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ORIGINAL ARTICLE

Fenestration versus Conventional Laminectomy with and without Transpedicular Fixation for Secondary Lumbar Canal Stenosis

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ABSTRACT

Background: One of the most prevalent disorders among the elderly is spinal stenosis. It is described as the spinal canal narrowing. The first line therapy for lumbar canal stenosis (LCS) should be conservative ideally using a multimodal strategy. The current study aims to compare the radiological and clinical outcome of bilateral fenestration canal decompression and conventional laminectomy with or without fixation in secondary LCS.

Methods: This clinical trial study was performed in Department of Neurosurgery, Faculty of Medicine, Zagazig University Hospitals. 21 cases in three groups each group includes 7 patients, (Group 1) Conventional Laminectomy without fixation, (Group 2) Conventional Laminectomy with fixation, and (Group 3) Bilateral fenestration. All patients were subjected to complete history taking, clinical examination, laboratory tests, and radiographical assessment.

Results: There was substantial variance between groups concerning VAS low back and after 2 weeks and 3 months ($P<0.01$), within groups, there was remarkable variation ($P<0.01$). Regarding complications, there was no significant variance between groups respecting neurological deficit, dural tear, wound infection and epidural hematoma ($P>0.05$). There was significant variance between the studied groups regarding satisfaction scoring ($p=0.03$).

Conclusion: Bilateral fenestration appears to be a highly effective and potentially superior technique for treating secondary lumbar canal stenosis, offering benefits in terms of operative parameters, clinical outcomes, and patient satisfaction.

Keywords: Fenestration, Conventional Laminectomy, Transpedicular Fixation, Secondary Lumbar Canal Stenosis.

INTRODUCTION

Spinal canal stenosis (CS) is a disorder in which neural structures are compressed in the narrower spinal canal and are often located just in one specific region of the spine, most commonly in the lumbar spine [1].

Degenerative disc bulging and facet expansion result in lumbar lateral recess stenosis, a fairly prevalent reason for lumbar radiculopathy in elderly people [2].

CS can take many forms; symptomatic lumbar canal stenosis (LCS) affects roughly 10% of the subjects, whereas cervical CS affects 9% of people over the age of 70. As health services advance, cases' longevity expectations rise, and the number of cases with LCS grows continuously [3].

Essentially, managing LCS should begin with conservative management and optimally with a multimodal strategy (medical therapy, bed rest, and physiotherapy), but in situations of severe discomfort with significant neurogenic claudication symptoms, surgical intervention is recommended [4].

Lumbar decompression surgery is a frequent therapeutic option for degenerative LCS. Conventional surgical therapy of LCS entails extensive laminectomy, discectomy, foraminotomy, and medial facetectomy, if indicated [5].

Nevertheless, decompression surgery could additionally destabilize a problematic motion segment, resulting in symptomatic spinal instability. Spinal instability following simple decompression encouraged the development of fusion techniques [6].

The common surgical approach for LCS is decompression, which allows for maximum surgical decompression of the neural canal and/or bilateral foramina, but there is harm to the the interspinous ligament, paraspinal muscles, the supraspinous ligament, the posterior bone compartment, and occasionally the capsular facet [7].

Several procedures for LCS decompression have been documented, involving segmental microsublaminoplasty, recapturing microlaminoplasty, interlaminar and intersegmental microdecompression, and microhemilaminotomy [8].

The microsurgical approach is ideal for achieving adequate bilateral minimum paraspinal muscle separation. Therefore, it serves to support the spine whereas the important bones and soft tissues are stabilized, while simultaneously decompressing the spinal canal and/or foramen [9].

The present work aim was to compare the radiological and clinical outcome of bilateral fenestration canal decompression and conventional laminectomy with or without fixation in secondary LCS.

METHODS

Patients:

This clinical trial study was subjected in Department of Neurosurgery, Faculty of Medicine, Zagazig University Hospitals. Sample size was calculated with Open Epi program with confidence level 95% and power 80%. 21 patients in three groups each group includes 7 patients, (Group 1) Conventional Laminectomy without fixation, (Group 2) Conventional Laminectomy with fixation, (Group 3) Bilateral fenestration. The study lasts for 6 months

The current study was conducted after obtaining approval from Institutional Review Board (IRB#160/28-Feb-2024) and written informed consent from all cases. The research was conducted under the World Medical Association's Code of Ethics (Helsinki Declaration) for human research.

All patients presented with secondary lumbar canal stenosis and with chronic refractory pain to conservative therapy for 6 weeks and presence of neural compromise were included in the study.

Cases with the following characteristics were excluded; Patients with primary LCS. Patients unfit for surgical intervention. All patients underwent previous spine operation. Patients with neurological disease other than LCS. Patients with spinal instability. Patients with osteoporosis.

Preoperative data:

All patients conducted to complete history taking full history taking clinical examination including neurological assessment including visual analog score (VAS) for pain. Assess severity of claudication using the Zurich Claudication Questionnaire (ZCQ) [10]. Disability was self-assessed according to the Oswestry Disability Index (ODI) questionnaire [11].

Preoperative radiological assessment (lateral plain radiographs and dynamic views, MRI LSS without contrast, and CT spine), preoperative laboratory tests (Complete blood picture, liver and renal function tests, and coagulation profile).

Operative procedure

The surgical method used depends on numerous aspects, most crucially, the etiology of compression, the major site of compression, the number of levels concerned, and the sagittal alignment of the spine. General anesthesia with endotracheal intubation, it is necessary to avoid hypotensive anesthesia and keep the mean arterial blood pressure over 80mmHg.

C-arm imaging is available to avoid wrong level operation. The case is lying prone on a Jackson table with rubber foam blocks (Wilson frame). To prevent pressure sores, utilize a head rest with support for the mouth, nose, and eyes. The abdomen should be freely hanging and not squeezed. The arms must be abducted by less than 90°, elbows flexed, and put on arm boards. The hips are positioned in extension to enhance lumbar lordosis. All pressure points are cushioned to avoid peripheral nerve palsies and skin breakdown.

Postoperative data

Clinical symptoms and signs were assessed postoperatively by using full neurological assessment and the VAS score for back and leg pain and performance by ODI.

Postoperative Lateral LSS X-Ray and CT LSS to assess diameter of bony canal after decompression, hardware system of fixation. Postoperative MRI were done in all cases after 3 months to assess efficacy of decompression in all groups. The postoperative complications were documented

Statistical Analysis:

Data analysis were carried out with SPSS version 28 (IBM, Armonk, New York, United States). The Shapiro-Wilk test and direct data visualization approaches were used to determine the normality of quantitative data. Normality dictated that quantitative data be presented as means and standard deviations, or medians and ranges. Categorical data were presented using numbers and percentages. The ANOVA test was developed to evaluate multiple groups of normally distributed variables. P values <0.05 were considered significant

RESULTS

There was non-significant variance between groups regarding demographic, CT, MRI, and preoperative ZCQ data (p>0.05). (Table 1)

There was remarkable variance between the studied groups regarding VAS low back and after 1 and 3 months. Within groups, there was significant variation (P<0.05). Respecting preoperative VAS leg, there was substantial difference within groups (P<0.001). (Table 2)

There was significant variance between the studied groups concerning VAS low back and after 2 weeks and 3 months (P<0.01). Within groups, there was substantial variation (P<0.01). (Table 3)

There was non-significant variance between the studied groups concerning operative data, EBL, length of incision, and hospital stays. (Table 4)

Regarding complications, there was no significant variance between the studied groups concerning neurological deficit, dural tear, wound infection and epidural hematoma (P>0.05). There was remarkable variance between groups regarding satisfaction scoring (p=0.03). (Table 5)

Table (1): Distribution of demographic, CT, MRI, and preoperative ZCQ data between studied groups.

	Group (1) N=7	**Group (2)** N=7	**Group (3)** N=7	**P value**
Age Mean ±SD	52.95±4.16	52.78±4.45	52.49±2.27	0.97
Gender				
Male	4 (57.1%)	2 (28.6%)	4 (57.1%)	0.47
Female	3 (42.9%)	5 (71.4%)	3 (42.9%)	
BMI Mean ±SD	27.83±2.21	28.52±2.06	29.94±1.45	0.15
Canal AP diameter (mm) Mean ±SD	11.28±1.11	11.14±1.06	11.28±0.95	0.95
Lateral recess height (mm) Mean ±SD	2.85±0.89	3.14±0.89	3.1±0.81	0.79
Level of stenosis				
L2-L3 & L3-L4	1 (14.3%)	2 (28.6%)	2 (28.6%)	0.82
L3-L4 & L4-L5	5 (71.4%)	4 (57.1%)	3 (42.9%)	
L4-L5 & L5-S1	1 (14.3%)	1 (14.3%)	1 (14.3%)	
L3-L4 & L4-L5 & L5-S1	0 (0%)	0 (0%)	1 (14.3%)	
Symptom severity Mean ±SD	3.84±0.62	3.71±1.10	3.36±0.45	0.5
Physical function Mean ±SD	2.30±1.01	2.08±1.04	1.95±0.59	0.77

AP diameter: Anterior-Posterior diameter, BMI; Body Mass Index

Table (2): Distribution of VAS low back and leg at interval times between studied groups.

	Group (1) N=7	**Group (2) N=7**	**Group (3) N=7**	**P value**
VAS low back				
Preoperative	6.57±1.52	6.37±1.19	6.39±1.13	0.95
After 2 weeks	6.00±1.41	5.71±1.11	5.00±1.00	0.29
After 1 months	5.39±0.96	4.86±0.69	3.09±0.64	<0.001
After 3 months	4.50±1.04	3.43±0.53	2.14±0.69	<0.001
P value	0.03	<0.001	<0.001	
VAS leg				
Preoprative	7.71±1.25	7.44±1.09	7.4±0.84	0.65
After 2 weeks	4.57±0.98	4.42±1.13	4.14±0.69	0.69
After 1 months	2.63±0.68	2.57±0.53	2.35±1.17	0.80
After 3 months	2.14±0.38	2±0.82	1.85±0.90	0.77
P value	<0.001	<0.001	<0.001	
P value <0.05 is statistically significant, p<0.001 is highly significant., SD: standard deviation.				

VAS: **Visual Analog Scale**

Table (3): Distribution of Oswestry Disability Index questionnaire (ODI) at interval times between studied groups.

	Group (1) N=7	**Group (2) N=7**	**Group (3) N=7**	**P value**
Preoperative	33.43±4.40	32.64±3.68	32.29±4.64	0.88
After 2 weeks	23.06±3.76	21.29±1.80	17.57±3.74	0.02
After 1 months	17.83±3.35	15.71±1.60	13.80±4.62	0.12
After 3 months	15.29±3.15	12.57±2.23	8.86±1.95	<0.001
P value	<0.001	<0.001	<0.001	

Table (4): Distribution of operative data between studied groups.

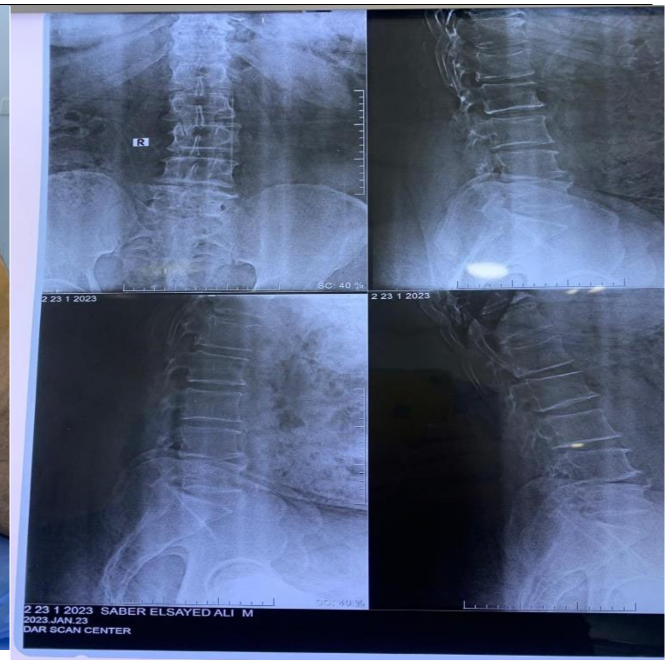
	Group (1) N=7	Group (2) N=7	Group (3) N=7	P value
operative time (min)	146.42±10.36	142.93±9.12	124.85±21.3	**0.02**
EBL (CC)	464.51±47.13	491.65±32.28	260.31±59.9	**<0.001**
Length of incision	8.29±0.47	7.77±0.46	5.89±0.66	**<0.001**
Hospital stays (days)	3.45±0.89	3.55±0.54	2.84±0.69	0.16

EBL: **Estimated Blood Loss**

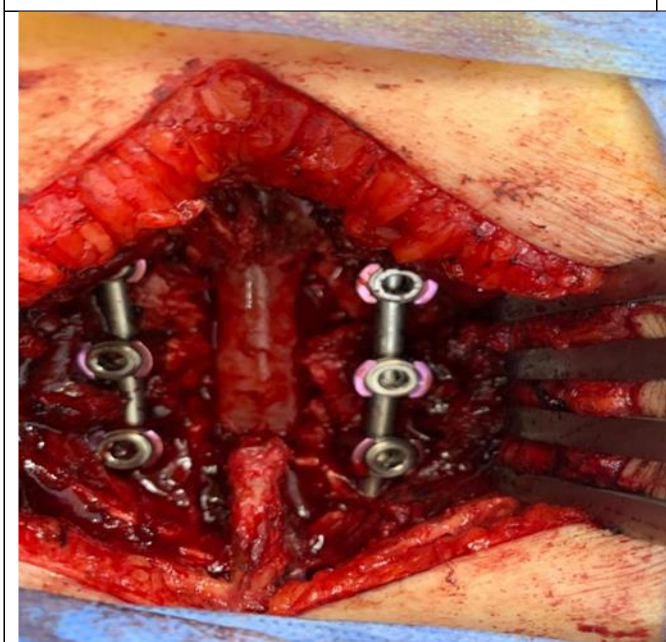
Table (5): Distribution of complications and satisfaction score between studied groups.

	Group (1) N=7	Group (2) N=7	Group (3) N=7	P value
Complications				
neurological deficit	1 (14.3%)	1 (14.3%)	0 (0%)	0.58
Dural tear	1 (14.3%)	1 (14.3%)	0 (0%)	0.58
wound infection	0 (0%)	0 (0%)	1 (14.3%)	0.35
Epidural hematoma	0 (0%)	0 (0%)	1 (14.3%)	0.35
Satisfaction score				
Very satisfied	1 (14.3%)	4 (57.1%)	7 (100%)	0.03
Satisfied	5 (71.4%)	2 (28.6%)	0 (0%)	
Dissatisfied	1 (14.3%)	1 (14.3%)	0 (0%)	

(A)



(B)



(C)

(D)

Figure (1): (A): Pre operative prone position, (B): Pre operative x ray showing spondylolisthesis with decreased disc space, (C):Intra operative fixation with trans pedicular screws and 2 rods ,(D): Post operative x ray showing laminectomy with fixation with trans pedicular screws.

DISCUSSION

This prospective clinical trial provides a comprehensive comparison of radiological and clinical outcomes between bilateral fenestration (BF) canal decompression and conventional laminectomy (CL), with or without transpedicular fixation, in a cohort of 21 cases diagnosed with secondary LCS. The primary objective was to elucidate the optimal surgical intervention and to refine the selection criteria for each surgical approach, thereby contributing to enhanced patient outcomes and surgical decision-making processes.

The study meticulously divided patients into three treatment groups: CL without fixation (Group 1, n=7), CL with fixation (Group 2, n=7), and BF (Group 3, n=7). Initial assessments revealed no significant variances across groups in terms of mean age (52.95, 52.78, 52.49 years), gender distribution (57.1%, 28.6%, 57.1% male), or body mass index (BMI: 27.83, 28.52, 29.94 kg/m²). This homogeneity is crucial as it indicates that randomization was effective, ensuring that demographic variables did not confound the treatment outcomes. Such meticulous matching is essential in clinical trials to isolate the effect of the intervention from other potential influencing factors.

However, it is important to acknowledge the limitation posed by the small sample size of 21 patients. While the homogeneity in baseline characteristics suggests robust randomization, the limited number of cases decreases the statistical power of the study, potentially masking subtle but clinically relevant differences between the treatment groups. This limitation echoes findings by Soliman [5], who similarly reported no significant baseline variations in age, gender ratio, or clinical presentations between BF and CL cohorts, highlighting the consistency and potential challenges in detecting differences in small-scale studies.

A key finding of this study is the differential impact of the surgical methods on low back pain as measured by VAS. Preoperatively and at two weeks postoperatively, there were no remarkable variations in VAS scores for low back pain among the CL without fixation, CL with fixation, and BF groups. This suggests that immediate postoperative pain relief may be similar across the surgical techniques. However, a divergent trend emerges at one-month post-surgery, where the BF group reported significantly lower pain (VAS score of 3.09) compared to both CL without fixation (5.39) and CL with fixation (4.86) groups ($p<0.001$). This trend persisted at the three-month mark (BF: 2.14 vs. CL without fixation: 4.50 vs. CL with fixation: 3.43; $p<0.001$). These findings indicate an early and sustained advantage of BF in alleviating low back pain.

Within each group, significant reductions in VAS scores from preoperative levels to three months post-surgery ($p\leq0.03$) underscore the efficacy of all surgical interventions in managing pain. The more pronounced and rapid improvement in back pain with BF compared to CL corroborates prior research. For instance, El Tabl et al. [12] conducted a retrospective analysis which similarly observed lower VAS back pain scores at both one and three months postoperatively in patients undergoing standalone laminectomy versus those receiving laminectomy with fixation. The authors suggested that the enhanced pain relief in the standalone group might be attributable to reduced paraspinal muscle dissection and the absence of hardware-related discomfort, factors that potentially contribute to less postoperative pain and faster recovery.

Guiot et al. [9] further support these observations, reporting rapid pain relief and functional improvement within one month following microendoscopic decompression, a variant of BF that employs minimally invasive techniques. Their study noted a substantial drop in VAS scores from 8.1 preoperatively to 2.4 at one month, highlighting the efficacy of minimally invasive approaches in delivering swift pain relief. These findings collectively reinforce the notion that BF, particularly when performed using minimally invasive methods, can offer superior and more prompt pain relief compared to traditional open laminectomy techniques.

Conversely, when assessing leg pain, the study found no substantial variance between the treatment groups from preoperative assessments to three months post-surgery. All groups experienced significant reductions in VAS scores for leg pain ($p<0.001$), suggesting that both BF and CL are equally effective in alleviating radicular symptoms associated with LCS. This outcome aligns with the findings of Lurie & Tomkins-Lane [13], who emphasized that radicular symptoms are a primary indication for surgical intervention in LCS and that effective decompression is crucial for alleviating these symptoms.

Further supporting this, Pao et al. [14] reported comparable leg pain relief between BF and open laminectomy, with mean VAS scores decreasing from 7.1 to 2.3 and 6.9 to 2.3, respectively, at a two-year follow-up. However, Yagi et al. [15] observed more substantial improvements in leg pain at two years with microendoscopic BF (from 6.5 to 1.8) compared to open laminectomy (from 7.8 to 3.2). These discrepancies may be attributed to variations in stenosis severity and the adequacy of decompression achieved in different studies, underscoring the need for standardized surgical techniques and comprehensive decompression to optimize outcomes.

Functional assessment using the ODI revealed that the BF group experienced significantly lower mean ODI scores at both two weeks (17.57 vs. 23.06 and 21.29; $p=0.02$) and three months (8.86 vs. 15.29 and 12.57; $p<0.001$) postoperatively compared to the CL without and with fixation groups. These results indicate superior functional outcomes and reduced disability in patients undergoing BF. Notably, there were no remarkable variations in ODI scores between the CL groups, suggesting that the addition of fixation to laminectomy does not confer additional functional benefits within the short-term follow-up period.

All groups demonstrated significant improvements in ODI scores from preoperative assessments to three months post-surgery ($p<0.001$), demonstrating that surgical intervention effectively enhances functional capabilities regardless of the specific technique employed. The superior functional improvements observed in the BF group are consistent with findings from multiple studies advocating for minimally invasive BF techniques. For example, Rahman et al. [16] reported a 53% improvement in ODI scores at three months following microendoscopic BF, compared to a 29% improvement with open laminectomy. Similarly, Khoo & Fessler [17] documented a decrease in ODI from 48 to 15 following microendoscopic decompression, highlighting the profound functional gains achievable with minimally invasive approaches.

The lower short-term disability observed in the BF cohort is likely a reflection of a less invasive surgical approach, resulting in reduced iatrogenic trauma and faster physiological recovery. Soliman [5] demonstrated that ultra-minimally invasive endoscopic decompression allowed patients to ambulate within an average of 8.7 hours postoperatively and achieve discharge within 15.9 hours, with ODI scores decreasing substantially from 64.2 to 23.1. This rapid recovery trajectory underscores the benefits of minimally invasive techniques in enhancing patient recovery times and reducing hospital resource utilization.

However, contrasting findings from larger trials like the Spine Outcomes Research Trial (SPORT) highlight the complexity of functional outcomes over longer follow-up periods. The SPORT trial reported greater ODI improvements with open laminectomy (from 42.8 to 21.5) at one year, suggesting that while BF may offer superior short-term benefits, the long-term functional gains may equilibrate with those achieved through more traditional open methods [18]. This divergence emphasizes the necessity for extended follow-up periods in further investigations to fully capture the trajectory of functional recovery and to assess the durability of the benefits conferred by BF.

The BF group demonstrated significantly shorter mean operative times (124.85 minutes) compared to CL without fixation (146.42 minutes) and CL with fixation (142.93 minutes) ($p=0.02$). Additionally, estimated blood loss was markedly lower in the BF group (260.31 ml) compared to CL without fixation (464.51 ml) and CL with fixation (491.65 ml) ($p<0.001$). The BF approach also necessitated a shorter incision length (5.89 cm) relative to CL with fixation (7.77 cm) and CL without fixation (8.29 cm) ($p<0.001$). These findings highlight the inherent advantages of minimally invasive BF techniques in reducing operative duration, minimizing blood loss, and decreasing the extent of surgical incision.

The reduced operative time and blood loss associated with BF are well-documented benefits of minimally invasive spine surgery. Khoo & Fessler [17] revealed mean operative times of 109 minutes and blood loss of 68 ml for microendoscopic decompression, in stark contrast to the 175 minutes and 193 ml of blood loss observed with open laminectomy. Similarly, Asgarzadie & Khoo [19] documented an average surgery duration of 97 minutes, with blood loss of 30 ml and an incision length of 18 mm for BF procedures. These metrics not only underscore the efficiency of BF approaches but also translate into tangible clinical benefits, including reduced transfusion rates, lower infection risks, and enhanced postoperative recovery.

The study exhibited no remarkable variances between the treatment groups in the rates of neurological deficits (0-14.3%), dural tears (0-14.3%), wound infections (0-14.3%), or epidural hematomas (0-14.3%). The overall complication rate was slightly lower in the BF group (28.6%) compared to CL without (28.6%) and with fixation (28.6%), although this variation was not remarkable. These results suggest that BF is at least as safe as CL, with a comparable complication profile.

Previous studies corroborate the notion that minimally invasive BF approaches are correlated with reduced surgical morbidity. Khoo & Fessler [17] reported no complications in 25 patients undergoing microendoscopic decompression, compared to a 16% complication rate in an open laminectomy control group. Similarly, Yagi et al. [15] found lower incidences of dural tears (8.3% vs. 15.6%) and wound infections (0% vs. 3.1%) with microendoscopic BF compared to open laminectomy. These findings collectively suggest that BF, particularly when performed using minimally invasive techniques, may offer a safer surgical profile by minimizing tissue trauma and decreasing the risk of common surgical complications.

In a systematic review, Overdevest et al. [20] noted an overall complication rate of 12.7% for minimally invasive decompression compared to 16.8% for open surgery, with dural tears occurring in 5.8% and 8.5% of cases, respectively. The 6% prevalence of dural tears in our study aligns with Soliman's [5] findings of a similar rate using ultra-minimally invasive endoscopic BF. These parallel outcomes across different studies enhance the external validity of our findings, indicating that the safety profile of BF is consistently favorable across various clinical settings and surgical techniques.

The absence of significant differences in complication rates between our groups may be attributed to the small sample sizes, which limit the statistical power to detect variations. Additionally, the study's design did not incorporate standardized reporting mechanisms for complications, potentially leading to underreporting or misclassification of adverse events. Shih et al. [21] identified a higher complication rate of 18.8% with microendoscopic decompression in a large prospective cohort, suggesting that more rigorous and standardized reporting protocols are essential for accurately capturing the true incidence of surgical complications.

Patient satisfaction, a critical measure of surgical success, was markedly higher in the BF group, with 100% of patients reporting themselves as "very satisfied" compared to 57.1% in the CL with fixation group and a mere 14.3% in the CL without fixation group (p=0.03). Additionally, the proportion of "satisfied" cases was highest in the CL without fixation group (71.4%), followed by CL with fixation (28.6%), and BF (0%). Notably, no patients in the BF group expressed dissatisfaction, whereas one patient each in the CL groups reported being "dissatisfied" (14.3%).

High satisfaction rates in the BF group are consistent with existing literature advocating for minimally invasive surgical techniques. Pao et al. [14] reported that 89% of patients undergoing BF achieved good to excellent outcomes based on a modified Macnab criteria, which assesses patient satisfaction and functional status post-surgery. Rahman et al. [16] similarly noted satisfactory outcomes in 84% of patients following microendoscopic decompression, compared to 63% in the open laminectomy group.

The markedly higher satisfaction rates in the BF group likely reflect multiple factors intrinsic to minimally invasive techniques, including reduced postoperative pain, smaller incisions, faster recovery times, and less complication rates. These elements collectively contribute to a more favorable patient experience and perception of surgical success. In contrast, the lower satisfaction rates observed in the CL groups may result from persistent pain, prolonged recovery periods, and unmet patient expectations regarding postoperative outcomes.

Additionally, Lurie & Tomkins-Lane [13] emphasized the importance of managing patient expectations preoperatively, noting that unrealistic anticipations of complete pain resolution and rapid resumption of activities can lead to dissatisfaction if not met. Therefore, the higher satisfaction rates in the BF group may also reflect better alignment between surgical outcomes and patient expectations, possibly facilitated by the more favorable postoperative recovery associated with minimally invasive techniques.

The study found no significant correlations between the number of operated levels and postoperative VAS leg pain, VAS back pain, or ODI scores within any treatment group. This suggests that the anatomical location and extent of stenosis did not significantly influence the clinical outcomes within each surgical approach in this cohort.

However, broader research has identified several prognostic factors that can influence surgical outcomes in LCS. For example, Fu et al. [22] reported that patients with two or more stenotic levels exhibited worse ODI scores compared to those with single-level disease, highlighting the impact of disease complexity on functional recovery. Aalto et al. [23] similarly found that higher preoperative disability, cardiovascular comorbidities, and depression were independent predictors of poorer one-year ODI outcomes following laminectomy, underscoring the multifactorial nature of recovery and the importance of holistic patient assessment.

Lastly, the study was performed in a single-surgeon, single-center setting, which may limit the external validity of the findings. Future research should prioritize larger, multicenter randomized controlled trials with adequate sample sizes to enhance the statistical power and generalizability of results.

CONCLUSION

Bilateral fenestration appears to be a highly effective and potentially superior technique for treating secondary lumbar canal stenosis, offering benefits in terms of operative parameters, clinical outcomes, and patient satisfaction. However, longer-term follow-up studies with larger patient cohorts are needed to confirm these findings and to further refine patient selection criteria for each surgical approach. Future research should also focus on the long-term stability and reoperation rates associated with each technique to provide a more comprehensive understanding of their relative merits.

Conflict of Interest or financial disclosure: No potential conflict of interest to be reported by the authors.

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