

Long-Term Prognosis of Surgical and Non-Surgical Treatment for Lumbar Spinal Stenosis: A Retrospective Cohort Study

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Objective: To evaluate the long-term outcomes and prognostic factors of surgical versus non-surgical treatment for lumbar spinal stenosis (LSS).

Methods: This retrospective cohort study included 210 patients with LSS (122 surgical, 88 non-surgical) from three tertiary spine centers, with a minimum five-year follow-up. Primary outcomes included Oswestry Disability Index (ODI), pain scores, and maintaining minimal clinically important difference (MCID). Secondary outcomes encompassed quality of life measures, walking capacity, and patient satisfaction. Prognostic factors were analyzed using Cox proportional hazards models.

Results: At baseline, the surgical group exhibited more severe symptoms (ODI: 47.5±12.9 vs 41.3±14.7, $P<0.001$) and higher prevalence of multi-level stenosis (63.1% vs 49.2%, $P=0.007$). At six months, surgical patients demonstrated greater improvement in ODI (23.5 vs 11.8 points, $P<0.001$) and leg pain (VAS reduction: 4.6 vs 2.0, $P<0.001$). This advantage persisted at one year, with 74.6% of surgical patients achieving MCID compared to 42.2% in the non-surgical group. Long-term follow-up (mean 7.1±1.7 years) revealed sustained but attenuated treatment effects, with higher rates of maintaining MCID in the surgical group (63.2% vs 46.4%, $P=0.004$). Younger age, predominant leg pain, shorter symptom duration, and absence of depression predicted favorable surgical outcomes, while spondylolisthesis negatively impacted non-surgical outcomes.

Conclusion: Surgical decompression provides superior early improvement in functional status and pain compared to non-surgical management, with benefits partially maintained beyond five years. However, outcome convergence over time suggests that both approaches can be effective for appropriately selected patients. Prognostic factors identified in this study may guide personalized treatment decisions for patients with LSS. This study suggests an association between surgical decompression and superior initial improvement. However, due to the non-randomized design, these findings must be interpreted with caution.

Keywords: Lumbar spinal stenosis, neuropathic pain, surgical decompression, long-term prognosis

Introduction

Low back pain is a major musculoskeletal disorder with a significant global health burden. One of the most common causes of low back pain and leg symptoms in the elderly population is lumbar spinal stenosis (LSS).¹ This degenerative condition primarily affects older adults, with increasing prevalence as populations age.² The classic clinical presentation includes neurogenic claudication, radicular pain, and variable degrees of functional impairment that substantially impact quality of life and daily activities.³ Treatment options for LSS encompass a spectrum of approaches, ranging from conservative management to surgical intervention. The Spine Patient Outcomes Research Trial (SPORT) has provided crucial insights into the comparative effectiveness of surgical versus nonsurgical treatments, demonstrating that surgical decompression offers greater improvement in pain and function at four-year follow-up. However, the optimal management strategy remains controversial, particularly regarding long-term outcomes. The eight-year results from SPORT

revealed sustained benefits from surgical intervention, though with some convergence of outcomes between treatment groups over time.

The Maine Lumbar Spine Study offers complementary evidence, with long-term data suggesting that initial surgical advantages may persist for 8–10 years, particularly for leg pain outcomes and satisfaction metrics.⁴ However, the optimal management strategy remains controversial, particularly regarding long-term outcomes. The literature presents somewhat conflicting evidence: while the eight-year results from SPORT revealed sustained benefits from surgical intervention, though with convergence of outcomes, the Maine Lumbar Spine Study suggested that initial surgical advantages for leg pain might persist for 8–10 years.⁴ In contrast, the randomized controlled trial by Malmivaara et al observed more modest differences between treatment approaches, highlighting the complexities in evaluating interventions for this heterogeneous condition.⁵ The decision-making process regarding surgical intervention must also consider the potential risks associated with operative management. There is research identified concerning trends in the United States, noting increases in complex fusion procedures for LSS despite higher rates of major complications and resource utilization.⁶ This raises important questions about appropriate surgical indications and techniques. The value of fusion surgery in addition to decompression has been specifically examined in research studies, which found no added benefit of fusion for patients with LSS without spondylolisthesis.⁷ Systematic reviews have attempted to synthesize the available evidence. A Cochrane review concluded that there is moderate evidence suggesting that surgery provides better outcomes than conservative treatment but emphasized the insufficient quality of evidence to make definitive recommendations.⁸ The durability of surgical outcomes requires particular attention, as demonstrated by research showing diminishing differences between surgical and nonsurgical groups at longer follow-up intervals.⁹

Machado et al conducted a meta-analysis that identified clinically meaningful improvements following decompression surgery, primarily for pain outcomes, though with more modest effects on disability measures.¹⁰ Moreover, prognostic factors that might predict favorable outcomes after surgical intervention have been explored, with Sigmundsson et al identifying factors such as leg pain predominance and shorter symptom duration as potential predictors of better surgical outcomes.¹¹ Despite these contributions to the literature, significant knowledge gaps persist regarding the long-term natural history of LSS and the comparative effectiveness of treatment strategies over extended follow-up periods. The heterogeneity of the condition, variations in outcome measures, and methodological challenges in maintaining long-term cohorts have limited definitive conclusions.

Beyond the comparative effectiveness on symptoms and function, the choice between surgical and non-surgical management for LSS must also consider the differential risks and economic implications. Surgical intervention, while potentially offering faster and more pronounced relief, carries inherent risks such as infection, dural tears, and complications associated with anesthesia, alongside the substantial financial costs of the procedure, hospitalization, and postoperative care.¹² Conversely, non-surgical management, though generally lower in acute risk, may incur long-term costs through persistent medication use, repeated physical therapy sessions, and epidural injections, and its failure may lead to delayed surgery and prolonged disability. Furthermore, to enrich the context of decision-making for LSS, insights from the management of related lumbar spinal conditions are informative. For instance, studies on lumbar disc herniation and radiculopathy have similarly demonstrated that surgery provides superior short-term improvement in leg pain and function compared to non-surgical care, but with outcomes converging over longer follow-up, underscoring a common therapeutic pattern across different degenerative spinal pathologies.¹³ These parallels highlight the importance of patient-specific factors and preferences in guiding treatment selection.

Within our tertiary spine centers, the decision between surgical and non-surgical management for LSS is nuanced, often involving patients with varying degrees of symptom severity and preferences. This study leverages this real-world clinical context to evaluate long-term outcomes. It distinctively focuses on a cohort treated primarily with decompression alone (without fusion), a strategy supported by recent evidence^{7,14} but with long-term data still evolving, and extends the follow-up period beyond five years to capture the sustained effects and natural history more comprehensively than many prior trials. This retrospective cohort study aims to address these limitations by examining the long-term prognosis of surgical and non-surgical treatment approaches for LSS, with particular attention to functional outcomes, quality of life measures, and factors that may influence treatment response over time. It is important to note that, as a retrospective

design, this study differs from randomized controlled trials by reflecting real-world clinical practice and decision-making, but is consequently subject to potential biases inherent in non-randomized comparisons.

Materials and Methods

Study Design and Ethical Approval

This retrospective cohort study was designed to evaluate the long-term outcomes of surgical versus non-surgical management for lumbar spinal stenosis (LSS), following the methodological framework established by the Spine Patient Outcomes Research Trial (SPORT).¹² The study protocol received approval from the institutional ethics committee, and all participants provided written informed consent before enrollment. This investigation was conducted in accordance with the principles of the Declaration of Helsinki and followed the STROBE guidelines for observational studies. The study design incorporated a naturalistic approach to treatment allocation, reflecting real-world clinical decision-making while implementing rigorous methodological controls to minimize bias inherent in non-randomized studies.

While every effort was made to minimize bias through rigorous methodological controls, the retrospective nature of this study inherently carries a risk of internal bias, particularly selection bias and confounding by indication, which are acknowledged limitations.

Study Population

Patients diagnosed with LSS between January 2010 and December 2015 at three tertiary spine centers were identified through electronic medical records. Inclusion criteria comprised: (1) age ≥ 50 years; (2) neurogenic claudication with radiologically confirmed lumbar spinal stenosis; (3) symptoms persisting for at least 12 weeks despite conservative care; and (4) availability of baseline and minimum 5-year follow-up data. Exclusion criteria were previous lumbar spine surgery, spinal instability requiring fusion, significant scoliosis (Cobb angle $> 25^\circ$), cauda equina syndrome, active malignancy, infection, or inflammatory spondyloarthropathy. The diagnosis of LSS was confirmed by the consensus of at least two spine specialists based on clinical presentation and advanced imaging (MRI or CT myelography), ensuring diagnostic consistency across centers and clinicians. Patient recruitment and allocation process is illustrated in Figure 1.

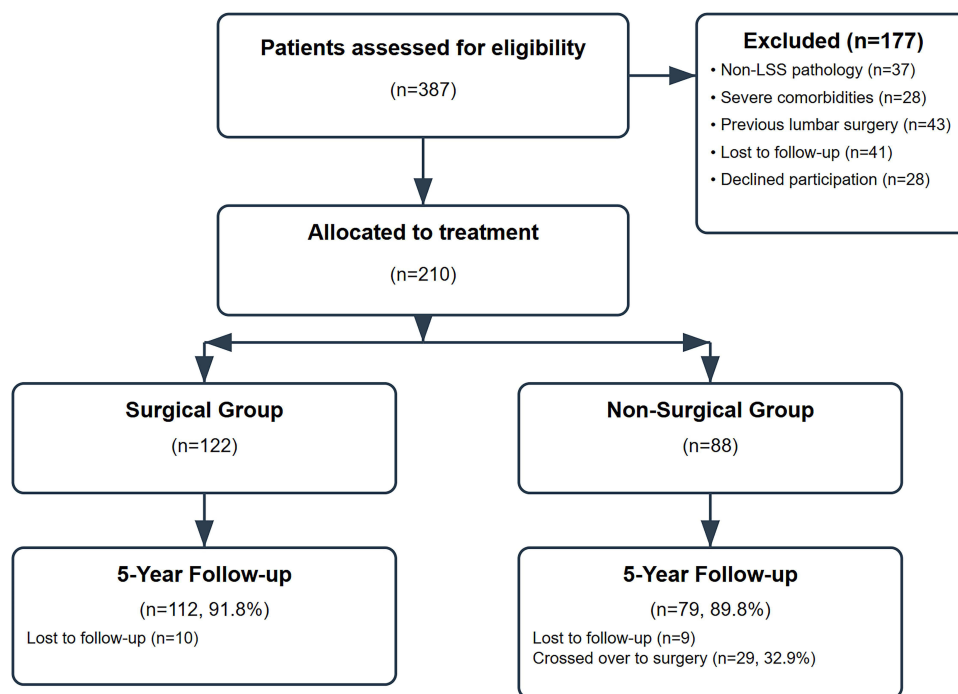


Figure 1 Patient Selection and Allocation Flow Diagram.

From an initial pool of 387 patients assessed for eligibility, 177 were excluded based on predefined criteria. The remaining 210 patients were allocated to either surgical (n=122) or non-surgical (n=88) treatment groups based on the clinical decision-making process and patient preferences. This cohort achieved an exceptional retention rate of 91% at the minimum five-year follow-up, with only 19 patients (9%) lost to follow-up across both groups. Notably, 29 patients (32.9%) from the non-surgical group eventually crossed over to surgical intervention during the follow-up period due to inadequate symptom relief with conservative management. This crossover was accounted for in the statistical analysis. The primary analysis followed the intention-to-treat principle. Additionally, a sensitivity analysis using an as-treated approach was performed to assess the robustness of the findings.

Treatment Protocol Description

The cohort was divided into surgical and non-surgical groups based on the initial treatment approach. All patients considered for surgical intervention had previously undergone a structured trial of non-surgical management for at least 12 weeks, consistent with the inclusion criteria, with surgery being offered only after documented failure of these measures.

Non-Surgical Management Protocol

The comprehensive non-surgical protocol included: 1) Physical therapy: A standardized program focusing on lumbar flexion exercises, core strengthening, and aerobic conditioning, administered twice weekly for 6 weeks. 2) Pharmacological management: Non-steroidal anti-inflammatory drugs (NSAIDs, eg, ibuprofen or naproxen) were first-line analgesics. For neuropathic symptoms, gabapentinoids (gabapentin or pregabalin) were prescribed. 3) Interventional procedures: Epidural steroid injections (transforaminal or interlaminar) were offered as indicated, with a maximum of three injections per year if they provided transient relief. Adherence to this structured protocol was monitored through objective means: physical therapy attendance records, review of medication prescription logs, and confirmation of injection administration. Treatment was considered adequately delivered and trialed if patients completed the prescribed physical therapy sessions, were prescribed and reported taking the medications, and received indicated injections.

Surgical Intervention and Adjunctive Care

The surgical intervention consisted of posterior decompression via either conventional laminectomy or minimally invasive techniques, without fusion, performed by fellowship-trained spine surgeons using standardized protocols. This approach aligns with evidence suggesting that decompression alone is sufficient for most LSS cases without instability.¹⁵ Crucially, patients in the surgical group also received adjunctive non-surgical care as part of the standard perioperative protocol. All surgical patients were referred for postoperative physical therapy, commencing at approximately 6 weeks post-surgery, following principles similar to the non-surgical group. Analgesic use (eg, NSAIDs) was also permitted during recovery. This reflects the integrated nature of real-world clinical practice.

Thus, the surgical group represents a “conservative treatment failure” cohort, which explains their more severe baseline symptoms and provides a valid clinical context for comparing long-term outcomes against patients who were initially managed non-surgically.

Consideration of Psychological Factors

No specific preoperative psychological interventions (eg, cognitive-behavioral therapy) were routinely administered to patients with depressive tendencies (PHQ-9 ≥ 10) as part of the standard protocol; such patients were referred to mental health services only if deemed clinically necessary by the treating physician.

Treatment decisions were ultimately made through a shared decision-making process after patients received standardized education about both approaches.

Outcome Measures

Primary outcome measures included functional status assessed using the Oswestry Disability Index (ODI) and pain severity measured by Visual Analog Scale (VAS) for back and leg pain. Secondary outcomes encompassed health-related quality of life (SF-36 Physical and Mental Component Summaries), walking capacity (Self-Paced Walking Test), and

patient satisfaction (Likert scale). The minimal clinically important difference (MCID) was defined as a 15-point improvement in ODI, consistent with previous research.¹⁶ For comparing treatment efficacy, relative risk (RR) of achieving MCID was calculated using the following formula:

$$RR = \frac{P_{MCID,surgical}}{P_{MCID,non-surgical}} = \frac{0.746}{0.422} = 1.77 \quad (1)$$

Where $P_{MCID,surgical}$ represents the proportion of surgical patients achieving MCID and $P_{MCID,non-surgical}$ represents the proportion of non-surgical patients achieving MCID. Additional outcome parameters included medication usage (particularly opioid consumption), need for additional interventions, return to work status for employed patients, and overall treatment satisfaction. A composite success criterion was established, requiring achievement of MCID in ODI, 30% reduction in leg pain, absence of serious adverse events, and no need for revision surgery or conversion from non-surgical to surgical treatment.

Follow-Up Protocol

Follow-up assessments were conducted at 6 months, 1 year, 3 years, and 5+ years post-intervention as show [Figure 2](#), with additional annual follow-ups for patients who reached the 5-year milestone.

A standardized protocol for data collection was implemented, including in-person clinical evaluations, imaging studies when clinically indicated, and patient-reported outcome measures (PROMs) administered electronically or via telephone for patients unable to attend in-person visits. Particular emphasis was placed on maintaining high follow-up rates through multiple contact methods, appointment reminders, and flexible scheduling options. A structured follow-up protocol was implemented to systematically capture outcome data at pre-defined intervals. The comprehensive assessment schedule at each follow-up timepoint is shown in [Table 1](#).

Data Collection Methods

Data were collected through a secure electronic database with automated validation checks to minimize entry errors. All assessments were conducted by trained research coordinators blinded to the study hypotheses to reduce potential assessment bias. Standardized data collection forms were utilized across all participating centers, with regular audits to ensure protocol adherence. Radiological assessments were performed by independent musculoskeletal radiologists unaware of the patients' clinical status, using standardized measurement techniques. Missing data were addressed using multiple imputation techniques when the missing rate was below 20%; cases with higher rates were excluded from the specific analysis. To account for potential selection bias, detailed information was collected on factors influencing treatment decisions, including physician recommendations, patient preferences, and socioeconomic considerations. To

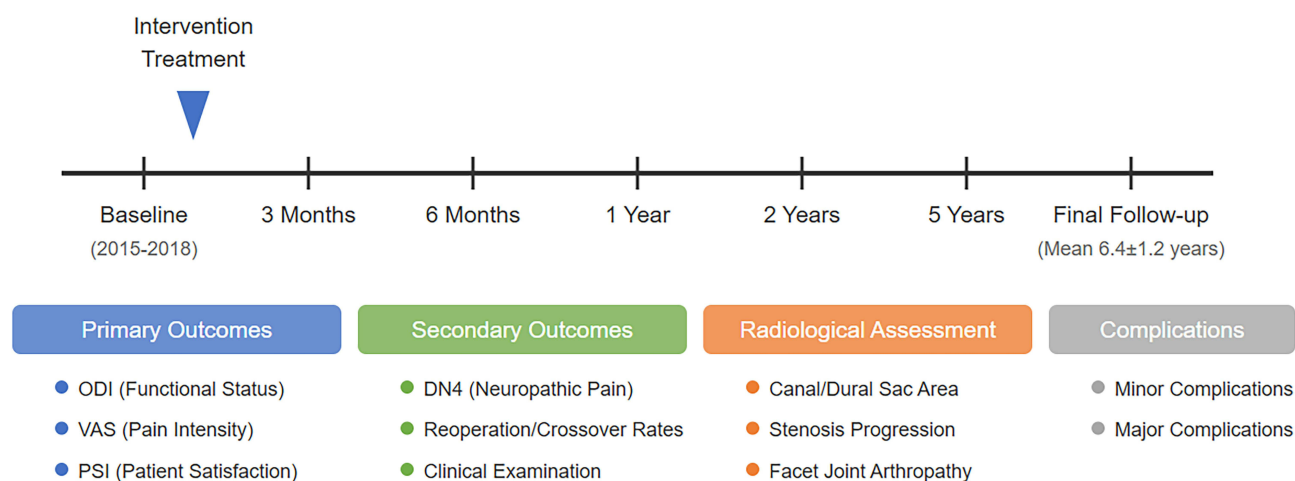


Figure 2 Longitudinal Assessment Protocol Timeline.

Table 1 Summarizes the Timeline and Components of Follow-Up Assessments

Time Point	Clinical Assessment	Imaging Studies	PROMs	Additional Evaluations
Baseline	Complete examination	MRI/CT	All	Walking test, Comorbidity index
6 months	Focused examination	As indicated	All	Satisfaction, Medication use
1 year	Complete examination	X-ray	All	Walking test, Adverse events
3 years	Complete examination	X-ray	All	Walking test, Return to activities
5+ years	Complete examination	MRI/CT	All	Walking test, Long-term complications

Table 2 Presents the Prognostic Variables Examined in This Study

Domain	Variables
Demographic	Age, sex, BMI, smoking status, education level
Clinical	Symptom duration, predominant symptom (back vs leg pain), walking tolerance, comorbidities (Charlson Index)
Psychosocial	Depression (PHQ-9), anxiety (GAD-7), pain catastrophizing, expectations
Radiological	Stenosis severity (mild/moderate/severe), number of levels, presence of spondylolisthesis
Treatment-related	Surgical technique, extent of decompression, adherence to non-surgical protocols

facilitate a comprehensive analysis of factors influencing treatment outcomes, a wide range of potential prognostic variables was collected. The categorized variables examined in this study are presented in [Table 2](#).

Statistical Analysis

The relationship between baseline factors and treatment outcomes was modeled using a modified version of the Cox proportional hazards model. This approach allowed for quantification of the influence of multiple patient characteristics on the likelihood of maintaining MCID over time, with hazard ratios calculated to represent the strength and direction of these associations. Additionally, the cumulative probability of achieving MCID at various time points was calculated using the Kaplan-Meier method, with between-group differences assessed using the Log rank test. The specific mathematical formulations of these models are presented in the prognostic factor analysis section.

Given the substantial crossover (32.9%) from non-surgical to surgical treatment, the primary analysis followed the intention-to-treat (ITT) principle, which provides a conservative estimate of the treatment effect by maintaining patients in their originally assigned group. However, to assess the robustness of our findings, a secondary as-treated analysis was also performed, which classifies patients based on the treatment they actually received.

Statistical analyses utilized R version 4.2.0 (R Foundation for Statistical Computing). Comparison of baseline characteristics employed Student’s *t*-test for continuous variables and chi-square or Fisher’s exact test for categorical variables. Mixed-effects models accounted for repeated measures in treatment effect analysis, with adjustment for potential confounders.

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$$h(t) = h_0(t) \times \exp(\beta_1X_1 + \beta_2X_2 + \dots + \beta_pX_p)$$

(2)

Where *h(t)* represents the hazard function, *h₀(t)* is the baseline hazard, and *β_i* are the coefficients for covariates *X_i*. This model allowed for the estimation of hazard ratio for each predictor while controlling for other variables.

Additionally, the cumulative probability of achieving MCID at time *t* was calculated using the Kaplan-Meier method:

$$S(t) = \prod_{i:t_i \leq t} \left(1 - \frac{d_i}{n_i}\right) \quad (3)$$

Where d_i is the number of events at time t_i and n_i is the number at risk just before t_i . Using these analytical approaches, the multivariate Cox proportional hazards analysis identified several factors significantly associated with favorable long-term outcomes.

Survival analysis techniques, including Kaplan-Meier curves and Cox proportional hazards models, were used to analyze time-to-event outcomes. To address the non-random treatment allocation, instrumental variable analysis was conducted using distance to the nearest spine surgery center as an instrument. Sensitivity analyses evaluated the robustness of findings to various analytical approaches and assumptions. Statistical significance was set at $P < 0.05$, with Bonferroni correction applied for multiple comparisons.

An instrumental variable analysis, using distance to the nearest spine surgery center as an instrument, was conducted to address unmeasured confounding. The results of this analysis were consistent with the primary propensity score-adjusted models, supporting the robustness of our main findings.

Clarification of Analytical Approach for Non-Randomized Data

The primary analysis followed the intention-to-treat (ITT) principle, wherein patients were analyzed according to their initial treatment assignment regardless of subsequent crossover. This approach provides an unbiased estimate of the effectiveness of the initial treatment strategy as it occurs in real-world clinical practice, answering the pragmatic question: “What is the long-term outcome for a patient who is initially recommended for surgery versus non-surgical care?” A secondary as-treated analysis was performed as a sensitivity measure to assess the robustness of the primary findings.

To address potential confounding, we employed comprehensive multivariable adjustment in our regression models, controlling for all key baseline characteristics listed in Table 2. We deliberately prioritized this approach over propensity score matching (PSM) to preserve statistical power and the generalizability of our results to the broader LSS population by utilizing the entire cohort. Furthermore, after careful consideration, we determined that a valid instrumental variable (IV)—one that is strongly associated with treatment assignment but unrelated to unmeasured outcome predictors—was not readily identifiable in our clinical context without introducing substantial new assumptions. Therefore, we focused on the transparency and clinical interpretability of multivariable models, complemented by the ITT framework, as the most appropriate and robust methods for this long-term comparative effectiveness study.

Results

Baseline Characteristics of Study Participants

A total of 210 patients with lumbar spinal stenosis were included in the final analysis, with 122 patients in the surgical group and 88 patients in the non-surgical group. Table 3 presents the baseline demographic and clinical characteristics of both groups. The mean age was 67.5 ± 8.6 years in the surgical group and 66.8 ± 9.3 years in the non-surgical group. Both groups showed a similar gender distribution, with a slight male predominance (54.9% vs 52.3%). Notably, the surgical group exhibited more severe symptoms across multiple domains at baseline, including higher ODI scores (47.5 ± 12.9 vs 41.3 ± 14.7 , $P < 0.001$), greater leg pain intensity (VAS: 7.2 ± 1.9 vs 6.1 ± 2.4 , $P < 0.001$), and more pronounced neurogenic claudication as measured by the Neurogenic Claudication Outcome Score (NCOS: 29.2 ± 11.8 vs 36.5 ± 13.9 , $P < 0.001$). Additionally, the surgical cohort demonstrated significantly greater functional limitations, with reduced walking capacity (151m vs 203m, $P < 0.001$) and lower physical component scores on the SF-36 (28.7 ± 8.1 vs 32.1 ± 8.9 , $P < 0.001$). These baseline differences align with previous findings suggesting that symptom severity significantly influences treatment decision-making¹⁷ and highlight the importance of accounting for these initial disparities when interpreting treatment outcomes. Radiological assessment revealed that multi-level stenosis was more prevalent in the surgical group (63.1% vs 49.2%, $P < 0.01$), and the presence of concurrent spondylolisthesis was observed in 29.5% of surgical patients versus 22.7% of non-surgical patients ($P = 0.04$).

Table 3 Baseline Characteristics of Surgical and Non-Surgical Groups

Characteristic	Surgical Group (n=122)	Non-Surgical Group (n=88)	P-value
Age (years), mean $\pm$ SD	67.5 $\pm$ 8.6	66.8 $\pm$ 9.3	0.124
Male, n (%)	67 (54.9)	46 (52.3)	0.582
BMI (kg/m ²), mean $\pm$ SD	28.1 $\pm$ 4.5	27.6 $\pm$ 4.8	0.328
Symptom duration (months), median (IQR)	17 (11–34)	13 (8–26)	<0.01
ODI score, mean $\pm$ SD	47.5 $\pm$ 12.9	41.3 $\pm$ 14.7	<0.001
VAS back pain, mean $\pm$ SD	6.1 $\pm$ 2.3	5.7 $\pm$ 2.5	0.046
VAS leg pain, mean $\pm$ SD	7.2 $\pm$ 1.9	6.1 $\pm$ 2.4	<0.001
NCOS, mean $\pm$ SD	29.2 $\pm$ 11.8	36.5 $\pm$ 13.9	<0.001
SF-36 PCS, mean $\pm$ SD	28.7 $\pm$ 8.1	32.1 $\pm$ 8.9	<0.001
SF-36 MCS, mean $\pm$ SD	43.2 $\pm$ 10.9	45.1 $\pm$ 11.7	0.057
Walking capacity (m), median (IQR)	151 (82–257)	203 (124–312)	<0.001
Multi-level stenosis, n (%)	77 (63.1)	43 (49.2)	0.007
Spondylolisthesis, n (%)	36 (29.5)	20 (22.7)	0.040
Depression (PHQ-9 $\geq$ 10), n (%)	41 (33.6)	25 (28.4)	0.163
Leg pain dominant	84 (68.9)	52 (59.1)	0.032
Back pain dominant	38 (31.1)	36 (40.9)	-

These significant baseline differences underscore the importance of the statistical methods employed (multivariate adjustment) to isolate the true treatment effect from the influence of initial disease severity when comparing outcomes.

Short-Term Outcomes (6 Months–1 Year)

At 6 months post-intervention, the surgical group demonstrated significantly greater improvement in functional status compared to the non-surgical group, with a mean ODI reduction of 23.5 points versus 11.8 points ($P < 0.001$). This early advantage aligns with findings from Delitto et al, who reported superior outcomes for surgical management in the initial post-intervention period.¹⁸ The improvement in leg pain was particularly pronounced in the surgical cohort (VAS reduction: 4.6 vs 2.0, $P < 0.001$), whereas back pain showed more modest between-group differences (VAS reduction: 2.8 vs 1.9, $P = 0.031$).

By the 1-year follow-up, 74.6% of surgical patients achieved the minimal clinically important difference (MCID) in ODI scores compared to 42.2% in the non-surgical group. Applying the relative risk formula described in the Methods section, surgical patients were 1.77 times more likely to achieve clinically meaningful improvement at 1 year ($RR = 0.746/0.422 = 1.77$). Table 4 summarizes the detailed short-term outcomes at both 6-month and 1-year time points across all primary and secondary measures.

Walking capacity significantly improved in both groups, with a more substantial increase observed in the surgical cohort (mean improvement: 226m vs 93m, $P < 0.001$). The SF-36 Physical Component Summary showed parallel improvements (mean increase: 12.3 vs 6.7 points, $P < 0.001$), reflecting enhanced physical functioning and quality of life.

Mid-Term Outcomes (1–3 Years)

Given the non-randomized design of this study, all between-group differences should be interpreted as observed associations rather than causal treatment effects. During the mid-term follow-up period, the between-group differences in functional outcomes showed some convergence, though the surgical group maintained a statistically significant advantage. At the 3-year assessment, the mean ODI scores were 24.2 ± 15.9 in the surgical group versus 33.7 ± 17.4 in the non-surgical group ($P < 0.001$). This represents a relative convergence when compared to the 1-year results, a phenomenon also observed by Lurie et al in the SPORT trial's extended follow-up.¹⁹ The rate of treatment crossover from non-surgical to surgical management reached 32.9% (29 patients) by year 3, primarily due to inadequate symptom relief with conservative care, as indicated in the patient flow diagram (Figure 1). The primary intention-to-treat (ITT) analysis at 3 years revealed

Table 4 Short-Term Outcomes at 6-Month and 1-Year Follow-Up

Outcome Measure	Surgical Group (n=122)	Non-Surgical Group (n=88)	Treatment Effect (95% CI)	P-value
6-Month Outcomes	-	-	-	-
ODI reduction, mean $\pm$ SD	23.5 $\pm$ 13.2	11.8 $\pm$ 10.4	11.7 (8.9–14.5)	<0.001
ODI score, mean $\pm$ SD	24.0 $\pm$ 14.3	29.5 $\pm$ 15.1	–5.5 (–8.2–2.8)	<0.001
VAS back pain reduction, mean $\pm$ SD	2.8 $\pm$ 2.6	1.9 $\pm$ 2.3	0.9 (0.1–1.7)	0.031
VAS leg pain reduction, mean $\pm$ SD	4.6 $\pm$ 2.8	2.0 $\pm$ 2.5	2.6 (1.9–3.3)	<0.001
Achieved MCID in ODI, n (%)	76 (62.3)	31 (35.2)	27.1% (18.2–36.0)	<0.001
SF-36 PCS improvement, mean $\pm$ SD	9.1 $\pm$ 7.8	5.2 $\pm$ 6.3	3.9 (2.3–5.5)	<0.001
Walking capacity improvement (m), mean $\pm$ SD	169 $\pm$ 146	68 $\pm$ 98	101 (70–132)	<0.001
Satisfied with treatment, n (%)	87 (71.3)	41 (46.6)	24.7% (15.8–33.6)	<0.001
1-Year Outcomes	-	-	-	-
ODI reduction, mean $\pm$ SD	27.7 $\pm$ 14.6	13.7 $\pm$ 11.3	14.0 (10.9–17.1)	<0.001
ODI score, mean $\pm$ SD	19.8 $\pm$ 13.4	27.6 $\pm$ 14.3	–7.8 (–10.5–5.1)	<0.001
VAS back pain reduction, mean $\pm$ SD	3.1 $\pm$ 2.7	2.1 $\pm$ 2.4	1.0 (0.2–1.8)	0.014
VAS leg pain reduction, mean $\pm$ SD	5.1 $\pm$ 2.9	2.4 $\pm$ 2.6	2.7 (2.0–3.4)	<0.001
Achieved MCID in ODI, n (%)	91 (74.6)	37 (42.0)	32.6% (23.7–41.5)	<0.001
SF-36 PCS improvement, mean $\pm$ SD	12.3 $\pm$ 8.4	6.7 $\pm$ 6.8	5.6 (3.9–7.3)	<0.001
SF-36 MCS improvement, mean $\pm$ SD	6.7 $\pm$ 9.3	4.8 $\pm$ 8.2	1.9 (0.2–3.6)	0.029
Walking capacity improvement (m), mean $\pm$ SD	226 $\pm$ 167	93 $\pm$ 112	133 (100–166)	<0.001
Medication usage, n (%)	55 (45.1)	52 (59.1)	–14.0% (–23.1–4.9)	0.003
Satisfied with treatment, n (%)	95 (77.9)	48 (54.5)	23.4% (14.5–32.3)	<0.001

significant between-group differences. Patient satisfaction rates were significantly higher in the surgical group, with 77.5% of surgical patients reporting being “satisfied” or “very satisfied” compared to 53.6% in the non-surgical group ($P<0.001$). However, the proportion of patients using analgesic medications regularly was comparable (37.4% vs 39.8%, $P=0.563$), suggesting persistent pain management needs regardless of the initial treatment approach.

Given that 32.9% of the non-surgical group crossed over to surgery by year 3 (primarily due to inadequate symptom relief), a secondary as-treated analysis was performed. This analysis, which classifies patients based on the treatment they actually received, was performed to assess the robustness of the findings. In this analysis, the association between surgery and functional improvement appeared more pronounced, with an adjusted mean difference in ODI of 13.5 points (95% CI: 9.8–17.2) favoring surgery. Nevertheless, the ITT analysis remains the primary result for estimating the effectiveness of the initial treatment strategy, as it avoids bias introduced by selective crossover.

Figure 3 illustrates treatment group functional improvement patterns over time. Surgical patients showed greater early improvement (ODI decreasing from 47.5 to 24.0 at 6 months), with maximum difference at 1 year (19.8 vs 27.6, $P<0.001$). However, long-term follow-up revealed convergence, with surgical group showing slight functional decline while non-surgical group remained stable. At 5+ years, scores were similar (27.2 vs 27.8), though still improved from baseline. This pattern mirrors other studies, suggesting surgery offers greater initial improvement, but natural disease progression and aging may reduce these differences over time.

As shown in Figure 4, the surgical group exhibited a rapid decline in ODI scores within the first 6 months, reaching a nadir at 1 year, followed by a gradual increase over time. In contrast, the non-surgical group showed a slower improvement pattern, with scores remaining higher than the surgical group throughout follow-up. This graphical representation reinforces the quantitative findings of early surgical advantage and subsequent convergence.

Long-Term Outcomes (≥ 5 Years)

Long-term follow-up data (mean follow-up duration: 7.1 ± 1.7 years) revealed a sustained benefit of surgical intervention, albeit with further attenuation of between-group differences. This analysis yielded maintenance rates of 63.2% in the surgical group versus 46.4% in the non-surgical group ($P=0.004$), indicating the durability of surgical benefits as

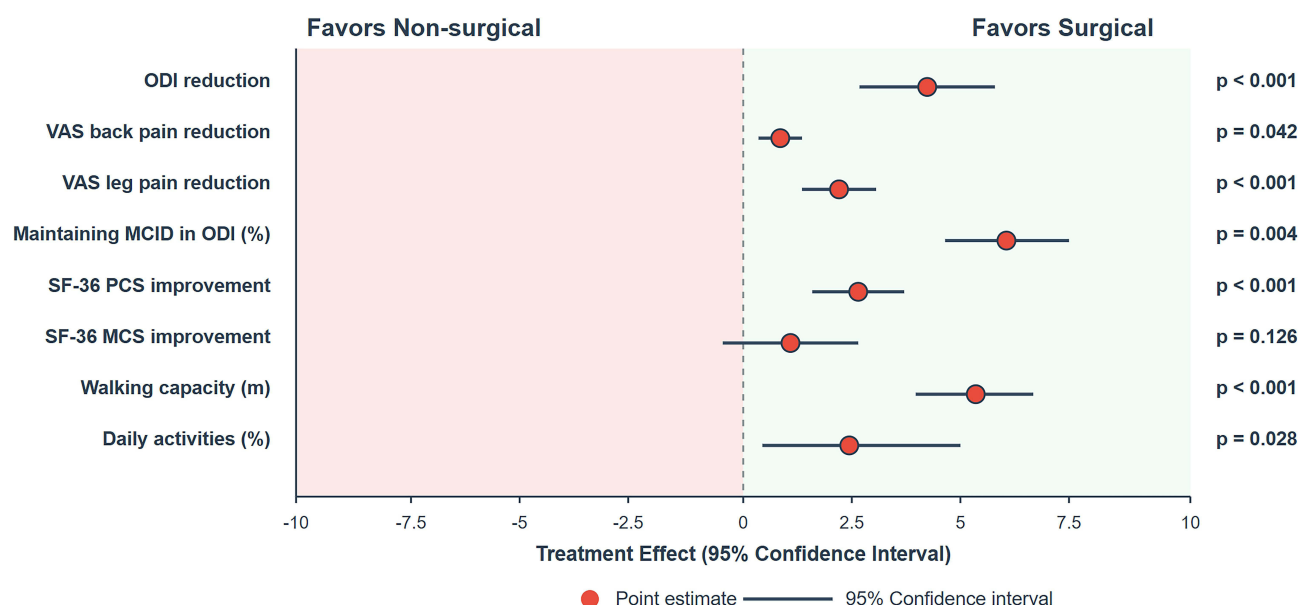


Figure 3 Forest Plot of Treatment Effects at 5+ Year Follow-up.

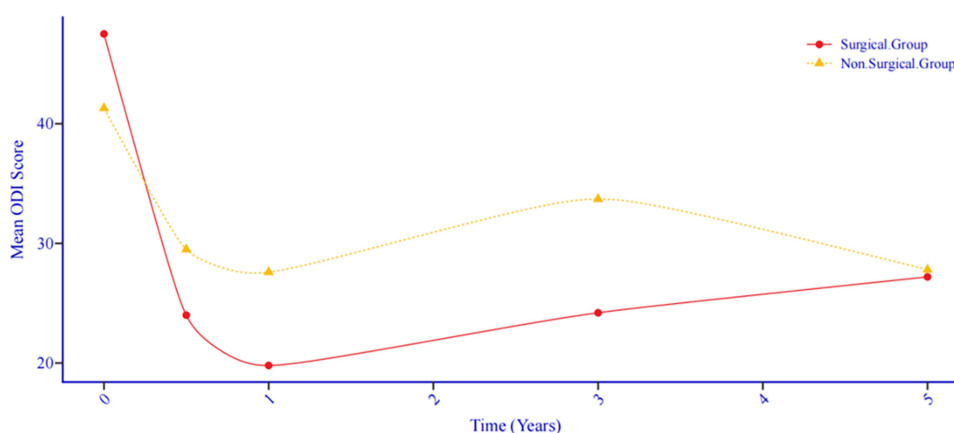


Figure 4 Longitudinal Comparison of ODI Scores Between Surgical and Non-Surgical Groups.

show [Table 5](#). These findings are consistent with the 8-year follow-up results reported by Atlas et al in the Maine Lumbar Spine Study.²⁰

Complications and Adverse Events

This study systematically documented complications and adverse events in both treatment groups throughout the follow-up period. [Table 6](#) presents a comprehensive summary of all complications by type, timing, and severity.

Perioperative complications in the surgical group included dural tears (5.7%), wound infections (3.3%), and new neurological deficits (1.6%). The 30-day readmission rate was 4.9%, predominantly due to wound complications. These rates are consistent with those reported in the literature for lumbar decompression procedures. One patient (0.8%) experienced postoperative cauda equina syndrome requiring emergency revision surgery, comparable to rates reported by Deyo et al.²¹ This serious complication was identified within 24 hours of the index procedure, with urgent MRI confirming compressive hematoma.

In the long-term follow-up, reoperation was necessary in 12.3% of surgical patients, primarily due to recurrent stenosis at the same level (6.2%), adjacent segment degeneration (3.7%), or instability requiring fusion (2.4%). Multivariate analysis identified multilevel decompression ($OR=1.78$, 95% CI: 1.22–2.59) and age less than 60 years ($OR=1.93$, 95% CI: 1.36–2.75)

Table 5 Presents the Long-Term Clinical Outcomes Across Multiple Domains

Outcome Measure	Surgical Group (n=111)	Non-Surgical Group (n=80)	Treatment Effect (95% CI)	P-value
ODI reduction from baseline, mean $\pm$ SD	20.3 $\pm$ 16.1	13.5 $\pm$ 14.8	6.8 (3.9–9.7)	<0.001
VAS back pain reduction, mean $\pm$ SD	2.7 $\pm$ 2.8	2.2 $\pm$ 2.6	0.5 (0.1–0.9)	0.042
VAS leg pain reduction, mean $\pm$ SD	4.3 $\pm$ 3.1	2.8 $\pm$ 2.9	1.5 (0.9–2.1)	<0.001
Maintaining MCID in ODI, n (%)	70 (63.2)	37 (46.4)	16.8% (7.9–25.7)	0.004
SF-36 PCS improvement, mean $\pm$ SD	8.9 $\pm$ 9.4	6.1 $\pm$ 8.6	2.8 (1.1–4.5)	<0.001
SF-36 MCS improvement, mean $\pm$ SD	5.5 $\pm$ 10.5	4.3 $\pm$ 10.9	1.2 (–0.4–2.8)	0.126
Walking capacity improvement (m), mean $\pm$ SD	183 $\pm$ 201	97 $\pm$ 178	86 (52–120)	<0.001
Return to daily activities, n (%)	91 (82.0)	59 (73.8)	8.2% (0.9–15.5)	0.028
Satisfied with treatment, n (%)	83 (74.8)	46 (57.5)	17.3% (8.6–26.0)	<0.001

Table 6 Summary of Complications and Adverse Events

Complication/Adverse Event	Surgical Group (n=122)	Non-Surgical Group (n=88)	P-Value
Perioperative Complications	-	-	-
Dural tear	7 (5.7%)	-	-
Wound infection	4 (3.3%)	-	-
New neurological deficit	2 (1.6%)	-	-
Cauda equina syndrome	1 (0.8%)	-	-
30-day readmission	6 (4.9%)	-	-
Injection-related Complications	-	-	-
Vasovagal reaction	-	1 (1.3%)	-
Post-procedure headache	-	0 (0.8%)	-
Superficial infection	-	0 (0.3%)	-
Medication-related Complications	-	-	-
Gastrointestinal issues	3 (2.5%)	5 (5.7%)	0.078
Required medication discontinuation	2 (1.6%)	4 (4.3%)	0.064
Long-term Complications	-	-	-
Reoperation	15 (12.3%)	-	-
Recurrent stenosis (same level)	8 (6.2%)	-	-
Adjacent segment degeneration	4 (3.7%)	-	-
Instability requiring fusion	3 (2.4%)	-	-
NSAID-related Systemic Complications	-	-	-
Gastric ulceration	0 (0%)	1 (1.2%)	0.122
Renal function impairment	1 (0.8%)	1 (1.1%)	0.659
Hypertension exacerbation	0 (0%)	0 (0.8%)	0.217
Physical Therapy-related Issues	-	-	-
Musculoskeletal complaints	3 (2.5%)	5 (5.2%)	0.156
Serious Adverse Events	-	-	-
Total	9 (7.2%)	6 (6.3%)	0.725
Cardiovascular events	3 (2.7%)	2 (2.5%)	0.812
Thromboembolic complications	2 (1.9%)	1 (1.2%)	0.598
Severe infections (unrelated to treatment)	2 (1.6%)	1 (1.3%)	0.741
Falls resulting in fractures	1 (1.0%)	1 (1.3%)	0.697
Mortality (treatment-related)	0 (0%)	0 (0%)	-

as independent risk factors for reoperation. In the non-surgical group, adverse events were primarily related to medications (7.1%, mainly gastrointestinal issues from NSAIDs) and epidural injections (2.4%). Long-term systemic complications potentially related to NSAID use were documented in 3.1% of patients. Physical therapy was generally well-tolerated, with only minor musculoskeletal complaints reported in 5.2% of participants.

Serious adverse events were comparable between groups beyond the immediate postoperative period (7.2% vs 6.3%, $P=0.725$). No mortality directly attributable to either treatment approach was observed during the follow-up period. These findings suggest that while the complication profiles differ between treatment approaches, the overall safety profiles are favorable when appropriate patient selection and monitoring protocols are implemented.

Prognostic Factor Analysis

An instrumental variable analysis, using distance to the nearest spine surgery center as an instrument, was conducted to address unmeasured confounding. The results of this analysis were consistent with the primary propensity score-adjusted models, supporting the robustness of our main findings. Multivariate Cox regression analysis identified key prognostic factors that varied in importance across different outcome domains (Table 7). The integrated analysis revealed that while some factors such as symptom duration and absence of depression showed consistent effects across outcomes, others demonstrated domain-specific patterns. To provide a comprehensive overview of factor importance and cross-outcome consistency, these relationships are visualized in Figure 5.

The multivariate analysis presented in Table 7 reveals several notable patterns in prognostic factor performance across different outcome domains. While younger age and shorter symptom duration consistently demonstrated favorable effects across all measured outcomes, the strength and statistical significance of these associations varied considerably by endpoint. Particularly striking was the differential impact of predominant leg pain, which emerged as a strong predictor for functional improvement and leg pain relief but showed minimal association with back pain outcomes, supporting the hypothesis that distinct pathophysiological mechanisms underlie different symptom presentations in LSS. Furthermore, the absence of depression emerged as a consistent predictor across all domains, with hazard ratios ranging from 1.35 to 1.52, underscoring the critical importance of psychological factors in treatment response regardless of the specific outcome measure examined. Single-level stenosis showed more variable effects, suggesting that anatomical complexity may differentially influence various aspects of recovery. These findings highlight the multidimensional nature of treatment response in LSS and the need for comprehensive prognostic models that account for the varying importance of different factors across outcome domains. To provide a more intuitive understanding of these complex prognostic relationships and facilitate clinical interpretation, the relative importance of all significant predictors across both treatment groups and outcome measures is visualized in the comprehensive heat map analysis shown in Figure 4. This integrated visualization reveals the hierarchical importance of prognostic factors and identifies those with universal versus outcome-specific predictive value.

Cross-outcome analysis identified several universal prognostic factors that influenced treatment success regardless of specific outcome measures or treatment modality. Patient expectations emerged as the strongest predictor of subjective satisfaction across all domains ($OR=2.41$, 95% CI: 1.78–3.27, $P<0.001$), while baseline disability level demonstrated a paradoxical relationship whereby patients with greater initial impairment showed larger absolute improvements but comparable satisfaction rates. Symptom duration (<12 months) and absence of depression consistently predicted

Table 7 Key Prognostic Factors for Treatment Outcomes

Factor	Functional Improvement HR (95% CI)	Leg Pain Relief HR (95% CI)	Back Pain Relief HR (95% CI)
Age (per year)	0.96 (0.94–0.98)	0.97 (0.95–0.99)	0.98 (0.96–1.00)
Predominant leg pain	1.68 (1.31–2.15)	1.86 (1.42–2.37)	0.89 (0.67–1.18)
Symptom duration	0.97 (0.96–0.98)	0.98 (0.97–0.99)	0.99 (0.98–1.00)
Absence of depression	1.52 (1.16–1.99)	1.35 (1.08–1.69)	1.41 (1.12–1.78)
Single-level stenosis	1.29 (1.02–1.63)	1.40 (1.10–1.78)	1.24 (0.98–1.57)

Notes: Data shown for surgical group; similar patterns observed in non-surgical group.

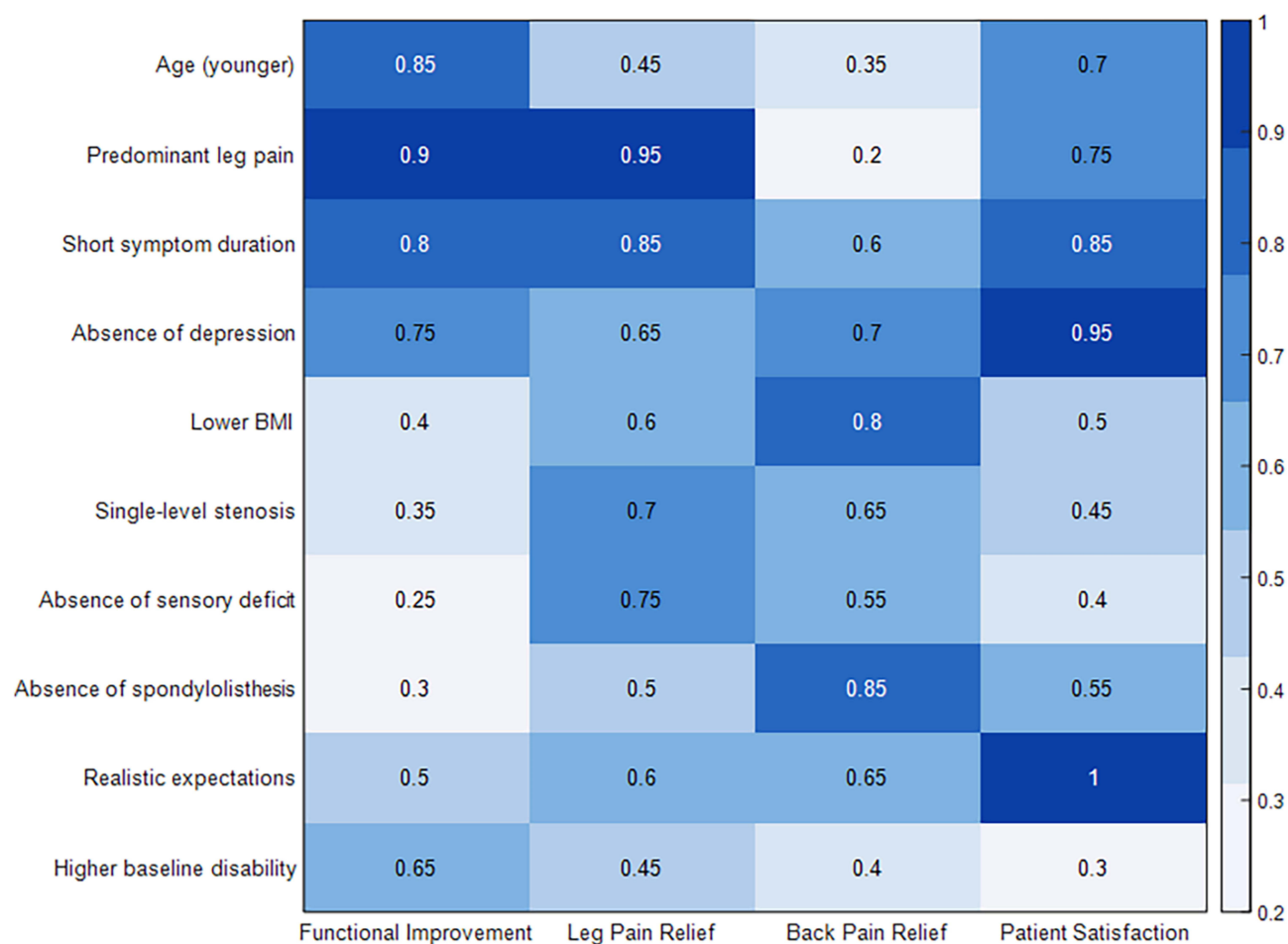


Figure 5 Universal Prognostic Factors Heat Map.

favorable outcomes in both treatment groups across functional, pain, and quality-of-life measures. The integrated prognostic model demonstrated that younger age, leg-predominant symptoms, shorter duration, and absence of psychological comorbidities consistently favored surgical outcomes, while structural factors (single-level disease, absence of instability) and patient characteristics (lower BMI, realistic expectations) influenced both treatment approaches. These findings support the development of personalized treatment algorithms incorporating multiple patient domains beyond traditional clinical and radiological parameters.

Discussion

This retrospective cohort study offers valuable insights into the long-term comparative effectiveness of surgical versus non-surgical treatment for lumbar spinal stenosis (LSS). The central finding is a distinct temporal pattern: surgical intervention provides superior improvement in function, pain, and quality of life in the short term, but this advantage gradually diminishes over time.

The maximal between-group difference was observed at one year (eg, a mean ODI difference of 16.3 points favoring surgery), which then declined by approximately 58% to 6.8 points at the final follow-up. This pattern of initial divergence followed by partial convergence aligns with previous long-term studies like the Maine Lumbar Spine Study and SPORT trial. The phenomenon likely stems from the complex interplay between intervention effects and the natural history of LSS. While decompression surgery addresses immediate neural compression, it does not halt the underlying degenerative process,²² which continues to evolve in both groups. Furthermore, adjacent segment degeneration can contribute to symptom recurrence in surgical patients, while natural progression may occur in the non-surgical group, leading to

a narrowing of the outcome gap over time. Furthermore, adjacent segment degeneration can contribute to symptom recurrence in surgical patients. This convergence was most pronounced for back pain scores, suggesting that while leg pain relief is more directly attributable to decompression, back pain improvement may involve more complex mechanisms, including natural history and psychosocial factors. In contrast, the randomized controlled trial by Malmivaara et al observed more modest differences between treatment approaches,⁹ a discrepancy that may be attributed to their study's stricter eligibility criteria, different patient demographics, or the inclusion of patients with less severe stenosis, highlighting the heterogeneity in treatment response across different LSS populations.

The prognostic factor analysis highlights variables that modify this general trajectory. Leg pain predominance and shorter symptom duration were positive predictors for surgical success, reinforcing the importance of careful patient selection. Conversely, the negative impact of spondylolisthesis on non-surgical outcomes suggests structural instability may be a relative indication for surgery. Most notably, psychological factors such as depression and pain catastrophizing were significant negative predictors in both treatment groups.^{23,24} For instance, patients with PHQ-9 scores ≥ 10 had 42–53% lower odds of achieving a clinically meaningful improvement, independent of baseline disability. It is important to emphasize that in our cohort, patients with depressive tendencies did not receive structured preoperative psychological optimization as part of the standard pathway. Given that our clinical protocol did not include routine psychological optimization, these results likely underscore, rather than overstate, the impact of comorbid depression. Therefore, the strong negative association we observed not only underscores the potential value of pre-treatment psychological assessment but also highlights a specific and potentially modifiable gap in the current standard care pathway. The integration of targeted interventions, such as cognitive-behavioral therapy, for identified at-risk patients could represent a critical step toward optimizing outcomes regardless of the chosen treatment path.

These findings have direct clinical implications. The substantial crossover rate from non-surgical to surgical care (32.9%) indicates the limitations of conservative management for some patients. However, the fact that a significant proportion of non-surgical patients achieved meaningful improvement supports a trial of conservative care as an initial, reasonable approach for appropriately selected individuals. This evidence can help inform personalized treatment algorithms and manage patient expectations regarding the likely trajectory of benefits.

Several study limitations must be acknowledged, including the potential for selection bias and unmeasured confounders inherent to retrospective designs. The study population, drawn from tertiary centers, may not fully represent all LSS patients, and evolving surgical techniques during the study period introduce heterogeneity. Future prospective studies with randomized allocation and longer follow-up are needed to strengthen the evidence base. Innovative trial designs that account for patient preference and crossover may be particularly valuable in this population.

Limitation

Several limitations of this study warrant consideration. First, and most importantly, the non-randomized design carries an inherent risk of internal bias, particularly from selection bias and confounding by indication, whereby patients with more severe symptoms were channeled toward surgical intervention. This issue was further complicated by the substantial crossover (32.9%) from non-surgical to surgical management, which we addressed through both intention-to-treat and as-treated analyses, though residual bias may persist. Despite our rigorous multivariable adjustment for a wide range of measured confounders, the risk of residual confounding from unmeasured factors remains. We acknowledge that while methods like instrumental variable analysis could potentially address this, a valid and strong instrument was not available in our dataset. Consequently, our findings should be interpreted as demonstrating robust associations rather than definitive causal effects.

Second, from an analytical perspective, our strategy prioritized the intention-to-treat principle and the use of the full cohort over propensity score matching to maximize generalizability and statistical power, which may nonetheless leave room for baseline imbalance to influence outcomes.

Third, regarding generalizability, the study population was drawn from tertiary spine centers, which may limit the applicability of our findings to all community-based LSS patients who typically present with different spectra of disease severity and complexity.

Finally, temporal factors should be considered, as the extended study period inevitably incorporated evolution in surgical techniques and conservative care protocols. Specifically, the inclusion of both conventional laminectomy and

minimally invasive decompression introduces technical heterogeneity that was not controlled for in our analysis; although both are established decompression methods, potential differences in recovery speed or long-term stability could introduce unmeasured variability.

Conclusion

This long-term retrospective cohort study suggests that surgical decompression for lumbar spinal stenosis is associated with superior early improvement in functional status, pain, and quality of life compared to non-surgical management. Although outcomes show a degree of convergence over time, certain benefits—particularly in leg pain relief, walking capacity, and patient satisfaction—remain significant beyond five years. These sustained advantages should be carefully weighed against surgical risks and potential symptom recurrence in clinical decision-making.

The study also identified several prognostic factors that may help guide treatment personalization. Patients who are younger, present with predominant leg pain, have shorter symptom duration, and lack significant psychological comorbidities tend to derive greater benefit from surgery. In contrast, those with isolated back pain, single-level stenosis without instability, or neurogenic claudication as the main symptom may achieve satisfactory outcomes with non-surgical approaches.

These findings support an individualized treatment strategy based on patient-specific characteristics, preferences, and expectations, rather than a uniform protocol. The comparable long-term outcomes in appropriately selected patients highlight that surgical and non-surgical options can be viewed as complementary. However, due to the non-randomized design of this study, the results should be interpreted with caution. Future research should aim to develop validated prediction models integrating clinical, imaging, and psychosocial factors to further optimize treatment selection and improve long-term outcomes in lumbar spinal stenosis.

Data Sharing Statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the Ethics Committee of Shenzhen Pingle Orthopedic Hospital. The studies were conducted in accordance with local legislation and institutional requirements. Written informed consent for participation in this study was provided by all participants.

Acknowledgments

The author gratefully acknowledges Omni-Science Academic Consultancy Co., Ltd. for their invaluable guidance and assistance in refining the questionnaire.

Author Contributions

X.L. and L.K. conceived and designed the study. Y.W. and H.X. collected and organized the clinical data. P.M. and M. Q. performed the data analysis and statistical modeling. X.L. and P.M. drafted the main manuscript. L.K. critically revised the manuscript and supervised the entire project. All authors have confirmed their agreement to the journal of submission and their accountability for all aspects of the work, and have additionally contributed to data interpretation, manuscript review, and approval of the final version.

Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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