Radiological Analysis of Minimally Invasive Microscopic Laminectomy for Lumbar Canal Stenosis with a Focus on Multilevel Stenosis and Spondylolisthesis

Takayuki Awaya[1], Yusuke Nishimura[1], Kaoru Eguchi[1], Yoshitaka Nagashima[1], Ryo Ando[1], Sho Akahori[1], Satoshi Yoshikawa[1], Shoichi Haimoto[1], Masahito Hara[2], Masakazu Takayasu[3], Ryuta Saito[1]

■ OBJECTIVE: **We retrospectively compared the radiological and clinical outcomes of two different surgical techniques (lumbar spinous process splitting laminectomy [LSPSL] and unilateral laminotomy for bilateral decompression [ULBD]) to treat lumbar spinal canal stenosis (LCS).**

■ METHODS: **We performed a retrospective comparative study of 141 consecutive patients with an average age of 70.8 ± 9.4 years who had undergone LSPSL or ULBD for LCS between April 2015 and April 2019. None of the patients had developed remote fractures of the spinous processes using either technique. These cases were divided into 2 groups: group L, 73 patients who had undergone LSPSL from April 2015 to April 2017; and group U, 68 patients who had undergone ULBD from May 2017 to April 2019. The clinical and radiological outcomes and surgical complications at the 1-year postoperative follow-up period were evaluated.**

■ RESULTS: **We found no significant differences in the operative time between the 2 groups. However, group U had had significantly less blood loss than group L. The facet joints were significantly well preserved in group U. We examined the multilevel and spondylolisthesis cases separately and found that both surgical procedures were equally effective and that the visual analog scale scores for back or leg pain and Japanese Orthopaedic Association scores had significantly improved postoperatively in each group. Group U showed better outcomes in terms of LCS recurrence, with 3 patients in the group L requiring repeat surgery.**

■ CONCLUSIONS: **We found both ULBD and LSPSL to be safe and effective techniques for LCS, even for patients with spondylolisthesis and multilevel disease. ULBD was superior in terms of recurrence prevention, preservation of the facet joints, and less blood loss.**

INTRODUCTION

Lumbar spinal canal stenosis (LCS) is characterized by a narrowing of the spinal canal with compression of the cauda equina and nerve roots.[1] Its prevalence has been reported to be ∼10% in the general population.[2] Historically, posterior lumbar decompression surgery began with extensive resection of the posterior midline structures. However, concern was raised regarding the postoperative progression of degenerative changes and spinal instability, in particular, for those with multilevel disease and spondylolisthesis.[3-7] Thus, a variety of minimally invasive procedures have been developed and

Key words
- Green stick fracture method
- Lumbar spinous process splitting laminectomy
- Minimally invasive microscopic laminectomy
- Multilevel disease
- Spondylolisthesis
- Unilateral laminotomy for bilateral decompression

Abbreviations and Acronyms
CT: Computed tomography
FSU: Functional spinal unit
GF: Green stick fracture
JOA: Japanese Orthopaedic Association
LCS: Lumbar spinal canal stenosis
LL: Lumbar lordosis
LSPSL: Lumbar spinous process splitting laminectomy
MRI: Magnetic resonance imaging
ROM: Range of motion
ULBD: Unilateral laminotomy for bilateral decompression
VAS: Visual analog scale
VASBL: Visual analog scale for back or leg pain
VASW: Visual analog scale for wound pain

From the [1]Department of Neurosurgery, Nagoya University Hospital, Nagoya; [2]Department of Neurosurgery, Aichi Medical University Hospital, Nagakute; and [3]Department of Neurosurgery, Inazawa Municipal Hospital, Inazawa, Japan

To whom correspondence should be addressed: Yusuke Nishimura, M.D., Ph.D. [E-mail: yusuken0411@med.nagoya-u.ac.jp]

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received attention. At present, minimally invasive microscopic lumbar decompression is widely performed using techniques such as lumbar spinous process splitting laminectomy (LSPSL)[8-10] and unilateral laminotomy for bilateral decompression (ULBD).[11-20] We had exclusively performed LSPSL for LCS until April 2017 and then converted to ULBD from May 2017 onward, because several patients had experienced recurrence and had required reoperation, possibly caused by postoperative instability after LSPSL. Furthermore, we thought the bleeding from the split spinous process in LSPSL, which often blocked our surgical view, should be alleviated. We expected that subperiosteal dissection of the paravertebral muscle from the laminae during ULBD would result in less hemorrhage than splitting of the spinous process in LSPSL. However, it has generally been accepted that LSPSL can preserve the integrity of the bilateral facet joints via the midline surgical view, with the posterior midline structures partially injured. In contrast, ULBD will result in a narrower surgical trajectory to the lateral recess on the approach side with the posterior midline structures maintained. To overcome this issue, we developed the green stick fracture (GF) method for ULBD to achieve oblique visual trajectory over the tilted spinous process to the lateral recess and widen the surgical field on the approach side. This technique can effectively preserve the integrity of the facet joint on both sides and minimizes removal of the laminae and muscle dissection. Therefore, we compared the surgical outcomes between LSPSL and ULBD with the GF method. We believed that ULBD with the GF method would result in less bleeding and preserve the posterior midline structures and bilateral facet joints, leading to better clinical outcomes.

In the present study, we retrospectively compared the radiological and clinical outcomes of two different surgical techniques (LSPSL and ULBD with the GF method) to treat LCS to clarify the effectiveness and lower invasiveness of ULBD with the GF method, with a focus on multilevel disease and spondylolisthesis. The present study investigated whether ULBD with the GF method would result in better surgical outcomes and reduce postoperative instability and LCS recurrence.

METHODS

Patient Selection

We performed a retrospective comparative study of 141 consecutive patients who had undergone LSPSL or ULBD with the GF method to treat LCS from April 2015 to April 2019 at Nagoya University Hospital and Sakura General Hospital. We included patients with surgically treated LCS with or without Meyerding grade 1 spondylolisthesis who had presented with intermittent neurologic claudication or radicular leg pain refractory to >8 weeks of conservative treatment. All the patients had had a diagnosis of LCS ranging from one- to four-level stenosis preoperatively according to their neurological symptoms and corresponding magnetic resonance imaging (MRI), computed tomography (CT), and upright radiographic findings. The patients' data were retrospectively collected, and the patients were followed up for a period of 1 year. These patients were divided into 2 groups. Group L included 73 patients who had undergone LSPSL from April 2015 to April 2017, and group U included 68 patients who had undergone ULBD with the GF method from May 2017 to April 2019. The clinical and radiological outcomes and surgical complications at 1 year postoperatively were compared between the 2 groups. Although LSPSL had been exclusively performed for all LCS cases from April 2015 to April 2017, ULBD with the GF method had been exclusively used from May 2017 to April 2019. Therefore, patient assignment to the 2 groups was unbiased, depending solely on the study period. The exclusion criteria were as follows: spine trauma, spinal tumor, concomitant instrumented fusion surgery, redo surgery at the same level, stenosis resulting from postoperative adjacent segment disease, and a herniated disc without canal stenosis. We also excluded patients with possible spinal instability, defined as 1) a Meyerding grade of ≥ 2 spondylolisthesis on an upright radiograph; 2) angulation of $>5^\circ$ with the patient bending forward on a dynamic flexion–extension upright radiograph; and/or 3) lateral angulation of $>25^\circ$ and lateral slippage of >5 mm on an upright radiograph. We performed instrumented fusion for patients with LCS with possible spinal instability.[21] The institutional review board of the Nagoya University and Sakura General Hospital approved the present study. All the procedures involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. All the patients included in the present study had provided written informed consent.

Operative Techniques

Lumbar Spinous Process Splitting Laminectomy. LSPSL was established by Watanabe et al.,[8] in which a posterior midline skin incision was made, and the soft tissue was dissected until the tip of the spinous process was reached. The spinous process was split longitudinally in the midline and broken at its base from the lamina, with the paraspinal muscles left intact. Laminotomy was performed in the midline with a high-speed drill, and the ligamentum flavum and osteophytes were removed using a Kerrison rongeur under a surgical microscope. The nerve roots on both sides were completely decompressed. The divided spinous process and interspinal ligament were sutured and reconstructed with absorbable threads (Figure 1). A suction drain tube was placed, and ambulation was allowed the following day.

ULBD with the GF Method. ULBD was first reported by Wiltse and Spencer[12] in 1988, followed by Poletti[13] in 1995, and Yamada et al.[14] in 1995. The more symptomatic side was selected as the approach side. The paraspinal muscles were dissected from the midline structures, with the supraspinous and interspinous ligaments left intact, and the interlaminar space was exposed. Under microscopic magnification, unilateral laminotomy was performed, and the ligamentum flavum and osteophytes were removed to expose the dural sac. After completion of nerve root decompression on the approach side, the microscope was tilted medially. The inner aspect of the contralateral lamina was removed, and the dural sac and nerve root were decompressed on the opposite side. The lateral aspect of the nerve roots was visualized, and full mobility of the nerve root was achieved at the final stage (Figure 2). Visualization to the lateral recess on the approach side was frequently blocked by the overhanging facet joint, especially at the upper level of the

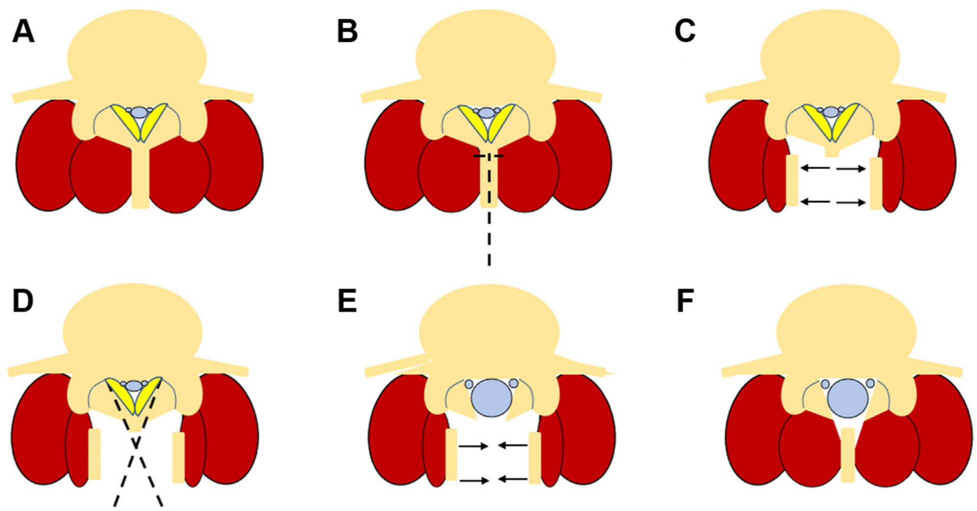

Figure 1. Drawings showing the schema of lumbar spinous process splitting laminectomy. The spinous process was split longitudinally in the midline (**A, B**) and broken at its base from the lamina (**C**). Laminotomy was performed in the midline with a high-speed drill and Kerrison rongeur (**D**). The divided spinous process and interspinal ligament were sutured and reconstructed with absorbable suture (**E, F**).

lumbar spine. In the GF method (Figure 3), the bottom of the spinous process was intentionally fractured and bent to allow the Kerrison rongeur to adequately tilt medially to reach the lateral recess on the approach side was used. This modified technique provided an oblique visual trajectory over the tilted spinous process to the lateral recess and widened the surgical field on the approach side. The structure of the facet joint on the approach side was effectively preserved using the GF method. A suction drain tube was placed, and ambulation was allowed the following day.

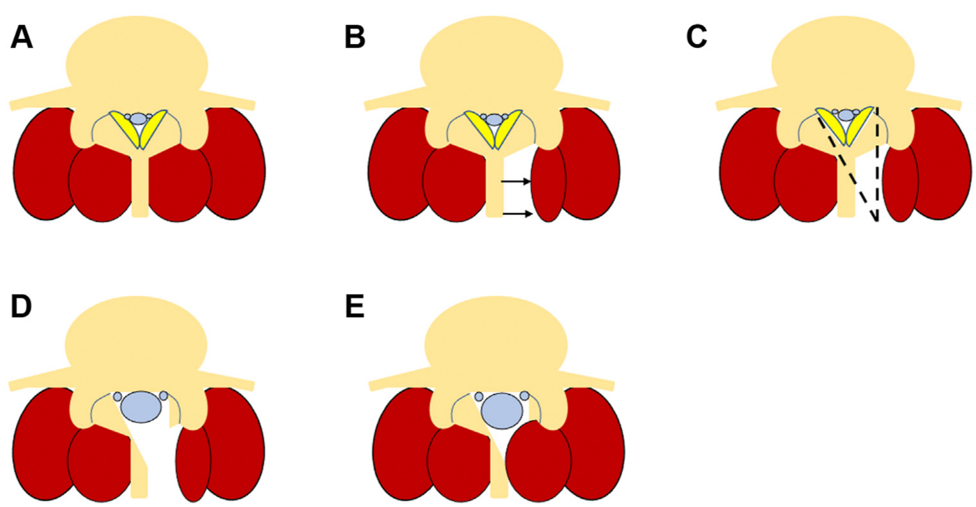

Figure 2. Drawing showing the schema of unilateral laminotomy for bilateral decompression. The paraspinal muscles were dissected from the midline structures, and the interlaminar space was exposed (**A, B**). Unilateral laminotomy was performed, and the ligamentum flavum and osteophytes were removed to expose the dural sac. The inner aspect of the contralateral lamina was removed, and the dural sac and nerve root were decompressed on the opposite side (**C, D**). The paravertebral muscle was sutured and reconstructed (**E**).

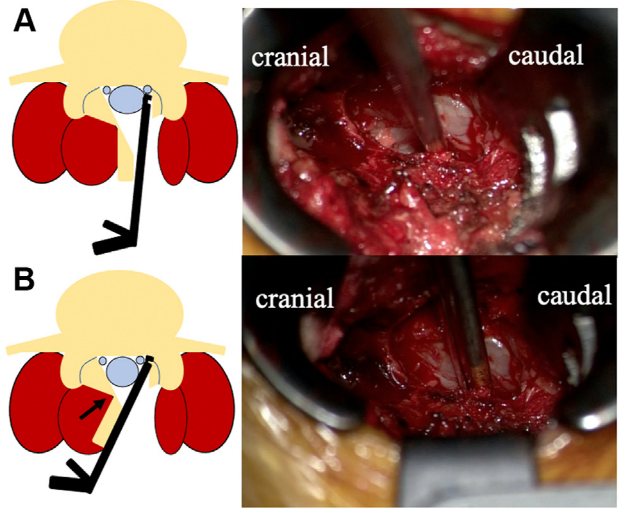

Figure 3. Drawings showing the schema of the greenstick fracture technique and photographs of the surgical field. (**A**) Schema and intraoperative photograph before the greenstick fracture. The Kerrison rongeur cannot be tilted toward the opposite side; thus, the lateral recess stenosis could not be effectively decompressed. (**B**) Schema and intraoperative photograph after the greenstick fracture. The intentional greenstick fracture at the bottom of the spinous process provides a wide surgical window of the ipsilateral lateral recess and enough working space to adequately tilt the Kerrison rongeur toward the opposite side. Use of the greenstick fracture can preserve the integrity of the musculoskeletal structures in the midline and on the opposite side.

Patient Demographics

Preoperative parameters such as age, gender, body mass index, and the number of operative levels were recorded.

Clinical Outcomes

The clinical outcomes were quantified using clinical parameters. These included the visual analog scale (VAS; score range, 0–10) for wound pain (VASW), VAS for back or leg pain (VASBL), and the Japanese Orthopaedic Association (JOA) scale. The VASW was obtained 1 week after surgery to avoid the effects of general anesthesia and postoperative fentanyl used within 24–48 hours after surgery. The VASBL and JOA scores were obtained from the electronic patient records or telephone questionnaires and had been measured preoperatively and at the 1-year postoperative follow-up.

Radiological Evaluation

Radiographs had been obtained preoperatively, on the day after surgery, and every 6 months postoperatively in the outpatient clinic. CT scans were obtained preoperatively and on the day after surgery. MRI was performed preoperatively, 1 week after surgery, and 1 year postoperatively. Lumbar lordosis (LL) was measured as the angle between the superior endplates of L1 and S1 using an upright lateral radiograph (Figure 4A). The range of motion (ROM) of LL was calculated from the flexion–extension radiograph. The functional spinal unit (FSU) consists of 2 adjacent vertebrae and the intervening intervertebral disc (Figure 4B). The height and segmental angle of the FSU at the operated segments were measured from an upright lateral radiograph (Figure 4B). The facet preservation rate and dural expansion rates were recorded from the electronic medical records using the axial CT images and axial T2-weighted MRI scans, respectively (Figure 4). The facet preservation rate was calculated as the longest distance of the facet joints postoperatively divided by the preoperative values. The dura expansion rate was defined as spinal canal area postoperatively divided by the spinal canal area preoperatively.

The surgical outcomes (estimated blood loss, operative time, and postoperative complications) were also evaluated. The postoperative complications were obtained at the 1-year postoperative follow-up. Multilevel cases and Meyerding grade 1 spondylolisthesis cases were analyzed separately. The flexion angle and anterior slip of the vertebral body at the operated segments on an upright flexion radiograph were recorded preoperatively and at 1 year postoperatively for the patients with Meyerding grade 1 spondylolisthesis (Figure 4C).

Statistical Analysis

All data are presented as the mean ± standard deviation. The Student t test was performed to investigate the continuous data for the radiological parameters. The Mann-Whitney U test was used to analyze the VAS and JOA scores. Finally, the χ^2 test was used to determine differences in gender. Statistical significance was set at $P < 0.05$.

RESULTS

Preoperative Parameters

No significant differences were found in the preoperative parameters, including age, gender, body mass index, and number of operated levels, between the 2 groups (Table 1). The preoperative VASBL and JOA scores were comparable. The radiological measurements, including LL, ROM of LL, FSU angle, and FSU height, were also equal between the 2 groups.

Surgical Outcomes

The surgical outcomes are presented in Table 2. Although no significant difference was found in the operative time between the 2 groups, group U had significantly less blood loss compared with group L. Early surgical complications included unintentional dura tear (1 case in group L and 2 in group U), postoperative hematoma requiring hematoma evacuation surgery (1 case in each group), and surgical site infection requiring incision and drainage (1 case in group L). The incidence of delayed surgical complications was investigated until the 1-year postoperative follow-up. Symptomatic recurrence at the operated level was not found in group U. However, 3 patients in group L had successfully undergone repeat instrumented fusion for recurrence. All patients with recurrence in group L had not had spondylolisthesis preoperatively. However, 2 of the 3 patients with recurrence had had multilevel lesions (1 with 3-level stenosis and 1 with 4-level stenosis). The remaining patient with single-level stenosis preoperatively showed severe L4-L5 disc degeneration with vacuum phenomenon without spondylolisthesis. He had

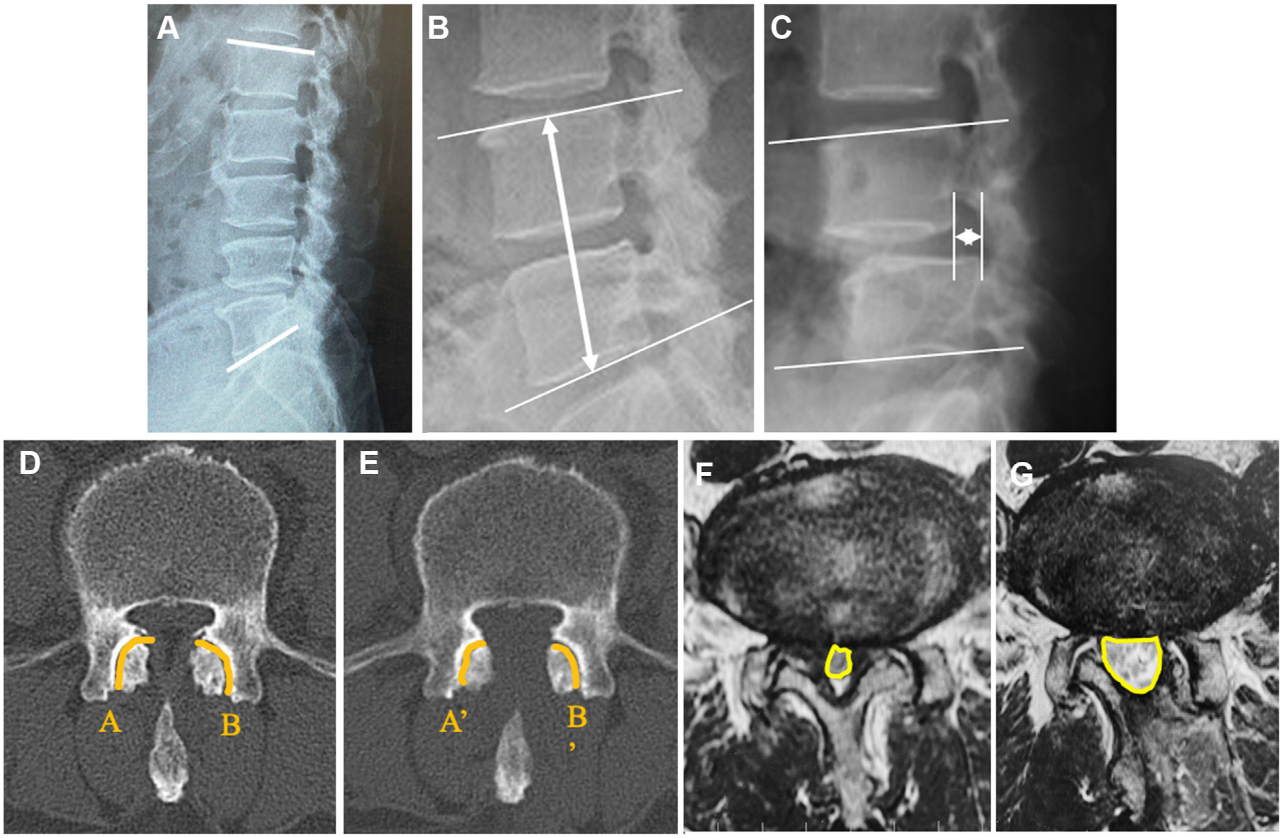

Figure 4. Lumbar lordosis was measured as the angle between the superior endplates of L1 and S1 using an upright lateral radiograph (**A**). The range of motion of lumbar lordosis was calculated from the flexion—extension radiograph. The functional spinal unit consisted of 2 adjacent vertebrae and an intervening intervertebral disc (**B**). The height and segmental angle of the functional spinal unit at the operated segments were measured from an upright lateral radiograph. The flexion angle and anterior slip of the vertebral body at the operated segments on an upright flexion radiograph were measured preoperatively and at 1 year postoperatively for those with Meyerding grade 1 spondylolisthesis (**C**). The facet preservation rates were calculated. The facet length was measured at the longest distance on the axial section of the computed tomography scan preoperatively (**D**; facet length = $A + B$) and postoperatively (**E**; facet length = $A' + B'$). The facet preservation rate was as follows: % = $A' + B'/A + B$. The dura expansion rates were calculated using axial T2-weighted magnetic resonance imaging: preoperatively (**F**) and postoperatively (**G**). The spinal canal area was measured as the area circled by the *yellow line* preoperatively and postoperatively. The dura expansion rate was calculated as the *yellow circle* in **F** divided by the *yellow circle* in **G**.

experienced recurrence of his neurological symptoms with new-onset grade 1 spondylolisthesis postoperatively.

Postoperative Clinical and Radiological Outcomes for All Patients

The postoperative clinical and radiological outcomes for all the patients are presented in Table 3. No significant differences were found between the 2 groups in the VASW scores recorded 1 week after surgery. The VASBL and JOA scores had significantly improved postoperatively in both groups ($P < 0.05$ for both; Figure 5A) and showed no significant differences between the 2 groups at 1 year postoperatively. The facet joints were significantly well preserved in group U. The spinal canal was effectively expanded in group L, although not significantly. No differences were found in the postoperative spinal alignment, including LL, ROM of LL, FSU height, and FSU angle, between the 2 groups.

Postoperative Clinical and Radiological Outcomes for Multilevel Cases

Analysis of only the patients with multilevel LCS of ≥2 levels demonstrated that the preoperative VASBL and JOA scores, LL, ROM of LL, FSU height, and FSU angle were not significantly different between the 2 groups. These clinical and radiological parameters did not differ postoperatively between the 2 groups (Table 4). The VASBL and JOA scores showed significant improvement in each group postoperatively ($P < 0.05$ for both; Figure 5B).

Postoperative Clinical and Radiological Outcomes of Spondylolisthesis Cases

To clarify the effects of the 2 different surgical procedures on spondylolisthesis, patients with Meyerding grade 1 spondylolisthesis were investigated separately. No differences were found in

Table 1. Preoperative Parameters

Parameter	Group L	Group U	*P* Value
Patients (*n*)	73	68	
Age (years)	71.5 ± 9.2	70.2 ± 9.6	0.50
Male gender (%)	60	54	0.69
BMI (kg/m^2)	23.5 ± 2.9	23.7 ± 3.3	0.70
Operated levels (*n*)	1.8 ± 0.9	1.7 ± 0.8	0.62
Disease (*n*)			NA
Single level	25	28	
Multilevel	48	40	
VASBL score	4.5 ± 1.0	4.4 ±1.2	0.72
JOA score	16.9 ± 1.8	17.1 ± 2.2	0.67
LL (°)	35.9 ± 12.7	36.8 ± 11.2	0.71
ROM of LL (°)	26.5 ± 8.9	22.7 ± 9.2	0.06
FSU angle (°)	19.9 ± 10.6	19.0 ± 8.8	0.62
FSU height (mm)	88.8 ± 32.6	88.9 ± 30.5	0.99

Data presented as mean ± standard deviation, unless noted otherwise.
L, lumbar spinous process splitting laminectomy; U, unilateral laminotomy for bilateral decompression; BMI, body mass index; NA, not applicable; VASBL, visual analog scale for back or leg pain; JOA, Japanese Orthopaedic Association; ROM, range of motion; LL, lumbar lordosis; FSU, functional spinal unit.

the preoperative clinical and radiological parameters between the 2 groups. The VASBL and JOA scores showed excellent improvement postoperatively in both groups ($P < 0.05$ for both; Figure 5C). All parameters were equally well maintained postoperatively. Furthermore, the parameters related to spondylolisthesis such as the flexion angle in a forward-bending position, anterior slip distance between 2 vertebrae in a neutral position (listhesis neutral) or in a forward-bending position (listhesis flexion) were unchanged postoperatively between the 2 groups. Both procedures proved to be equally minimally invasive techniques for LCS with Meyerding grade 1 spondylolisthesis (Table 5).

DISCUSSION

An increasing number of studies have compared different surgical procedures for LCS, including standard open laminectomy, ULBD, LSPSL, and endoscopic surgery,[9,20,22-25] in the context of an increasing demand for minimally invasive surgery. In general, ULBD and LSPSL are both superior to standard open laminectomy in the reduction of the hospital stay, postoperative lumbar instability, blood loss, and wound pain.[7,26,27] In contrast, Ulrich et al.[23] reported that a comparison of ULBD and standard open laminectomy showed comparable results in a quality-of-life assessment. Arai et al.[17] also concluded that an analysis of ULBD and muscle-preserving interlaminar decompression

Table 2. Surgical Outcomes

Outcome	Group L	Group U	*P* Value
Surgical time (minutes)	124.3 ± 48.1	108.2 ± 37.3	0.065
Blood loss (mL)	107.0 ± 129.7	44.3 ± 42.5	<0.05
Early surgical complications (*n*)			NA
Dural tear	1	2	
Hematoma (reoperation)	1	1	
SSI (reoperation)	1	0	
Delayed recurrence of canal stenosis at operated level (reoperation) at 1 year (*n*)	3	0	NA

Data presented as mean ± standard deviation, unless noted otherwise.
L, lumbar spinous process splitting laminectomy; U, unilateral laminotomy for bilateral decompression; NA, not applicable; SSI, surgical site infection.

Table 3. Postoperative Clinical and Radiological Outcomes for All Patients

Postoperative Outcome	Group L	Group U	*P* Value
VASW score	1.3 ± 1.1	1.2 ± 0.7	0.42
VASBL score	0.7 ± 0.9	0.5 ± 0.7	0.17
JOA score	24.2 ± 2.3	25.0 ± 2.4	0.25
Facet preservation rate (%)	90.4 ± 4.7	93.1 ± 3.8	<0.05
Canal area (mm^2)	81.3 ± 36.1	69.4 ± 28.1	0.06
LL (°)	37.1 ± 11.7	38.8 ± 11.3	0.49
ROM of LL (°)	22.2 ± 7.6	21.4 ± 9.3	0.68
FSU height (mm)	86.4 ± 30.1	87.9 ± 28.8	0.81
FSU angle (°)	21.8 ± 11.9	19.7 ± 9.3	0.34

Data presented as mean ± standard deviation.
L, lumbar spinous process splitting laminectomy; U, unilateral laminotomy for bilateral decompression; VASW, visual analog scale for wound pain; VASBL, visual analog scale for back or leg pain; JOA, Japanese Orthopaedic Association; LL, lumbar lordosis; ROM: range of motion; FSU, functional spinal unit.

(or modified LSPSL) demonstrated equally favorable outcomes. Endoscopy has also been receiving attention owing to its small skin incision and quick postoperative recovery. However, previous studies of endoscopic surgery for LCS mostly analyzed only single-level cases, with no mention of multilevel cases, spondylolisthesis, or spinal instability.[28-30] Although the effectiveness of

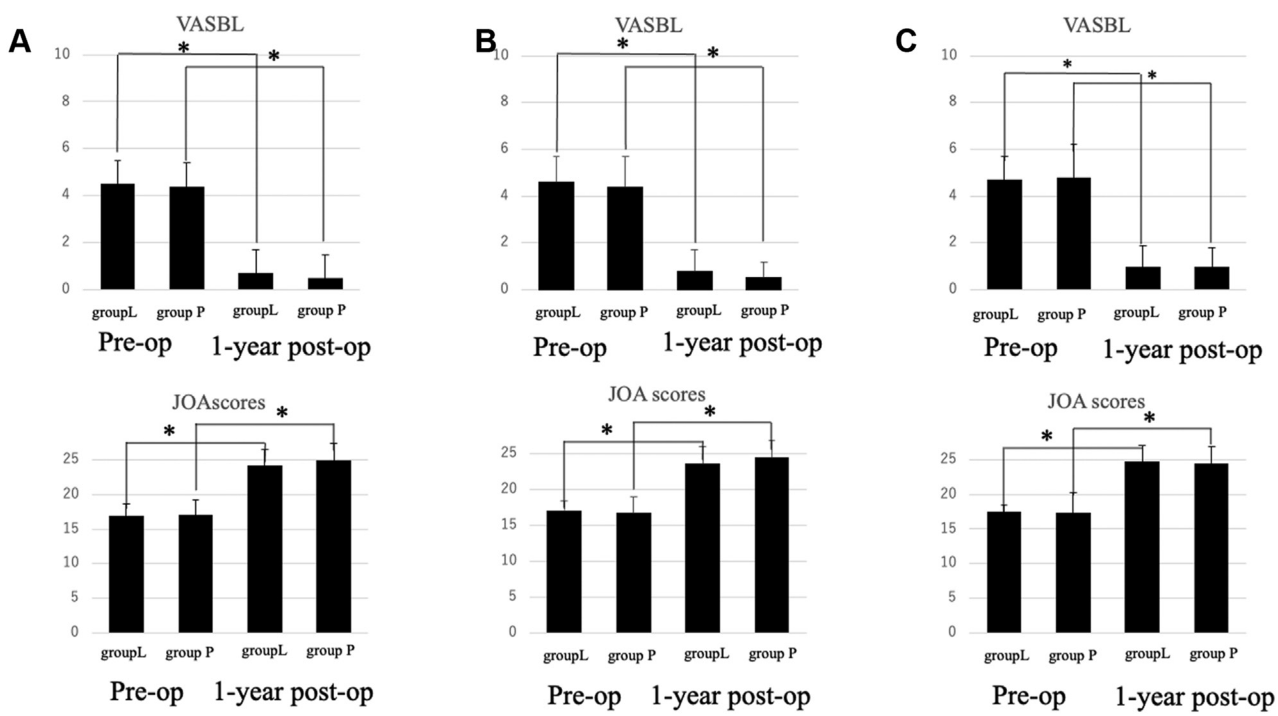

Figure 5. The preoperative and postoperative visual analog scale for back or leg pain (VASBL) and Japanese Orthopaedic Association (JOA) scores in all cases (**A**), multilevel cases (**B**), and Meyerding grade 1 spondylolisthesis cases (**C**). Although the VASBL and JOA scores were not significantly different between lumbar spinous process splitting laminectomy and unilateral laminotomy for bilateral decompression preoperatively and postoperatively, the VASBL and JOA scores both showed significant improvement postoperatively in all cases, multilevel cases, and Meyerding grade 1 spondylolisthesis cases.

Table 4. Preoperative and Postoperative Clinical and Radiological Parameters of Multilevel Cases

Parameter	Group L	Group U	*P* Value
Preoperatively			
Patients (*n*)	25	28	NA
VASBL score	4.6 ± 1.1	4.4 ± 1.3	0.51
JOA score	17.1 ± 1.3	16.7 ± 2.3	0.32
LL (°)	36.0 ± 12.8	33.4 ± 12.2	0.45
ROM of LL (°)	24.7 ± 10.2	23.2 ± 8.4	0.60
FSU height (mm)	99.8 ± 30.8	105.1 ± 31.7	0.53
FSU angle (°)	25.3 ± 11.3	20.4 ± 10.3	0.10
Postoperatively			
Patients (*n*)	25	28	NA
VASBL score	0.8 ± 0.9	0.5 ± 0.7	0.26
JOA score	23.6 ± 2.3	24.4 ± 2.4	0.41
LL (°)	38.6 ± 13.1	35.8 ± 12.3	0.46
ROM of LL (°)	22.6 ± 7.9	20.4 ± 8.6	0.37
FSU height (mm)	99.1 ± 30.8	102.8 ± 30.0	0.68
FSU angle (°)	25.0 ± 10.4	22.4 ± 11.5	0.51

Data presented as mean ± standard deviation.
L, lumbar spinous process splitting laminectomy; U, unilateral laminotomy for bilateral decompression; NA, not applicable; VASBL, visual analog scale for back or leg pain; JOA, Japanese Orthopaedic Association; LL, lumbar lordosis; ROM: range of motion; FSU, functional spinal unit.

endoscopy might be comparable to that of microsurgery, further studies are required to analyze the versatility of endoscopy for multilevel canal stenosis and spondylolisthesis.

In the present study, the minimally invasive microscopic techniques of LSPSL and ULBD with the GF method were compared with a focus on multilevel canal stenosis and spondylolisthesis. Although ULBD with the GF method we have described is a mild modification of the widely used surgical procedure (ULBD), this technique provides an oblique visual trajectory over the tilted spinous process to the lateral recess on the approach side and a wider surgical field. This allows for effective decompression of the nerve roots on the approach side and minimizes removal of the lamina, facet capsule violation, and paraspinal muscle dissection. We, therefore, expect our GF method could lead to minimally invasive microscopic decompression for LCS. The findings from the present study revealed significantly more blood loss in group L than in group U. Bleeding from the split spinous processes and laminae often blocks the visual field throughout the procedure during LSPSL. In contrast, subperiosteal dissection of the paravertebral muscle from the lamina causes minimal blood loss during ULBD. However, both procedures showed equally excellent clinical and radiological outcomes. LSPSL has been reported to provide better orientation via the midline approach and easy access to the bilateral lateral recess without damaging the facet joints. Arai et al.[17] reported that a postoperative lateral wedging deformity at the L2-L3 and L3-L4 levels more frequently occurred after ULBD than after LSPSL, although ULBD was more beneficial than LSPSL at lower levels (L4-L5). They advocated that LSPSL should be used for sagittal facet orientation, as usually seen in the upper lumbar levels, or in cases of severe facet joint osteoarthritis.[17] In contrast, our modified technique of ULBD with the GF method can be applied even to upper lumbar levels because the oblique visual trajectory on the approach side can minimize removal of the laminae and facet joints.

Although we found no differences in postoperative spinal alignment between ULBD with the GF method and LSPSL, 3 patients in group L had experienced recurrence at 1 year postoperatively. Of these 3 patients, 2 had undergone multilevel surgery (3 and 4 levels) and 1 had undergone single-level surgery. Thus, multilevel surgery is suitable using ULBD with the GF method. Arai et al.[17] also reported that ULBD was superior to LSPSL in the improvement of low back pain and lumbar function for multilevel surgery. This is because the disruption of the posterior midline ligamentous complex and possible bilateral facet joint violation during LSPSL can provoke spinal micro-instability in patients undergoing multilevel surgery that was not clarified radiographically (Table 4). Bresnahan et al.[31] used a lumbar decompression model to study the implications of preserved posterior midline structures on the lumbar spine and concluded that disruption of the posterior midline ligamentous complex increases the range of motion of the lumbar spine, leading to progressive spinal degeneration.[31] Schär et al.[32] also reported that laminotomy with the midline tension band preserved can be successfully performed even for multilevel or

Table 5. Preoperative and Postoperative Clinical and Radiological Parameters of Spondylolisthesis Cases (Meyerding Grade 1)

Parameter	Group L	Group U	*P* Value
Preoperatively			
Patients (*n*)	10	16	NA
VASBL score	4.7 ± 1.0	4.8 ± 1.4	1.00
JOA score	17.5 ± 1.0	17.4 ± 2.8	0.84
LL (°)	39.2 ± 8.1	31.9 ± 11.0	0.10
FSU angle (°)	16.0 ± 9.2	16.7 ± 6.8	0.59
FSU ROM (°)	5.9 ± 3.5	4.2 ± 1.7	0.24
Flexion angle (°)	9.0 ± 10.1	8.5 ± 6.0	0.97
Listhesis neutral (mm)	7.1 ± 1.6	6.9 ± 1.3	0.81
Listhesis flexion (mm)	7.8 ± 1.7	8.0 ± 1.8	0.56
Postoperatively			
Patients (*n*)	10	16	NA
VASBL score	1.0 ± 0.9	1.0 ± 0.8	0.96
JOA score	24.8 ± 2.2	24.4 ± 2.5	0.79
LL (°)	36.1 ± 10.4	36.0 ± 10.5	0.97
FSU angle (°)	15.3 ± 9.0	18.4 ± 9.3	0.32
FSU ROM (°)	3.7 ± 3.2	4.9 ± 1.9	0.25
Flexion angle (°)	10.0 ± 9.2	8.2 ± 6.9	0.75
Listhesis neutral (mm)	7.7 ± 2.2	7.1 ± 1.3	0.83
Listhesis flexion (mm)	8.1 ± 2.0	8.2 ± 1.7	0.83

Data presented as mean ± standard deviation.

L, lumbar spinous process splitting laminectomy; U, unilateral laminotomy for bilateral decompression; NA, not applicable; VASBL, visual analog scale for back or leg pain; JOA, Japanese Orthopaedic Association; LL, lumbar lordosis; FSU, functional spinal unit; ROM, range of motion.

spondylolisthesis cases without instability, which might positively support our results.

The average rate of the facet joint preservation on both sides was significantly greater in the ULBD group owing to the intentional use of the GF method we have described, which successfully provided a tilted trajectory to the ipsilateral lateral recess and facilitated its sufficient decompression with minimal damage to the overhanging facet joint. Therefore, ULBD with the GF method can prevent postoperative spinal micro-instability in patients with multilevel disease.

It has remained controversial whether decompression without instrumented fusion will always be effective for spondylolisthesis.[26,32,33] Analysis of Meyerding grade 1 spondylolisthesis cases demonstrated excellent postoperative neurological improvement in both groups in the present study. Although previous studies have shown that the vacuum phenomenon in the disc space on CT and the facet joint fluid signal on MRI are associated with lumbar instability,[34-36] not a few cases with these signs were included and analyzed in the present study. The results have shown that ULBD with the GF method or LSPSL was effective and satisfactory for these cases, unless obvious spinal instability signs were evident on the dynamic radiographs. Therefore, even if the vacuum phenomenon in the disc space and facet joint fluid signal signs are noted, LCS can be safely treated using ULBD with the GF method or LSPSL. However, cases with multilevel stenosis might be more suitable for ULBD with the GF method in consideration of the recurrent cases in our study after LSPSL.

The advantage of these microsurgical procedures compared with endoscopy is the broad versatility with easy application to LCS cases even in the presence of multilevel disease and spondylolisthesis. The patients with a maximum of four levels included in the present study showed good clinical and radiological outcomes. Most patients with LCS seen in daily clinical practice would have met the inclusion criteria of the present study. Therefore, most cases of LCS could have a good indication for microscopic lumbar decompression surgery.

The present study had a retrospective design. Nonetheless, the pathology and indications were exactly the same in both groups, and the conditions of the study were similar to those of a randomized trial. However, the present study had the following limitations: 1) no long-term follow-up was performed; 2) the sample size was small; and 3) the outcomes were from a single-surgeon group. Thus, it might be necessary to accumulate more patients with multilevel disease or spondylolisthesis for a separate analysis to clarify the effectiveness of LSPSL and ULBD with the GF method. In addition, other signs of possible spinal instability, such as the vacuum phenomenon and facet joint signal changes, should be separately analyzed to assess the versatility of these surgical procedures. A multicenter prospective study might also reveal more valuable data that could help differentiate the usefulness of these 2 techniques.

CONCLUSIONS

Both ULBD with the GF method and LSPSL are safe and effective techniques for the treatment of LCS. ULBD with the GF method might be superior for the preservation of the facet joints and posterior midline ligamentous complex, which could minimize postoperative recurrence of canal stenosis and progression of lumbar spine degeneration in patients with multilevel disease.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Takayuki Awaya: Conceptualization, Methodology, Acquisition of data, Formal analysis, Data curation, Writing — original draft, Approval of the version of the manuscript to be published. **Yusuke Nishimura:** Conceptualization, Methodology, Acquisition of data, Formal analysis, Data curation, Writing — original draft, Approval of the version of the manuscript to be published. **Kaoru Eguchi:** Acquisition of data, Approval of the version of the manuscript to be published. **Yoshitaka Nagashima:** Acquisition of data, Approval of the version of the manuscript to be published. **Ryo Ando:** Acquisition of data, Approval of the version of the manuscript to be published. **Sho Akahori:** Acquisition of data, Approval of the version of the manuscript to be published. **Satoshi Yoshikawa:** Acquisition of data, Approval of the version of the manuscript to be published. **Shoichi Haimoto:** Acquisition of data, Approval of the version of the manuscript to be published. **Masahito Hara:** Writing — review & editing, Approval of the version of the manuscript to be published. **Masakazu Takayasu:** Writing — review & editing, Approval of the version of the manuscript to be published. **Ryuta Saito:** Writing — review & editing, Approval of the version of the manuscript to be published.

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