Degenerative lumbar spinal stenosis is a major cause of pain and dysfunction in the elderly. Most patients report leg and/or back pain and have progressive symptoms after walking or standing for even short periods of time. Diagnosis is typically made based on clinical history and physical examination and is confirmed on imaging studies. In most cases, treatment should begin with nonsurgical management. In the rare case of a progressive neurologic deficit or cauda equina syndrome, urgent surgical decompression is indicated. In most cases, the natural history of degenerative lumbar stenosis is variable and does not follow a progressively deteriorating course.

Recent prospective randomized trials, particularly the Spine Patient Outcomes Research Trial (SPORT) study, have provided compelling evidence that decompressive surgery is an effective treatment that provides pain relief and functional improvement in patients with degenerative lumbar spinal stenosis.2,3

Etiology

Lumbar spinal stenosis is a reduction in the volume of the central spinal canal, the lateral recesses, and/or neuroforamina that decreases the space available for the thecal sac and/or exiting nerve roots.4,5 Approximately 20% of the time, this condition is caused or exacerbated by mechanical factors and/or biochemical alterations within the intervertebral disk that lead to disk space collapse, facet joint hypertrophy, soft-tissue infolding, and osteophyte formation, which narrows the space available for the thecal sac and exiting nerve roots. The clinical consequence of this compression is neurogenic claudication and varying degrees of leg and back pain. Degenerative lumbar spinal stenosis is a major cause of pain and impaired quality of life in the elderly. The natural history of this condition varies; however, it has not been shown to worsen progressively. Nonsurgical management consists of nonsteroidal anti-inflammatory drugs, physical therapy, and epidural steroid injections. If nonsurgical management is unsuccessful and neurologic decline persists or progresses, surgical treatment, most commonly laminectomy, is indicated. Recent prospective randomized studies have demonstrated that surgery is superior to nonsurgical management in terms of controlling pain and improving function in patients with lumbar spinal stenosis.

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Degenerative Lumbar Spinal Stenosis: Evaluation and Management

by congenital causes, such as failure of the posterior elements to develop, resulting in short pedicles and laminae. More commonly, lumbar stenosis is the result of degenerative changes. The degenerative process is thought to be initiated by disk dehydration, disk bulging, and collapse of the disk space, which sets in motion the sequence of events that result in narrowing of the spinal canal. Disk space narrowing and loss of the normal shock absorptive capacity of the spinal segment results in an increased transfer of stress to the facet joints, which accelerates facet joint cartilage degeneration and osteophyte formation. Facet joint hypertrophy, in- folding of the ligamentum flavum, and development of bulging disk osteophyte complexes all contribute to circumferential narrowing of the central spinal canal and lateral recesses, that is, the area of the spine bordered by the superior articular facet posteriorly, the disk and vertebral body anteriorly, the thecal sac medially, and the pedicle laterally. These stenotic changes cause neural compression that presents clinically as variable degrees of leg and back pain, as well as gait deterioration and other neurologic deficits (eg, numbness and weakness).

Natural History

Prevalence of degenerative lumbar spondylosis in the general population ranges from 20% to 25% and increases with age >50 years. The natural history of this disease remains unclear given the lack of prospective studies with observational cohorts. Johnson et al9 followed 32 untreated patients with spinal stenosis over 49 months. Symptoms of neurogenic claudication remained unchanged in 22 patients (70%), symptoms improved in 5 patients (15%), and symptoms worsened in 5 patients (15%). None of the patients had severe deterioration.

Cauda equina syndrome is a rare condition caused by compression of the lumbosacral nerve roots within the spinal canal that produces varying degrees of motor weakness; saddle anesthesia; and bowel, bladder, and gait dysfunction. Acute presentation frequently occurs in patients with large central disk herniation, whereas delayed presentation often occurs in patients with chronic spinal stenosis. Surgical decompression should be performed as soon as possible to avoid progression of neurologic deficits.

Diagnosis

Clinical Presentation

Patients with lumbar spondylotic stenosis most commonly present with neurogenic claudication and report discomfort while standing as well as diminished walking capacity. In a series of 68 patients with lumbar spinal stenosis confirmed with myelography and surgery, neurogenic claudication was observed in 94% of patients, with primary symptoms of pain (93%), numbness (63%), or weakness (43%) reported. These symptoms may be localized to the buttocks and can radiate to the lower extremities in a proximal to distal fashion. Patients with lumbar spondylotic stenosis have diminished standing and walking tolerance; however, their ability to walk distances can be increased by ambulating with the spine in a flexed-forward posture such as that used when pushing a shopping cart. Typically, spinal extension narrows the spinal canal and worsens neurogenic symptoms, whereas spinal flexion and sitting increases the diameter of the spinal canal, partially alleviating symptoms.

On physical examination, back pain or lower extremity symptoms can be elicited with lumbar extension. Objective sensory findings such as diminished sensation along a specific dermatome or motor weakness suggest long-standing neural compression. Radicular symptoms are most commonly seen in patients with lateral recess or foraminal stenosis.

Patients with spondylotic stenosis may also present with neurogenic or vascular claudication. The orthopaedic surgeon must distinguish neurogenic claudication from vascular claudication; patients with vascular claudication may present with diminished walking capacity due to cramping of lower extremity muscles on exertion. Unlike patients with neurogenic claudication, patients with vascular claudication cannot improve walking tolerance with postural changes. Patients with neuro-

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genic claudication typically cannot alleviate symptoms simply by ceasing to walk; these patients must sit or adopt a flexed-forward posture to alleviate symptoms. Patients with vascular claudication have similar symptoms whether ambulating or riding a stationary bicycle, whereas patients with neurogenic claudication have diminished symptoms of claudication while in a seated position. In addition, patients with vascular claudication may have evidence of vascular changes such as trophic changes in the skin of the legs and feet as well as diminished distal pulses; this is typically not observed in patients with neurogenic claudication.12

Radiographic Evaluation
Clinical history and physical examination aid in diagnosis of degenerative lumbar spinal stenosis. Typically, imaging studies are used to confirm the diagnosis and identify the levels involved as well as any associated pathology. Plain standing AP and lateral radiographs may demonstrate spondylolisthesis, disk space narrowing, end-plate sclerosis, osteophytes, and facet hypertrophy.13 Lateral and flexion and extension stress radiographs may be helpful in determining whether spondylolisthesis is mobile and may demonstrate a slip that is not visible on the plain standing lateral view.

No consensus exists regarding the definition of spinal stenosis in terms of the diameter of the spinal canal or area measurements. Often, the degree of soft-tissue compression that can be caused by ligament infolding is underestimated when these measurements are used to assess spinal stenosis on CT. Furthermore, measurements of midsagittal and anterior-posterior canal diameter may appear normal in patients with trefoil-shaped spinal canals who have clinically relevant lateral recess stenosis with compression of traversing nerve roots. The degree of spinal stenosis is best evaluated on MRI because it can demonstrate disk degeneration or herniation, hypertrophy of the ligamentum flavum and facet capsule, and narrowing of the central canal and lateral recess (Figure 1, A and B). Parasagittal T1-weighted magnetic resonance images may demonstrate loss of epidural fat at the exiting nerve root or frank nerve root deformation, which suggests entrapment of the root in the foraminal13 (Figure 1, C). Radiographic findings that indicate likely instability include the presence of gapped facets on axial CT scan and fluid-filled facets visible on axial T2-weighted magnetic resonance images.14 In patients without lumbar spinal stenosis, supine magnetic resonance images show sedimentation of the lumbar nerve roots to the dorsal part of the thecal sac as a result of gravity. The absence of normal sedi-

![Figure 1](image-url)
magnified in the elderly population. When MRI cannot be obtained, myelography followed by CT may be used to assess the degree and location of stenosis; these imaging modalities are helpful for preoperative identification of locations that require decompression. Radiographic changes are often seen in patients who are asymptomatic; therefore, correlation of imaging results with clinical findings is essential for identification of relevant pathology. In a study of 67 asymptomatic patients who had no reports of low back pain, sciatica, or neurogenic claudication, Boden et al reported that MRI findings in patients aged ≥60 years were abnormal on approximately 57% of the scans, with 21% of scans demonstrating spinal stenosis.

Management

Nonsurgical

The goals of therapy in patients with degenerative lumbar stenosis are to alleviate pain and improve function. Nonsteroidal anti-inflammatory drugs (NSAIDs) may temporarily and partially alleviate pain. In general, narcotic analgesics should be avoided or used on a short-term basis preoperatively and as needed in the immediate postoperative period. Both NSAIDs and narcotic analgesics can be especially problematic in the elderly patient population. NSAIDs have been associated with an increased risk of bleeding, gastrointestinal, liver, renal, cardiovascular, and central nervous system complications in the elderly. Narcotic analgesics are associated with significant alterations in normal mood and sleepwake cycle as well as gastrointestinal complications and potential respiratory suppression; these symptoms are magnified in the elderly population. Physical therapy, with an emphasis on abdominal flexion exercises and core muscle strengthening, may help to improve muscle strength, maintain range of motion, and improve global functioning. In a randomized clinical trial that compared two physical therapy programs for patients with lumbar spinal stenosis, 18 of 29 patients (62%) treated with a 6-week regimen of manual physical therapy, body weight supported treadmill walking, and exercise demonstrated improvement in disability, satisfaction, and treadmill walking tests at 1-year follow-up.

Epidural steroid injections can also be used to provide temporary relief of radicular symptoms in select patients.20 In a prospective study of 34 patients with radicular pain caused by degenerative lumbar spinal stenosis, Botwin et al treated patients with fluoroscopy-guided lumbar transforaminal epidural injections. The authors reported that 75% of patients noted at least a >50% reduction in pain scores, 64% had improved walking tolerance, and 57% had improved standing tolerance at 1-year follow-up. Other studies have reported temporary improvement in pain and function following epidural injection. Tran et al performed a meta-analysis of randomized controlled trials to examine nonsurgical management of lumbar spinal stenosis, including the use of lumbar epidural injection used to manage lumbar spondylotic stenosis. They determined that there may be no added benefit in adding steroids to the anesthetic injection. Additionally, concerns exist regarding the effects on bone quality and blood glucose levels with repetitive use of steroids. In patients with severe neurologic deficit, including limited walking capacity or cauda equina syndrome, epidural steroid injections can exacerbate symptoms; case reports have described complications such as vascular injury, hematoma formation, and paralysis. Furthermore, clear evidence-based guidelines are lacking regarding the number and frequency of injections needed to manage spinal stenosis.

Surgical

Surgery is indicated in patients with clinical and radiographic evidence of spinal stenosis who have intractable pain, altered quality of life, or substantially diminished functional capacity and have either failed nonsurgical treatment or are not candidates for nonsurgical treatment. Surgery can predictably address positional back pain and neurogenic claudication, but may not adequately address pain secondary to degenerative disk disease (eg, low back pain, referred pain).

The method of surgical intervention is based on the location and character of stenosis. Spinal stenosis usually occurs as the result of a global degenerative process that involves the central canal, lateral recesses, neuroforamina, or a combination of these structures. Compression may be isolated or may extend to multiple levels and can involve the central or lateral nerve roots, those in the foramen, or a combination of all three. Radicular symptoms or motor weakness along specific nerve root distributions require careful assessment of the lateral recess and foramen.4,6 Relative stability of the diseased segment should also be assessed. Hypermobile segments (ie, segments demonstrating spondylolisthesis, lateral listhesis, widened facets with fluid visible on MRI) adjacent to more normal segments may require stabilization with in situ fusion techniques or instrumented arthrodesis and fusion. Neurogenic claudication with central canal stenosis may require laminectomy, laminotomy, or indirect reduction
techniques for decompression of the
central canal. These techniques can
be performed via traditional open
approaches or minimally invasive
techniques.

Laminectomy
Laminectomy is performed with
the patient positioned prone on a
supportive frame that allows the
abdomen to hang free to decrease epi-
dural venous pressure and surgical
site bleeding. Exposure of the poste-
rior elements is performed from the
midline to the lateral pars interarticularis and facets with great care
taken to avoid damage to the facet
joint or pars interarticularis. After
resection of the spinous processes
and superficial dorsal lamina, central
decompression is performed with re-
moval of the midline laminae and
underlying ligamentum flavum (Fig-
ure 2, A-C). Partial medial facetecto-
 mies can then be performed to de-
compress the lateral recess and
expose the neuroforamina and exit-
ing nerve roots, which may be de-
compressed using Kerrison rongeurs
(Figure 2, D). A ball-tipped probe,
Woodson elevator, or angled dural
separator should be used to assess
the anteroposterior and proximal-
distal volume of the neuroforamina.

Several studies have evaluated out-
comes of decompressive laminecto-
y for spinal stenosis. Some of
these studies reported on outcomes
of decompressive laminectomy and
nonsurgical treatment in a cohort of
148 patients with symptomatic lum-
bar stenosis who were followed for
10 years.26-28 Eighty-one patients un-
derwent laminectomy, and 67 re-
ceived nonsurgical treatment, with
both groups assessed at 1, 4, and 8
to 10 years following treatment.26
Leg or back pain was substantially
improved in 55% of patients in the
surgical group and 28% in the non-
surgical group at 1-year follow-up.26
However, these differences became
less substantial over time; at 8- to
10-year follow-up, leg or back pain
was significantly improved in 54%
of surgically treated patients com-
pared with 42% of nonsurgically
treated patients.28 These studies were
limited by their nonrandomized de-
sign in which potential confounders
cannot be excluded, the high rate of
loss to follow-up, and various de-
grees of decompression; these issues
make it difficult to assess the value
of decompression surgery.26-28

More recently, prospective ran-
domized studies have rigorously
evaluated surgical management of
spinal stenosis.3,29,30 Amundsen et al29
reported on the results of 100 pa-
tients with symptomatic lumbar spi-
nal stenosis who were assigned to
either surgical or nonsurgical treat-
ment. A partial randomization was
done, with 31 patients assigned to ei-
ther nonsurgical or surgical treat-
ment groups. At 4-year follow-up,
excellent or fair results were ob-

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**Figure 2**

A, Illustration demonstrating resection of the spinous processes and
detachment of ligamentum flavum from the ventral aspect of the lamina with
a curet. B, Laminectomy and central decompression with a Kerrison rongeur.
C, Partial medial facetectomy and foraminotomy are performed with a 45°
Kerrison rongeur. D, The superior tip of the superior facet is resected with a
45° Kerrison rongeur for decompression of the neuroforamen.
served in 9 of 18 patients in the nonsurgical group and 10 of 13 patients in the surgical group. Malmivaara et al.\textsuperscript{30} evaluated 94 patients with lumbar spinal stenosis treated either surgically (50 patients) or nonsurgically (44 patients) in randomized multicenter trial. The surgical group included 10 patients treated with instrumented posterolateral fusion. At 2-year follow-up, disability, leg pain, and back pain were improved to a greater degree in the surgical group than in the nonsurgical group. Walking ability did not differ between the two treatment groups. A drawback of the study is that inclusion of patients treated with fusion makes it difficult to attribute good outcomes to decompression alone. Crossover of the patient population is another limitation of this study; 9% of the nonsurgical group underwent surgical intervention due to exacerbation of symptoms, and 8% of the decompressive surgery group did not undergo surgery due to relief of symptoms, thereby further confounding the researchers’ ability to detect differences between the groups.

Effectiveness of surgical management of lumbar spinal stenosis was evaluated in the SPORT study. This prospective randomized multicenter trial had three study arms based on diagnosis: lumbar disk herniation, degenerative spondylolisthesis or spinal stenosis.\textsuperscript{2,3} Patients with spinal stenosis without spondylolisthesis who had symptoms for at least 12 weeks and failed nonsurgical treatment were enrolled in the spinal stenosis arm of the study. These patients were assigned to either a randomized or an observational cohort and underwent decompressive surgery or nonsurgical care, respectively. Nonsurgical care consisted of physical therapy, education and/or counseling with home exercise instruction, and NSAIDs. Initially, 365 patients were assigned to the observational cohort; however, many patients in the nonsurgical group opted to have surgery. At 2-year follow-up, 193 of 289 patients (67%) in the randomized cohort had undergone surgery, whereas 157 patients (43%) in the observational cohort received nonsurgical care and underwent surgery. As-treated analysis, which combined both cohorts, showed that surgery had a marked advantage over nonsurgical treatment, with substantial decreases in pain and improvement in physical function as measured by the Medical Outcomes Study 36-item Short-Form General Health Survey and the modified Oswestry Disability Index (ODI). These differences remained significant at 2 and 4 years.\textsuperscript{2,3}

Complications associated with laminectomy include infection, dural tear, epidural hematoma, and instability. One study reported that, following laminectomy, 2 of 103 patients (2%) with lumbar stenosis developed deep infection, requiring irrigation and débridement.\textsuperscript{31} Recently, a 10.5% incidence of durotomy was reported in 389 patients who underwent laminectomy for lumbar degenerative spondylolisthesis. No significant differences in pain or physical function based on Medical Outcomes Study 36-item Short Form scores or ODI were observed at 1, 2, 3, and 4 years in patients with or without durotomy, which suggests that incidental durotomy does not significantly affect outcome.\textsuperscript{32} Epidural hematoma following laminectomy is rare and requires urgent surgical decompression to avoid neurologic deficit.\textsuperscript{33} In a study of 27 patients treated with posterior spinal decompression procedures, the incidence of postlaminectomy instability was 3.7%; this complication can be avoided by preserving the pars interarticularis and at least 50% of the facet joints.\textsuperscript{34}

Minimally Invasive Surgical Approaches

Compared with traditional open techniques, minimally invasive surgery (MIS) for management of spinal stenosis results in better preservation of posterior musculature, diminished intraoperative bleeding, and requires less recovery time.\textsuperscript{35,36} MIS approaches for stenosis include laminotomy, microendoscopic laminotomy with tubular retractors, and laminoplasty. Although MIS approaches have some advantages over open procedures, the economic value and cost-effectiveness of MIS requires further investigation.\textsuperscript{37}

Laminotomy

Laminotomy involves removal of a small portion of one side of the lamina. Resection of the distal half of the superior hemilamina is often necessary to identify and remove the insertion site of the ligamentum flavum. Contralateral decompression can be performed with preservation of the spinous processes and supraspinous and interspinous ligaments by tilting the operating table away from the surgeon. Using an operating microscope, the contralateral ligamentum can be visualized and resected and then the lamina can be undercut\textsuperscript{38,39} (Figure 3). Toyoda et al.\textsuperscript{38} reported on 57 patients who underwent bilateral decompression via unilateral laminotomies. Of these patients, 27 had lumbar spinal stenosis without instability, 20 had degenerative lumbar spondylolisthesis, and 10 had degenerative lumbar scoliosis. At a mean 6-year follow-up, the average Japanese Orthopaedic Association (JOA) score improved from 13.8 ± 3.6 points preoperatively to 22.6 ± 4.7 points at final follow-up. At final follow-up, no significant differences in JOA score or percentage of slippage were noted among patients with these three diagnoses. This technique is limited because of

\textsuperscript{2} Malfait F, et al.\textsuperscript{30}
the difficulty in accessing stenosis in the lateral canal and foramen.

Microendoscopic Laminotomy
In a prospective study of 53 patients with spinal stenosis, Pao et al\textsuperscript{40} performed microendoscopic laminotomy using a tubular retractor and a fiberoptic endoscopic system. Of these patients, 45 (85\%) were satisfied with treatment at an average 16-month follow-up. Significant improvement in ODI and JOA scores was noted, and 40 patients (80\%) had good to excellent results. Complication rates were high and included dural tears in five patients and transient neuralgia in four patients. Khoo and Fessler\textsuperscript{41} compared microendoscopic decompressive laminotomy with open decompression in patients with lumbar spinal stenosis and noted that the microendoscopic procedure was associated with reduced blood loss, shorter postoperative hospital stay, and diminished use of narcotics. A drawback of this technique is that the ipsilateral lateral recess is difficult to access without extensive facetectomy.\textsuperscript{42}

Interspinous Process Devices
Recently, interspinous process devices have been used to manage lumbar spinal stenosis. These implants block spinal extension at the level of the facet joint and limit canal narrowing associated with spinal extension. In a prospective randomized controlled multicenter trial, Zucherman et al\textsuperscript{43} analyzed outcomes of 191 patients with symptomatic spinal stenosis. Ninety-one patients were treated nonsurgically and 100 were treated with the X-STOP interspinous implant (Medtronic, Memphis, TN). At 2-year follow-up, symptom scores improved by 45\% over baseline in patients treated with the X-STOP implant compared with 7\% improvement in the control group. The X-STOP group had a 44\% mean improvement in function compared with no improvement in the control group. In addition, 73\% of patients treated with the X-STOP device were satisfied with surgery compared with 36\% of control patients. Tusche\textsuperscript{44} et al recently reported on 46 patients with spinal stenosis who underwent implantation of the X-STOP device. At a mean 40-month follow-up, no improvement was noted, and the revision rate was approximately 30\%. Most revisions occurred within the first year. In addition, there is evidence that implantation of these devices may not improve outcomes and in fact may worsen neural compression in severely stenotic patients.\textsuperscript{45,46} Indications for the use of these implants are not well defined, and long-term studies are lacking at this time.

Economics
A cost analysis performed using a subset of patients with spinal stenosis from the SPORT study showed that surgical management of spinal stenosis improved health to a greater extent than nonsurgical care (quality adjusted life year [QALY] gained, 0.17) at a cost of $77,600 per QALY gained at 2-year follow-up.\textsuperscript{47} At 4-year follow-up, QALY gains were maintained (0.22) and costs per QALY gained decreased to $59,400.\textsuperscript{48} The authors concluded that the economic value of surgery for spinal stenosis compares favorably with many health interventions.\textsuperscript{47,48}

Summary
Degenerative lumbar spinal stenosis is a major cause of impaired quality of life and diminished functional capacity in the elderly. Patients commonly present with neurogenic claudication and diminished standing and walking tolerance; however, their ability to walk distances can be increased by ambulating with the spine in a flexed-forward posture. On physical examination, back pain or lower extremity symptoms can often be elicited with lumbar exte-
sion. Radicular symptoms may be seen in patients with lateral recess or foraminal stenosis.

Plain AP and lateral radiographs may demonstrate spondylolisthesis, disk space narrowing, end plate sclerosis, osteophytes, and facet hypertrophy. MRI can best demonstrate the degree of narrowing in the central canal and lateral recess. Because the natural history of spinal stenosis is generally benign but progressive, initial treatment with NSAIDs; physical therapy, with an emphasis on core strengthening; and epidural steroid injections may be beneficial.

Surgical management is indicated following failure of nonsurgical measures. Recent prospective randomized controlled studies have demonstrated a definite advantage of surgery over nonsurgical treatment in decreasing pain and improving function in patients with degenerative spinal stenosis. Decompressive laminectomy is the most commonly performed procedure used to address global stenosis. MIS approaches include laminotomy, microendoscopic laminotomy, and laminoplasty. Fusion is not indicated except in the setting of concomitant spondylolisthesis, scoliosis, or iatrogenic instability. In well-selected patients, surgical decompression can provide marked pain relief and restore physical function and quality of life.

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