Surgical management of lumbar stenosis: decompression and indications for fusion

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Review of the clinical, neuroradiological, and surgical management of lumbar spinal stenosis reveals that 90 to 95% of congenital or acquired variants may be adequately managed by means of decompression without fusion. These decompressive procedures often simultaneously treat disc herniations, limbus fractures, degenerative spondylolisthesis, rare selected cases of spondylolisthesis accompanied by lysis in older patients, and degenerative scoliosis. Fusion should be reserved for the approximately 5 to 10% of patients in whom there is clinical evidence of instability prior to surgery or for the few who develop slippage following laminectomy and facetectomy.

Key Words * spine * lumbar stenosis, congenital, acquired * decompression * fusion

Lumbar stenosis, with or without attendant disc herniations, limbus fractures, degenerative spondylolisthesis, degenerative scoliosis, or other disease, may be managed solely by means of laminectomy without fusion 90 to 95% of the time. Fusion should be reserved for the remaining 5 to 10% of patients in whom radiographic and clinical evidence of instability exists. To determine how best to manage patients with lumbar stenosis, the pathophysiology, types of stenosis, clinical and neurodiagnostic findings, and available surgical procedures (with or without fusion) are presented.

PATHOPHYSIOLOGY OF THE LUMBAR SPINE

Cryomicrotome sections of the stenosed lumbar spine show the multisegmental soft-tissue configuration of the epidural compartment constrained dorsally by the ligamentum flavum and fat pedicle and ventrally by the veins and posterior longitudinal ligament.[52] In humans, direct mechanical and indirect vascular compromise in the lumbar canal lead to neurogenic claudicatory and radicular complaints attributed to primary or secondary ischemia of the cauda equina with ectopic neural impulses.

Experimental Models

Experimental models of lumbar stenosis reveal the pathological changes that occur with increasing compression of the cauda equina. In dogs, Delamarter, et al.,[18] found that after 3 months of 50% lumbar canal compromise, vascular changes included weakness with markedly abnormal evoked potentials on electrodiagnostic studies and pathological findings of edema, root demyelination, and
moderate venous congestion. Severe weakness, tail paralysis, urinary incontinence, and marked evoked potential changes were noted after 3 months of 75% compression. The chronic venous congestion contributed to "demyelinization, pia-arachnoidal adhesions, interstitial fibrosis, and thick-walled congested veins."[109]

**TYPES OF LUMBAR STENOSIS**

*Difusse Stenosis*

Verbiest[104-108] defined two types of lumbar stenosis after he observed four patients with narrowed canals and sciatica who improved following laminectomy. Those patients with congenital or short pedicle stenosis (absolute stenosis defined as an anteroposterior diameter of 10-12 mm) and the narrowest canals developed cauda equina and nerve root compression earlier than those with developmental or acquired stenosis (relative stenosis defined as a diameter of > 13 mm). The latter patients exhibited milder symptoms initially or a gradual onset of symptoms resulting from increased spondylotic intrusion due predominantly to hypertrophied yellow and capsular ligaments; later they developed medially impinging arthrotic facets. Further degenerative changes developing in conjunction with a baseline normal lumbar canal diameter of 22 to 25 mm, if of sufficient magnitude, could precipitate the onset of claudicatory symptoms.

Lumbar stenosis is classically managed by performing a decompressive laminectomy followed by a medial facetectomy and foraminotomy. Preservation of the articular facets is accomplished with angled, narrow-tipped, filed-down Kerrison rongeurs by using an undercutting technique.

*Lateral Recess Stenosis*

In the 1960s, 1970s, and 1980s, Epstein and coworkers,[24,25,27] and Getty, et al.,[40] defined lateral recess and subarticular stenosis without sagittal narrowing of the lumbar canal. Radiculopathy in 15 patients treated by Epstein and colleagues was relieved by performing focal interlaminar laminotomy and medial facetectomy and foraminotomy to unroof the lateral recesses and subarticular path of the compromised nerve root. For years bilateral lateral recess compromise was also managed by means of coronal hemilaminectomy, essentially the same procedure as the trumpet laminectomy performed by Kanamori, et al.[57] Using this procedure, Kanamori, et al., attained continued stability in 35 of 50 patients as demonstrated on dynamic x-rays films obtained 5.2 years postoperatively.

*Acute Disc Herniations*

In spinal stenosis, acute disc herniations, even if they are relatively small, may precipitate severe neural compression and increased neurological deficit, which is characterized by cauda equina syndromes when central or radiculopathic.[26,108] Neurological findings are often located more unilaterally, with compression occurring along the nerve root toward its exit from the thecal sac, over the caudal disc space, beneath the superior articular facet and around the pedicle, to and through the neural foramen into the far-lateral compartment. Narrowing may be further exacerbated by spondylosis, with hypertrophy of the ligamentum flavum and facet joints.

*Levels of Stenosis*

Lumbar stenosis may be limited to one or two disc segments or it may be multisegmental. The most frequent site of involvement is the L4-5 level, followed in descending order by L3-4, L2-3, L5-S1, and
L1-2. Hyperlordosis, laminar shingling, infolding of the ligamenta flava and capsular ligaments, and degenerative discal changes with marginal osteophytes increase stenosis, precipitating the onset of symptoms.

Other Types Of Stenosis

Several other entities mimic the claudicatory findings associated with lumbar stenosis. Patients with peripheral vascular claudication requiring revascularization may experience similar pain when walking; however, they achieve relief by stopping to rest, not by sitting down or bending forward.[42] One-third of patients with severe cervical stenosis and apparent lumbar claudication improve following cervical decompression.[5,35] Patients with tumors of the cauda equina or conus medullaris, such as ependymomas, neurofibromas, meningiomas, and metastatic carcinomas, can present with the symptoms of spinal stenosis; similar symptoms may occur in patients with herniated thoracic discs, spondylisis, stenosis, ankylosing spondylitis, osteochondrodystrophy, familial hypophosphatemic Vitamin D refractory rickets, Scheuermann's disease, ossification of the posterior longitudinal ligament (OPLL), ossification of the yellow ligament (OYL), Paget's disease, and acromegaly.[71,85] In achondroplasia, trapezoidal vertebral bodies, short, thickened pedicles, hypertrophied lamina, and vertebral end plates often contribute to early and severe cauda equina syndromes.[28]

CLINICAL FINDINGS

Patients with severe congenital lumbar stenosis begin to show symptoms when aged in their 30s and 40s, whereas those with acquired stenosis develop complaints when aged in their 50s through 80s. Low-back pain is often accompanied by asymmetrical, unilateral more than bilateral, radicular, or claudicatory complaints. Standing and walking, which causes an acute increase in lumbar lordosis and infolding of the ligamenta flava, precipitates claudication that can be readily reversed on flexion (by sitting or lying down). These patients are often able to drive a car even if they cannot walk. Sphincteric changes are rare, occurring late in the clinical course. In the 350 patients undergoing lumbar surgery for stenosis reported by Louis and Nazarian,[68] 57% exhibited unilateral radiculopathy, 43% had bilateral findings, and 67% presented with neurogenic claudication. Similarly, of the patients reported by Verbiest,[104-108] 80% had absolute stenosis and 55% had relative stenosis; all of these exhibited claudicatory symptoms. Of the patients with stenosis reported by Heath,[47] 20% exhibited claudicatory findings.

It is not unusual not to find significant neurological deficits in patients with stenosis. Positive mechanical findings of entrapment (Lasègue's sign, Femoral Stretch Test) occur in 60% of patients with absolute and 43% of patients with mixed stenosis.[105] Mild motor dysfunction most frequently involves the extensor hallucis longus and peroneal muscle groups (L-5), and reflexes may be diffusely diminished or absent, for example, at the Achilles level. Sensory deficits, usually noted in the L-5 or S-1 distributions, are rarely seen in more cephalad L2-4 or more caudad (sacral) distributions.

NEURODIAGNOSTIC STUDIES

Plain X-Ray Films

Plain anteroposterior and lateral lumbar x-ray films allow for assessment of pedicle length, facet joint orientation, and the presence of stenosis with or without superimposed arthrosis. Hyperlordosis, degenerative spondylolisthesis, spondylolisthesis with or without lysis, degenerative scoliosis, OYL, and other pathology may also be identified. Whereas benign lesions may lead to scalloping of the vertebrae (such as a neurofibroma), more destructive changes may indicate the presence of etastic tumors.
Dynamic X-Ray Films

The lumbar ligaments constrain flexion rotation movements and resist posterior shear, whereas the facet joints constrain expansive extension rotation movements along with anterior displacement.[95] Typically lumbar flexion-extension x-ray films, and more recently lateral decubitus dynamic studies, have contributed significantly to the documentation of lumbar instability by demonstrating more than 12° of angulation or 8% active translation.[115] Of note is the somewhat different clinical definition of instability offered by White and Panjabi: "the loss of the ability of the spine under physiologic loads to maintain relationships between vertebrae in such a way that there is neither initial damage nor subsequent irritation to the spinal cord or nerve roots, and, in addition, there is no development of incapacitating deformity or pain due to structural changes."[112] Although some dynamic studies may confirm the presence of instability, using computer-based analyses of data obtained in 101 patients Dvorak, et al.,[23] showed that these studies were not always reliable. Furthermore, Amundsen, et al.,[2] noted a lack of correlation between radiographic findings (computerized tomography [CT]/magnetic resonance [MR]/x-ray studies) and clinical complaints; for example the presence of a slipped disc in a patient who experienced no increase in symptoms.

At the other extreme, Sano and coworkers[94] simply inferred that micromotion and hypermobility were present postoperatively in all patients and that these small movements could not be defined using dynamic x-ray studies. Unfortunately, this led to the performance of postoperative fusions requiring instrumentation in all of his patients to avoid the adhesions between the dura, nerve roots, and surrounding structures associated with instability.

Magnetic Resonance Imaging

Magnetic resonance imaging now increasingly demonstrates evidence of stenosis in older patients who are often asymptomatic. One-third of the asymptomatic patients in the series reported by Boden, et al.,[6] showed significant MR evidence of stenosis. Those patients younger than 60 years of age had a 20% incidence of disc disease, with only one patient showing stenosis. In those patients older than 60 years of age, 36% had herniated discs and 21% had spinal stenosis. Ross and Modic[92] prospectively found a correlation between operative and MR findings in 82.6% of their cases. Additionally, MR imaging provides visualization of the thoracolumbar region and conus medullaris, helping to identify thoracic stenosis or other abnormalities.[90]

Dynamic MR Imaging

Flexion-extension MR studies may help to determine whether dynamic intrusions are clinically significant. When performing dynamic MR imaging in 10 cadavers, Dai, et al.,[16] observed the thecal sac to have an altered volume, particularly when flexion maneuvers were induced: the volume of the thecal sac increased by 3.5 to 6 ml (4.85 ± 0.75 ml) along with an increase in its sagittal diameter and length.

Magnetic Resonance Imaging With Gadolinium-DTPA

Magnetic resonance imaging with gadolinium-diethylenetriamine pentaacetic acid (DTPA), which is often obtained to identify a tumor, may also be used postoperatively in patients to differentiate between scar tissue, which enhances, and the disc, which does not. Ross and Modic,[92] reported MR imaging with gadolinium-DTPA to be 96% accurate in differentiating scar tissue from disc herniations in 44 patients at 50 reoperated levels. Djukic, et al.,[22] determined that enhanced MR imaging readily
differentiated recurrent disc herniation from postoperative scarring while also defining residual or recurrent central or lateral stenosis. Jia and Shi[53] compared MR images with myelographic images in 78 patients with lumbar stenosis and/or disc disease and found that MR imaging was accurate in 88.5% of cases and myelography was accurate in 92.3% of cases. Other types of pathology demonstrated included adhesive arachnoiditis, neural compression from oversized fat grafts, postoperative hematomas, pseudomeningoceles, and infection.[22,53,92]

**Magnetic Resonance Imaging Compared With Myelography**

Annertz, et al.,[3] reported MR imaging to be superior to myelography, especially for identifying lateral and foraminal nerve root compression with isthmic lumbar spondylolisthesis, when comparing the imaging studies in 17 patients. Sagittal MR imaging also better defined the shape and adequacy of the neural foramina.

![Fig. 1. Left: Posterior three-dimensional CT view revealing L2-S1 stenosis in a 69-year-old patient with multilevel degenerative changes involving the laminae and facet joints (arrows). Right: Anterior three-dimensional CT view demonstrating L2-S1 stenosis in the same patient. Marked osteophytic lipping can be seen to occur across different vertebral levels: L3-4 on the left (single arrow) and L4-5 on the right (double arrows). There is a mild degree of resultant degenerative scoliosis.](image)

**Magnetic Resonance Imaging Compared With CT Scanning**

Giles and Kaveri,[41] found MR and noncontrast-enhanced CT studies to be of equal value when used to corroborate low magnification photomicrographs of far-lateral stenosis with findings of vascular compression and venous stasis in cadavers.
Fig. 2. Left: This slightly parasagittal three-dimensional CT view of the lumbar spine reveals that the most marked stenosis occurs at the L2-3 (top open arrow) and L3-4 levels (bottom open arrow). Of interest, this was not related to degenerative slippage but rather to a congenitally narrowed canal with additional superimposed spondyloarthrotic changes. Because CT myelography also revealed stenotic changes involving L4-5 through L5-S1, this patient underwent a laminectomy at L2-S1. One year postoperatively, the patient continues to do well. Right: Anterior three-dimensional CT study obtained in this 71-year-old man revealing that the most marked anterior osteophytic lipping occurs at the L2-3 level (small arrows), the site of retrolisthesis and the most severe stenosis.

**Computerized Tomography Scanning**

Noncontrast enhanced and three-dimensional CT scanning more readily defines the bone configuration of the lumbar canal than does MR imaging. Three-dimensional CT scanning better demonstrates the presence of accompanying lateral and far-lateral discs, limbus vertebral fractures, spondylolisthesis, retrospondylolisthesis, degenerative scoliosis, OYL, and OPLL in anterior, lateral, posterior, axial, and parasagittal views (Figs. 1-4).
Fig. 3. Left: Lateral three-dimensional CT study confirming the severity of circumferential osteophytic lipping occurring at the L2-3 level, the level of retrolisthesis (arrows). A multitude of degenerative changes involving the facet joints and compromised neural foramina can also be visualized. Right: Parasagittal three-dimensional CT study confirming the marked degree of canal narrowing occurring at the L2-3 level due to retrolisthesis of the L-2 vertebral body (open arrow) over the L-3 body. The posterior impingement is due to the leading edge of the L-3 lamina (curved arrow). Note additional shingling of the lumbar lamina contributing to further stenotic changes at L3-4 and L4-5.

Laasonen and Soini[62] reported that postoperative CT studies identified 157 abnormalities in 48 patients in whom residual symptoms were present following lumbar fusions: 27 major lesions were found, including fusion mass fractures, hair line pseudarthroses, and spinal stenosis.
Fig. 4. Transaxial noncontrast-enhanced CT study revealing the marked trefoil configuration of the spinal canal associated with congenital stenosis. Additional arthrotic changes in the facet joints (acquired stenosis) and the acquired degenerative slippage superimposed on this narrowing of the baseline (arrows) contributes to marked compromise of the thecal sac and nerve roots at L2-3.

**Computerized Tomography Myelography**

The CT myelography scanning continues to be the best study for demonstrating initial and recurrent lumbar stenosis. Static studies provide a good overview of calcified or soft-tissue abnormalities and flexion-extension studies reveal dynamic neural compromise along with instability (Figs. 5 and 6).

Fig. 5. Left: Flexion-extension CT myelogram obtained in a 57-year-old woman 1 year after she underwent a L4-5 coronal hemilaminectomy for decompression of Grade I degenerative
spondylolisthesis with an intact neural arch. On the flexion examination the 6-mm chronic slippage progressed acutely to 10 mm and resulted in increased thecal sac and L-5 root impingement (arrows). Right: Postoperative flexion-extension CT myelography study obtained in the same patient, revealing realignment of the L4-5 vertebrae posteriorly (arrows); this is consistent with an active slippage of 1 cm at the level of previous surgery.

The author and coworkers[37] found that CT myelography examinations in 60 patients with far-lateral disc herniations demonstrated the need for more extensive surgery 72% of the time. The use of a contrast agent in the thoracic and cervical spinal canal may also mitigate against overlooking other pathology such as attendant cervical stenosis, which is seen in 10% of patients with lumbar stenosis.[35] If a total myelographic block is encountered, increased flexion often opens the obstruction, allowing adequate contrast material to pass to assess both cephalad and caudal pathology.

Fig. 6. Transaxial CT myelography study showing the marked bilateral thecal sac and nerve root compression recurring at L4-5 due to the hypertrophic facet joints and proliferation of scar tissue (double arrows) which resulted from postoperative instability at this level. Note the posterior defect, indicating a postoperative laminectomy membrane at the site of midline decompression following an initial coronal hemilaminectomy (large single arrow).

**Somatosensory Evoked Potential Monitoring**

Somatosensory evoked potential recordings may be used as a prognostic indicator in patients with lumbar stenosis. Gepstein and Brown's[39] somatosensory evoked potential recordings successfully predicted adequate nerve root untethering in 27 patients with herniated discs and 14 with spinal stenosis. Good intraoperative, 3-week, and 3-month latency and amplitude recordings were also associated with improved postoperative results.

**CONSERVATIVE MANAGEMENT OF SPINAL STENOSIS**

Patients with minor complaints and minimal symptoms related to spinal stenosis, as well as select
individuals who demonstrate greater neurological dysfunction, may be managed without surgery. Rosomoff and Rosomoff[91] successfully treated this type of patient population, including a number of individuals who were severely impaired, by using a combination of sophisticated behavioral, physical, and rehabilitative methods. Nevertheless, most surgeons would consider those patients exhibiting severe neurological dysfunction to be candidates for surgery, provided there were no attendant prohibitive medical risk factors.

**SURGICAL TREATMENT OF LUMBAR STENOSIS**

**Positioning for Surgery**

Single- or multilevel laminotomies, hemilaminectomies, and complete laminectomies are performed with the patient in the knee-chest position, except when hip or knee replacements or other conditions mandate the use of the Cloward saddle. The knee-chest position opens the spinal canal and facilitates dissection, while freeing the abdomen and limiting blood loss and the need for transfusion. During surgery, most patients wear a hard collar with a gel pad under the chin. Nasotracheal fiberoptic intubation while the patient is conscious is reserved for those with significant, documented cervical stenosis. An added advantage to the use of the latter technique is that morbidly obese patients can position themselves for surgery.

**Intraoperative X-Ray Films**

A lateral confirmatory film, suitably marked, is routinely used so that the correct operative levels may be unequivocally confirmed at surgery. Unfortunately, operating at the wrong level without x-ray confirmation still accounts for many failures. The presence of lumbosacral anomalies such as transitional vertebrae mandate that both pre- and intraoperative films be obtained.

**Fenestration Procedures**

Single- or multilevel unilateral or bilateral laminotomies constitute the major alternative to laminectomy in the management of lateral recess stenosis.[66,116] Bilateral laminotomy, or the fenestration technique, preserves the spinous processes and interspinous and supraspinous ligaments, while removing segments of cephalad and especially the leading portion of the caudal lamina, which angulates deeply into the spinal canal. When combined with undercutting medial facetectomies and foraminotomies, nerve roots may be decompressed in the lateral recesses once overhanging portions of hypertrophied facets, lamina, and ligamentum flavum are excised. Preservation of the lateral two-thirds of the facet joint and pars interarticularis preserves the integrity of the facet, limiting postoperative instability. Aryanpur and Ducker[4] performed fenestration procedures in 32 patients with lateral recess stenosis, resulting in good-to-excellent results in 90% of patients 5 years postoperatively. Central canal stenosis and lateral recess stenosis may be managed with the use of a wide fenestration technique. In 34 patients with stenosis followed for an average of 5.5 years, Nakai and coworkers[80] performed fenestration procedures that produced new bone deposition contributing to stability and lasting symptomatic relief for those patients with central stenosis, but not for patients with recurrent stenosis.

In patients with severe degenerative stenosis, hyperlordosis, advanced arthrosis, and scoliosis, restricted procedures are of limited value. Postacchini and Cinotti[86] found in their evaluation of 67 patients with lumbar stenosis who were followed an average of 3.7 years that laminectomy was safer than laminotomy for decompression of severe stenosis, especially when degenerative spondylolisthesis was present.
Fig. 7. Artist's renderings. Left: Prior to surgery, this patient exhibited unilateral lateral recess stenosis and nerve root compression, which was attributed to marked facet arthropathy (single arrowhead), hypertrophy of the yellow ligament, and ventral spur formation (double arrowheads). Right: Removal of the left hemilamina (single arrowhead) combined with medial facetectomy and foraminotomy allowed removal of the compressive portion of the arthrotic facet joint and ligamentum flavum, causing the root to move dorsally into the decompression provided.

**Hemilaminectomy**

Hemilaminectomy provides complete unilateral decompression of lateral recess stenosis at single or multiple levels; the preservation of the contralateral lamina and facets contributes to spinal stability (Figs. 7 and 8).
Fig. 8. Artist's rendering showing that multilevel lateral recess stenosis may be managed by means of multilevel hemilaminectomy and contralateral selective interlaminar laminotomy for focal levels of bilateral disease. At L-3, L-4, L-5, the hemilaminectomies have been completed along with medial facetectomies and foraminotomies (double arrowheads) for decompression of the respective L-4, L-5, and S-1 nerve roots (single arrowheads). Contralaterally, at the L4-5 level, an interlaminar laminotomy with medial facetectomy and foraminotomy provides decompression of the lateral recess containing the exiting L-5 nerve root (three arrowheads).

Ipsi-Contra Procedure

DiPierro, et al.,[21] describe an ipsi-contra procedure performed after completion of typical unilateral decompression(s) that enlarges the central and opposite spinal canal by undercutting the spinous processes and contralateral laminae. In cases where bilateral thecal sac and nerve root decompressions are not feasible, a laminectomy is readily substituted. After the decompression is completed, bone removed at surgery is packed against the decorticated contralateral facet, laminae, and spinous processes to form a fusion mass.

Trumpet Laminectomy

The trumpet laminectomy described by Kanamori, et al.,[57] is comparable to the coronal hemilaminectomy and facilitates segmental decompression of both the anteroposterior diameter and lateral recess (Fig. 9). Degenerative spondylolisthesis may also be treated with this technique by
preserving portions of the cephalad and caudal laminae and thus contributing to postoperative stability.

Fig. 9. Artist's rendering showing a trumpet laminectomy (coronal hemilaminectomy), including removal of half of the cephalad and half of the caudal lamina. Toward the left of the midline, additional removal of the interspinous and supraspinous ligaments and half of their respective spinous processes are included in the resection. This procedure provides adequate bilateral decompression of the nerve roots in the lateral recesses (double arrowheads) and neural foramina (single arrowheads), while enhancing stability.

**Laminectomy**

Laminectomy is usually chosen to manage severe central and lateral stenosis, which includes, especially in older patients, multilevel removal of portions of markedly hypertrophied inferior articular processes that severely impinge on the midline.[4]

The outcome of surgery may be improved by using intraoperative ultrasonography. Using intraoperative ultrasonography in 104 patients, Montalvo, et al.,[78] found they could resect residual disc 41% of the time and correct residual stenosis 23% of the time.

**Expansive Laminoplasty**

Expansive laminoplasty may also be used to manage lumbar stenosis, particularly in younger patients with low-back pain and sciatica associated with primary stenosis, or secondary stenosis attributed to lumbar OPLL. Tsuji, et al.,[101] reported that laminoplasty enlarged the spinal canal and contributed to continued stability. Matsui, et al.,[72] determined by means of CT studies that 10 of 18 patients showed 119% enlargement of the canal, correlating with a 73% improvement in the mean postoperative score.

**OUTCOME ASSESSMENT**

**Primary Operative Success**
Success rates following initial decompressive laminectomy vary from 64 to 80%.[20,21,32-34,82,97,99,102] Nasca[82] found that 71% of 80 patients followed for 5 years experienced good outcomes following laminectomy, even with complete facetectomy for stenosis. Silvers, et al.[97] reported that 75% of 258 patients followed for 4.7 years achieved good-to-excellent results after laminectomy alone; only two of the 258 later required secondary fusions. When Turner and colleagues[102] evaluated 74 published articles on lumbar stenosis, they found that 64% of patients enjoyed excellent outcomes. They found no correlation between outcome quality and the number of levels decompressed, the presence of preoperative disc slippage, or the performance of a primary fusion.

**Frequency of Reoperation**

Katz, et al.[59] noted a 17% rate of reoperation in their 88 patients with stenosis who were followed for 6 years. Herno and coworkers[49] found a slightly lower reoperation frequency (9.8%) among their 108 patients, and Epstein and colleagues[32-34] found that 53 (6%) of our 857 patients with stenosis warranted secondary intervention. Second procedures addressed not only residual, recurrent, and new stenosis at previously decompressed or more cephalad levels, but also dealt with new or recurrent disc herniations, slippage, limbus fractures, instability, and, occasionally, facet fractures.[32-34,59,89] Success rates in the 6 to 17% of cases requiring secondary lumbar decompressions for recurrent or residual lumbar stenosis have been noted to deteriorate to the 50% level.[32-34,49,59,114]

**Criteria For Operative Success And Failure**

Critical to operative success is the initial selection of the appropriate patient to undergo lumbar surgery. Deen and coworkers[17] experienced early failures in 45 patients because of the absence of significant preoperative neurogenic claudication, the lack of severe preoperative stenosis, and inadequate decompressions. Katz and colleagues[59] reported a 17% reoperation rate that was due largely to recurrent stenosis or instability; the poorest long-term outcomes were observed in patients in whom only one level had been treated or in whom there were significant comorbidities such as cardiac, pulmonary, or rheumatoid disease. In their long-term outcome study, Katz and colleagues[58] confirmed that poor prognoses correlated with the presence of preoperative back pain alone, significant medical comorbidities, and attendant functional disabilities. Herno, et al.,[49] used the Oswestry questionnaire in 108 patients older than 50 years of age with stenosis and found that the best outcomes were achieved when only one operation was performed and in patients in whom there was a marked preoperative myelographic block. The poorest outcomes were found in those patients requiring second operations in whom there were significant comorbidities. Of interest, patients who were followed for an average of 12.8 years exhibited better outcomes than those followed for 6.8 years.

The majority of secondary surgeries for lumbar stenosis are performed to treat recurrent, residual, or new cephalad stenosis. Sharply limited primary procedures most commonly contributed to the need for secondary operations. When secondary decompressions to treat recurrent lumbar disease were prospectively completed over a 2-year period, Jonsson and Stromqvist[56] found that the best outcomes were achieved in patients undergoing a second operation for herniated disc or stenosis, the poorest results being noted where fibrosis or scarring alone was present. Caputy and Luessenhop[10] found a failure rate of 27% in 100 patients who averaged 67 years of age and who had been followed for an average of 5 years. Failures in 16 patients were attributed to recurrent stenosis at or above the levels of previous surgery. In their study the most common error was failure to decompress both the primary and adjacent stenosis adequately. Chen and coworkers[12] observed the presence of bone regrowth 41 to 100% of the
time; however, this did not necessarily correlate with the need for additional surgery.

**Equal Outcomes With and Without Fusion**

Grob, et al.,[43] determined that fusion did not appear to improve outcome in their series of 45 patients with degenerative lumbar stenosis who were managed by means of decompression alone (Group I), decompression with focal fusion (Group II), or decompression with complete fusion (Group III). Equal outcomes were achieved in all three groups, fusion not offering any noted benefits.

**Increased Morbidity and Mortality Rates in Fusion**

Deyo and coworkers[19,20] determined that performing fusions in patients with lumbar stenosis, particularly in the geriatric population, resulted in a marked increase in morbidity and mortality rates. In the 1992 study by Deyo, et al.,[19] in which 84% of 122 lumbar procedures were performed between 1986 and 1988 to treat disc disease or stenosis, morbidity and mortality rates increased with patient age and the performance of fusion. An 18% complication rate was observed in those patients older than 75 years of age. Later, Deyo, et al.,[20] reviewed 1789 (6.6%) of 27,111 patients undergoing surgery (average 72 years of age) in whom fusions had been performed and who were followed for an average of 4 years. The 6-week mortality rate following fusion in this older age group was twice that for the overall population, and the complication rate was 1.9 times higher. Blood transfusion requirements were 5.8 times greater, nursing home referrals were 2.2 times more frequent, and hospital charges were 1.5-fold above the average for patients who did not undergo fusion. Additionally, performing an initial fusion did not alter the requirement for subsequent secondary surgery.

**Cerebrospinal Fluid Fistulas**

A cerebrospinal fluid fistula may occur in 5% of primary and 10% or more of secondary lumbar decompressions for stenosis.[32-34] Primary closure of the dural defect at the time of surgery is critical. Direct suturing of the defect with 7-0 Gor-Tex, nonresorbable suture is advantageous because the needle is smaller in diameter than the suture itself. Newly available titanium dural staples, varying in size from 1.4 to 3 mm, may be used to repair the deepest and most difficult to reach defects. Occasionally, dural grafts are also needed; they should be directly sutured or stapled into place. Cryoglue, composed of cryoprecipitate and calcium-thrombin, is effective only when used in conjunction with a good direct dural closure, because it will be reabsorbed 5 to 7 days postoperatively. Lumboperitoneal shunts are rarely required.

**ASSOCIATED CONDITIONS**

**Disc Herniations**

The frequency of disc herniations in the presence of spinal stenosis is 15% in the series by Hall, et al.,[45] 33% in the study by Heath,[47] and 45% in the author's recent series of 857 individuals with spinal stenosis.[32-34] Disc herniations associated with degenerative spondylolisthesis and an intact neural arch occurred in 20% of Alexander and coworker's[1] 50 patients; however, Tsou and Hopp[100] found a lesser incidence of 4.3%. Our recent data show that 74 (23%) of 320 patients with degenerative spondylolisthesis exhibited attendant, extruded, or sequestered disc herniations.

**Far-Lateral Lesions**

Far-lateral discs are defined as those that are located beyond the dural sleeve in the far-lateral
compartment beyond the level of the pedicle.[29-31] However, many far-lateral lesions including herniated discs, limbus fractures with or without accompanying stenosis, and slippage, occur with significantly more medial and subarticular foraminal conditions. Computerized tomography myelography studies of these lesions in older individuals identify these additional problems 72% of the time and most warrant more extensive surgical decompression.[37] A recent assessment of 170 patients with far-lateral disc herniations showed comparable outcomes for those managed with partial facetectomy, complete facetectomy, or the intertransverse approach.[30] These patients often had associated evidence of intraspinal conditions that required more extensive decompression.

**Limbus Vertebral Fractures**

Four types of limbus fractures may accompany lumbar stenosis and/or the disc herniations seen in conjunction with stenosis.[32-34] Type I limbus fractures at the vertebral margins span the width of the disc space. Type II lesions consist of both cortical and cancellous bone fragments located medially at the interspace. Type III lesions are lateral chip fractures. Type IV fractures span the entire length and breadth of a vertebral body. These fractures, depending on their size and location, may contribute to cauda equina and nerve root compression.

**Degenerative Spondylolisthesis With An Intact Neural Arch**

**Levels.** Degenerative spondylolisthesis is an acquired variant of lumbar stenosis found most commonly at the L4-5 level, followed with decreasing frequency by L3-4, L2-3, L5-S1, and L1-2.[7,11,32-34,36,67] Of the 60 patients with degenerative spondylolisthesis studied by Epstein, et al.,[36] 56 had lesions at L4-5, followed by two at L3-4, and two at L5-S1. Women aged 40 through 60 years exhibit slippage in a 2:1 to 10:1 prevalence compared with men.[7]

**Cause.** Degenerative spondylolisthesis is caused largely by exaggerated sagittal rather than coronal orientation of the facet joints (Fig. 10).[44] The facets play a major role in resistance to large extension rotation maneuvers while resisting anterior displacement. The increased sagittal configuration predisposes to a Grade I anterolisthesis, restricted to one-quarter of the vertebral body because of hypertrophied posterior facets that limit forward displacement.[28,95] The relative stability and lack of slippage at L5-S1 can be attributed to its location below the intercrestal line and the added support provided by the elongated transverse processes and strong iliotransverse ligaments.
Fig. 10. Left: Illustration of degenerative spondylolisthesis with an intact neural arch resulting in the compromise of the lumbar spinal canal, most typically at L4-5. An abnormal sagittal rather than coronal orientation of the facet joints (single arrowhead) predisposes to slippage (double arrowheads) which then contributes to progressive arthrotic changes of the facet joints. Secondary stenosis results in both thecal sac and bilateral nerve root compression, in this instance compromising the L-5 root (triple arrowheads). Right: A laminectomy of L-4 (single arrowhead), coronal hemilaminectomy of the cephalad portion of L-5 (double arrowheads), and medial facetectomy and foraminotomy at both L3-4 and L4-5 allow for adequate decompression of severe L4-5 degenerative spondylolisthesis. Note the relief of compromise for the entire thecal sac and exiting L-5 nerve roots (triple arrowheads).

Fenestration Approach. Mild-to-moderate single-level degenerative spondylolisthesis may be treated by means of a bilateral fenestration (laminotomy) or the trumpet laminectomy (coronal hemilaminectomy) technique.[26,32-34,36] Getty and coworkers successfully managed 78 patients by using this type of decompression without fusion.

Laminectomy. Laminectomy is warranted for the management of more extensive stenosis in conjunction with slippage.[51] In a 1983 report by Epstein and coworkers,[36] 40 of their patients underwent multilevel laminectomies, 14 underwent coronal hemilaminectomies, and six underwent interlaminar laminotomies or fenestration procedures to treat degenerative spondylolisthetic stenosis. In an earlier series of 191 patients with degenerative spondylolisthesis, we performed four primary fusions and three secondary fusions, encompassing 3.7% of our patient population.[32-34] In our updated series, 30 (9.4%) of the 320 patients required fusion.

Author's Series of 320 Patients With Degenerative Spondylolisthesis. Recently, the author and her colleagues assessed the management of 320 of their patients with degenerative spondylolisthesis (unpublished data). These patients averaged 66 years of age and the female/male ratio was 2:1. During an average follow-up period of at least 10 years, these patients required 279 laminectomies and 41 hemilaminectomies/laminotomies. Laminectomy decompressions covered an average of 3.2 levels, and hemilaminectomies/laminotomies averaged 1.7 levels. A single-level of disc slippage was demonstrated
in 277 patients (87%): at L3-4 in 24 patients, at L4-5 in 234 patients, and at L5-S1 in 19 patients. Two-level slippage was noted in 43 patients (13%): most occurring at the L3-4/L4-5 interspace. Disc herniations were present at the first procedure in 74 patients (23%).

Of these 320 patients, fusions were performed in 30 during the first surgery (9.3%). A second fusion was required in another nine, and two underwent tertiary fusions. The types of fusions included 25 Texas Scottish Rite Hospital (TSRH) instrumented procedures, and five Hibbs fusions covering an average of 3.5 levels.

Disc herniations found in the 30 patients who underwent primary fusions included six single routine disc, six double-disc, and three far-lateral disc herniations. These herniations were located at the level of the disc slippage in 10 patients and at another interspace in five.

**Outcomes For Degenerative Spondylolisthesis.** In both the old and new series, good-to-excellent outcomes have been observed in more than 80% of our patients with degenerative spondylolisthesis.[36] During an 18-month follow-up period, Herron and Mangelsdorf[50] found that 20 (83%) of their 24 patients with degenerative spondylolisthesis in whom laminectomy alone had been performed did well despite a slight increase in slippage. The average 7-mm preoperative chronic slippage (active < 2 mm) increased postoperatively to 8 mm (active < 4 mm), as documented on lateral flexion-extension x-ray films. Similarly, Sanderson and Wood[93] reported that 19 of their 31 patients older than 65 years of age in whom lumbar decompression without fusion was performed to treat degenerative spondylolisthesis had the same good-to-excellent outcome rate (81%) as their younger cohort. Preoperative slippage was not a factor in either group. Johnsson, et al.,[54] reported that 20 of 45 patients remained asymptomatic despite postoperative progression of preoperative slippage.

**When to Fuse in Degenerative Spondylolisthesis.** Assessing preoperative stability in patients with degenerative spondylolisthesis is critical. Those patients who exhibit clearly symptomatic and clinically unstable slippage on flexion-extension or lateral decubitus x-ray films should undergo primary fusion.[32-34,112,115] In our experience, this group constitutes from 5 to 10% of the population presenting with slippage.

On the contrary, others like Bolesta and Bohlman[7] have determined that patients with spondylolisthesis should undergo fusion. McCullen, et al.,[76] came to the same conclusion after an 11-year follow-up in 50 patients who had undergone laminectomy. They observed poorer outcomes for those who had demonstrated preoperative slippage. However, performing fusion may also increase the probability of precipitating a secondary degenerative slippage above the fusion site. Lee[63] found this to be the case in two of 18 patients followed 8.5 years. Both exhibited new slippage.

**Degenerative Scoliosis.** Degenerative scoliosis may contribute to asymmetrical nerve root and cauda equina compression. Vertebral body rotation and loss of alignment may prompt performance of complete rather than medial facetectomy, particularly in the hollow of the curve where the pedicles approximate each other. Although the author advocates limited decompression for scoliotic stenosis with radiculopathy in most patients, attention must be directed to the increased morbidity and mortality rates in these older patients when advocating fusion. Simmons and Simmons[98] performed fusion in 40 such patients and achieved postoperative pain relief in 93%, with a 19° deformity correction. These patients were followed for an average of 44 months. The laminectomy and pedicle screw fixation techniques they used included the Zielke (24 patients), the Cotrel-Dubousset (eight patients), and the TSRH (eight patients) systems.
Spondylolisthesis With Lysis in Older Patients. Older individuals with spondylolisthesis and lysis rarely exhibit symptoms of central stenosis because the lytic defect allows the lamina to "rise" away from the underlying neural structures. However, late lateral arthrotic changes and subarticular masses contribute to the compromise of available space for the superiorly and inferiorly exiting nerve roots. The lamina and bilateral facets may be resected in selected older patients without producing pathological motion at the level of slippage, thus avoiding attendant fusion. Conversely, if significant motion is demonstrated prior to surgery in these older patients, the necessity for a fusion should be anticipated because the additional facet decompression will further destabilize the spine.[3,8,60,61,70,103]

SUMMARY

Fusion for Spinal Stenosis

Younger patients with spinal stenosis in whom radiographic and clinical instability are demonstrated should undergo primary fusion, whereas the majority of older individuals should be treated by laminectomy alone. Of 857 patients with spinal stenosis who underwent laminectomy or medial facetectomy, only 39 (4.6%) required fusion.[32–34] Of 320 individuals recently diagnosed with degenerative spondylolisthesis, 30 (9.4%) warranted fusion at the first surgery, whereas only nine (2.8%) underwent secondary fusion. Rosomoff and Rosomoff[91] observed that only one patient (2%) of 50 in whom laminectomy with complete facetectomy had been performed required a secondary fusion. Thirty-six of these 50 patients had undergone a previous surgery. Similarly, Shenkin and Hash[96] treated 59 patients with stenosis by means of multilevel laminectomies and full inferior facetectomies and these patients demonstrated a 10% incidence of increased slippage; however, only two (3.4%) required secondary fusion. The frequency of postoperative slippage progressed with the number of levels decompressed, from 6% for two levels to 15% for three or more. After performing 342 laminectomies for lumbar stenosis, Tsou and Hopp[100] found a comparable frequency (4.6%) of increased slippage that warranted secondary fusion. Young, et al.,[116] reported 50 patients with Grade I degenerative spondylolisthesis who were managed by means of laminectomy and medial facetectomy, and only 4% required a second fusion.

Fusion Frequency

Some authors maintain that primary fusion is a necessary compliment to decompression.[11,46,54,55,64,67] For example, Johnsson, et al.,[55] observed a marked increase in slippage and poorer clinical results following decompression alone in 45 patients with lumbar stenosis. Of note in their series was the use of extended laminectomies that included complete bilateral facetectomies rather than restricted medial facetectomies. In 1989, the same authors[54] reported on 61 patients with spondylolisthesis, 43% of whom were symptomatic. These patients underwent wide laminectomies and complete multilevel facetectomies, and experienced increased postoperative slippage. Similarily, Cauchoix and coworkers[11] noted an increase (13%) in slippage among their patients with degenerative spondylolisthesis. Nasca and Littlefield[83] evaluated the outcome of decompression with frequent fusion, and found that two of 15 patients with lateral recess narrowing who underwent fusion did well, as did 70% of 15 patients with mixed central stenosis. Additionally, in 43 patients with postoperative stenosis and 11 with scoliosis/stenosis, patients who underwent fusion achieved a better outcome.

However, fusion does not guarantee success. Lee[64,65] observed a 27.3% incidence of pseudarthrosis
among 22 patients in whom initial laminectomies with fusion were performed; 18% of these showed an increase in postoperative slippage. Cauchoix, et al.,[11] performed primary fusion in three of 26 patients with degenerative spondylolisthesis, as well as secondary fusion in another three patients (12%) because of slippage progression.

Evaluation of recurrent symptoms in patients who have previously undergone fusion is another problem. Using CT scanning, Laasonen and Soini[62] documented 157 abnormalities in 48 individuals who had previously undergone fusion for stenosis. Computerized tomography examinations demonstrated fusion mass fractures in 16 patients, hair-line fractures with pseudarthroses in nine, and recurrent stenosis in eight. Recurrent stenosis significantly contributed to the 20 (42%) second operations that were performed. Outcomes, evaluated over periods ranging from 6 months to 4 years, remained good in spite of this relatively high frequency of secondary surgery.

**Fusion Techniques**

**Bilateral Intertransverse Process Fusions.** Brodsky[9] reviewed a 32-year experience with 184 patients treated by means of L4-5 floating fusions for disc disease and instability and found that 83.7% of patients exhibited excellent-to-good outcomes, 15.2% experienced fair outcomes, and 2% had poor results. Only 2.7% of patients developed new L5-S1 disc herniations that mandated excision and fusion to the sacrum.

**Posterior Lumbar Interbody Fusion.** Cloward[13] advocated posterior lumbar interbody fusion (PLIF) in the treatment of disc herniation or single-level instability. Mitsunaga and coworkers[77] achieved successful fusion and the resolution of symptoms in 22 of 27 patients who had undergone prior surgery for spondylolisthesis or chronic low-back pain by using PLIF. Wetzel and LaRocca[111] performed 37 procedures in 12 patients, averaging 40 years of age, in whom PLIFs had failed. Eleven of these failures were attributed to instances of marked epidural fibrosis, nine to pseudarthroses, and four to instances of instability at nearby levels. Twenty-two new operations, followed by 10 repeated decompressions, led to seven successful fusions. Five patients improved. Fusion did not directly correlate with the quality of outcome.

**Pedicle Fixation.** Pedicle fixation offers immediate stabilization and increases the success of fusion achieved by the application of bone graft. Whitecloud, et al.,[113] observed a 62.5% incidence of initial excellent-to-good results, with a 45% rate of operative complications. The rate of poor outcomes was 29% when no prior surgery had been performed, but rose to 63% in the face of previous surgery. Marchesi, et al.,[69] cited an 88% incidence of good results, with a 6% frequency of pseudarthrosis in 68 patients treated with the AO internal fixation system for spondylolisthesis, postlaminectomy instability, posttraumatic kyphosis, degenerative scoliosis, stenosis, tumors, and infections.

Screw misplacement associated with the use of these systems likely contributes to some of the complications seen in those patients treated with screw plate/rod systems. It is hard to believe that Marchesi, et al.,[69] achieved perfect placement of 322 transpedicular screws in his series, particularly when Weinstein, et al.,[110] found that 21% of screws were inaccurately placed in his series of cadavers. Furthermore, inaccurate screw placement and broken screws (5.7% in 21 patients) likely accounted for 11% of new motor deficits and 3.5% of new sensory deficits observed in 57 patients who underwent fusion with instrumentation reported by MatsuZaki, et al.[73]

In patients with spondylolisthesis, the initial degree of slippage correction often decreased over time. Colemont and colleagues[14] observed that 84% of excellent-to-good results observed in the first 6
months after surgery declined to 56% over the next 1 to 2 years. McAfee and coworkers[75] in their review of 78 Steffee plate and 42 Cotrel-Dubousset rod placements noted that of 526 pedicle screws placed, 22 (4.18%) problems arose in 12 patients. Puno, et al.,[87] found the TSRH and Cotrel-Dubousset devices to be less rigid than the plate systems (Steffée plate), but more rigid than wired implants (Luque system). Advantages of the rod system include more available space for the application of bone graft, with rods being more easily contoured.[87] An added consideration in the older patients is osteoporosis, which increases the likelihood of postoperative pedicle fractures with resultant screw pull out.

**Knodt Rods.** Conley and coworkers[15] and Nasca[81] showed that older patients with one- or two-level stenosis and/or spondylolisthesis could be successfully managed using Knodt rods. However, this hardware has not proven to be an optimal construct and is therefore used by few surgeons.

**Stainless Steel Rectangles** Although Ogilvie and Bradford[84] achieved an 84% rate of fusion following decompression supplemented by stainless steel rectangles, they have since abandoned the technique.

**Success Without Fusion**

Decompressive laminectomy without fusion is successful 80 to 96% of the time. Alexander, et al.,[1] noted a 91% frequency of good outcomes after 3 years and an 87% frequency of good outcomes 6 years later in 50 patients with degenerative spondylolisthesis who were treated by laminectomy alone. Hall and colleagues[45] reported a success rate of 84% in 68 patients treated by means of decompression and studied for 4 years postoperatively. Ganz[38] observed an 82% frequency of good results in 33 consecutive patients undergoing lumbar decompression for stenosis. Mauersberger and Nietgen[74] similarly noted that 80% of their patients with lumbar stenosis improved after surgery. These results were not dependent on age, as documented by Katz, et al.[59]

**Successful Fusion Without Instrumentation**

Herkowitz and Kurz,[48] Lombardi, et al.,[67] and Louis and Nazarian[68] believed that better postoperative results may be achieved by performing laminectomy supplemented by earlier noninstrumented fusions. These fusions were performed to avert the 27% failure rate observed 5 years following decompressive laminectomy in such series as that published by Caputy, et al.[10] To assess the impact of fusion on the management of degenerative spondylolisthesis, Herkowitz and Kurz[48] conducted a 3-year, prospective trial in 50 patients with degenerative spondylolisthesis: half underwent fusion and the other half underwent decompression. The patients who underwent fusion experienced better outcomes. Similarly, the patients with degenerative spondylolisthesis reported by Lombardi, et al.,[69] who were treated by means of additional intertransverse process fusion after laminectomy demonstrated a 90% incidence of good-to-excellent results, compared with an 80% frequency of good outcomes following laminectomy and a 33% frequency of good outcomes after laminectomy with complete facetectomies. In the 350 patients with spinal stenosis reported by Louis and Nazarian,[68] 65% of those undergoing decompression alone did well, whereas 85% of those in whom fusion was simultaneously performed improved.

**Surgical Complications**

The most common reason for operative failure in lumbar stenosis is poor patient selection, including those who receive financial compensation through litigation whereby "failure" is rewarded.[50,79] Morbidity, mortality, and complication rates are lower among those patients undergoing laminectomy...
alone, compared with those undergoing fusion, particularly in the geriatric population.[19,105] Quigley, et al.[88] successfully treated 143 patients older than 70 years of age. They performed 155 operations: 32 for disc disease, 29 for disc disease and stenosis, and 94 for stenosis alone. They observed that the average hospital stay of 7.5 days was not prolonged by the advanced age of these patients and there was no significant increase in the 6.9% incidence of major morbidity without mortality as long as fusions were not performed. Also, 34.3 months postoperatively, 66.6% of the patients had few or minimal symptoms and 77.3% enjoyed good postoperative outcomes.

Postoperative stenosis related to bone regrowth contributes to recurrent symptoms.[86] Postacchini and Cinotti[86] studied 50 patients over an 8.6-year period, in whom they performed 32 laminectomies and eight fenestration procedures. Thirty-four patients suffered stenosis and 16 suffered degenerative spondylolisthesis. Ten of these 16 patients with slippage underwent fusion. They were then divided into four groups according to the amount of bone regrowth contributing to recurrent stenosis. The best long-term results for lumbar stenosis were achieved when bone regrowth was limited by primary fusion, especially for those patients with degenerative spondylolisthesis.

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