The possibility that degenerative changes of the lumbar spine can lead to compression of the spinal cord and/or its nerve roots has been recognized for some time. It was not until the descriptions provided by Van Gelderen and Verbiest that the clinical syndrome of lumbar spinal stenosis was systemically described. Van Gelderen reported on two patients, in one of whom successful decompression was performed. Verbiest reported the first series of patients and emphasized that a major contributing factor was developmental narrowing of the lumbar spinal canal. Subsequent descriptions by Verbiest, Epstein and colleagues, and others helped to further define congenital compared with acquired stenosis, the relative contributions of degenerative changes involving various anatomical components of the spine, and the concept of lateral recess stenosis.

Also prominent in the early work on the clinical syndrome of lumbar stenosis were Blau and Logue at the National Hospital, Queen Square. After examining six patients with symptoms potentially attributed to lumbar stenosis, they proposed the label “intermittent claudication of the cauda equina” to describe the syndrome in 1961. Around this time, our senior author (J.A.J.) was a senior resident at the Illinois Neuropsychiatric Institute and was impressed by this pioneering work on lumbar stenosis. In 1978 Blau and Logue published further details of their experience and it remains a lasting contribution in the field.

Early Experience in Montreal: 1956 to 1960

The time spent at the Montreal Neurological Institute between 1956 and 1960 provided the senior author with an important exposure to the management of patients with disorders of the lumbar spine and, in particular, to some of Dr. W. V. Cone’s ideas. Although unrecognized at the time, some of these ideas would continue to influence the senior surgeon’s treatment of lumbar stenosis.

Dr. Cone was neurosurgeon-in-chief, neuropathologist, and cofounder along with Dr. Wilder Penfield of the Montreal Neurological Institute. Although Penfield was the most famous figure at the institute, it was Cone who was directly responsible for the care of patients with spinal disease. He was a gifted surgeon and innovator, particularly skilled at spine surgery whose treatment of lumbar disease proved influential on the senior author. When performing a standard lumbar discectomy, Cone...
removed the entire disc. He also opened the facet capsules as part of the procedure (a maneuver that would influence the senior author’s treatment of lumbar stenosis, although the genesis of this practice was heretofore unrecognized until the preparation of this presentation). In this way, Cone often achieved a “three-point fusion.”

Further Experience With Lumbar Stenosis: 1961 to 1965

The senior author came across the work of Blau and Logue, and from this he began to learn about neurogenic claudication (intermittent claudication of the cauda equina) and its underlying pathoanatomical basis. During this era, this disease was commonly not recognized despite the often disabling symptoms it provoked. The underlying pathological substrates leading to stenosis, and hence clinical symptomatology, were being methodically investigated and documented by Blau and Logue at the time of surgery. For instance, contributing pathological factors were identified as thickened laminae, thickened ligamentum flavum, disc protrusions, narrowed canal laterally, and thickened or adherent nerve roots. Blau and Logue performed decompressive laminectomy, and their patients often fared well after surgery.

Returning to Chicago following a year in England, the senior author attempted applying the teachings of Blau and Logue to his undertakings of lumbar stenosis at the Illinois Neuropsychiatric Institute. Primitive imaging studies, imprecise localization, and inexperience made treatment of lumbar stenosis both interesting and relatively challenging. Although he was more interested in other disorders, including cerebral vascular disease and intracranial tumors, spinal disorders comprised a significant component of the clinical caseload. Over the next several years in Chicago, decompressive laminectomies were commonly performed to treat lumbar stenosis.

Cleveland, Ohio, and Charlottesville, Virginia: Continuation of Decompressive Laminectomy: 1965 to 1982

After finishing training in Chicago, the senior surgeon worked at Case Western Reserve University in Cleveland, Ohio, under the leadership of Dr. Frank Nulsen between 1965 and 1969. Patients underwent a standard laminectomy. In retrospect, lumbar stenosis was still somewhat poorly recognized and its treatment was still in its infancy. Much attention was focused on other areas of clinical and research interest.

After moving to Charlottesville, Virginia, the senior author continued to treat patients with lumbar stenosis and the technique would evolve during the next 35 years. He was still concerned with other neurosurgical topics, particularly cerebral vascular disease, trauma, and basic neuroscience research. Lumbar surgery was viewed as beneficial to patients but the procedure was his area of focus. Decompressive laminectomy was the standard intervention during this time.

During the next decade at the University of Virginia, case volume significantly increased and additional faculty members in various subspecialty areas were recruited. As a result of this new-found subspecialization among the faculty, several areas needed to be covered by the department chairman; one of these areas was spinal disorders. It was ironic that things had now come full circle. After arriving in Charlottesville in 1969, the senior author was disconcerted by how great a proportion of the caseload involved patients with spinal disorders. Although he was skeptical at the time, a secretary suggested that this too would be the experience of the senior author’s in the future.

As a result of the changing dynamics of the department, the need for an individual dedicated to spinal disorders, and his personal dissatisfaction with the challenge, concept, and, at times, results of the standard decompressive laminectomy for lumbar stenosis, the senior author became newly dedicated to spinal disorders.

Introduction of the “Ipsilateral–Contralateral” Procedure: 1982

The observation that many patients with lumbar stenosis suffered symptoms of classic neurogenic claudication but also asymmetrical or entirely unilateral radicular symptoms prompted a reevaluation and individualization of treatment strategies. Patients with claudication, believed to arise from central canal stenosis, had been routinely treated by standard laminectomy. Patients with radicular symptoms, secondary to lateral recess/foraminal stenosis, underwent foraminotomy and discectomy (if disc herniation was a significant contributor). An early form of the “ipsilateral–contralateral” procedure was proposed to address a common subset of patients who suffered from neurogenic claudication and asymmetrical or unilateral radiculopathy.

The “ipsi–contra” fusion was performed via a midline approach. The spinous process and supra- and interspinous ligaments were left intact. A hemilaminectomy was performed on the side of symptomatic radiculopathy. Under the operating microscope a cottonoid patty was placed over the dura mater, and this was followed by extensive undercutting of the spinous process and removal of the ligamentum flavum to its insertion on the contralateral superior facet. In this fashion, a radical bilateral decompression of the central canal was conducted via an ipsilateral surgical corridor in attempt to address the claudication component of the presenting symptomatology. The ipsilateral side of symptomatic radiculopathy was then treated. A radical decompression was undertaken, including partial (or complete) facetectomy and discectomy, when disc herniation was significantly involved. Additionally, after satisfactory radical decompression, the exiting and passing nerve roots were directly inspected through the operating microscope. Particular attention was paid to the relationship of the nerve to the pedicle. At times, despite radical facetectomy/decompression, the nerve root remained tethered due to superolateral compression by its corresponding pedicle. In these instances, a medial pediculectomy was performed. The nerve root was protected, and a high-speed drill with a diamond bit was used to shave the medial aspect of the pedicle. Essentially the drill was used to remove the medial edge of the pedicle, but a thin shell of cortical bone remained between the site of drilling and the nerve root (Fig. 1 upper). This was subsequently removed using a...
curette whose vector of force was directed away from the nerve root and thecal sac (Fig. 1 lower). An interesting observation, made in both cadavers and humans, was that the nerve root shifted superolaterally into the area formerly occupied by the medial edge of the pedicle. At this point, all nerve roots on the ipsilateral side were entirely decompressed (Fig. 2 left). Hemostasis was achieved in routine microsurgical fashion and autologous bone, harvested from the site where bone was removed earlier, was then placed along the contralateral lamina and facet complex (Fig. 2 center). Thus, the so-called ipsi–contra derived from the performance of a radical ipsilateral decompression, contralateral decompression of the central canal and lateral recess, and extensive contralateral fusion.

Outcome, assessed by multiple measures, was generally satisfactory. In a mean follow-up period of 30 months, 62% of patients were pain free or experienced only mild pain that did not hinder their usual activities.6 The surgery proved to be successful across subtypes of patients with or without prior surgery. Flexion–extension radiography revealed no motion at the fused segments in any patient. Long-term follow-up study of these patients is important. One might expect that degenerative lumbar stenosis would continue to worsen. Analysis of our long-term results (≥ 8 years) has indicated continual spinal stability and durability of clinical outcome, perhaps emphasizing the potential importance of fusion.

Derivations of this procedure have continued into the present and are applied effectively in certain instances; however, the procedure is less frequently performed. Analysis of long-term follow-up data has demonstrated that some patients eventually become symptomatic on the side of the contralateral fusion. Repeated operation in these cases is more difficult than in others because of the massive fusion mass hindering subsequent decompression (Fig. 2 right). The solid fusion mass must often be removed using a combination of rongeuring and high-speed drilling. Normal anatomical landmarks are camouflaged amidst a mass of solid bone. In any event, repeated operation in these cases is feasible and can be successful, despite its difficulty.

Introduction of the Unilateral Cage: a Prelude to the TLIF

Another tool in the armamentarium is a supplemental unilateral cage. Credit for the senior author’s application of this technique is given to Dr. Christopher Shaffrey who brought this technique to his attention during a national meeting. Shaffrey demonstrated the technique in cadavers and presented it as a relatively simple adjunct to current procedures. In some ways it is quite similar to the transfornaminal lumbar interbody fusion procedures performed today.

Some justification of the biomechanical basis for the technique arose from the work of Tencer and colleagues.25 Biomechanical data were procured from studies in which investigators examined the stability of various constructs for interbody fusion. If the contralateral facet was intact, unilateral placement of a single construct was biomechanically equivalent to the placement of a single or double constructs in various geometrical configurations.

The unilateral cage was applied as an adjunct to cases in which a radical ipsilateral decompression was undertaken in combination with a contralateral fusion, often in cases of reoperation as well. Much of the technique was the same as that described for the ipsi–contra procedure; however, when a cage was placed, the ipsilateral facet joint was totally removed. The ipsilateral nerve root was completely untethered (including removal of scar tissue, if present) and the ipsilateral disc space was prepared to accept the cage. The superior face of the inferior pedicle and the inferior face of the superior pedicle were drilled to allow displacement of the exiting nerve upward and the nerve of passage medially. The cage was then introduced and a contralateral autologous bone–assisted fusion was performed (Fig. 3).

The technique proved to provide gratifying results immediately. Improvement in pain was marked, and no evidence of spinal instability was demonstrated. Cerebrospinal leakage and complications attributed to nerve root injury were not evident; however, long-term follow-up

FIG. 1. Upper: Initial phase of pediculectomy using the high-speed drill. The medial portion of the pedicle is shaved down, leaving a thin shell of cortical bone medially adjacent to the nerve root that is being protected. Lower: Final phase of pediculectomy. The thin shell of cortical bone is removed using a curette directed laterally.
evaluation demonstrated that cage backout, although infrequent, was a major problem when it occurred. Repeated operation in these cases was very difficult, and removal of scarred titanium cages or bone dowels often required creative intraoperative maneuvers, not to mention patience. This technique, as originally applied, has been supplanted by modern techniques of interbody fusion.

Lumbar Stenosis: Techniques in Evolution

Combinations of standard lumbar laminectomies and the aforementioned variations in technique were performed through the late 1990s. Results were critically analyzed, and particular attention was given to outcome in various subgroups of lumbar stenosis.

In our experience, management of patients with lumbar stenosis and degenerative scoliosis is particularly problematic. Others have also noted such an association, and higher degrees of scoliosis have correlated with worse surgery-related outcomes. Various surgical procedures have been attempted with mixed results. There are some data to support the notion that patients with degenerative scoliosis are at higher risk for postoperative spinal instability after extensive decompression. Additionally, laudable results have been reported after aggressive decompression and subsequent instrumentation-assisted fusion in patients with degenerative scoliosis. Our present management of patients with severe symptomatic lumbar stenosis and concomitant degenerative scoliosis has involved radical decompression and instrumentation-assisted fusion. The final 18 patients in this subgroup underwent this surgery.

A consecutive series of 106 patients with symptomatic lumbar stenosis were retrospectively reviewed. Initially, patients were seen after surgery and thereafter at 6-month intervals for clinical examination. Additionally, radiographic follow-up examination and the administration of subjective questionnaires were included. This series is not unlike most reported series in which lumbar stenosis is surgically treated, and only key data are presented here to emphasize certain points. The mean follow-up period was 32 months and no patient was lost to follow up. During this time (when pressure for expeditious patient discharge was not ubiquitous), hospital stay was reasonable (median 2 and 3 days for male and female patients, respectively).
Forty-year experience with lumbar stenosis

TABLE 1

<table>
<thead>
<tr>
<th>Grade Work Scale</th>
<th>Criteria</th>
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<tr>
<td>W1</td>
<td>return to previous (heavy labor) or physically demanding activities</td>
</tr>
<tr>
<td>W2</td>
<td>able to return to previous employment (sedentary) or return to heavy labor w/ lifting restrictions</td>
</tr>
<tr>
<td>W3</td>
<td>unable to return to previous employment but working full time at new job</td>
</tr>
<tr>
<td>W4</td>
<td>unable to return to full-time work</td>
</tr>
<tr>
<td>W5</td>
<td>no work, completely disabled</td>
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<table>
<thead>
<tr>
<th>Grade Pain Scale</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>no pain</td>
</tr>
<tr>
<td>P2</td>
<td>occasional minimal pain; no need for medication</td>
</tr>
<tr>
<td>P3</td>
<td>mod pain, occasional medication, no interruption of work or ADL</td>
</tr>
<tr>
<td>P4</td>
<td>mod to severe pain, occasional absence from work, significant in ADL</td>
</tr>
<tr>
<td>P5</td>
<td>constant severe pain, chronic medication</td>
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Pain Scale score was 4.6; postoperatively it was 2.3 and 2.2 (p < 0.05 compared with preoperative score) at 32 and 64 months, respectively. Again, patients with scoliosis also improved following surgery, but the magnitude of improvement was less than in other subgroups. Thus, long-term follow-up assessment of patients who underwent treatment for lumbar stenosis demonstrated both efficacy and durability of treatment.

### A New Time of Transition: 2000 to 2003

Perhaps appropriate for the first decade of the new millennium, techniques for treatment of lumbar stenosis were again changing. Between July 1, 2000, and June 30, 2001, the senior author treated 235 patients with lumbar spine disease. The mean patient age was 59 years (range 18–89 years), and the mean hospital LOS following surgery was 1.32 days. Operations (in descending order of frequency) included an intralaminar decompression with or without posterolateral autologous fusion, ipsilateral decompression and contralateral fusion (modified ipsi–contra), ipsilateral decompression with unilateral cage placement and contralateral fusion, and total laminectomy with or without transverse process fusion with or without instrumentation.

Another modification for the treatment of lumbar stenosis was being refined and implemented. Termed an intralaminar decompression or fenestration, the technique involved a midline approach and decompression within the boundaries of the lamina. It was a derivative of fenestration procedures first described by Lin and subsequently characterized by others. Its theoretical advantages were that some normal anatomy remained, spinal stability was possibly enhanced, and repeated operation, if necessary, was simplified. At each motion segment treated, the upper third of the spinous process was removed. The intervening supra- and interspinous ligaments were resected. The ligamentum flavum was identified. Hypertrophied facet joints were often trimmed down and the facet capsule opened. The purpose of this maneuver was twofold: to denervate the recurrent nerve of Luschka (hypothesized to contribute to back pain) and to clearly identify the superior articular facet as a landmark for further decompression. Under the operating microscope, the ligamentum flavum, posterior pedicles, and the superior aspect of the inferior lamina were removed. The majority of the spinous processes and laminae remained.
were left in situ. Aggressive bilateral medial facetectomies, foraminotomies, and/or discectomies were performed as dictated by clinical, radiological, and intraoperative data. Medial pediculectomies were performed if indicated. A posterolateral autologous fusion was also usually performed with bone obtained during the decompression.

Since 2001, 73 patients underwent intralaminar decompression and fusion, 64 underwent intralaminar decompression without fusion, 15 underwent ipsilateral decompression and contralateral fusion, 30 underwent total laminectomies and fusion, and 13 patients underwent total laminectomies alone.

Patients also generally fared well following the intralaminar decompression procedure; however, careful follow-up assessment revealed that patients who did not improve or who experienced delayed onset of new symptoms (over months to years) harbored residual disease at the most rostral aspect of the decompression. As a result, repeated operation was necessary at which time a total laminectomy was performed. This also provided the basis for the present method of treatment for lumbar stenosis.

The Present Procedure

Limitations of the various procedures have been previously outlined. This coupled with emerging data supporting the use of BMP-supplemented noninstrumented fusion prompted an additional change to the preferred technique. Total laminectomies were revisited but were combined with aggressive lateral decompression and transverse process fusion supplemented with BMP. During the last 5 months, 38 patients underwent total laminectomies, lateral decompression, and BMP-supplemented transverse process fusion. The mean LOS was 2.5 days, which is slightly longer than for some of the earlier pro-
Forty-year experience with lumbar stenosis

cedures. The reason for this has been attributed to the increased discomfort associated with the additional exposure required for transverse process fusion. In most recent cases, however, a reduction in LOS to levels comparable to earlier procedures occurred. Local anesthetic (0.2% bupivacaine) is also generously administered in the skin and paraspinal musculature before incision and prior to closure to help reduce postoperative discomfort.

The present technique involves a standard midline approach. The facet joints are opened bilaterally for denervation and to identify normal anatomy (particularly the superior articular facet) to facilitate subsequent decompression (Fig. 5 upper left). Total laminectomies are performed, and medial facetectomies are also generally performed (Fig. 5 upper right and center left). Adjunctive measures to achieve complete decompression (such as medial pediculotomy or discectomy) are performed when necessary. After adequate decompression and meticulous hemostasis are achieved, the transverse processes are prepared for placement of the rolls containing BMP and either autologous bone or bone substitute (Fig. 5 center right, lower left and right).

Although longer-term follow-up review is necessary for adequate evaluation of this modification, preliminary data are encouraging in terms of outcome measures assessed to date (pain alleviation, functional improvement, and osseous fusion).

Conclusions

Contemporary understanding of lumbar stenosis and its treatment continues to evolve. Considerable changes have occurred since the earliest descriptions of the syndrome by Van Gelderen, Verbiest, Blau and Logue, and others. Conceptualization and treatment of lumbar stenosis at the authors’ institution has benefited from the influence of many individuals including Blau, Logue, and Cone; discussion and intellectual input from spine surgeons around the world; careful, critical, and honest appraisal of outcome; and a desire for constant improvement of patient care. Our present treatment of lumbar stenosis can be viewed as a work in progress, and, if the past is predictive of the future, it will continue to evolve to the benefit of patients with lumbar stenosis.

References


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Address reprint requests to: John A. Jane Sr., M.D., Ph.D., Box 800212, Department of Neurological Surgery, University of Virginia Health Sciences Center, Charlottesville, Virginia 22908. email: kes4a@virginia.edu.