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# Expansive Suspension Laminoplasty Using a Spinous Process–Splitting Approach for Lumbar Spinal Stenosis: Surgical Technique and Outcomes Over 8 Years of Follow-up

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## Abstract

**Introduction:** To maximize the benefits of posterior decompression for severe multilevel lumbar spinal stenosis, we refined the expansive laminoplasty technique using a spinous process–splitting approach. This study tests the hypothesis that the surgical benefit of adequate decompression with posterior element preservation is maintained in the long term, over 8 years of follow-up.

**Methods:** Fifty-eight patients were followed up yearly for 8 years. Eight patients having nonlumbar spine surgery or Parkinson disease were excluded. The noninferiority of the 8-year versus peak-year outcomes was tested, with margins of 5 points for the Oswestry disability index and 1 point for the numeric rating scales (NRSs).

**Results:** In the 50 patients available for follow-up, the peak values of the mean improvements from baseline within the first 7 years were 35.8, 5.7, 5.9, and 2.8 points for the Oswestry disability index, low back pain NRS, leg pain NRS, and leg numbness NRS, respectively. The 95% lower confidence limits for the differences between the mean improvements from baseline at 8 years and the peak year were within the noninferiority margins for each scale.

**Conclusion:** Our technique was associated with substantial improvement from baseline for each scale. The initial improvements in function and symptoms were maintained for 8 years.

Laminectomy and laminotomy are commonly used surgical treatments for lumbar spinal stenosis. Laminotomy preserves more posterior elements than laminectomy, reducing the risk of postoperative

instability. However, in cases of severe multilevel stenosis with narrowing of the spinal canal throughout the disk and vertebral body levels, adequate decompression cannot be achieved in all patients via laminotomy.<sup>1</sup>

Adequate decompression throughout an affected spinal canal with the preservation of the lamina may be achieved with expansive laminoplasty.<sup>2-4</sup> If combined with a spinous process–splitting approach,<sup>5</sup> expansive open-door laminoplasty also preserves the spinous processes and their multifidus attachments.<sup>2</sup> However, nonunion between the spinous process and the lamina often occurs, resulting in worsening symptoms and function at the long-term follow-up evaluation.<sup>2</sup> To maximize the beneficial effects of posterior decompression surgery, we refined the technique of spinous process–splitting laminoplasty. Our refined technique focuses on the reconstruction of the spinous process integrity and the preservation of the multifidus attachment to the spinous process in combination with spinal canal expansion throughout the disk and vertebral body levels.

After posterior decompression for lumbar spinal stenosis, improvements in symptoms and function peak in an early postoperative period, with gradual deterioration thereafter.<sup>6</sup> Such deterioration is an inevitable process, but it may be minimized by refining the surgical procedures. Following the application of our procedure for the treatment of severe lumbar spinal stenosis, the outcomes in this study were analyzed yearly for 8 years using the Oswestry disability index (ODI)<sup>7</sup> and numeric rating scales (NRSs) for symptoms. We hypothesized that the posterior element preservation and sufficient spinal canal expansion achieved by our procedure would favor maintaining the surgical benefits over 8 years in patients with severe multilevel stenosis with nar-

rowing of the spinal canal throughout the disk and vertebral body levels. This study clarifies the following issues: whether osseous continuity in the posterior elements could be reconstructed, the extents to which symptoms and function improved, and whether the improvements in symptoms and function were maintained for 8 years postoperatively (ie, whether the outcomes at 8 years were not inferior to the outcomes at the peak year).

## Methods

### Patients

This investigation was a retrospective, observational, single-institution study based on a review of the database and imaging data. All patients provided informed consent. The Osaka Police Hospital Institutional Review Board approved this study. All patients who underwent spine surgery were scheduled to visit our institution yearly for periodic medical examinations. The patients completed the questionnaire from the surgeon independently before each medical examination. The patients who did not visit on the scheduled day were sent a follow-up questionnaire. The data from the patient reports were recorded in the database. The data for consecutive patients who were treated by the first author from September 2004 to December 2008 were obtained from the database. The data included information from the questionnaires completed preoperatively and yearly for 8 years postoperatively.

The inclusion criteria were multilevel lumbar spinal stenosis and narrowing of the spinal canal throughout

the disk and vertebral body levels, that is, a maximum AP diameter of the dural sac of 12 mm at the affected vertebral body levels on MRI scans. The use of a maximum dural sac diameter of 12 mm at the vertebral body level as an inclusion criterion was based on a previous report that classified patients with AP dural sac diameters of 10 to 12 mm at the disk level as a relative stenosis group.<sup>8</sup> Patients with a herniated lumbar disk or lumbar scoliosis of more than 10° were not included.

Eighty-two patients met the inclusion criteria. Of these, three patients were unable to answer the questionnaire because of cognitive impairment, three patients preoperatively declined to undergo long-term follow-up examinations because they lived far from our institution, and 18 patients dropped out. The dropouts included two patients who died at 4.4 and 5.2 years. Consequently, complete yearly follow-up data for 8 postoperative years were obtained from 58 patients. Baseline characteristics, except age, and the preoperative scores for each outcome measure were similar between the 58 patients followed for 8 years and the 18 dropouts (Table 1).

Of the 58 patients, 1 patient had Parkinson disease preoperatively, 3 underwent nonlumbar spine surgery (NLSS) within 6 months preoperatively (Table 1), and 4 underwent additional NLSS postoperatively (Table 2). To minimize variability among the subjects, the analyses were performed for 50 patients after excluding these 8 patients.

### Surgical Techniques

The procedures consisted of splitting the spinous process while maintaining

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Name of Institutional Review Board: Osaka Police Hospital Institutional Review Board.

Table 1

Baseline Characteristics of the Patients<sup>a,b,c</sup>

Characteristic	58 Patients Followed for 8 Years				P Value (58 Patients Followed for 8 Years Versus Dropouts)
	Patients Without PD or NLSS (n = 50)	Patients With PD or NLSS (n = 8)	All Patients (n = 58)	Dropouts (n = 18)	
Female (no. [%])	15 (30)	1 (13)	16 (28)	8 (44)	0.25
Age at the time of surgery (yr)	66.5 ± 7.3	74.0 ± 4.5	67.5 ± 7.5	73.4 ± 5.0	<b>0.0026</b>
Body mass index (kg/m <sup>2</sup> )	24.6 ± 3.0	23.5 ± 3.1	24.4 ± 3.0	23.0 ± 2.8	0.070
Duration of leg symptoms (yr)	2.4 ± 4.5	3.3 ± 3.3	2.6 ± 4.4	1.1 ± 1.1	0.16
Urgent surgery (no. [%])	0	0	0	1 (6)	0.24
Current smoker (no. [%])	6 (12)	0	6 (10)	4 (22)	0.23
Diabetes (no. [%])	14 (28)	4 (50)	18 (31)	2 (11)	0.13
PD (no. [%])	0	1 (13)	1 (2)	0	1.00
Heart problem (no. [%])	12 (24)	4 (50)	16 (28)	2 (11)	0.21
Sensory deficit (no. [%])	14 (28)	4 (50)	18 (31)	9 (50)	0.17
Motor deficit, MMT grade 3 or less (no. [%])	4 (8)	2 (25)	6 (10)	3 (17)	0.43
Decompression level (no. [%])					
Th12-L1	1 (2)	0	1 (2)	0	1.00
L1-L2	6 (12)	1 (13)	7 (12)	1 (6)	0.67
L2-L3	20 (40)	4 (50)	24 (41)	7 (39)	1.00
L3-L4	49 (98)	7 (88)	56 (97)	18 (100)	1.00
L4-L5	50 (100)	6 (75)	56 (97)	17 (94)	0.56
L5-S1	11 (22)	3 (38)	14 (24)	4 (22)	1.00
Disk levels decompressed (no.) <sup>d</sup>	2.7 ± 0.9	2.6 ± 1.1	2.7 ± 0.9	2.6 ± 0.8	0.63
Disk levels of severe or extreme stenosis (no.)	1.4 ± 1.0	1.0 ± 0.5	1.3 ± 0.9	1.6 ± 0.9	0.33
Advanced foraminal stenosis (no. [%])	18 (36)	5 (63)	23 (40)	10 (56)	0.28
Maximum anterior vertebral slipping (%) <sup>e</sup>	7.5 ± 8.5	3.5 ± 5.2	7.0 ± 8.2	6.5 ± 8.0	0.84
Maximum lateral vertebral translation (mm) <sup>e</sup>	1.3 ± 2.2	0.9 ± 1.7	1.2 ± 2.1	1.2 ± 2.2	0.94
Lumbar scoliosis (deg.)	6.2 ± 3.3	6.1 ± 2.6	6.2 ± 3.2	5.9 ± 2.1	0.72
Lumbar lordosis (deg.)	34.2 ± 15.9	33.2 ± 8.8	34.1 ± 15.1	35.1 ± 14.4	0.80
Prior spine surgery (no. [%])					
Lumbar, the same levels	0	0	0	1 (6)	0.24
Lumbar, other levels	0	1 (13)	1 (2)	0	1.00
Nonlumbar (cervical or thoracic)					
Less than 6 months before surgery	0	3 (38)	3 (5)	1 (6)	1.00
6 months or more before surgery	6 (12)	0	6 (10)	1 (6)	1.00
Preoperative outcome scores (point)					
ODI <sup>f</sup>	52.1 ± 13.5	50.6 ± 15.7	51.9 ± 13.7	55.8 ± 11.6	0.28
Leg pain NRS <sup>g</sup>	7.7 ± 3.0	5.0 ± 3.7	7.3 ± 3.2	7.6 ± 2.7	0.74
Leg numbness NRS <sup>g</sup>	5.2 ± 3.0	5.8 ± 3.0	5.3 ± 3.0	6.3 ± 3.3	0.23
Low back pain NRS <sup>g</sup>	8.0 ± 2.4	6.6 ± 2.6	7.8 ± 2.5	7.4 ± 2.9	0.63

ODI = Oswestry disability index, PD = Parkinson disease, NLSS, nonlumbar spine surgery performed postoperatively or within 6 months preoperatively, NRS = numeric rating scale, MMT = manual muscle testing (0 to 5 point scale)

<sup>a</sup> Plus-minus values are given as the mean and the SD.

<sup>b</sup> For each scale, the score increases as a disability or symptom worsens.

<sup>c</sup> Boldface type indicates statistical significance.

<sup>d</sup> The number of disk levels decompressed is 1 more than the number of elevated laminae.

<sup>e</sup> The maximum values for each patient were used.

<sup>f</sup> Scale from zero to 100.

<sup>g</sup> Scale from zero to 10.

Table 2

Category	58 Patients Followed for 8 Years		
	50 Patients Without PD or NLSS (n = 50)	8 Patients With PD or NLSS (n = 8)	All Patients (n = 82)
Intraoperative blood loss (g)	466 ± 352	316 ± 190	402 ± 311
Surgery time (min)	273 ± 89	244 ± 98	263 ± 85
Dural tear (no. [%])	1 (2)	0	2 (2)
Symptomatic wound hematoma (no. [%])	0	0	0
Deep wound infection (no. [%])	0	0	0
Additional spine surgery (no. [%])			
Lumbar, the same levels			
Within 8 yr	0	1 (13)	—
Within 4 yr	0	0	—
Lumbar, other levels			
Within 8 yr	1 (2)	3 (38)	—
Within 4 yr	0	1 (13)	—
Within 2 yr	0	0	—
Cervical			
Within 8 yr	0	4 (50)	—
Within 4 yr	0	2 (25)	—
Within 2 yr	0	2 (25)	—

PD = Parkinson disease, NLSS, nonlumbar spine surgery performed postoperatively or within 6 months preoperatively

<sup>a</sup> Plus-minus values indicate the mean and the SD.

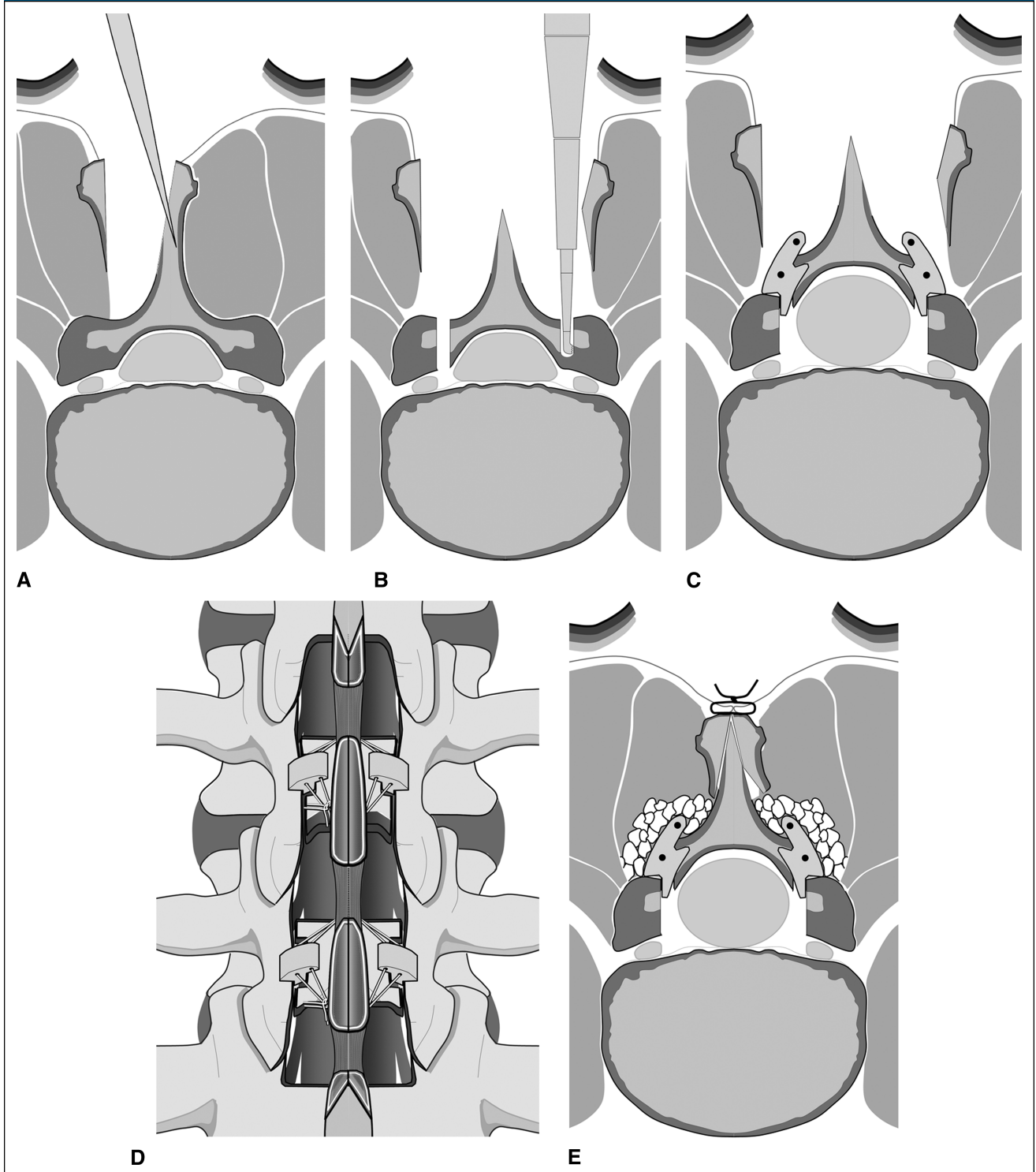
the origin of the multifidus muscle at the spinous process, performing a standard laminotomy with medial facetectomy, and elevating the lamina. The supraspinous and interspinous ligaments were also preserved. Each patient stood and walked the day after the surgery and wore a rigid corset for 3 weeks. Heavy activities were avoided for approximately 3 months. A decompression procedure between L2-L3 and L4-L5 is described as an example below.

Through a midline skin incision, the L3 and L4 spinous processes were longitudinally split down to the base using a chisel and were separated into one midline and two outer portions, as briefly mentioned previously.<sup>2</sup> The midline portion was held connected to the lamina (Figure 1, A). Similarly, the caudal half of the L2 and the cephalad one third of the L5 spinous

processes were split. A standard laminotomy and medial facetectomy were performed at the L2-L3, L3-L4, and L4-L5 levels while preserving the interspinous ligament. At the level of the caudal margin of each of the L3 and L4 laminae, the base of the spinous process was punctured using pointed bone holding forceps to create a small hole for the suture. To create a laminar flap, bilateral gutters were fashioned longitudinally and were extended ventrally to remove the anterior cortex of the lamina using an ultrasonic bone curet; a spatula was used to protect the nerve root from the ultrasonic bone curet. The gutters extended laterally to the medial margin of the pedicle (Figure 1, B). Two Teflon-impregnated braided polyester fiber sutures ranging from 0.4 to 0.5 mm in diameter (TEVDEK II,

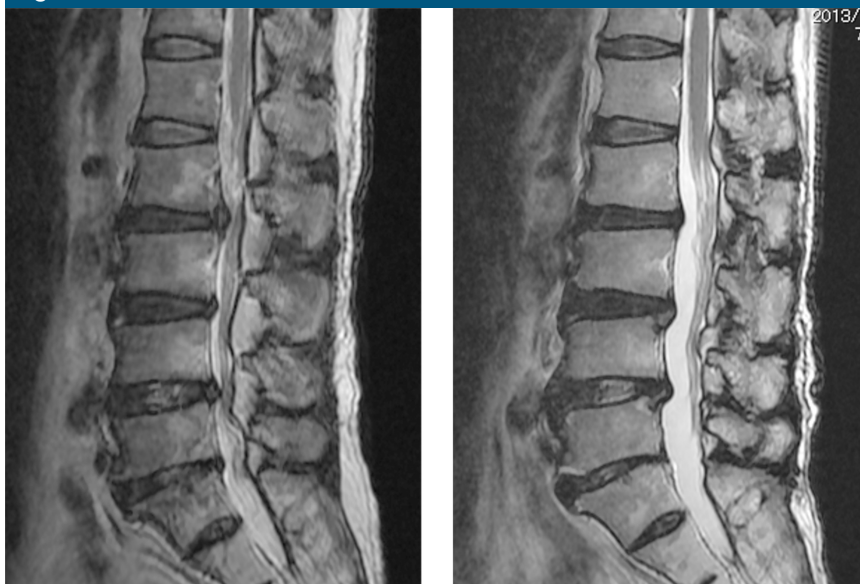
No.1; Akiyama Medical MFG) were passed through the cephalad margin of the base of the spinous process, the two holes of the hydroxyapatite laminar spacers (model numbers L2-157-XC-350 and 351; HOYA Corporation, PENTAX New Ceramic Division), and the hole created at the caudal margin of the laminar flap. The laminar flap was elevated as required without disrupting the soft-tissue connection to the lateral elements (ie, the pars interarticularis and articular process) and was suspended with bilateral hydroxyapatite laminar spacers (Figure 1, C). The fibrous attachments between the dural sac and the laminae were retained as much as possible to avoid increasing the space for epidural hematoma or scar formation. The sutures were subsequently tied, securing the laminar spacers to the lamina (Figure 1,

Figure 1



**A–E,** Diagram demonstrating surgical technique. **A,** Axial plane: the spinous process is split into one midline and two outer portions. **B,** Axial plane: bilateral gutters are longitudinally created. **C,** Axial plane: the laminar flap is elevated and kept suspended with bilateral laminar spacers. **D,** Posterior view: the laminar flap is elevated and kept suspended with bilateral laminar spacers. The spacers are fixed with two nonabsorbable sutures. **E,** Axial plane: bone autografts obtained from the excised laminae or facet joints are placed around the spacers. The bilateral outer portions of the spinous processes are reattached to each other.

Figure 2



A

B

**A and B**, Preoperative and postoperative MRI scans of a patient who underwent surgery at the levels between L1-L2 and L5-S1 at the age of 71 years. **A**, Preoperative scan. **B**, Five years postoperatively, an enlarged spinal canal throughout the disk and vertebral body levels and preserved spinous processes are evident. Little epidural fibrosis is seen between the dural sac and the laminae.

D). Bone autografts obtained from the excised laminae or facet joints were placed around the spacers to facilitate the osseous union between the laminar flap and the lateral elements. The outer portions of the L2 and L5 spinous processes were tightly fixed to the original positions with nonabsorbable sutures (TEVDEK II). The dorsal edges of the bilateral outer portions of the L3 and L4 spinous processes were reattached to each other via the application of absorbable sutures around the supraspinous ligament; this procedure further stabilized the suspended laminar flap by sandwiching the midline portion of the spinous process (Figure 1, E). Figure 2, A and B show the preoperative and postoperative MRI scans.

### Radiographic Measures

The preoperative radiographic data included anterior vertebral slipping,

lumbar lordosis (between the upper endplates of L1 and S1), lumbar scoliosis (as measured using the Cobb method), and lateral vertebral translation on standing plain radiographs and the degrees of foraminal and spinal canal stenoses on MRI scans. Severe and extreme stenosis was defined as follows: no rootlets were identified, and the dural sac exhibited a homogeneous gray signal with or without posterior epidural fat.<sup>9</sup> Advanced foraminal stenosis was defined by the complete obliteration of the foraminal epidural fat.<sup>10</sup> Osseous union between the midline and outer portions of the spinous process and between the laminar flap and the lateral elements was judged on CT scans, which were obtained two years postoperatively or later (Figure 3, A and B). Foraminal and spinal canal stenoses and osseous union were judged by two spine surgeons. When they

disagreed, a consensus opinion was reached.

### Outcome Measures

The primary outcome measure was the ODI,<sup>7</sup> omitting a question relating to sex life because of the poor response rate. The results are expressed as percentages of the maximum possible score. The secondary measures were the NRS scores for low back pain, leg pain, and leg numbness. For patients undergoing additional lumbar spine surgery, outcome scores obtained immediately before the additional surgery were used as scores after the additional surgery.

### Statistical Analysis

Serial changes in the mean improvement from baseline from 1 to 8 years were estimated using linear mixed models for repeated measurements, which included a random individual effect. Noninferiority of the mean improvement from baseline at 8 years was tested against the peak value of the mean improvement from baseline within the first 7 postoperative years using the estimated parameters of the linear mixed models. The 95% lower confidence limit (LCL) is defined as the lower bound of the two-sided 95% confidence interval. If the 95% LCL of the difference between the 8-year outcome and the peak-year outcome was not less than the threshold of the noninferiority margin (expressed as a negative number), the 8-year outcome was considered to be noninferior to the peak-year outcome. For these calculations, SAS 9.3 (SAS Institute) was used. Statistical significance was defined as  $P < 0.05$ , and all statistical tests except noninferiority tests were two tailed.

In previous studies, the noninferiority margin of the ODI has been set at the same value as the minimal important change value,<sup>11,12</sup> which was proposed to be 10 points for the ODI and 2

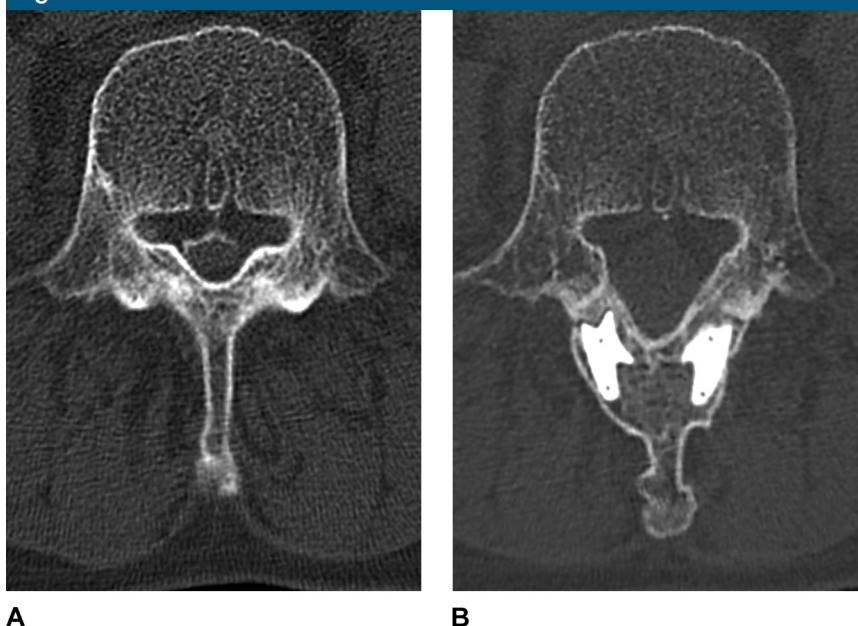
points for the NRS.<sup>13</sup> However, a noninferiority margin of 10 points for the ODI appeared to be generous. In our previous study on posterior decompression for lumbar spinal stenosis, it was determined that 10-year outcomes were inferior to 2-year outcomes and 4-year outcomes were not inferior to 2-year outcomes; the 95% LCLs of differences between the mean scores at 10 and 2 years were  $-9.9$  points for the ODI,  $-1.29$  points for low back pain NRS,  $-1.35$  points for leg pain NRS, and  $-1.48$  points for leg numbness NRS. The 95% LCLs of differences between the mean scores at 4 and 2 years were  $-2.8$  points for the ODI,  $-0.35$  points for low back pain NRS,  $-0.39$  points for leg pain NRS, and  $-0.60$  points for leg numbness NRS. Using this information, we set the noninferiority margins at five points for the ODI and 1 point for the NRS, which were one half of the proposed minimal important change values.

## Results

Of all 82 patients, two patients experienced a dural tear; none of the patients developed symptomatic wound hematoma or deep wound infection. Additional lumbar surgery at the same levels was performed in none of the 50 patients and in 1 of the 8 patients, who had PD or nonlumbar spine surgery performed postoperatively or within six months preoperatively (Table 2).

In the 50 patients, there were 87 split spinous processes with elevated laminae. Seven split spinous processes exhibited nonunion between the outer and midline portions. Four elevated laminae exhibited nonunion with lateral elements but union with bilateral laminar spacers. There was no dislodgement of laminar spacers, and no additional surgery associated with nonunion or implant failure was reported. The prevalence of

Figure 3



**A and B**, Preoperative and postoperative CT scans of the L4 vertebra of a man who underwent surgery at the levels between L3-L4 and L4-L5 at the age of 67 years. **A**, Preoperative CT scan after myelography indicating a narrowing of the spinal canal at the vertebral body level. **B**, A scan, obtained 4.6 years postoperatively, indicating enlargement of the spinal canal and successful reconstruction of the osseous continuities between the midline and outer portions of the spinous process and between the laminar flap and the lateral elements. Hydroxyapatite spacers were incorporated into the surrounding regenerated bone.

nonunion of the spinous process or lamina was similar among the different levels (Table 3). Two and no patients exhibited multilevel nonunions of the spinous processes and laminae, respectively (Table 4).

The peak values of the mean improvements from baseline within the first 7 years were 35.8 points at 6 years for the ODI, 5.7 points at 1 year for the low back pain NRS, 5.9 points at 6 years for the leg pain NRS, and 2.8 points at 2 years for the leg numbness NRS (Table 5). The 95% LCLs for the differences between the mean improvements from baseline at 8 years and the peak year were  $-3.3$ ,  $-0.88$ ,  $-0.82$ , and  $-0.52$  points for the ODI, low back pain NRS, leg pain NRS, and leg numbness NRS, respectively. Those values were all within the noninferiority margins (Table 6).

## Discussion

The present investigation comprised an 8-year follow-up study of spinous process-splitting suspension laminoplasty for severe lumbar spinal stenosis with narrowing of the spinal canal at the vertebral body levels. Our procedure is a refinement of spinous process-splitting open-door laminoplasty<sup>2</sup> and aimed to obtain greater posterior element preservation and adequate decompression throughout the affected spinal canal. We demonstrated that (1) osseous continuity in the posterior elements was reconstructed in most cases, (2) substantial improvements from baseline were identified for all scales, and (3) the improvements in the function and symptoms identified in the postoperative follow-up period were maintained

**Table 3****Number of Ununited Spinous Processes or Ununited Laminae in the 50 Patients<sup>a</sup>**

Category	Overall (N = 87)	Level of Elevated Laminae or Split Spinous Processes					P Value (Fisher Exact Test)
		L1 (n = 1)	L2 (n = 6)	L3 (n = 20)	L4 (n = 49)	L5 (n = 11)	
No. of united spinous processes <sup>b</sup>	80	1	6	19	46	8	0.19
No. of ununited spinous processes <sup>b</sup>	7	0	0	1	3	3	
No. of united laminae <sup>c</sup>	83	1	5	18	49	10	0.059
No. of ununited laminae <sup>c</sup>	4	0	1	2	0	1	

<sup>a</sup> The 50 patients without Parkinson disease or nonlumbar spine surgery performed postoperatively or within 6 months preoperatively. The number of elevated laminae is 1 less than the number of disk levels decompressed. As the spinous processes adjacent to the elevated laminae, which underwent partial splitting of their cephalad or caudal portions, were not included in the number of split spinous processes, the numbers of the split spinous processes and the elevated laminae in this table were the same for each patient.

<sup>b</sup> Osseous union between the midline and outer portions of the spinous process.

<sup>c</sup> Osseous union between the lamina flap and the lateral elements.

**Table 4****Number of Patients With Ununited Spinous Processes or Ununited Laminae in the 50 Patients<sup>a</sup>**

Category	Overall (N = 50)	No. of Elevated Laminae or Split Spinous Processes			
		1 (N = 24)	2 (N = 18)	3 (N = 5)	4 (N = 3)
No. of patients with					
No ununited spinous processes <sup>b</sup>	45	23	16	5	1
One ununited spinous process <sup>b</sup>	3	1	1	0	1
Two ununited spinous processes <sup>b</sup>	2	0	1	0	1
No ununited laminae <sup>c</sup>	46	24	17	3	2
One ununited lamina <sup>c</sup>	4	0	1	2	1

<sup>a</sup> The 50 patients without Parkinson disease or nonlumbar spine surgery performed postoperatively or within 6 months preoperatively. The number of elevated laminae is 1 less than the number of disk levels decompressed. As the spinous processes adjacent to the elevated laminae, which underwent partial splitting of their cephalad or caudal portions, were not included in the number of split spinous processes, the numbers of the split spinous processes and the elevated laminae in this table were the same for each patient.

<sup>b</sup> Osseous union between the midline and outer portions of the spinous process.

<sup>c</sup> Osseous union between the lamina flap and the lateral elements.

for 8 years; noninferiority of the 8-year outcomes to the peak-year outcomes was detected. Our findings suggest that the benefits of our procedure were well maintained over 8 years.

This work proposes a new surgical treatment option for patients with severe lumbar spinal stenosis with narrowing of the spinal canal at the vertebral body level for which adequate decompression may not be achieved by standard laminotomy. These patients may be treated with standard laminectomy or spinous

process–splitting laminectomy. Theoretical advantages of our technique over these laminectomy techniques include the preservation of the lamina and the reconstruction of osseous continuity between the spinous process and the lamina. The importance of the osseous continuity between the spinous process and the lamina was evaluated in a previous study of lumbar open-door laminoplasty that used a spinous process–splitting approach;<sup>2</sup> mean deteriorations in the ODI scores from 4 to 10 years

were 11.9 points in patients with two or more ununited spinous processes but only 2.4 points in those with no or one ununited spinous processes. These findings suggest that spinous process integrity is key to successful long-term outcomes after two or more lamina levels (ie, three or more disk levels) are decompressed. In actuality, mean deterioration in the ODI scores from 4 to 8 years was only 1.8 points in our series of 26 patients undergoing decompression at three or more disk levels (this



**Table 5****Outcomes at 1 to 8 Years Postoperatively in the 50 Patients<sup>a</sup>**

Scale	Mean Improvement From Baseline (95% Confidence Interval)							
	1 Year	2 Years	3 Years	4 Years	5 Years	6 Years	7 Years	8 Years
ODI (point)	31.3 (26.5-36.1)	31.7 (26.6-36.9)	33.3 (28.4-38.3)	35.4 (30.7-40.2)	34.8 (30.3-39.4)	<b>35.8</b> (30.5-41.0)	34.2 (29.1-39.3)	34.4 (29.2-39.6)
Low back pain NRS (point)	<b>5.7</b> (4.7-6.6)	5.5 (4.5-6.4)	5.3 (4.5-6.2)	5.5 (4.8-6.3)	5.0 (4.1-6.0)	5.6 (4.8-6.4)	5.3 (4.5-6.1)	5.4 (4.4-6.5)
Leg pain NRS (point)	5.6 (4.6-6.6)	5.6 (4.6-6.6)	5.6 (4.6-6.6)	5.7 (4.7-6.7)	5.8 (4.8-6.8)	<b>5.9</b> (5.0-6.8)	5.5 (4.5-6.4)	5.6 (4.6-6.6)
Leg numbness NRS (point)	2.7 (1.6-3.7)	<b>2.8</b> (1.8-3.8)	2.7 (1.7-3.8)	2.6 (1.6-3.6)	2.5 (1.4-3.5)	2.8 (1.8-3.8)	2.8 (1.8-3.7)	2.9 (1.9-3.8)

NRS = numeric rating scale, ODI = Oswestry disability index

<sup>a</sup> The 50 patients without Parkinson disease or nonlumbar spine surgery performed postoperatively or within 6 months preoperatively. Boldface type indicates peak value within the first 7 postoperative years.

subgroup analysis is not included in the present study). Therefore, our technique may largely benefit patients with stenosis at three or more disk levels and narrowing of the spinal canal at the vertebral body level. If the indication for our technique is limited to use in such patients, the increased complexity of our technique may be justified.

As a preventive measure against spinous process nonunion, osteotomy should be precisely performed to ensure that a sufficient height of the midline portion of the spinous process is obtained to achieve wider areas for osseous union. Another preventive measure may be the tight

fixation of the outer portions of the split spinous process to the midline portion; however, this procedure may increase mechanical stress on the laminar flap, resulting in nonunion between the laminar flap and the lateral elements.

A measure to prevent the nonunion of the laminae may be tight fixation of the elevated lamina to the lateral elements. In the procedure presented, laminar spacers were secured to the suspended lamina but not tied to the lateral elements to prevent postoperative pars fracture through the suture hole. A possible solution may be the use of a miniplate equipped on the laminar spacer; if the shape of

the miniplate is adjusted so that the entry point for screw insertion is located around the pedicle, away from the pars interarticularis. Such dedicated implants may also simplify the procedure, decreasing the surgery time and blood loss.

The advantages of an ultrasonic bone curet for lamina osteotomy are the facilitation of precise cutting and the prevention of nerve injury; but, a major drawback is the consumption of time. Although the maximum available power was used, the surgery time with the ultrasonic bone curet accounted for more than half of the total surgery time. If the power of the ultrasonic bone curet is increased by

**Table 6****Difference Between the Mean Improvements From Baseline at 8 Years and at the Peak Year in the 50 Patients<sup>a</sup>**

Scale	Mean Improvement From Baseline (Point)				Noninferiority		
	8 Years	Peak Year <sup>b</sup>		Difference (95% Lower Confidence Limit)	Margin (Point)	P Value	Power
ODI	34.4	35.8	6 years	-1.3 (-3.3) <sup>c</sup>	-5.0	0.0008	0.99
Low back pain NRS	5.4	5.7	1 year	-0.22 (-0.88) <sup>c</sup>	-1.0	0.025	0.81
Leg pain NRS	5.6	5.9	6 years	-0.30 (-0.82) <sup>c</sup>	-1.0	0.012	0.94
Leg numbness NRS	2.9	2.8	2 years	0.08 (-0.52) <sup>c</sup>	-1.0	0.0012	0.87

NRS = numeric rating scale, ODI = Oswestry disability index

<sup>a</sup> The 50 patients without Parkinson disease or nonlumbar spine surgery performed postoperatively or within 6 months preoperatively.

<sup>b</sup> The values are those at the peak year within the first 7 postoperative years.

<sup>c</sup> Noninferiority is present.

Table 7

## Comparison Between Our Technique and Previously Reported Spinous Process–Splitting Decompression

Study	Surgical Technique	Outcome Measure	Timepoint and Variable	Low Back Pain	Leg Pain	Leg Numbness
Kawakami et al <sup>15</sup>	Marmot surgery <sup>a</sup>	VAS <sup>b</sup>	Baseline (point)	57.3	49.9	58.0
			1 year (point)	23.8	23.8	23.8
			Improvement (point) <sup>c</sup>	33.5	26.1	34.2
			Improvement (%) <sup>c</sup>	58.5	52.3	59.0
Cho et al <sup>16</sup>	Marmot surgery <sup>a</sup>	VAS <sup>d</sup>	Baseline (point)	6.45	—	—
			1 year (point)	2.38	—	—
			Improvement (point) <sup>c</sup>	4.07	—	—
			Improvement (%) <sup>c</sup>	63.1	—	—
Rajasekaran et al <sup>17</sup>	Spinous process, Splitting laminotomy	VAS <sup>d</sup>	Baseline (point)	5.35	—	—
			1 year (point)	2.46	—	—
			Improvement (point) <sup>c</sup>	2.89	—	—
			Improvement (%) <sup>c</sup>	54.0	—	—
Our study		NRS <sup>d</sup>	Baseline (point)	8.0	7.7	5.2
			1 year (point)	2.3	2.1	2.5
			Improvement (point) <sup>c</sup>	5.7	5.6	2.7
			Improvement (%) <sup>c</sup>	71	73	52

VAS = visual analogue scale, NRS = numeric rating scale

<sup>a</sup> Modified microscopic technique used for spinous process–splitting decompression.

<sup>b</sup> Scale from 0 to 100.

<sup>c</sup> Improvement from baseline to 1 year.

<sup>d</sup> Scale from 0 to 10.

improvements made to the device, the entire surgery time and blood loss could be markedly reduced.

The aim of conventional lumbar laminoplasty is laminar preservation and not on midline posterior element preservation; for example, the origin of the multifidus muscle at the spinous process is routinely disrupted or the spinous processes are often removed.<sup>3,4</sup> These techniques provide no clear advantages over laminotomy or laminectomy. In contrast, our procedure is more likely to preserve posterior element integrity. The spinous process–splitting approach itself reportedly minimizes damage to the paraspinal muscles.<sup>5</sup> In a rabbit experiment, the dissection of the multifidus muscle from the spinous process was an important cause of multifidus muscle atrophy.<sup>14</sup>

In a previous study where most subjects underwent laminectomy, the benchmark for spinal stenosis without instability, the best mean ODI scores over 8 years were seen at 6 months; differences between the

mean ODI scores at 8 years and 6 months were  $-10.5$  and  $-6.5$  points in patients from randomized and observational cohorts, respectively.<sup>6</sup> In our procedure, the ODI scores showed steady improvement for up to 6 years; differences between the mean improvements of the ODI score at 8 years and the peak year were  $-1.3$  points. These findings suggest that our procedure may result in more durable outcomes over 8 years than laminectomy. However, a head-to-head study with long-term follow-up will be necessary before reaching a conclusion.

To our knowledge, previous studies of spinous process–splitting decompression for lumbar spinal stenosis lacked long-term follow-up data and did not use the ODI or the NRS, but the visual analogue scale for symptoms was used in three short-term studies (Table 7), including one that used spinous process–splitting laminotomy and two that used a modified microscopic technique (Marmot surgery).<sup>15-17</sup>

Except for the leg numbness scale, our procedure appeared to result in better outcomes than those previously reported in spinous process–splitting decompression; but, the difference in the mean baseline scores between the studies was too large to compare the efficacy of our technique to that achieved by previously reported techniques.

There are several limitations to the current study. First, this was a retrospective, observational investigation with a loss to follow-up, which limits conclusions regarding durability. Second, a single surgeon performed all surgeries and postoperative follow-ups in a nonblinded fashion, although the patients completed the questionnaire independently from the surgeon before each medical examination. Third, we cannot exclude potential selection bias as a result of undetermined differences between our patients and the general population with lumbar spinal stenosis. Finally, this study lacks a control group with the standard technique.

## Conclusion

Suspension laminoplasty using a spinous process-splitting approach is characterized by the expansion of the spinal canal throughout the disk and vertebral body levels and the preservation of the spinous processes and laminae without disrupting the origin of the multifidus muscle at the spinous process. This procedure aims to maintain adequate spinal canal decompression with preserved stability from posterior elements over many years. Our findings indicate that the procedure leads to durable outcomes over 8 years. Improvement in surgical tools should simplify the procedure and make more usable.

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