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Lumbar Disk Herniation and Canal Stenosis: Value of Intraoperative Sonography in Diagnosis and Surgical Management

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One hundred four patients with preoperative diagnoses of lumbar canal stenosis, disk herniation, or a combination of both were evaluated with intraoperative sonography with the intent of (1) describing the sonographic characteristics of herniated disks and distinguishing these from bulging anuli, epidural fat, scar tissue, and spondylolisthesis; (2) establishing criteria for adequate decompression of canal stenosis; and (3) determining the usefulness of sonography in monitoring disk removal. Disk material demonstrates medium echogenicity, different in its sonographic features from bone, epidural fat, scar tissue, and epidural veins. A sonographic diagnosis of disk herniation was made in 43 cases, 41 of which were confirmed during surgery. Sonography established the presence or absence of disk herniation (confirmed by surgery) in 14 of 19 patients who had equivocal preoperative findings. After routine diskectomy, residual disk material was found in 17 (41%) of 41 patients, which led to further surgery in 16 patients with removal of the additional disk fragments. In 84 patients undergoing decompressive surgery for canal stenosis, sonography detected residual canal compression in 19 (23%), which led to a widened decompression in 15 of these patients. Sonography can differentiate disk material from other normal or abnormal structures in the canal; therefore, sonographic monitoring helps to ensure adequate bony decompression and complete diskectomy.

We conclude that intraoperative sonography is an important tool in the surgical management of lumbar disk disease and stenosis.

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In laminectomies performed for suspected disk herniation and/or degenerative spondylosis/canal stenosis of the lumbar spine, proper patient selection, accurate preoperative diagnoses, and good surgical technique are important factors in decreasing the number of "failed backs." Intraoperative spinal sonography is an imaging technique that has been reported to be useful in the surgical biopsy or removal of soft-tissue masses [1], the shunting of congenital [2] and posttraumatic [3, 4] cysts of the cord and subarachnoid space, and the placement of Harrington rods in previously injured spines [4–6]. An early article reported the sonographic findings in six patients who had disk herniation and spondylosis and concluded that sonography might be useful in these lesions [7]. At our institution over the past 4 years, we have used intraoperative spinal sonography in a large number of patients who had undergone surgery for abnormalities related to degenerative disk disease and spondylosis of the lumbar spine. It was our intention to determine the role sonography could play in the intraoperative evaluation of the spine in these conditions and to see how this information could assist in surgical management. In this report, we describe our experience with this technique; illustrate the sonographic findings; and establish sonographic criteria for the diagnosis of disk herniation, complete diskectomy, and adequate decompression in canal stenosis.

Materials and Methods

One hundred four patients with the preoperative diagnosis of spondylosis, canal stenosis, and/or herniated disk of the lumbar spine were examined with intraoperative spinal sonog-

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raphy over a 4-year period. The preoperative diagnoses were made with one or more of the following techniques: myelography, non–contrast-enhanced CT, CT myelography, or MR imaging. The preoperative diagnoses were disk herniation alone (20), spondylosis alone with focal or generalized canal stenosis at one or multiple levels (42), and a combination of disk herniation and spondylosis (42). In 29 of these 104 cases, the patients had undergone prior surgery at the same level or levels. Both single- and multilevel disease were evaluated. Only patients with technically adequate examinations are reported here. Seven other patients who had sonograms are not reported in this study. In three there was insufficient clinical, operative, and sonographic information; in four the sonograms were inadequate.

The patients examined by intraoperative sonography were not consecutive. We had planned to make this a consecutive study including all patients with spondylosis and/or herniated disk undergoing laminectomy, but a number of patients in the time period of the study were not examined with intraoperative spinal sonography. No patients undergoing a "microlaminectomy" were examined, since the field of view in such an exposure is inadequate for our probe. In a small group of patients, the decision to request intraoperative sonography was made late and the delay involved in transporting the ultrasound unit to the operating room would have added too much time to the surgical procedure, so these patients were not studied.

In those patients operated on for herniated disk alone, the surgical procedure consisted of bilateral laminectomy or a hemilaminectomy with a 1.5-cm opening. If there was associated canal stenosis or if only degenerative or congenital canal stenosis was present, a posterolateral decompression consisting of laminectomy and medial facetectomy was performed. Such operations allowed an adequate window for sonography.

Intraoperative spinal sonography was performed with a 7.5-MHz transducer encased in a sterile sheath. After laminectomy or posterolateral decompression, the wound was filled with sterile solution such as Ringer lactate or normal saline and a baseline sonogram was

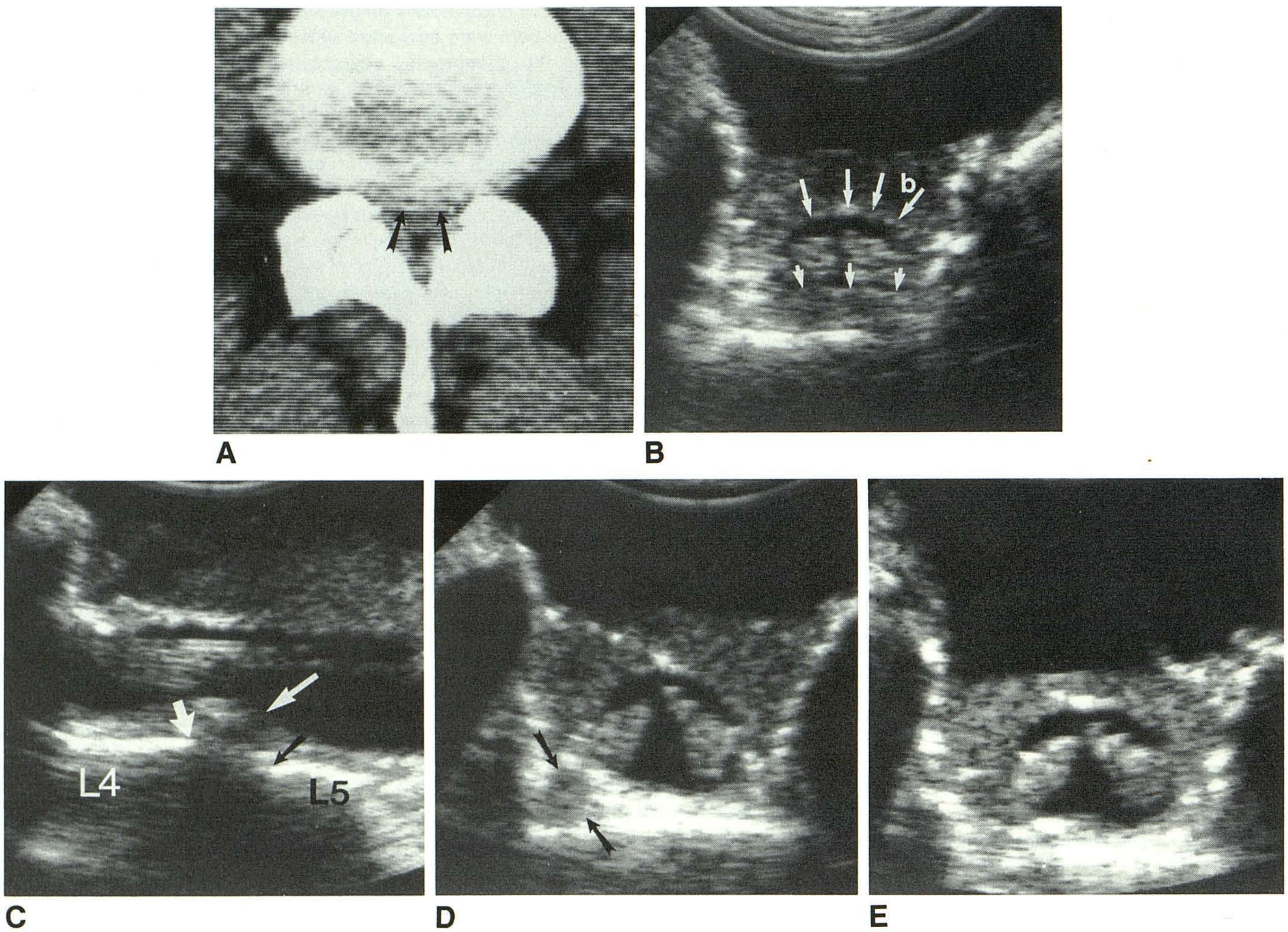

Fig. 1.—Herniated disk and canal stenosis.

***A*, Unenhanced CT scan at L4–L5 level shows central disk (*arrows*) with associated canal stenosis.**

***B*, Axial sonogram after bilateral laminectomy and medial facetectomies shows soft-tissue mass (*short arrows*) of medium echogenicity flattening ventral sac and compressing lumbar roots (compare with *A*). Note well-defined interface between disk and sac. Echogenic material (b) overlying dura (*long arrows*) represents fresh blood.**

***C*, Longitudinal sonogram. Disk has appearance of soft-tissue mass (*long white arrow*) at level of interspace. Interspace is bounded by inferior edge of L4 (*short white arrow*) and superior edge of L5 (*black arrow*) vertebral body. Disk protrudes into canal and narrows anteroposterior diameter of sac. Disk is of heterogeneous medium echogenicity; brighter echoes represent specular reflections.**

***D*, After what the surgeon believed was a complete diskectomy the sac regained a more rounded shape, but residual disk (*arrows*) compressing sac remains in left lateral aspect of canal (compare with *B*).**

***E*, Final sonogram after removal of disk fragment shown in *D* shows symmetric rounded shape to thecal sac, no compression of lumbar roots, and no residual disk material.**

obtained with images in the axial and longitudinal planes. The sonographic appearance of herniated disk(s), epidural soft tissue, residual scarring from prior procedures, swollen nerve roots, subluxation, or arachnoiditis were noted and correlated with the radiographic and surgical findings. Observations were also made of the sonographic appearance of normal structures of the spinal canal including disk material, epidural fat, epidural veins, nerve roots, CSF, and bony contours of the surrounding spine. In patients with canal stenosis, the configuration of the canal and the thecal sac was studied and compared with the radiographic findings.

After the baseline sonogram, further surgery was performed as warranted. For example, in instances of herniated disk, diskectomy was undertaken, and in cases of canal stenosis, bone was removed to decompress neural structures. The adequacy of these surgical procedures was monitored sonographically and was assessed by the amount of disk or bone removed and the subsequent increased space in the spinal canal and the amount of CSF surrounding neural tissue as compared with the appearance on the initial sonogram. As the surgery progressed, the results of the sonograms were compared with the operative findings, and continued surgery was undertaken as deemed necessary from these sonographic images and the patient's clinical presentation.

The number of cases in which sonography added diagnostic information and the impact of intraoperative sonography on surgical management as evidenced by further diskectomy or bony decompression were recorded. The criteria used to judge the adequacy of diskectomy or canal decompression are described in the Results section. The data were analyzed in order to evaluate to what extent sonography was useful in lumbar disk herniation and canal stenosis.

Results

Sonographic Appearance of Normal and Abnormal Structures of the Lumbar Spinal Canal

Disk material.—Herniated disks have the appearance of a solid mass with smooth borders and well-defined margins. They display medium echogenicity and are generally less bright than adjacent epidural fat (Figs. 1 and 2). They may have internal punctate bright echoes that represent calcifications or exhibit dense shadowing if the periphery of the disk is densely calcified. Herniated disks can be seen to protrude into the spinal canal, where they may deform the thecal sac and displace nerve roots. Lateral disk herniations (either far-lateral herniated disks or disk herniation in the neural foramen) either are obscured by overlying bone or are beyond the field of view of the transducer. The intervertebral disk space can be identified best on longitudinal scans, where this space is marked by the interruption of the bright interface formed by the dorsal edge of the vertebral bodies (Figs. 1C and 2C). Disk material allows acoustic transmission to occur; this phenomenon is best seen when the interspace is perpendicular to the sonographic beam. Calcified disks may be differentiated from osteophytic spurs on longitudinal sonography by noting the location of the intervertebral disk space in relation to such abnormalities. Although sequestered fragments of disk in the epidural space can be seen cephalad or caudad (Fig. 3) to the vertebral interspace, it is possible that the normal epidural soft tissue may obscure these migrated disk fragments, particularly when they are small.

Epidural fat.—The predominant soft-tissue density in the epidural space is fat, which appears brightly echogenic (Figs. 2C and 4), is symmetric in distribution (Fig. 4B), and tends to become thinner in the interspace. When it is adherent to the dorsal dura (Fig. 4A), it attenuates the sonographic beam and interferes with adequate visualization of the canal and the dural sac. Overabundant fat ventrally may cause confusion since it may appear to displace the sac posteriorly (Fig. 4B). Fat is homogeneously bright in echogenicity and symmetric in distribution, facts that help distinguish it from scar and disk material.

Epidural veins.—Prominent epidural veins appear as hypoechoic spaces within the epidural space (Fig. 5). Flowing low-amplitude blood echoes may be observed within the epidural veins during real-time examination. These veins,

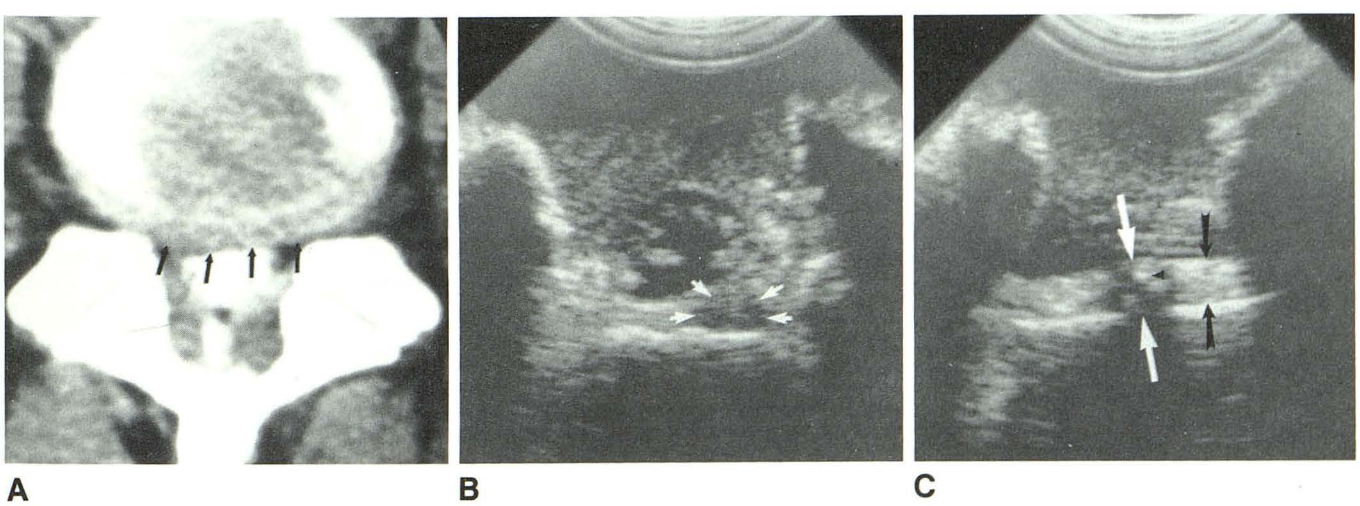

Fig. 2.—Herniated disk, shown by sonography in a patient with canal stenosis.

***A*, Preoperative CT myelogram shows bilateral hypertrophied ligamenta flava, bony hypertrophy, and ventral soft-tissue density (*arrows*) interpreted prospectively as bulging anulus.**

***B*, Axial sonogram. Right ventral disk is well demarcated (*arrows*) and causing compression of roots in lateral recess.**

***C*, Longitudinal sonogram. Disk (*between white arrows*) is seen to be less echogenic than lumbar epidural fat (*between black arrows*). Internal bright echoes (*arrowhead*) probably represent calcifications within herniated disk. After surgical excision, no residual disk was visualized on final sonogram.**

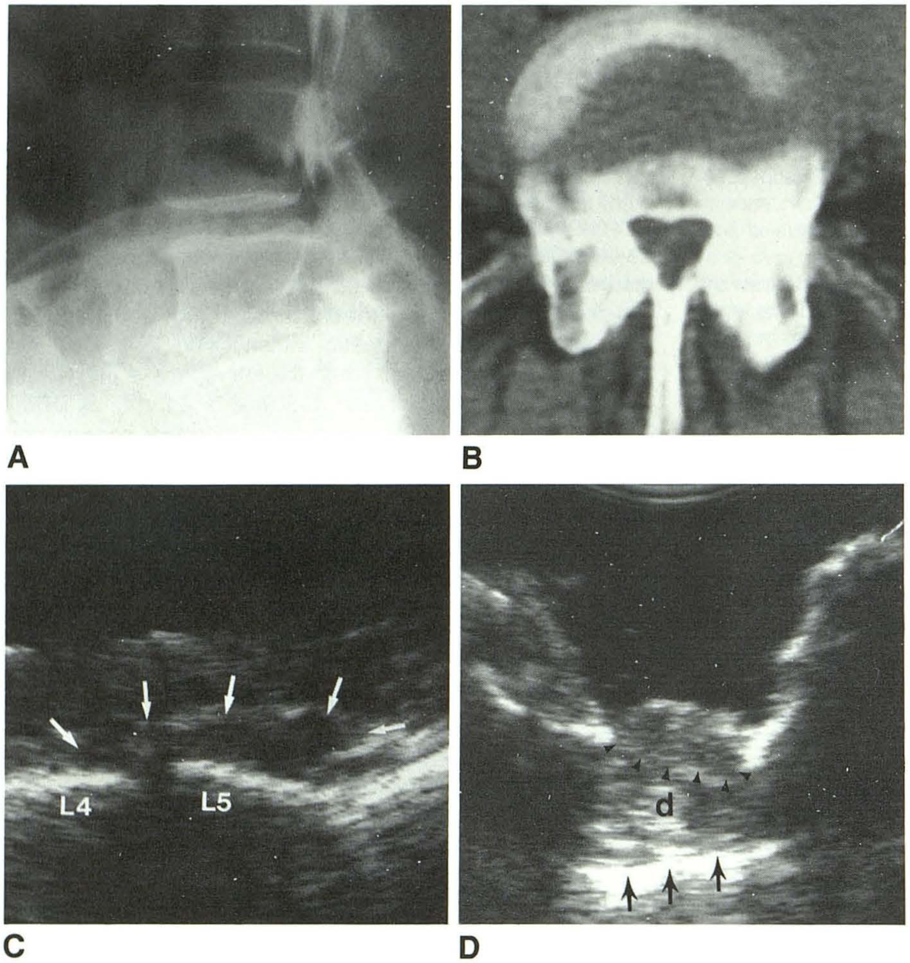

Fig. 3.—Disk with sequestered fragment in patient with canal stenosis.

***A*, Myelogram shows high-grade block at L4–L5 in patient with low-back pain.**

***B*, Interpretation of postmyelographic CT scan is limited because of lack of intrathecal contrast material at L4–L5.**

***C*, Longitudinal sonogram clearly shows soft-tissue mass (*arrows*), which originates at L4–L5 interspace, extends inferiorly, and elevates dura. This large disk is partially sequestered behind L5 vertebral body, a crucial observation prior to diskectomy.**

***D*, Transverse sonogram confirms presence of soft-tissue mass representing sequestered disk (d), located dorsal to vertebrae (*arrows*) and compressing thecal sac (*arrowheads*).**

which taper in size toward the interspace, may represent normal structures ventral to the thecal sac or they may indicate the presence of an abnormality that is obstructing the normal epidural venous flow.

Scar.—Scar can be difficult to differentiate from a disk or epidural fat because it may be either brightly echogenic (Figs. 6A and 6B) and mimic fat or may be of medium to low echogenicity (Fig. 6C) and mimic disk material. One helpful distinguishing feature of scar tissue is that it appears to merge with the dura without a distinct margin (Fig. 6). If the scar is located dorsally, it attenuates the sonographic beam and interferes with visualization of the spinal canal and thecal sac. Five patients who had prior surgery were noted to have residual scar tissue. In two patients, the scar was brightly echogenic, lateral in location, and at the level of the intervertebral disk space. In three patients, the scars were of medium to low echogenicity with poorly defined borders that merged with the dural surface. In all cases, surgical excision showed scar tissue.

Swollen nerve roots.—Swollen nerve roots may be mistaken for herniated disks as they exit the thecal sac since they can be of similar echogenicity and are also well marginated; however, typically they are round and well defined on transverse views (Fig. 7) but poorly defined on longitudinal views, cannot be traced back to the disk space, and do not compress the adjoining dura.

Bulging anuli.—Diagnosis of a bulging anulus is made on the longitudinal view by observing a small soft-tissue density at the interspace bulging into the canal. When larger in size, a bulging anulus may be difficult to distinguish from central disk herniation (Fig. 8). Longitudinal and axial views show no significant thecal sac compression in bulging anuli.

Subluxation.—On a longitudinal sonogram, vertebral body subluxations can be detected by finding the intervertebral disk space, determining the location of the posterior surface of each vertebra caudad and cephalad to the disk space, and observing their relative alignments (Fig. 9). Epidural soft tissues and disk material may be visible between the edge of the more anterior vertebra and the dura (Figs. 9B and 9C). Axial views at the interspace where the subluxation occurred may incorrectly suggest the presence of herniated disk since the anteroposterior diameter of the sac may be decreased and soft tissue is present ventral to the sac (Fig. 9D). A straight longitudinal scan is crucial in these instances since normal soft tissues dorsal to a subluxed vertebral body do not protrude posterior to the more posterior vertebral body (Fig. 9). When subluxation and disk herniation coexist, establishing the diagnosis of a herniated disk and monitoring its

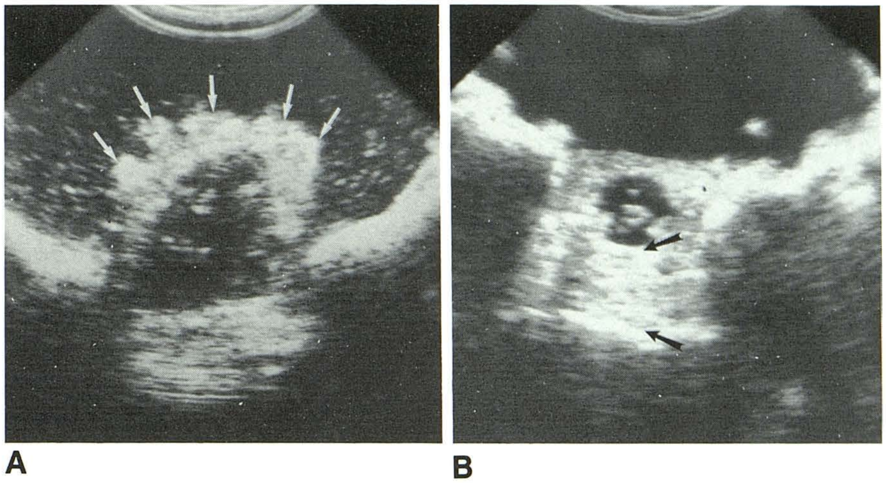

Fig. 4.—Epidural fat (canal stenosis).
A, Axial sonogram. Clusters of bright echogenic masses (*arrows*) adherent to dorsum of dura represent epidural fat (surgical observation). Note relatively poor visualization of contents of thecal sac owing to attenuation of beam.
B, Axial sonogram in another patient. Depth of epidural soft tissues (*arrows*) posterior to S1 is considerable. However, bright echogenicity, uniformity of distribution, and lack of deformity of ventral aspect of thecal sac are criteria indicating this represents epidural fat rather than disk material or soft-tissue tumor.

Fig. 5.—Epidural veins (canal stenosis). On longitudinal sonogram, epidural soft tissues, bounded dorsally by ventral dura (*solid arrows*), are prominent; within them are hypoechoic areas representing veins (*arrowheads*). Epidural soft tissues taper toward interspace (*open arrows*). When prominent veins such as these are present, small particles representing flowing blood may be seen during real-time sonography.

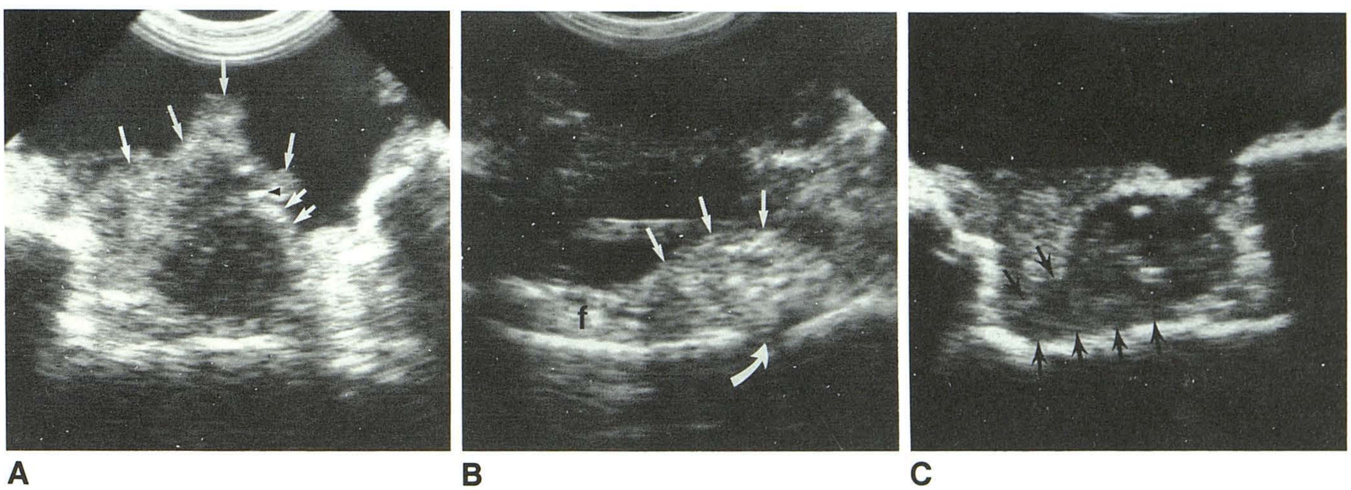

Fig. 6.—Scar in three patients who had undergone surgery previously.
A, Axial sonogram. Dorsal scar (*long arrows*) is irregular and heterogeneous in echogenicity; its interface with dura is effaced. The only portion of dura (*short arrows*) that is clearly visualized is surrounded by CSF. Thecal sac is poorly visualized because of diminished sonographic penetration. Small bright echo (*arrowhead*) represents calcification.
B, Right parasagittal sonogram. Hyperechoic soft-tissue mass (*straight arrows*), inseparable and indistinguishable from epidural fat (f), is seen at L5–S1 interface (*curved arrow*). Mass was suspicious for herniated disk because of its location and its mass effect; however, when this space was explored, soft tissue proved to be a scar.
C, Axial sonogram. Hypoechoic scar (*arrows*) is seen on left as an irregularly shaped soft-tissue mass with poorly defined edges silhouetting dura.

removal may be difficult. In this situation the presence of thecal sac compression is the key point in establishing the proper diagnosis (Fig. 10).

Arachnoiditis.—Intradural arachnoiditis is seen sonographically as tethered, clumped, and deformed nerve roots and thecal sac deformity [6, 7]. On real-time evaluation there is lack of the typical CSF pulsations when the arachnoiditis is severe. Two of our patients who had prior surgery and one of whom had prior Pantopaque myelography had evidence of arachnoiditis on sonography (Fig. 11). The diagnosis of arachnoiditis is difficult to establish sonographically in the face of substantial chronic compression of the thecal sac or if a dural tear has occurred because CSF may not be present to serve as a hypoechoic contrast to the nerve roots and dura. Pan-

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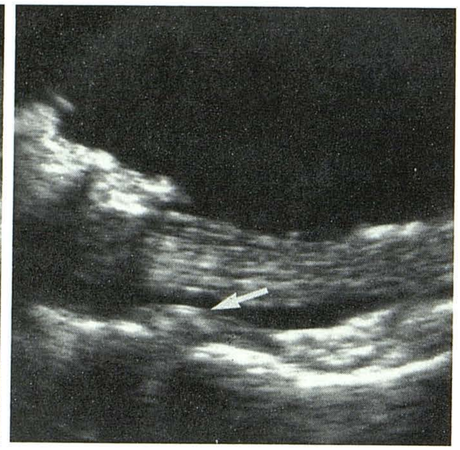

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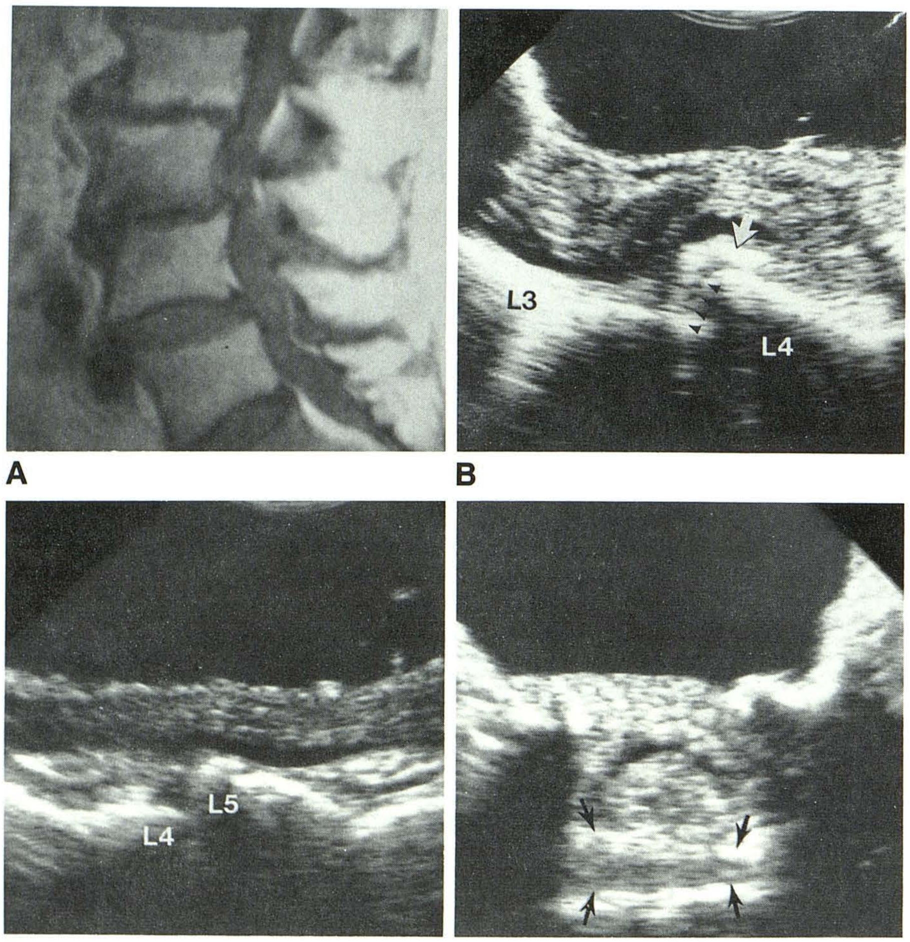
Fig. 7.—Swollen nerve root (canal stenosis). Axial sonogram shows well-defined round soft-tissue mass (*arrows*) within lateral epidural fat on right. Note that thecal sac is not compressed. This appearance is typical of swollen nerve root.

Fig. 8.—Bulging anulus (canal stenosis). When a prominent soft-tissue mass (*arrow*) is seen, such as this one at L3–L4 level, differentiation from a small central disk herniation is difficult. This was considered to most likely represent a bulging anulus because of absence of nerve-root compression.



C D

Fig. 9.—Spondylolisthesis and canal stenosis.

***A*, At L3–L4, MR shows anterior displacement of L3 on L4, a degenerative disk, and an osteophyte protruding into canal.**

***B*, Longitudinal sonogram correlates well with preoperative MR, showing osteophytic spur (*arrow*), spondylolisthesis (*arrowheads*), and resultant thecal sac compression. Sonography serves to rule out any associated disk herniation.**

***C*, Longitudinal sonogram in another patient shows anterior displacement of L4 on L5. At L4–L5 interspace, disk material does not protrude beyond dorsum of L5 into canal. Sonography indicates absence of herniated nucleus pulposus, which could not be ruled out on preoperative myelography or CT myelogram because of severe canal narrowing with a high-grade block.**

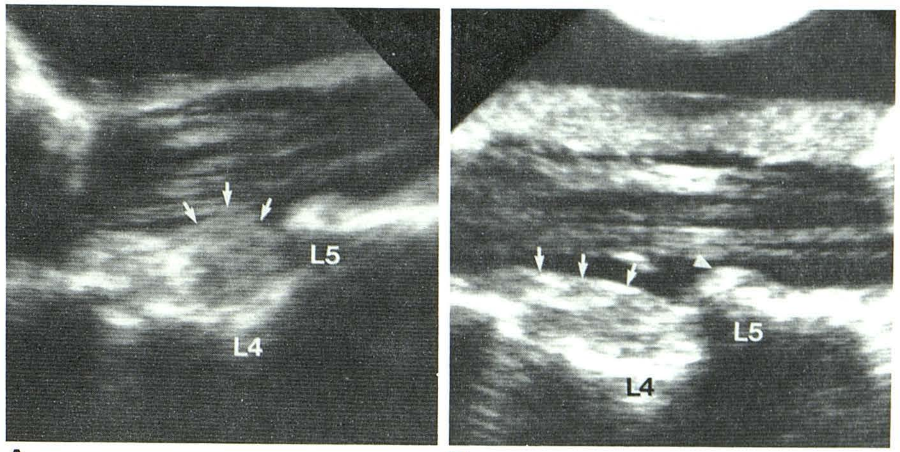
***D*, Axial sonogram in a different patient may be misleading, since ventral epidural soft tissues (*arrows*) at site of subluxation mimic a central disk flattening thecal sac. Longitudinal sonogram showed spondylolisthesis without herniated nucleus pulposus.**

topaque droplets within the thecal sac have a characteristic hyperechoic interface with the CSF, which should not be mistaken for adhesions (Fig. 12).

Application of Intraoperative Sonography in Disk Herniation, Canal Stenosis, and Spondylosis

For the sake of simplicity, our results in disk herniation and canal stenosis, whether congenital or secondary to spondylosis or trauma, are reported and discussed separately, even though they were often noted to occur simultaneously.

Herniated disk.—We include in this group a total of 63 patients, 42 with a definitive preoperative diagnosis of lumbar herniated disk, 20 with a diagnosis of suspected herniated disk, and one in whom the diagnosis of herniated disk was not suspected preoperatively but was made at surgery (this patient had canal stenosis) (see Tables 1 and 2).

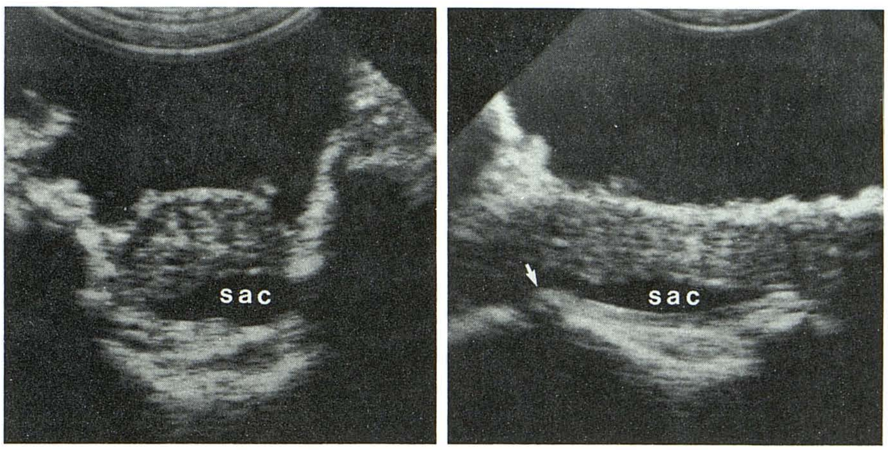


A B

Fig. 10.—Herniated disk, spondylolisthesis, and canal stenosis.

A, Longitudinal sonogram shows significant anterior displacement of L4 on L5 and epidural soft tissue (*arrows*) between subluxed bodies compressing thecal sac and roots. Since normal epidural soft tissues associated with spondylolisthesis do not cause such compression, a diagnosis of herniated nucleus pulposus was made.

B, Final longitudinal sonogram after diskectomy reveals no residual compressive soft-tissue mass at level of disk space. Note that nerve roots are not deviated. A spondylolisthesis is still noted along with normal epidural soft tissues (*arrows*) behind L4 body. A small spur from superior portion of L5 body is present (*arrowhead*).



A B

Fig. 11.—Arachnoiditis (previous surgery).

A and *B*, Axial (*A*) and longitudinal (*B*) scans. Clumped nerve roots that fill thecal sac are adherent to dorsal and lateral arachnoid walls. The only subarachnoid fluid present (sac) is loculated and causing a mass effect, an appearance characteristic of subarachnoid cyst. A bulging anulus (*arrow*) is present at L2–L3 interspace.

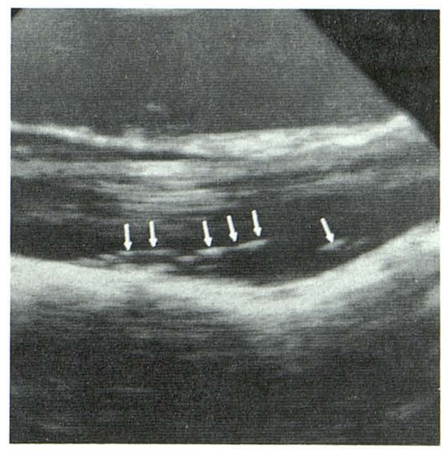


Fig. 12.—Pantopaque (previous surgery). Linear echoes (*arrows*) in dependent portion of thecal sac represent acoustic interface between CSF and oily medium Pantopaque. Pantopaque is anechoic. This appearance should not be mistaken for abnormally coursing roots or intradural scarring.

Intraoperative sonographic diagnosis and surgical correlation.—Fifty-nine of these 63 patients with herniated disk had a baseline sonogram following laminectomy (Table 2). Considering these 59 patients as a group, sonographic diagnosis of herniated disk was made in 43 and was confirmed surgically in 41; no herniated disk was found in two. In the remaining 16, the sonographic diagnosis of no herniated disk was made in 11 patients and confirmed surgically in 10, but sonography missed one herniated disk found at surgery. Sonography diagnosed scar in one patient and scar vs herniated disk in two; scar was found in all three at surgery. Sonography could not exclude the presence of herniated disk in two; in neither was a herniated disk found at surgery.

Within the group of 20 patients with the preoperative radiographic diagnosis of suspected or equivocal disk herniation and canal stenosis, one had no baseline sonogram. Of the remaining 19, 10 had severe canal narrowing with block (Table 2). Sonography showed associated disk herniation in four (Fig. 3) and no disk herniation in four (Fig. 9C) (all eight with surgical correlation); sonography was equivocal in two. Surgical exploration of the questionable area in these two patients revealed no disk herniation.

Sonography diagnosed and surgery found an unsuspected herniated disk in a patient undergoing surgery for canal stenosis (Fig. 2; see Table 2).

Criteria for complete diskectomy or further surgery.—The criteria established for complete removal of disk material (Fig. 1) include the absence of the initially identified soft-tissue mass and the return of the thecal sac to a normal or nearly normal shape. If residual mass and deformity of the thecal sac were identified (Fig. 1), they formed the basis for recommending reevaluation of the surgical field in hopes of finding and removing additional disk material.

Sonographic examination of the surgical field after diskectomy was performed in 41 patients (including three who had not had a baseline sonogram). Of these, 24 had no residual disk material by initial postdiskectomy sonographic criteria. In 17, however, residual disk fragments were identified by sonography. As a result, in 16 patients the operative site was reexplored, the presence of additional disk material was confirmed, and the extra fragments were removed. In all 16, the surgical field was monitored until no more disk material was present by sonographic criteria. In the other patient the surgeon judged that the presumed residual disk fragments were not significant and further surgery was not warranted.

Canal stenosis.—The preoperative diagnosis of focal or generalized canal stenosis was made in 84 cases, including those patients with (42) and without (42) associated herniated disks. Of these 84 cases, 79 had spondylosis (Figs. 13 and 14) (including degenerative spondylolisthesis), four had old fractures with secondary canal narrowing, and one had congenital canal stenosis. Eighteen patients had prior surgery at the levels of canal narrowing; 66 had no prior surgery.

Intraoperative sonographic evaluation and surgical correlation.—Canal stenosis secondary to enlarged facets resulted in a triangular or irregular shape to the thecal sac, a smaller transverse than anteroposterior canal diameter, and crowding of the nerve roots (Figs. 13A and 14A). The sonographic observations concerning bony impingement corresponded to the surgical findings in all cases.

Criteria for adequate decompression or further surgery.—Following bone resection in an adequately decompressed spine, sonography demonstrates a significant change in the contour of the thecal sac compared with the initial postlaminectomy scans. A round or nearly round sac should be seen in which there is no deviation of the roots from their normal course. The bony canal that results from this decompression should have an open rectangular shape (Fig. 13B) with a visualized space between the lateral wall of the thecal sac and the residual facets (Figs. 1E, 2B, and 13B).

In the 84 cases, 65 were judged by these sonographic criteria at the time of surgery to have an adequately decompressed canal. Nineteen patients were found to have residual bony compression of the sac (Figs. 13 and 14). Fifteen of these cases had further surgical manipulations in an attempt to achieve adequate decompression; on the final sonographic examination, two had residual but mild compression judged to be acceptable by the surgeon and the radiologist, while 13 were judged to have a good decompression. In the other four patients, the surgeons decided to do no further surgery despite the sonographic demonstration of residual sac compression. The reasons for this included mild compression (one patient), reluctance to perform more extensive laminectomies for fear of destabilizing the spine (two), and the lack of symptoms corresponding to the bony abnormality (one).

TABLE 1: Pre- and/or Operative Diagnoses

Diagnosis	No. of Patients
Disk herniation without canal stenosis	20
Canal stenosis without disk herniation	41
Disk herniation plus canal stenosis	43
Total	104

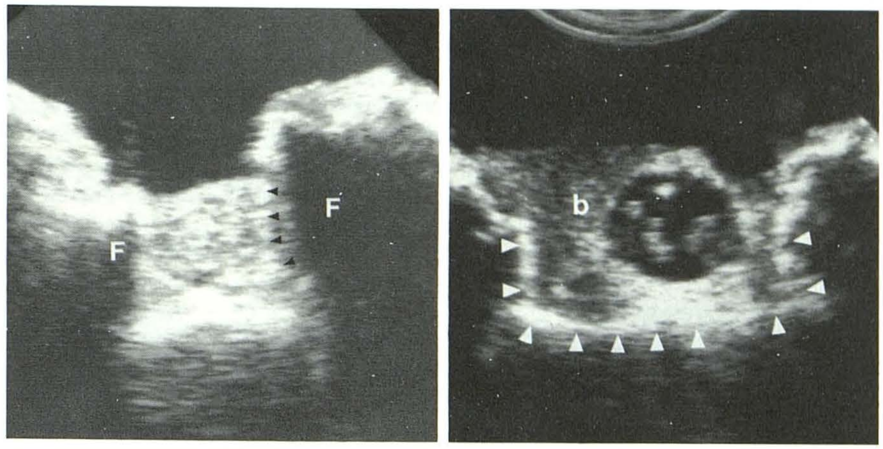
Discussion

In order to achieve clinically satisfactory long-term results in patients undergoing lumbar surgery for disk herniation, spondylosis, and/or canal stenosis, complete removal of the offending disk or bone is necessary. While imaging examinations such as myelography, CT myelography, and MR can accurately demonstrate preoperatively the symptom-producing abnormalities, the intraoperative assessment of the lumbar spine and the progress of the operative procedure is usually performed by simple visual inspection. Therefore, suboptimal evaluation of the surgical field may occur and a potential exists for the incomplete removal of herniated disk material and/or inadequate bony decompression of neural tissue. For this reason a more accurate method of assessing the progress of the surgical procedure is desirable. Intraoperative sonography can clearly display normal and abnormal intraspi-

TABLE 2: Baseline Sonographic Diagnoses and Surgical Correlation in 59 Patients Who Had Preoperative and/or Operative Diagnoses of Herniated Disk and Baseline Sonography

Preoperative Radiographic Diagnosis	No. of Cases	Findings on Baseline Sonogram	Surgical Findings
Herniated disk	39	36 Herniated disk	34 Herniated disk
		–	1 Scar
		–	1 No herniated disk
		1 Scar	1 Scar
		2 No herniated disk	2 No herniated disk
Suspected herniated disk			
Canal stenosis with block	10	4 Herniated disk	4 Herniated disk
		4 No herniated disk	4 No herniated disk
		2 ?Herniated disk	2 No herniated disk
Scar vs herniated disk	6	1 Herniated disk/swollen nerve root	1 Herniated disk/swollen nerve root
		2 Scar vs herniated disk	2 Scar
		3 No herniated disk	2 No herniated disk
		–	1 Herniated disk
?Herniated disk	2	2 No herniated disk	2 No herniated disk
Herniated disk vs lymphoma	1	1 Herniated disk	1 Herniated disk
No herniated disk (canal stenosis)	1	1 Herniated disk	1 Herniated disk

Note.—Only those patients in whom baseline sonograms were obtained are represented here.

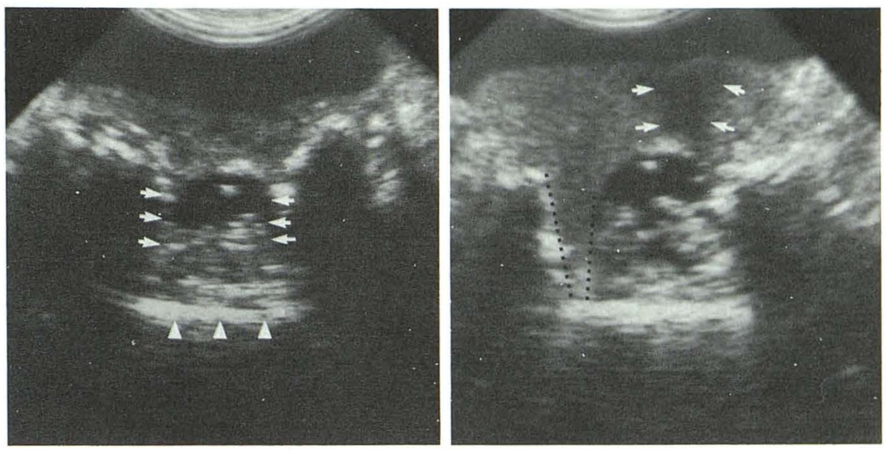


A B

Fig. 13.—Posterolateral bony decompression for canal stenosis. Two patients were examined with axial sonography after different degrees of bony decompression for canal stenosis.

***A*, Persistent bone compression in a patient with previous surgery. Following laminectomies and medial facetectomies, enlarged facets (F) are causing significant constriction (*arrowheads*) and irregularity of sac. Note crowded roots and lack of visualized CSF. Further bone removal followed this sonogram and included extending bilateral medial facetectomies, which resulted in a more normal-appearing sac and diminished root compression.**

***B*, Adequate lateral decompression, primary operative procedure. In the second patient, bilateral laminectomies and facetectomies resulted in a rounded (normal) thecal sac with no areas of bone compression. In the left lateral gutter, echogenic material represents fresh blood (b) in operative site. Bony canal now has shape of wide, open-ended rectangle (*arrowheads*).**



A B

Fig. 14.—Canal stenosis: residual bony compression of thecal sac at multiple levels in a patient with previous surgery. Sonography was performed after bilateral laminectomies and facetectomies in patient with multiple-level canal stenosis.

***A*, Axial view at L3–L4 shows continuing facet encroachment (*arrows*) on both lateral aspects of canal. There is no space between edges of facets and thecal sac. Posterior edge of vertebral body (*arrowheads*). Note that shape of canal is that of a narrow-based rectangle (compare with Fig. 13B).**

***B*, At L4–L5 level there is adequate decompression of left aspect of canal, while right is significantly compressed by facet. Note difference in space between facet on left and thecal sac (between *dotted lines*) and lack of space in same location on right.**

Facetectomies were extended at both levels; final sonogram was interpreted as showing adequate bony decompression at all levels. Blood is filling epidural space on left and is seen layering over dorsal dura on both images. Lucent area within settled blood (between *arrows* in *B*) represents active bleeding, a finding appreciated on real-time monitoring of surgical field.

nal structures [6, 8], thus permitting assessment of the spine during surgery. Early experience with sonography in patients with disk disease and canal stenosis suggests intraoperative spinal sonography has a role to play in the surgical management of these cases [7].

Herniated disk material (Figs. 1–3) can be distinguished from surrounding epidural fat, bone, scar tissue, and venous plexus by virtue of its medium echogenicity, its sharp margins, its relationship with the disk space, and its effect on adjacent neural structures. Bone (Fig. 1C) is of higher echogenicity than disk and exhibits dense shadowing. Ventral epidural fat (Figs. 2C and 4B), which may be abundant, has a symmetric distribution, lies directly posterior to the vertebral bodies, and is higher in echogenicity than disk material. Epidural veins (Fig. 5) are of low echogenicity and are most prominent posterior to the midportions of the vertebral bodies rather than at the disk levels. Observing bloodstream echoes in motion in real time permits easy differentiation from disk fragments. Scar tissue (Fig. 6) is of mixed echogenicity and its interface with surrounding tissues is poorly defined, while a herniated disk is sharply defined. The differentiation of bulging disk material (Fig. 8) from a central disk herniation is difficult with sonography; however, when this problem arises, one can clearly establish the presence or absence of root displacement. Problems do exist in identifying far-lateral disk herniations, that is, those that do not form a silhouette against either the anechoic CSF or adjacent nerve roots.

Pantopaque within the thecal sac forms a fluid level with the CSF, and its characteristic appearance (Fig. 12) can be differentiated from intradural adhesions or aberrantly coursing nerve roots. When intraarachnoid adhesions are present the nerve roots clump together, and whatever remaining CSF there may be is loculated in collections within the thecal sac (Fig. 11). If there are adhesions all around the sac, then no CSF may be seen. On real-time evaluation, the typical CSF pulsation is lacking when the arachnoiditis is severe. Knowledge of these sonographic characteristics of normal and abnormal intraspinal structures is crucial when monitoring the progress of spine surgery.

The ability to separate normal structures that occur in the epidural space directly adjacent to the thecal sac from disk material can have important implications in the surgical treatment of disk herniation. Sonography can readily identify the conus medullaris [8] and its relationship to herniated disks or compressing bony structures. The location of the conus may influence the surgical approach to decompression. In our series, residual disk material was identified intraoperatively in 17 of 41 patients examined after routine diskectomy (Fig. 1D). It is most likely that such disk fragments would not have been removed at the time of the original surgery. A common cause of failed backs is persistent disk herniation [9]. Whether these patients would have experienced recurrent low-back symptoms had these residual fragments not been removed is, of course, impossible to determine, but obviously the removal of as much abnormal material as possible is desirable.

Frequently in a patient with spondylolisthesis, it is difficult to be certain whether or not there is associated herniated disk material or whether the ventral impression on the thecal sac by disk material is mainly a manifestation of the forward positioning of a vertebral body relative to the disk material below it. Longitudinal sonograms can assist in this important distinction. When spondylolisthesis without disk herniation is present, just the highly echogenic borders of the malaligned vertebral bodies are seen (Figs. 9B and 9C). Conversely, when herniated disk material is present in conjunction with spondylolisthesis, the medium echogenicity of the disk can be identified between the edges of the subluxed vertebra (Fig. 10A). Similarly, when spondylosis causes severe narrowing of the canal it is often difficult to establish preoperatively whether herniated disk material is also present, and longitudinal sonograms are crucial to the diagnosis (Fig. 3). In eight of 10 patients with severe stenosis secondary to spondylosis, sonography was able to establish the presence or absence of disk herniation (Table 2; Figs. 3 and 9C). This has clear implications for the surgical management of such patients because the herniated disk will be removed after the laminectomy but before the lateral bone fusion (Fig. 10B).

When bony decompression of the lumbar canal is being performed either for degenerative spondylosis with secondary canal narrowing or for congenital canal stenosis, sonography provides an immediate evaluation of the effect of the bone on adjacent neural tissue (Figs. 13 and 14). It has been reported that the most common cause of failed backs is failure to recognize or adequately treat lateral stenosis [9]. Sonography can show when sufficient bone (lamina and facets) has been removed to result in a decompressed canal; when this has happened, the sac will assume a rounded configuration (Fig. 13B). However, the sonographic observation that the thecal sac is encroached on either by facets (Figs. 13A and 14) or by ventral spurs may convince the surgeon to extend the facetectomies or to attempt resection of the spur in order to relieve neural compression. In 84 of our patients who underwent bone removal for either generalized or focal canal narrowing, sonography showed residual compression in 19, after what was believed on initial inspection of the surgical field to be adequate bone removal. In 15 of those 19, further bony removal was undertaken to achieve optimal decompression of the canal. In the other four, clinical considerations convinced the surgeon that further surgery was not warranted.

Sonography does not significantly prolong surgical time [10]. An earlier report addressing the issue of time requirements in intraoperative neurosonography included a small group of patients with spondylosis and/or herniated disks. The actual scanning time did not exceed 10 min during routine lumbar diskectomy or 14 min during bony decompression. Although we have not continued to record scanning times, our impression is that as we gained experience and confidence in interpreting these examinations, time spent during actual scanning uncomplicated cases has decreased. When sonography demonstrates failure of bone decompression or the need to remove residual disk, additional time is required. We believe that the value of the information obtained balances the small amount of operative time involved.

In summary, we have described the sonographic appearance of normal and abnormal structures of the lumbar spinal canal and established diagnostic criteria for herniated disks that enable us to differentiate herniated disk from other structures, such as epidural fat, scar, swollen nerve roots, and spondylolisthesis. We have also established sonographic criteria for complete diskectomy and for adequate decompression of canal stenosis. A large percentage of patients who undergo diskectomy or have surgery for spinal stenosis have been reported in the literature to have persistent symptoms and significant disability [9]. The observations that 41% of the patients we examined with sonography after diskectomy had residual disk fragments and that 23% of the patients we examined after posterolateral decompression for canal stenosis had residual compression lead us to believe that the use of sonography can have a significant impact on the clinical outcome of patients undergoing these types of surgery.

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