Clinical Outcomes Following Decompression of Central Canal and Lateral Recess Simultaneous Stenosis, with a Focus on Multilevel Stenosis: A Randomized Comparison of Microscopic Bilateral Laminotomy versus Total Laminectomy with Posterior Spinal Fusion

Paria Shafiekhani[1], Melika Hajimohammadebrahim-Ketabforoush[1], Elnaz Amanzadeh Jajin[1], Sara Zandpazandi[2], Mohammadreza Shahmohammadi[1]

BACKGROUND: **In patients with simultaneous lumbar central spinal stenosis (LCSS) and lateral recess stenosis (LRS) at multiple levels, spinal decompression using microscopic bilateral laminotomy was compared to total laminectomy plus medial facetectomy and fusion (LF).**

METHODS: **From 2017 to 2022, this trial was performed to examine 96 patients with concomitant LCS and LRS at multilevel. Of the 96 patients, 48 were allocated to the following groups: LF (group I) or microscopic bilateral laminotomy (group II). However, 76 patients completed the study. We compared the outcomes in these 2 groups.**

RESULTS: **Microscopic bilateral laminotomy was superior in most outcome measures. Delta-visual analog scale leg pain in group II was significantly greater than in group I (mean-group I: 4.368 vs. group II: 5.368, *P* value = 0.001). Complication and revision rates were lower in the microscopic bilateral laminotomy than in group I, except for incidental durotomy occurrence (group II: 31.58% −group I: 7.89%, *P* value = 0.0190). The rate of revision surgery for group I compared with group II was 44.74% versus 13.16% (*P* value = 0.0047), indicating the superiority of laminotomy over LF. The mean length of hospital stay was 3.551 ± 0.6349 in group II versus 6.774 ± 1.197 in group I (*P* value <0.0001). Also, blood loss during surgery was significantly lower in group II (*P* value <0.0001).**

CONCLUSIONS: **The findings indicate that microscopic bilateral laminotomy provides favorable clinical and radiological outcomes for individuals experiencing multilevel lumbar central canal and LRS. However, a higher frequency of durotomy may occur during microsurgical procedures.**

INTRODUCTION

As the population ages, lumbar spinal stenosis (LSS), a progressive, degenerative disorder characterized by narrowing of the neural foramina or spinal canal, becomes increasingly prevalent. This process may result in a debilitating condition in the seniors that manifests initially as neurogenic claudication or leg and back pain. Spinal stenosis is anatomically classified into 3 subtypes: lumbar central spinal stenosis (LCSS), foraminal stenosis, and lateral recess stenosis (LRS).[1,2] LCSS and LRS often occur simultaneously. Their pathogenesis can arise from disc herniation, hypertrophic ligamentum flavum, and hypertrophic facet joints.[3] However, investigations generally

Key words
- Central canal stenosis
- Laminotomy
- Lateral recess stenosis
- Total laminectomy and fusion

Abbreviations and Acronyms
ASD: Adjacent segmental disease
LCSS: Lumbar central spinal stenosis
LF: Laminectomy plus medial facetectomy and fusion
LRS: Lateral recess stenosis
LSS: Lumbar spinal stenosis
MRI: Magnetic resonance imaging
ODI: Oswestry disability index
VAS: Visual analog scale

From the [1]Functional Neurosurgery Research Center, Shohada Tajrish Comprehensive Neurosurgical Center of Excellence, Shahid Beheshti University of Medical Sciences, Tehran, Iran; [2]STAR program Post-Doctoral Research Scholar, Department of Neurological Surgery, Medical University of South Carolina, Columbia, South Carolina, USA

To whom correspondence should be addressed: Mohammadreza Shahmohammadi, M.D. [E-mail: mr_shahmohammadi@sbmu.ac.ir]

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focus more on central stenosis than LRS. Since patients with lateral recess (foraminal) stenosis may experience severe radicular pain and require additional surgery, LRS could be misdiagnosed and mismanaged, causing lumbar spine surgeries to fail.[4]

The surgical intervention of choice to treat symptomatic LCSS and LRS typically involves a comprehensive laminectomy procedure. It is advisable to contemplate decompression, fusion, or a combination of both interventions. However, there is a growing popularity of tissue-sparing techniques. Several surgical procedures have been delineated, including midline laminectomy with partial medial facetectomy, total laminectomy and medial facetectomy with fusion, and microinvasive bilateral laminotomy. Nevertheless, determining the most suitable approach remains a topic of debate. Several factors can influence the surgeon's decision, including the location of the stenosis, the degree of involvement and the number of concomitant deformities, the surgeon's preference, and the patient's surgical history.[5-7]

According to the level of involvement, although laminectomy has traditionally been considered an effective treatment for single-level stenosis, removing the lamina, isthmus, and intervertebral facet joints disrupts the spine's stable structure. Furthermore, this surgical procedure can result in scar tissue within the epidural space, as well as postoperative back pain and other associated complications. The procedure can be performed independently or with lumbar fusion to treat multilevel spinal stenosis. However, there is an ongoing debate about the effectiveness of fusion for patients with isolated multilevel stenosis. The North American Spine Society has recommended decompression without fusion as a suitable course of action when leg symptoms are the primary concern, provided spinal instability, such as scoliosis and spondylolisthesis, is absent.[8-10] During multilevel laminectomy plus medial facetectomy and fusion (LF) procedures, surgeons may have the opportunity to remove additional bone without causing iatrogenic instability. However, instrumented fusion procedures can lead to implant complications, prolonged surgical time, significant blood loss, extended hospitalization, and the potential for symptomatic adjacent segmental disease (ASD) that may necessitate revision surgery.[3,11,12]

On the other hand, in recent years, more selective decompression (undercutting decompression) has emerged as a preferred alternative to more aggressive ones (laminectomy). Microscopic, microendoscopic, and endoscopic techniques have been devised to achieve decompression of the central and lateral recess through smaller incisions. This approach conserves midline structures and facet function, avoiding instability and arthrodesis surgery. Minimally invasive spinal surgeries, such as microscopic bilateral laminotomy, enable smaller incisions, minimize muscle detachment, and allow the targeted removal of an isolated ipsilateral facet joint.[6,7]

Therefore, the current trial was designed to compare the surgical complications and improvements in postoperative pain scores between bilateral multilevel microscopic laminotomy and LF in patients with simultaneous LCSS and LRS at multiple lumbar levels.

MATERIALS AND METHODS

Trial Design

This prospective, single-center, parallel-arm, randomized, open, interventional trial was conducted from 2017 to 2022 after receiving approval from the independent ethics committee of our institute, under the Declaration of Helsinki. The trial was registered at https://www.irct.ir/, number IRCT20190126042496N3. Our trial was designed based on "per-protocol analysis". According to this, we did not have any violations of the study protocol in population selection, patient entry, allocation, implementation of the plan, and our intervention. Therefore, the present study was conducted based on a per-protocol analysis. The present study, however, examined the actual received effect of interventions on patients during the follow-up period. It did not consider the assigned effect on patients who violated or withdrew from the study for any reasons.

Ninety-six patients with concomitant LCS and LRS at multilevel who met all inclusion and exclusion criteria were recruited consecutively from outpatient clinics. Written consent was also obtained from each one before enrollment. Then, with balanced randomization [1:1], a series of 48 patients were randomly assigned via a random number table to each of the following 2 arms: microscopic bilateral laminotomy or LF **Figure 1**.

The following were the patients' eligibility and exclusion criteria:

Inclusion criteria: patients between 30 and 75 years of age with multilevel LSS ($\geq$3 levels), both the central canal ($\leq$ grade II, according to Schizas grading) and the lateral recess simultaneously (anteroposterior diameter of central canal $<$10 mm and lateral recess diameter $<$3 mm or an inter pediculate distance $<$16 mm), failure of conservative therapy for radicular pain, and the predominance of the radicular pain over claudication (mild).

Exclusion criteria: patients with severe stenosis of the central canal suffering from severe neurogenic claudication that limits their ability to stand or walk, extruded discs or those requiring discectomy, osteoporotic patients with a T score < -1.5, previous history of spinal surgery, Serious medical conditions such as congestive heart failure, cirrhosis, and other chronic diseases precluding surgical procedures, current metabolic, rheumatologic, or inflammatory disorders requiring corticosteroid consumption, and spinal deformity.

Before obtaining written informed consent from patients, a senior surgeon provided them with information regarding the surgical procedures; patients were then scheduled to undergo microscopic bilateral laminotomy or LF.

Surgical Procedures and Postoperative Care

Under general anesthesia, all procedures were performed with the patient in a prone posture to decompress as much pressure as possible from the spinal canal and nerve roots at stenotic levels. The experienced neurosurgeon carried out all operations to eliminate any potential technical bias.

Microscopic Bilateral Laminotomy. After establishing the surgical level using fluoroscopic imaging, a 4 cm posterior midline incision was performed. The paraspinal and multifidus muscles were

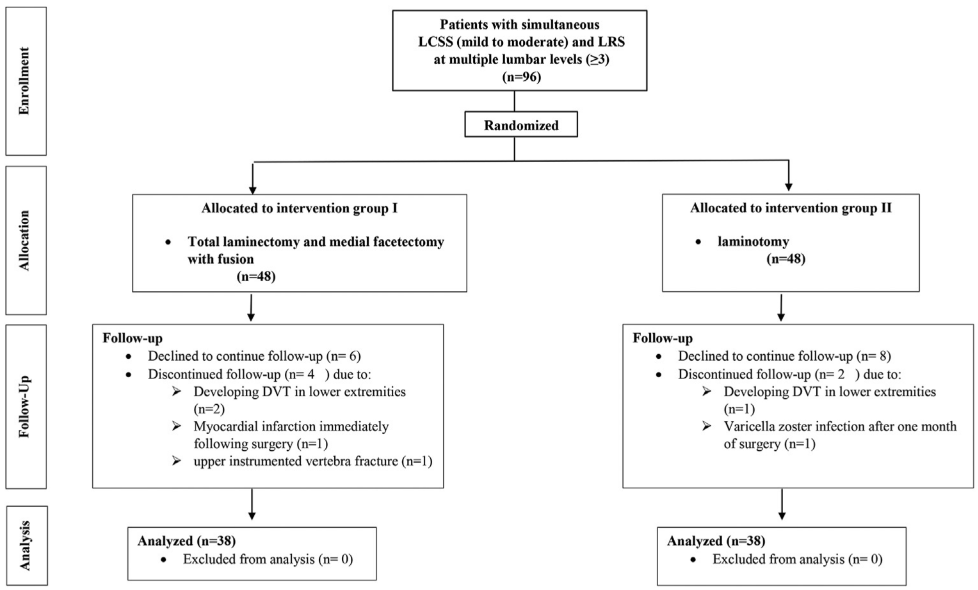

Figure 1. Patients' random allocation flow chart.

detached from their insertion to the spinous processes, followed by subperiosteal dissection downward until exposing the lamina and facets of the stenotic level; then, the spine retractor was applied.

Following laminar exposure, a micro drill was used under microscopic surgical guidance to remove the inferior portion of the superior lamina and a minimal part of the superior portion of the inferior lamina, the basal part of the spinous process, and two thirds of the medial facet. Following adequate bony resection, the ligamentum flavum is removed with a curette, followed by bilateral foraminotomy to increase neural decompression. Accordingly, nerve roots were significantly released from their attachment to the thecal sac in the midline to 1 cm after their entrance to the foramen. The same procedure was repeated on the contralateral side. The spinous process, supraspinous and interspinous ligaments were preserved, and a considerable percentage of the lamina stayed conserved in this technique.

Total Laminectomy with Fusion. The decompression procedure involves completely removing the posterior portion of the bony ring surrounding the spinal cord, including spinous processes and bilateral lamina, with partial removal of the medial facet joint and interspinous excision and interspinous and supraspinous ligaments under the direct vision of a surgical microscope. Following spinal canal decompression, posterolateral fusion was performed by implanting pedicle screws with rods plus auto graft. Hemostasis was then performed, a drain was inserted, and tissue layers were sutured.

After surgery, patients in each group underwent follow-up examinations on day 1, six–nine months, and 18–24 months.

Data Collection and Outcomes

Primary Outcome Measure. Clinical outcome evaluation consisted of comparing pain scores before surgery, after 6–9 months, and after 18–24 months for both groups to determine the extent of pain relief achieved by each approach. The pain scores were measured for the legs according to a self-assessment 10-point visual analog scale (VAS).

Secondary Outcome Measures. Regarding radiological/neuroimaging workup, anteroposterior and lateral plain radiographs, as well as computed tomography, magnetic resonance imaging (MRI), and flexion-extension radiographs, were obtained from each patient before surgery, at day 1, after 6–9 months, and after 18–24 months of follow-up to evaluate ASD. ASD is the degenerative changes at mobile segments located above or below a fused spinal segment. This condition is characterized by instability, evidenced by hypermobility and the vacuum sign, and canal stenosis, which is caused by ligamentous hypertrophy, hypertrophic facet joint arthritis, and herniated nucleus pulposus. The term "instability" denotes a displacement in the sagittal plane that exceeds 3–4 mm or an alteration in the angle that exceeds 10–15° between adjacent vertebral bodies. Before the surgery, the pathological level or levels were determined by MRI. Based on this, part of the pathological level(s) underwent surgery (fusion and laminectomy, or laminotomy). Afterward, the adjacent levels, which were healthy in preoperative MRI for all patients, were examined postoperatively for signs of hypermobility in the 2 groups during the predefined follow-up period. Furthermore, the presence of gas accumulation in the vertebral bodies, intervertebral discs, spinal canal, and articulating facet joints of the lumbar spine is responsible for the appearance of a lucency known as the vacuum sign.[13]

Assessment of Surgery-Related Morbidity. On a standardized form, intraoperative parameters, including duration of the operation, blood loss, and intraoperative complications-incidental durotomy-were recorded. The postoperative assessment parameters also included length of hospital stay, meningitis, wound infection and discharge, revision surgery, and increased postoperative radicular deficits, including neural injuries.

Statistical Analysis

The enrolled subjects were randomly divided into 2 groups, including LF (group I) and microscopic bilateral laminotomy (group II). The required subjects for each group were estimated based on expert opinion. The distribution of patients was normal in each study group. Basic characteristics and clinical outcomes were compared between 2 groups using an independent sample t-test for continuous variables, and ordinal variables were analyzed using the dichotomized standard summary measures, including Fisher exact test and Pearson χ^2 test. A significance level of 0.05 was used to establish statistical significance.

RESULTS

Patient Characteristics

A total of 76 out of the 96 included patients completed the 2-year follow-up (follow-up rate, 79.16%) (Figure 1).

Table 1 summarizes the patients' preoperative characteristics. There were no significant differences between the preoperative characteristics of the 2 groups' participants.

Primary Outcome

Comparison of the result of VAS (leg pain) before and after the surgery revealed that no significant difference was observed between 2 groups before surgery (P value = 0.1946); however, postoperative VAS in group I was significantly higher than group II (mean - group I: 4.842 vs. group II: 3.316, P value <0.0001). While comparing delta-VAS between the 2 study groups (mean - group I: 4.368 vs. group II: 5.368, P value = 0.001) revealed that delta-VAS in group II was significantly greater than those in group I (Figure 2.)

Secondary Outcomes

According to the results of statistical analysis, the number of patients with canal stenosis in group I (81.58%) was significantly higher than in group II (21.05%, P value <0.0001). Similar results were obtained for hypermobility (group I: 65.79% vs. group II: 10.53%, P value<0.0001) and vacuum sign (group I: 60.53% vs. group II: 21.05%, P value = 0.0009) (Table 2).

Table 1. Baseline Characteristics

Features	Group I	Group II	*P* Value
Number of cases	38	38	
Mean age (yrs.)	55.8 ± 8.215	53.77 ± 5.069	0.059
Male/female ratio	17/21	17/21	>0.999

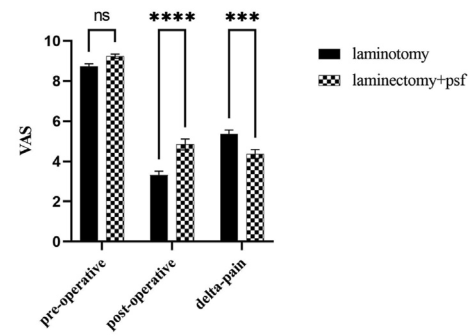

Figure 2. Comparison of visual analog scale (VAS) between study groups before and after the surgery.

Intraoperative Parameters and Surgery-Induced Morbidity

The planned technique was followed in all patients in order to achieve sufficient spinal decompression.

According to intraoperative parameters, group I had a significantly longer operating time than group II (P value< 0.0001). The estimated blood loss was also lower in patients who undertook the bilateral laminotomy than those in group I (411.3 ± 156.1 vs. 719.7 ± 243.4). Postoperative parameters demonstrated that patients in group I were hospitalized longer than those in group II (P value <0.0001) and experienced longer time to complete recovery (mean ± standard deviation: 70.83 ± 11.08 vs. 36.24 ± 5.053).

In terms of surgery-related morbidity, among all surgically treated patients, those who underwent bilateral laminotomy had a higher incidence of unintended durotomy (group II: 31.58% − group I: 7.89%, P value = 0.0190). It occurred following a very small surgical site in laminotomy procedure and we reported both microscopic and macroscopic lesions. Following laminotomy and LF, results showed 18.42% and 21.05% rates of wound infection, respectively.

Comparison of results obtained for radiculopathy pattern (group I: 42.11% vs. group II: 7.89%, P value = 0.0011) and paraspinal muscle atrophy (group I: 31.58% − group II: 10.53%, P value = 0.0467) showed a significantly higher rate of these complications in group I than group II, while meningitis (group I: 5.26% vs. group II: 5.41%, P value>0.999) showed no significant differences between study groups.

Table 2. Comparison of Radiological Findings Between Studied Groups

Variables		Group I	Group II	*P* Value
Canal stenosis	Yes	31 (81.58%)	8 (21.05%)	<0.0001****
Hypermobility	Yes	25 (65.79%)	4 (10.53%)	<0.0001****
Vacuum sign	Yes	23 (60.53%)	8 (21.05%)	0.0009***

*: significant at the level of *P* value<0.05, **: significant at the level of *P* value<0.01, ***: significant at the level of *P* value<0.001, ****: significant at the level of *P* value<0.0001.

The revision surgery rate following LF was significantly higher than that following microscopic bilateral laminotomy (P value = 0.0047) (Table 3).

DISCUSSION

Minimally invasive surgery has gained increasing popularity within the last decade in an effort to decrease iatrogenic injuries in patients with LSS requiring decompression, mainly as these patients are usually elderly and may have multiple comorbid conditions.[14] Nevertheless, it remains to be seen whether microscopic bilateral laminotomy can provide a sustained advantage over LF in terms of functionality, pain score, and intraoperative and postoperative complications for concurrent LCS and LRS treatment at multilevel lumbar stenosis.

Following a 24-month follow-up in our study, the microscopic bilateral laminotomy technique for simultaneous LCS and LRS decompression at multiple levels was found to be clinically effective and durable, with superior outcomes in nearly all endpoints compared with LF. A greater rate of incidental durotomy, however, was observed in this method because we reported both microscopic and macroscopic lesions. However, other studies so far have only reported macroscopic durotomies in their reports. These findings are in line with the results of the Thomé et al. trial, which reported that both unilateral and bilateral laminotomy for lumbar stenosis effectively alleviate symptoms and disability and enhance health-related quality of life. The outcomes of unilateral laminotomy and laminectomy and fusion were comparable. However, bilateral laminotomy surpassed laminectomy and fusion in most outcome measures (with the lowest residual pain).[12] On the other hand, a recent meta-analysis by Wei FL et al. demonstrated no statistically significant differences between the efficacies of various interventions for LSS in improving patient function.[15] According to another meta-analysis, bilateral laminotomy yielded better postoperative recovery, stability, and rehabilitation outcomes than standard laminectomy and fusion despite comparable outcomes for leg pain, back pain, and complications.[16]

A comparison of preoperative and postoperative leg pain VAS scores in our study revealed that, although there was no significant difference between the 2 groups before surgery, the postoperative VAS decreased dramatically after 24 months following bilateral laminotomy in our study, indicating adequate decompression. Consistent with these results, Yagi et al.[17] found that after 1 year's follow-up, patients who underwent minimally invasive midline laminotomy experienced much less pain than those who underwent open laminectomy and fusion. On the other hand, according to the previous meta-analysis, posterior decompression and conventional laminectomy and fusion had comparable benefits on functional disability and leg pain without a clinically meaningful reduction in leg pain. Furthermore, after ten years of follow-up, Pietrantonio et al.[18] found similar results for Oswestry disability index (ODI) and VAS pain. A study by Zouboulis et al.[19] indicated that wide decompressive laminectomy and fusion revealed comparable complications to those associated with multiple laminotomies, with statistically significant improvements in the ODI and VAS of patients suffering from multilevel, high-level stenosis (ODI >30%, VAS >5) (central and lateral). Given these findings, it can be said that most of the controversy appears to be related to the fact that minimally invasive spine surgery cannot provide complete decompression in cases of severe spinal stenosis that extends to the intervertebral foramen or which is extensive. Prior studies have indicated that several issues could influence clinical policymaking. These include the severity of the stenosis, segmental mobility before surgery, comorbid medications, facet tropism, and fluid within the facet

Table 3. Comparison of Intraoperative and Postoperative Findings Between Studied Groups

Variables		Group I	Group II	*P* Value
Intraoperative parameters				
Duration of operation (hr.)	Mean ± SD	6.968 ± 0.9467	2.792 ± 0.8205	<0.0001****
Estimated blood loss	Mean ± SD	719.7 ± 243.4	411.3 ± 156.1	<0.0001****
Postoperative parameters				
Length of hospital stay	Mean ± SD	6.774 ± 1.197	3.551 ± 0.6349	<0.0001****
Time to complete recovery	Mean ± SD	70.83 ± 11.08	36.24 ± 5.053	<0.0001****
Surgery-related morbidity				
Incidental durotomy	Yes (%)	3 (7.89%)	12 (31.58%)	0.0190*
Wound infection	Yes (%)	8 (21.05%)	7 (18.42%)	>0.9999
Radiculopathy pattern	Yes (%)	16 (42.11%)	3 (7.89%)	0.0011**
Paraspinal muscle atrophy	Yes (%)	12 (31.58%)	4 (10.53%)	0.0467*
Meningitis	Yes (%)	2 (5.26%)	2 (5.41%)	>0.9999
Revision surgery	Yes (%)	17 (44.74%)	5 (13.16%)	0.0047**

SD, standard deviation.

joints. It has been suggested that laminotomies are appropriate for mild to moderate stenosis, while LF procedure is preferred for severe stenosis or spondylolisthesis. The surgeon's experience may also significantly affect the outcome of a surgical procedure.[20,21]

LF procedure appears to provide sufficient visual clarity and working space for the posterior region by removing the spinous process, supraspinous ligament, and interspinous ligament. However, it may also present some disadvantages. As a consequence of the wide posterior decompression, the paraspinal muscles, posterior ligaments, and paravertebral muscles may atrophy, weaken, and may significantly damage spinal biomechanics and anatomy.[22,23] We found that compared to bilateral laminotomy, LF was associated with threefold higher rates of muscle atrophy. Furthermore, although considerable space is left after posterior elements removal, increasing the chance that bacteria may colonize the nerve and cause scarring, our study found no statistically significant differences in wound infection between the 2 surgical methods. However, radiculopathy pattern incidence was around 5 times higher in group I than in bilateral laminotomy. This finding may be attributed to the fact that when the vertebral lamina is removed in a total laminectomy, the intervertebral disc is exposed, which could be responsible for nerve root compression and inflammatory neurochemical release. Consequently, inflammation and ischemia of the nerve roots may induce postlaminectomy radiculopathy.[24] Our findings also showed that group I was significantly associated with a longer duration of operation, length of hospital stay, and time to complete recovery, as well as generating significant intraoperative bleeding[22,23]; thus, it supports the idea that significant blood loss, and prolonged operation times are other unanticipated adverse effects of total laminectomy with PSF that make it challenging for surgeons to perform.[25]

Similar to LF procedure, bilateral laminotomy have advantages and disadvantages. After laminotomy, the posterior ligamentous complex remains intact and can contribute to the lumbar movement by acting as a tension band. Nonetheless, it is crucial to be conscious of the possibility of incidental durotomy and neuronal damage in a restricted region, especially in individuals with severe central stenosis.[21,26] Similarly, we found that incidental durotomy was significantly more prevalent in patients undergoing microscopic bilateral laminotomy than in those undergoing LF (approximately fourfold). Contrary to our findings, Celik et al.[25] and Thome et al.[12] reported a significantly lower incidence of incidental dural tear in the bilateral laminotomy group compared with the laminectomy and fusion group (1/37 vs. 7/34 and 2/40 vs. 8/40, respectively). It appears that although microscopic visualization assists in improving the surgeon's ability to distinguish neural structures (such as the dura mater and roots) from non-neural structures (ligaments, bones, and annulus), the absence of epidural fat tissue coupled with extremely thin dura mater at the stenotic level may result in dural injury.[25] Moreover, despite the higher incidence of durotomy in group II, the incidence of meningitis was comparable in both groups. In cases complicated by incidental durotomy, it appears that the decreased dead space created by smaller incisions and the muscle-splitting technique utilized in minimally invasive spinal surgeries reduce the likelihood of pseudomeningocele formation and persistent cerebrospinal fluid leakage. In this way, fewer symptoms are experienced, and fewer postoperative immobilizations are required.[27]

According to our research, LF procedure was associated with higher rates of degenerative changes adjacent to the fused vertebrae than microscopic bilateral laminotomy, including instability (indicated by hypermobility and the vacuum sign) and canal stenosis (resulting from ligamentous hypertrophy and discopathy), both of which significantly could increase the chance of adjacent-level disease. Previous studies have demonstrated that bone regrowth following decompression surgery for LSS is a leading cause of spinal canal restenosis necessitating revision surgery. Frequently, this condition manifests at the facet junction but rarely at the laminar arch. Bone regeneration risk factors include younger age, several decompression levels, and a total block on myelogram, a longer follow-up period, and spinal instability after surgery. Given that segmental instability may be related to bone regrowth following decompressive surgery, microscopic bilateral decompression may successfully avoid postoperative spinal instability by protecting the facet joints, hence minimizing bone regrowth.[28,29] On the other hand, previous research has suggested that bone regeneration with clinically significant recurrent stenosis is more common after restricted bone removal.[30] Furthermore, stabilization of the decompressed spine segment via fusion may prevent recurrent stenosis; fusion rates and clinical results of segmental decompression with posterolateral fusion were comparable to those of wide decompression; this suggests that segmental decompression with posterolateral fusion may be an option for treating patients with multilevel foraminal stenosis. Despite this, patients with multiple levels of lumbar stenosis frequently suffer substantial complications due to these surgical procedures. In seniors with multiple comorbidities, surgeons face a challenging task when performing multilevel lumbar spinal fusion surgery as well.[20] On the other hand, microscopic bilateral laminotomy achieves physiological stability of the spine without requiring instrumentation. Therefore, this approach seems to be more efficacious in mitigating junctional hypermobility, a phenomenon observed in the fusion group, and the subsequent bone regrowth leading to recurrent spinal canal stenosis. Hence, it is plausible that the frequency of canal restenosis and the requirement for revision surgery could be lower compared to the fusion group.

Strengths and Limitations

This study excluded factors affecting outcomes, such as spinal instability and discogenic neural compression, to minimize the heterogeneity of the patient population. Our study has some limitations: the number of patients in each group is relatively small; hence, additional research, including large scale multicenter studies and a stricter selection of patients, is required to confirm and expand upon our conclusion.

CONCLUSION

For the simultaneous central canal and lateral recess stenosis at multilevel, microscopic bilateral laminotomy appears to be more advantageous than LF; nevertheless, the microsurgical field could increase the risk of incidental durotomy. Considering these results, if long-term follow-up results are consistent, bilateral laminotomy may be more beneficial for patients with multiple lumbar stenosis in terms of reducing the need for additional fusion surgery.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Paria Shafiekhani: Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Melika Hajimohammadebrahim-Ketabforoush:** Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing. **Elnaz Amanzadeh Jajin:** Writing – review & editing, Writing – original draft, Validation, Formal analysis. **Sara Zandpazandi:** Writing – review & editing, Writing – original draft, Resources, Investigation. **Mohammadreza Shahmohammadi:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization.

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