulging degenerated disk. It should also be pointed out that we observed anterior and posterior protrusion of disk material only on severely bulging disks (about 5 mm or larger). It was not seen in mild to moderately bulging disks, which showed predominantly posterior bulge with diminished MR signal.

Recently Modic et al. [4] reported that in their experience, herniated intervertebral disks were best defined using a pulse sequence with a 3000-msec TR and a 120-msec TE. Thus, the CSF, which has a very long T1 and T2, appears as relatively high intensity (white) on the MR images. While we agree with the desirability of rendering CSF as white on the images in order to outline the CSF-filled spinal canal, and concede that the long-TR, long-TE sequence is useful, we believe the early SE images are better for defining both normal and abnormal intervertebral disks. In our series the 1500- or 2000-msec-TR, 28-msec-TE sequence proved best for depicting the herniated disk fragment (fig. 1). The 56-msec-TE image of the same sequence was more useful for showing the nucleus pulposus in normal disks and for observing the homogeneously diminished signal intensity of the degenerated disk space (fig. 4). The latter effects probably would be further accentuated with longer echo-delay times as described by Modic et al., but we did not use that sequence in our series.

There are disadvantages to using the long-TR, long-TE sequence. With longer echo-delay times, the signal intensity of the image and thus the S/N ratio will continue to decrease. This effect is heightened in abnormal, degenerated disks (since they have a shortened T2 relaxation time), the net result being that the herniated fragment may not be distinguishable. If one relies *only* on an image with a long TE, it may be impossible to distinguish between disk bulge and disk herniation and to detect extruded fragments. On the basis of our experience, we believe an SE sequence with a long TR and both short and long TEs is most desirable.

Transaxial images were obtained in many patients in an attempt to localize the disk herniation. Although in most cases the transaxial study was useful for determining the side of a herniation, this view proved less valuable than the sagittal view as an initial screening sequence, for several reasons. First, only a limited length of the spine was viewed, generally 15–20 cm, on a single, multislice acquisition. Second, intervertebral disks were not well seen in this projection because of partial-volume effects in the 7-mm slice thickness, in which disk space, adjacent end-plate, and vertebral body were averaged together. Disk herniations, when seen, had diminished signal intensity on the transaxial view and were visualized indirectly by displacement of epidural fat in the ventral aspect of the spinal canal. Finally, it is difficult to determine precisely the level of the transaxial section. As a result, the configuration of the spinal canal and the vertebral bodies was used to determine the level of each section. This was feasible, however, only because the corresponding CT scan was obtained in the same projection (without gantry tilt) and was available for correlation. Had we used only the MR images for evaluation, accurate determination of level would have been more difficult.

We anticipate that use of thinner sections, elimination of the interslice gap currently encountered with the multislice technique, and improved S/N ratio through the use of surface coils will greatly improve the utility of MR imaging in defining normal and abnormal disks.

There were three postoperative cases among our 18 patients. The CT evaluation of postsurgical patients and the distinction between recurrent disk herniation and postoperative scar formation can be fraught with difficulty, and the results, even after intravenous infusion of contrast material, may be inconclusive [18, 19]. In each of the MR studies we were able to differentiate scar tissue from disk material easily. Recurrent disk herniation was identical in appearance to primary herniation, whereas scar tissue had an amorphous appearance and a variable signal intensity (often intermediate in intensity between disk material and epidural fat on the T2-weighted pulse sequence). In two cases, the MR study showed a recurrent disk herniation while the CT study was equivocal. The third postoperative patient had an interbody bone fusion and scar tissue within the spinal canal, which produced a signal easily differentiated from disk. These three cases illustrate the potential of MR imaging for distinguishing recurrent disk herniation from postoperative scar tissue.

Comparison of the type of diagnostic information obtained showed that CT was better at 10 disk levels whereas MR imaging was better at eight levels. Moreover, in nine of the 10 levels in which CT was believed to provide additional information, this information was critical to the patient's treatment. The single exception was a case of scar formation and interbody fusion that was better shown on the CT scan but was also seen on the MR image. On the other hand, of the eight levels in which MR imaging provided additional information, only three provided information on the MR images that would potentially affect treatment. In the other five levels, the MR images yielded information that better estimated the size of a disk herniation or showed early degenerative changes without bulge or herniation—information that would not significantly alter treatment and/or surgical planning. Thus, the CT studies overall proved superior to the MR studies, since they provided additional useful information that was necessary for planning optimal treatment.

We conclude that MR imaging and CT have approximately equal sensitivity for detecting disk herniation. The MR studies proved more sensitive than CT for detecting abnormal disks, if the four levels (7%) with normal CT findings that showed degenerative signal change on MR imaging are included. On the basis of our limited experience, MR imaging is able clearly to distinguish scar formation from recurrent disk herniation in postoperative patients, although proof of this assessment awaits additional experience. MR imaging can provide a more complete examination since it evaluates the entire lumbar spine as well as the intrathecal space and the conus medullaris. On the other hand, CT proved to have more specificity for the type of disk pathology present (i.e., disk herniation vs. bulge) and it was also more sensitive in determining the exact site of a disk herniation.

CT remains the preferred method for primary evaluation of the lumbar spine. However, MR imaging is useful in the clinical evaluation of degenerative lumbar disk disease as a complementary procedure to CT. It should prove useful in postoperative cases in which there is a problem differentiating between recurrent disk herniation and scar formation. Also, in equivocal cases in which the CT scan shows a mildly asymmetric disk bulge and a disk herniation is suspected, MR imaging may resolve the dilemma (as illustrated in fig. 8). Patients with signs or symptoms suggesting an intrathecal abnormality or a lower spinal cord or conus abnormality also are candidates for MR imaging evaluation.

With advances in MR imaging technology that provide thinner sections and improved S/N ratio, the problems involving specificity and accurate localization of disk herniation may be overcome. MR imaging may then displace CT as the preferred, primary noninvasive diagnostic technique for evaluation of lumbar spine intervertebral disk disease.

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