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Preoperative factors and four-year decompressive laminectomy success in symptomatic lumbar spinal stenosis

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Background/context: Decompressive laminectomy (DL) for lumbar spinal stenosis (LSS) is the most common spinal surgery for older adults. Biopsychosocial factors are associated with 1-year outcomes in these patients. While most surgical failures occur within 12 months, some are delayed, and factors responsible for delayed surgical failure are poorly understood.
Purpose: We sought to identify preoperative factors associated with long-term surgical success as defined by the Brigham Spinal Stenosis (BSS) questionnaire.
Study design/setting/patient sample: Within this prospective cohort study, we used logistic regression modeling to identify preoperative biopsychosocial factors that predict 4-year DL success in 110 prospectively evaluated veterans who underwent DL without fusion for LSS.
Outcome measures/methods: A questionnaire was used to evaluate BSS outcomes at 4 years post-DL.
Results: Overall, 69 participants (63%) demonstrated 4-year surgical success—sustained improvement in at least two of the three BSS domains (symptoms, function, and satisfaction). Greater catastrophizing [OR for 2 points 0.92 (0.84–1.00); $p = 0.0512$] and longer symptom duration [OR for 12 months 0.96 (0.93–0.99); $p = 0.0231$] were associated with lower likelihood of success, while presence of moderate/severe stenosis (OR 7.16–7.39; $p = 0.0195$–0.0260), college education [OR 2.93 (1.27–6.77); $p = 0.0120$], and greater treatment credibility [OR for 10 points 1.35 (1.10–1.66); $p = 0.0048$] were associated with greater likelihood of success in bivariate analyses. Symptom duration [OR 0.96 (0.92–0.99); $p = 0.0208$], treatment credibility [OR 1.51 (1.15–1.98); $p = 0.0031$], and stenosis severity (OR 14.4–17.4; $p = 0.0045$–0.0055) constituted a parsimonious set of factors in multivariable modeling.

Conclusions: Further work is needed to definitively identify preoperative factors that predict long-term outcomes. This may facilitate more accurate patient selection and counseling for patients undergoing DL for LSS.

KEYWORDS

lumbar spinal stenosis, decompressive laminectomy, long-term follow-up, function, symptom, veterans, lumbar stenosis

Introduction

Lumbar spinal stenosis (LSS) is a narrowing of the central spinal canal or lateral canal(s) caused by bone or soft tissue encroachment that causes mobility limitation because of pain and/or lower extremity paresthesias, i.e., neurogenic claudication. Lumbar stenosis impacts over 10% of older adults leading to millions of hospital visits annually (1–3). Decompressive laminectomy (DL) for LSS is the most common indication for spine surgery in older adults (1, 2). While DL provides symptom relief (i.e., reduction of pain and paresthesias) in some patients, nearly one-half of veterans undergoing DL will not achieve functional improvement at 12 months (4). Few studies have evaluated longer-term outcomes following DL, beyond 1 year, although some indicate that DL failure rates increase with extended follow-up beyond 1 year (5–7). As many as one in three DL for LSS patients undergo additional surgery within 5 years of the original procedure (8). While failed DL is often followed by more complex surgical procedures such as fusion, outcomes associated with these procedures are not superior (9).

A comprehensive understanding of factors associated with outcomes beyond 1 year is needed to optimize patient selection, surgical decision-making, and associated utilization of healthcare resources. Preliminary data raise the possibility that the more extensive the pathology (i.e., the greater the number of spinal levels decompressed), especially in the setting of altered spinal biomechanics, the greater the risk of DL failure (10). Others suggest that selecting patients with severe anatomical stenosis, no back pain, symptoms for less than 4 years, and no other conditions that impair walking will have superior DL outcomes (7). The burden of medical comorbidity also has been highlighted as a risk factor for worse long-term DL outcomes (11). Studies that examine a comprehensive set of predictors, including biopsychosocial factors, of long-term outcomes in patients undergoing DL for LSS are lacking (12). Such studies may inform patient selection and help identify patients likely to benefit from prehabilitation prior to DL for LSS.

We recently published the results of a prospective cohort study of Veterans with LSS who underwent DL. Among a comprehensive set of factors evaluated preoperatively, opioid use, apparent leg length inequality, and low self-efficacy were the strongest predictors of outcome 1 year following DL (3). We now examine predictors of 4-year DL success.

Methods

Participant cohort

The study protocol was approved by the Department of Veterans Affairs (VA) Central Institutional Review Board and at enrollment sites as described in Weiner et al. (3). All participants underwent DL without fusion at baseline.

Inclusion criteria were (1) preoperative neurogenic claudication for at least 3 months defined as pain, weakness, numbness, or tingling in the legs that are precipitated by walking or standing and relieved by sitting; (2) MRI evidence of lumbar spinal stenosis; and (3) failure of non-surgical management. Exclusion criteria included (1) prior lumbar surgery; (2) spondylolisthesis with ≥4 mm translation or ≥10° of angular motion; and (3) cognitive impairment that undermines the capacity to complete questionnaires (3, 13).

Outcomes

The Brigham Spinal Stenosis (BSS) score was the main outcome. It consists of three domains: physical function, symptom severity, and surgical satisfaction (14–16). Each domain is scored from one to five for symptom severity and one to four for physical function and satisfaction, with a higher score signifying a worse disability. Meaningful improvements from baseline are noted as reductions in a score of ≥0.42 in physical function, ≥0.46 in symptom severity, and ≥2.42 in satisfaction. Surgical success is defined as a meaningful improvement in at least two of three categories (3, 15).

Baseline variables

Table 1 summarizes baseline characters of the patient cohort.

1. Demographics—age, gender, race, ethnicity, education.
2. Physical characteristics—height, weight, pain characteristics (location, severity, duration).
3. Hip osteoarthritis (OA): participants reporting hip pain underwent x-rays with OA diagnosed by study radiologists according to American College of Rheumatology criteria (17).
4. Scoliosis/kyphosis: all participants underwent standing spine x-rays with lateral and anterior/posterior view projections. A radiologist who was blinded to outcomes reported Cobb's angle (scoliosis) and kyphosis from the uppermost tilted vertebra to the lowermost tilted vertebra (18).

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TABLE 1 Participant baseline characteristics.

Baseline characteristic	Mean ± SD or *N* (%)
N	110
Age (years)	65.1 ± 9.9
Weight (pounds)	220.7 ± 41.2
Height (inches)	69.2 ± 2.9
BMI	32.3 ± 5.3
BSS physical function (1–4)	2.78 ± 0.51
BSS symptom severity (1–5)	3.53 ± 0.54
CPSE pain management (10–100)	51.5 ± 27.2
CPSE physical function (10–100)	56.5 ± 25.7
CPSE coping (10–100)	56.7 ± 25.8
CSQ (catastrophizing scale (0–36)	9.56 ± 9.10
DAST-10 (0–20)	0.39 ± 0.97
Duke comorbidity index (0–8)	3.8 ± 1.4
Cardiac problems	35 (31.8)
Diabetes	46 (41.8)
FABQ (0–30)	22.4 ± 6.5
Widespread pain index	7.48 ± 3.37
GAD-7 (0–24)	6.21 ± 5.90
ISI (0–28)	9.16 ± 7.05
Leg length discrepancy (inches)	−0.104 ± 0.393
MMSE	28.5 ± 1.5
MOS emotional support (0–100)	72.8 ± 27.8
MOS tangible support (0–100)	80.4 ± 29.1
MOS affectionate support (0–100)	82.1 ± 29.2
MOS positive social interaction (0–100)	79.5 ± 28.5
Symptom duration (months)	146.1 ± 147.8
PHQ-9 (0–27)	7.69 ± 6.54
PTSD total (17–85)	35.1 ± 18.0
QMCI (0–100)	67.2 ± 11.7
SMAST (0–26)	2.64 ± 1.36
Lumbar scoliosis (degrees)	7.2 ± 8.2
Lumbar kyphosis (degrees)	4.1 ± 13.0
Stenosis severity	
NA	4 (3.6)
Normal	2 (1.8)
Mild	9 (8.2)
Moderate	28 (25.5)
Severe	67 (60.9)
Treatment credibility (1–100)	
Logical	93.3 ± 13.7
Successfully reducing limitations	81.7 ± 20.2
Recommending to a friend	71.3 ± 32.9
Expected improvement	78.9 ± 20.1
Surgery will reduce limitations	81.7 ± 20.1
Improvement after recuperation	80.2 ± 18.8
Smoking status	
Non-smoker	24 (21.8)
Prior smoker	66 (60.0)
Current smoker	20 (18.2)
Gender (male)	106 (96.4)
Ethnicity (Hispanic)	12 (10.9)
Race	
Native American	5 (4.6)
African American	16 (14.6)
Pacific Islander	0 (0.0)
Caucasian	78 (70.9)
Other	11 (10.0)
Education level	
Elementary school (K-8)	2 (1.8)
High school (9–12)	44 (40.0)
College (13–16)	55 (50.0)
Postgraduate	5 (4.6)
Other	4 (3.6)
Fibromyalgia (2016 criterion)	29 (26.4)
Hip osteoarthritis	42 (38.2)
Symptom location	
Low back	28 (25.5)
Leg	21 (19.1)
Both	61 (55.5)
Pain medications	
Opioid	41 (37.3)
Non-opioid non-CNS	49 (44.6)
Non-opioid CNS	47 (42.7)
Surgical variables	
Duration (hours)	2.58 ± 1.03
L1 decompression	2 (1.8)
L2 decompression	30 (27.3)
L3 decompression	73 (66.4)
L4 decompression	99 (90.0)
L5 decompression	68 (61.8)
S1 decompression	8 (7.3)
Other decompression	2 (1.8)
Decompressed levels	
N/A	5 (4.6)
1	22 (20.0)
2	45 (40.9)
3	31 (28.2)
4	4 (3.6)
5	3 (2.7)
Complications	
Cerebral spinal fluid leak	7 (6.4)
Deep venous thrombosis	0 (0.0)
Infection	1 (0.9)

Biopsychosocial characteristics at baseline. Values represent mean ± standard deviation for continuous variables or *N* (percentage) for categorical variables. BMI, body mass index; BSS, Brigham Spinal Stenosis questionnaire; CPSE, chronic pain self-efficacy; CSQ, coping strategies questionnaire; DAST-10, drug abuse screening tool-10; FABQ, fear avoidance beliefs questionnaire; GAD, generalized anxiety disorder; ISI, insomnia severity index; MOS, Medical Outcomes Survey; PHQ, patient health questionnaire; PTSD, post-traumatic stress disorder; QMCI, quick mild cognitive impairment screen; SMAST, short Michigan alcohol screening test; OA, osteoarthritis.

5. Leg length discrepancy: measured as the right vs. left difference in umbilicus to medial malleolus while laying supine. Each measurement was performed twice with the average reported (19).
6. Comorbidities: medical comorbidities were based on participant self-report and calculated according to the Duke comorbidity index (20).
7. Pain medication data: we categorized preoperative pain medication as opioid; central nervous system active non-opioid (gabapentin, pregabalin, muscle relaxants, tricyclic antidepressants, other antidepressants); and non-central nervous system active medications (salicylate, NSAID, acetaminophen, topical).

8. Additional specific conditions including generalized pain disorders (21), fibromyalgia (14), mild cognitive impairment (22), and insomnia were evaluated using standardized instruments (23).

Psychosocial factors

1. Depressive symptoms were evaluated using the patient health questionnaire (PHQ−9), a 10-item questionnaire widely used for depression screening (24).
2. Anxiety was evaluated with two measures: (a) generalized anxiety was evaluated using the seven-item generalized anxiety disorder (GAD) scale, and (b) post-traumatic stress disorder (PTSD) was evaluated using the PTSD checklist (25).
3. Pain coping skills were evaluated using three scales: (a) cognitive strategies questionnaire (26), chronic pain self-efficacy (CPSE) scale (27), and (c) fear avoidance beliefs questionnaire (28).
4. Substance use was evaluated using the short Michigan alcoholism screening test (SMAST-13) for alcoholism, drug use questionnaire (DAST-10) for illicit drug use, and previous and active smoking status for tobacco use (29).
5. Social support was evaluated using the Medical Outcomes Survey (MOS) Social Support Scale (30).
6. Treatment credibility/expectations were measured using the methods of Borkovec (31).

Anatomic and surgical factors

1. Severity of central canal stenosis was quantified by a blinded radiologist, using a validated scoring system (32).
2. Surgical variables including location and number of decompressive levels, duration of surgery, presence of postoperative complications, and revision surgeries were collected from participant medical records and surgical follow-up evaluations, as reported by surgeons.

Participant follow-up

Participant flow is depicted in Figure 1. Two hundred thirty-nine Veterans signed informed consent, 8 dropped out, and 231 underwent baseline testing. Thirty-eight did not proceed further with the study; 11 dropped out, and 27 were withdrawn by the site principal investigator for reasons listed in Figure 1. Participants were telephoned 1 and 4 years after DL, and the BSS was completed during each of these follow-ups. The original consent indicated a 1-year participation period. Subsequently, a waiver of the need for additional consent was obtained, and participants were sent a letter indicating that they would be telephoned 4 years after their DL and that they would be asked questions about their pain and function. The letter indicated that participation was not required. One hundred ninety-three underwent 1-year post-DL follow-up assessment, and 110 underwent 4-year post-DL follow-up assessment. The present

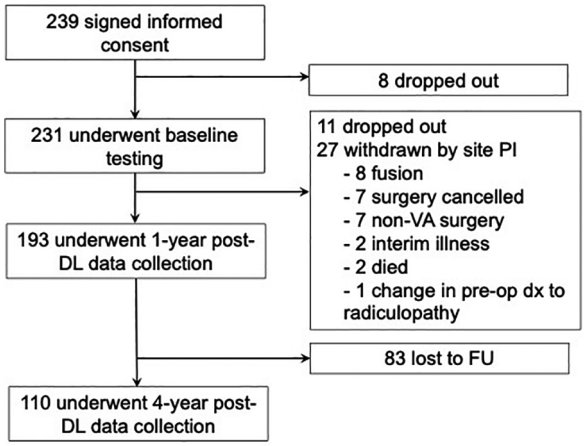

FIGURE 1
Study participant follow-up to 4-year outcomes. A total of 239 participants were originally enrolled in the study with 231 undergoing initial baseline follow-up. Of the 193 participants that completed 1-year outcomes, 83 were lost to follow-up resulting in 110 participants for 4-year follow-up. PI, principal investigator; dx, diagnosis; DL, decompressive laminectomy; FU, follow-up.

report focuses on 4-year post-DL data. Previous reports have endorsed a delayed decline in surgical success rate post 2 years in participants undergoing isolated DL without fusion (33, 34). We chose 4 years to enable sufficient time to capture delayed failure. All participants included in this study were derived from the original 1-year outcomes study by Weiner et al. (2021). We rigorously compared participants with non-participants, and there were no significant differences.

Statistical analysis

We used independent samples *t*-test, Wilcoxon rank sum, chi-square, and Fisher's exact tests to compare characteristics of participants within the 1-year cohort who were and were not included in the present 4-year analysis. Surgical success at 1 and 4 years was compared using the McNemar test for paired data. We fitted a series of logistic regression models. Dependent variables included participants who met the criteria for a successful DL at 4 years (yes/no). Independent variables included demographic and other pre-DL variables, each evaluated one at a time. Next, to obtain a parsimonious set of pre-DL measures independently associated with the likelihood of a successful DL with an exploratory view, we fitted a multivariable logistic model for each dependent variable with all the baseline measures as independent variables and a stepwise variable selection procedure. Odds ratios were rescaled to provide an intuitively relevant magnitude without altering their statistical significance. For example, odds ratios for weight were expressed per 10 pounds (a more meaningful magnitude) rather than per 1 pound (raw estimate by a regression coefficient; see Tables 3, 4). We used SAS software version 9.4 (SAS Institute, Inc., Cary, North Carolina, USA) for statistical analyses.

Results

This prospectively collected cohort of United States Veterans included 193 participants with symptomatic spinal stenosis who underwent elective DL surgery with 1-year follow-up of whom 110 (focused herein) had 4-year follow-up. Table 1 summarizes the baseline participant characteristics. Overall, the average age was 65.1 ± 9.9, BMI 32.3 ± 5.3 with 70.9% being Caucasian. The majority (60.0%) of participants previously smoked. Only 18.2% reported smoking currently. All participants exhibited neurogenic claudication with the majority (55.5%) endorsing concurrent back and leg pain with imaging respectively confirming moderate (25.5%) or severe (60.9%) stenosis. Those included in the 4-year analysis had greater stenosis, symptom severity, comorbidity, poorer self-efficacy, poorer mood, and lower treatment credibility ratings (all $p < 0.05$; Supplementary Table S1).

Of the 68 participants demonstrating surgical success at 1 year, 11 did not sustain surgical success at 4 years (16%). Of the 69 participants demonstrating surgical success at 4 years, 12 did not demonstrate initial surgical success at 1 year (17%). Comparing surgical success rates at 1 and 4 years, there was no statistically significant difference ($p = 0.8348$; Table 2). In addition, 1- vs. 4-year success rates in BSS physical function (50.9 vs. 49.1%; $p = 0.6831$), BSS symptoms severity (65.5 vs. 67.3%; $p = 0.6171$), and BSS satisfaction (68.2 vs. 71.8%; $p = 0.2850$) were not statistically different (Supplementary Tables S2–S4).

Figure 2 highlights the BSS metric associations at 4 years. Table 3 summarizes the bivariate associations between surgical success and preoperative factors. A 0.2-point greater (worse) baseline BSS physical function score was associated with a 27% increase in odds of physical function improvement [OR 1.27 (1.07–1.51); $p = 0.0063$]. In addition, being on a non-CNS pain medication conferred over twice the odds of improving BSS physical function [OR 2.43 (1.13–5.26); $p = 0.0237$], while 5 points in the PTSD scale decreased the odds by 13% [OR 0.87 (0.78–0.98); $p = 0.0186$].

Having a 0.2-point greater baseline BSS symptom severity score (i.e., worse symptoms) was associated with 24% increased odds of improving BSS symptom severity post-DL [OR 1.24 (1.05–1.46); $p = 0.0090$]. A 10-point difference in treatment credibility was associated with a 24% increase in odds of symptom improvement [OR 1.24 (1.02–1.52); $p = 0.0319$]. In addition, having a college education was associated with an over threefold increase in odds of improvement [OR 3.36 (1.39–8.09); $p = 0.0069$]. Conversely, an additional year of symptom duration was associated with a 3% decrease in odds [OR 0.97 (0.94–1.00); $p = 0.0409$] of an improvement in BSS symptom severity post-DL.

TABLE 2 Decompressive laminectomy rate of surgical success at 1 year and 4 years.

		One year		
		No	Yes	Total
Four years	No	30	11	41 (37.3)
	Yes	12	57	69 (62.7)
	Total	42 (38.2)	68 (61.8)	110 (100.0)

Values represent *N* (percentage). McNemar test $p = 0.8348$.

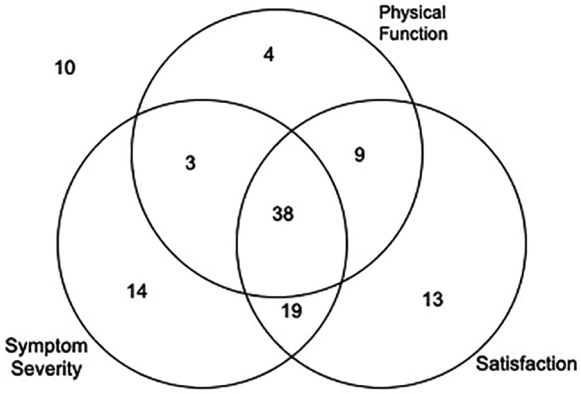

FIGURE 2
Decompressive laminectomy success rates by different BSS criteria. 10/110 (9.1%) did not improve by any of the three criteria. 31/110 (28.2%) improved by only one of the three criteria. 31/110 (28.2%) improved by only two of the three criteria. 38/110 (34.5%) improved by all three criteria.

Many variables demonstrated an association with BSS satisfaction. A 10-point greater CPSE physical function score (i.e., higher physical function disability) was associated with 20% greater odds [OR 1.20 (1.01–1.43); $p = 0.0358$] of BSS satisfaction. A 10-point greater CPSE coping score (i.e., better coping skills) was associated with a 23% increase in odds [OR 1.23 (1.04–1.47); $p = 0.0165$], a college education with an over twofold increase in odds [OR 2.81 (1.16–6.81); $p = 0.0217$], severe stenosis with an almost sevenfold increase in odds [OR 6.93 (1.55–31.1); $p = 0.0114$], and a 10-point increase in the preoperative expectations of postsurgical improvement score associated with a 23% increase in odds [OR 1.23 (1.00–1.51); $p = 0.0456$] of achieving BSS satisfaction. Conversely, each 1 kg/m^2 increase in BMI was associated with a 9% reduction in satisfaction [OR 0.91 (0.83–0.98); $p = 0.0172$], a 10-point greater BSS physical function score lowered the odds by 18% [OR 0.82 (0.68–0.99); $p = 0.0431$], and a 10-point greater BSS symptom severity resulted in a decrease of 29% [OR 0.71 (0.59–0.85); $p = 0.0003$]. Other factors associated with lower satisfaction included a 2 point greater coping strategies questionnaire (CSQ) score, which reduced the odds of achieving satisfaction by 14% [OR 0.86 (0.78–0.95); $p = 0.0018$], a year longer symptom duration with a decrease of 4% [OR 0.96 (0.93–1.00); $p = 0.0309$], 1 point in the widespread pain index with a 17% reduction [OR 0.83 (0.73–0.94); $p = 0.0039$]; and fibromyalgia, which decreased the odds of achieving satisfaction by 72% [OR 0.28 (0.12–0.70); $p = 0.0064$].

Factors demonstrating an association with improvements in at least two of three criteria, and thus overall surgical success at 4 years, include having some college education [OR 2.93 (1.27–6.77); $p = 0.0120$], moderate or severe stenosis on imaging (OR 7.16–7.39; $p = 0.0195$–0.0260), and having greater expectations for improvement and reduced limitations (OR for 10 points 1.24–1.35; $p = 0.0048$–0.0423). Prolonged symptom duration of an additional year [OR 0.96 (0.93–0.99); $p = 0.0231$] was associated with reduced odds of surgical success.

TABLE 3 Bivariate analysis of improvement by BSS criteria.

Baseline characteristic	BSS physical function change ≥0.42	BSS symptom severity change ≥0.46	Reporting BSS satisfaction ≥2.42	At least two of the three criteria
Age (5 years)	1.15 (0.94–1.40) 0.1858	0.96 (0.78–1.18) 0.7153	1.08 (0.88–1.32) 0.4803	1.06 (0.87–1.29) 0.5682
Weight (10 pounds)	0.95 (0.87–1.04) 0.2864	0.99 (0.90–1.10) 0.9165	0.90 (0.81–1.00) 0.0473	0.91 (0.83–1.00) 0.0603
Height (3 inches)	0.83 (0.56–1.24) 0.3649	0.95 (0.63–1.44) 0.8057	1.02 (0.66–1.57) 0.9222	0.91 (0.61–1.37) 0.6664
BMI (1 kg/m^2)	0.98 (0.91–1.05) 0.4880	1.01 (0.93–1.09) 0.8731	0.91 (0.83–0.98) 0.0172	0.93 (0.86–1.00) 0.0639
BSS physical function (0.2 point)	1.27 (1.07–1.50) 0.0063	1.03 (0.88–1.21) 0.6829	0.82 (0.68–0.99) 0.0431	1.06 (0.91–1.24) 0.4503
BSS symptom severity (0.2 point)	0.96 (0.83–1.10) 0.5190	1.24 (1.05–1.46) 0.0090	0.71 (0.59–0.85) 0.0003	0.96 (0.83–1.11) 0.5914
CPSE pain management (10 points)	1.04 (0.91–1.20) 0.5441	1.02 (0.88–1.19) 0.7541	1.09 (0.93–1.27) 0.2932	1.01 (0.88–1.17) 0.8509
CPSE physical function (10 points)	1.13 (0.97–1.31) 0.1178	1.03 (0.88–1.20) 0.7545	1.20 (1.01–1.43) 0.0358	1.07 (0.92–1.25) 0.3610
CPSE coping (10 points)	1.07 (0.93–1.24) 0.3547	0.97 (0.83–1.13) 0.6797	1.23 (1.04–1.47) 0.0165	1.06 (0.91–1.23) 0.4693
CSQ (catastrophizing scale, 2 points)	0.95 (0.87–1.03) 0.1957	0.97 (0.89–1.05) 0.4466	0.86 (0.78–0.95) 0.0018	0.92 (0.84–1.00) 0.0512
DAST-10 (1 point)	0.84 (0.54–1.30) 0.4324	1.55 (0.78–3.09) 0.2146	1.06 (0.67–1.68) 0.8065	1.32 (0.76–2.30) 0.3255
Duke comorbidity index (1 point)	0.81 (0.61–1.07) 0.1377	1.05 (0.78–1.40) 0.7483	0.85 (0.63–1.16) 0.3086	0.92 (0.69–1.22) 0.5590
Cardiac problems	1.36 (0.61–3.04) 0.4572	1.33 (0.55–3.18) 0.5263	0.79 (0.33–1.91) 0.6055	1.45 (0.62–3.40) 0.3877
Diabetes	0.68 (0.32–1.45) 0.3190	0.85 (0.38–1.91) 0.6970	1.20 (0.51–2.80) 0.6790	1.20 (0.55–2.64) 0.6472
FABQ (2 points)	0.95 (0.84–1.06) 0.3505	1.00 (0.88–1.13) 0.9762	0.96 (0.84–1.09) 0.5095	0.99 (0.88–1.12) 0.8819
Widespread pain index (1 point)	0.96 (0.85–1.07) 0.4268	1.02 (0.91–1.15) 0.7009	0.83 (0.73–0.94) 0.0039	0.90 (0.80–1.01) 0.0801
GAD-7 (1 point)	0.94 (0.88–1.00) 0.0673	0.99 (0.93–1.06) 0.7695	0.94 (0.88–1.01) 0.0848	0.98 (0.91–1.04) 0.4527
ISI (1 point)	1.00 (0.94–1.05) 0.8740	0.98 (0.92–1.04) 0.4506	0.96 (0.91–1.02) 0.2194	0.99 (0.93–1.04) 0.6076
Leg length discrepancy (0.25 inches)	1.00 (0.78–1.27) 0.9835	0.95 (0.73–1.22) 0.6726	0.84 (0.64–1.10) 0.1983	0.95 (0.74–1.22) 0.6738
MMSE	0.43 (0.11–1.62) 0.2119	0.91 (0.23–3.63) 0.8901	0.86 (0.20–3.69) 0.8435	0.78 (0.20–3.02) 0.7209
MOS emotional support (10 points)	1.00 (0.88–1.15) 0.9432	0.87 (0.74–1.02) 0.0831	0.95 (0.81–1.11) 0.5285	0.86 (0.74–1.01) 0.0622
MOS tangible support (10 points)	1.05 (0.93–1.20) 0.4273	0.87 (0.74–1.02) 0.0882	1.06 (0.92–1.22) 0.4185	1.00 (0.87–1.14) 0.9462
MOS affectionate support (10 points)	1.06 (0.93–1.20) 0.4189	0.97 (0.85–1.12) 0.7168	1.01 (0.87–1.16) 0.9274	0.98 (0.86–1.12) 0.7792
MOS positive social interaction (10 points)	1.12 (0.97–1.28) 0.1149	0.94 (0.81–1.09) 0.3932	1.08 (0.94–1.25) 0.2681	1.01 (0.88–1.15) 0.9368
Symptom duration (12 months)	0.98 (0.95–1.01) 0.2093	0.97 (0.94–1.00) 0.0409	0.96 (0.93–1.00) 0.0309	0.96 (0.93–0.99) 0.0231
PHQ-9 (1 point)	1.00 (0.94–1.05) 0.8765	1.00 (0.94–1.07) 0.9535	0.95 (0.90–1.02) 0.1428	1.02 (0.96–1.08) 0.6004
PTSD total (5 points)	0.87 (0.78–0.98) 0.0186	1.05 (0.94–1.18) 0.3698	0.91 (0.81–1.02) 0.0962	0.98 (0.88–1.09) 0.6458
QMCI (5 points)	1.13 (0.95–1.33) 0.1594	0.94 (0.79–1.11) 0.4601	1.15 (0.96–1.38) 0.1226	1.07 (0.91–1.27) 0.4119
SMAST (1 point)	1.30 (0.94–1.79) 0.1163	1.22 (0.87–1.71) 0.2393	0.97 (0.72–1.31) 0.8421	1.21 (0.88–1.67) 0.2455
Lumbar scoliosis (1 degree)	1.02 (0.98–1.07) 0.3402	1.03 (0.97–1.08) 0.3362	1.03 (0.98–1.09) 0.2516	1.02 (0.97–1.07) 0.5403
Lumbar kyphosis (1 degree)	1.01 (0.98–1.04) 0.4650	1.00 (0.97–1.03) 0.8782	1.00 (0.96–1.03) 0.7990	1.00 (0.97–1.03) 0.8202
Smoking status				
Current smoker vs. non-smoker	0.82 (0.25–2.69) 0.741	1.11 (0.32–3.83) 0.8637	0.39 (0.10–1.49) 0.1710	0.75 (0.22–2.57) 0.6475
Prior smoker vs. non-smoker	1.00 (0.39–2.55) 1.0000	1.38 (0.52–3.67) 0.5191	0.70 (0.23–2.16) 0.5369	0.82 (0.31–2.19) 0.6925
Ethnicity (Hispanic)	1.52 (0.45–5.12) 0.4997	0.65 (0.19–2.20) 0.4868	0.76 (0.21–2.73) 0.6750	1.21 (0.34–4.31) 0.7652
Race				
Black vs. Caucasian	0.95 (0.32–2.79) 0.9256	1.50 (0.44–5.11) 0.5169	0.54 (0.17–1.67) 0.2831	0.88 (0.29–2.69) 0.8258
Other vs. Caucasian	0.57 (0.19–1.72) 0.3189	0.83 (0.27–2.54) 0.7489	0.54 (0.17–1.67) 0.2831	0.53 (0.18–1.57) 0.2508
Education				
College vs. high school or less	1.22 (0.56–2.67) 0.6238	3.36 (1.39–8.09) 0.0069	2.81 (1.16–6.81) 0.0217	2.93 (1.27–6.77) 0.0120
Other vs. high school or less	0.55 (0.12–2.45) 0.4290	1.05 (0.25–4.42) 0.9469	5.63 (0.65–48.8) 0.1169	1.25 (0.30–5.26) 0.7607
Fibromyalgia (2016 criterion)	0.96 (0.41–2.24) 0.9185	1.75 (0.67–4.60) 0.2542	0.28 (0.12–0.70) 0.0064	0.79 (0.33–1.88) 0.5944
Predominant symptom location				
Low back vs. (back and leg both)	1.38 (0.56–3.39) 0.4858	0.47 (0.18–1.22) 0.1201	0.96 (0.37–2.50) 0.9252	0.61 (0.24–1.51) 0.2810
Leg vs. (back and leg both)	0.64 (0.23–1.75) 0.3814	0.58 (0.20–1.65) 0.3056	2.71 (0.71–10.3) 0.1433	1.05 (0.37–3.00) 0.9274
Pain medications				
Opioid	0.61 (0.28–1.34) 0.2188	1.08 (0.47–2.46) 0.8605	0.63 (0.27–1.47) 0.2855	0.64 (0.29–1.41) 0.2690
Non-opioid non-CNS	2.43 (1.13–5.26) 0.0237	1.41 (0.63–3.17) 0.4059	1.16 (0.50–2.68) 0.7302	1.99 (0.89–4.42) 0.0928
Non-opioid CNS	1.15 (0.54–2.44) 0.7208	1.50 (0.66–3.41) 0.3291	0.73 (0.31–1.67) 0.4530	1.09 (0.50–2.38) 0.8364
Hip OA	1.44 (0.67–3.13) 0.3506	1.14 (0.50–2.60) 0.7553	0.55 (0.24–1.29) 0.1700	1.11 (0.50–2.48) 0.7905
Worst stenosis (L1-S1)				
Moderate vs. none/mild	3.03 (0.53–17.3) 0.2108	4.58 (0.93–22.6) 0.0613	6.00 (1.18–30.6) 0.0311	7.39 (1.27–43.0) 0.0260
Severe vs. none/mild	4.06 (0.79–21.0) 0.0944	2.39 (0.58–9.78) 0.2250	6.93 (1.55–31.1) 0.0114	7.16 (1.37–37.4) 0.0195
Treatment credibility/expectations				
Logical (10 points)	1.01 (0.77–1.33) 0.9350	1.23 (0.93–1.63) 0.1461	1.31 (0.98–1.74) 0.0650	1.29 (0.97–1.72) 0.0772
Reducing limitations (10 points)	1.18 (0.97–1.43) 0.1066	1.24 (1.02–1.52) 0.0319	1.39 (1.12–1.73) 0.0026	1.35 (1.10–1.66) 0.0048
Recommending to a friend (10 points)	1.07 (0.95–1.20) 0.2677	0.97 (0.85–1.10) 0.6019	1.00 (0.88–1.14) 0.9972	0.98 (0.87–1.10) 0.7278
Expected improvement (10 points)	1.04 (0.86–1.26) 0.6631	1.08 (0.89–1.31) 0.4564	1.23 (1.00–1.51) 0.0456	1.19 (0.98–1.44) 0.0858
Surgery reduces limits (10 points)	1.19 (0.97–1.47) 0.0927	1.11 (0.92–1.35) 0.2829	1.19 (0.97–1.45) 0.0936	1.24 (1.01–1.51) 0.0423
Improvement after recovery (10 points)	1.14 (0.93–1.40) 0.2180	1.16 (0.94–1.43) 0.1712	1.26 (1.01–1.56) 0.0409	1.22 (0.99–1.50) 0.0660

Values represent odds ratio (95% confidence interval) *p*-value. BMI, body mass index; BSS, Brigham Spinal Stenosis questionnaire; CPSE, chronic pain self-efficacy; CSQ, coping strategies questionnaire; DAST-10, drug abuse screening tool-10; FABQ, fear avoidance beliefs questionnaire; GAD, generalized anxiety disorder; ISI, insomnia severity index; MOS, Medical Outcomes Survey; PHQ, patient health questionnaire; PTSD, post-traumatic stress disorder; QMCI, quick mild cognitive impairment screen; SMAST, short Michigan alcohol screening test; OA, osteoarthritis.

TABLE 4 Multivariable associations influencing categorical BSS success.

	BSS physical function change ≥0.42	BSS symptom severity change ≥0.46	Reporting BSS satisfaction ≥2.42	At least two of the three criteria
BMI			0.88 (0.79–0.98) 0.0172	
BSS physical function (0.2 point)	1.63 (1.28–2.07) <0.0001			
BSS symptom severity (0.2 point)		1.38 (1.14–1.67) 0.0011	0.67 (0.53–0.86) 0.0015	
CPSE physical function (10 points)	1.50 (1.19–1.89) 0.0006			
CPSE pain management (10 points)				0.81 (0.66–0.98) 0.0316
Symptom duration (12 months)		0.96 (0.92–1.00) 0.0320		0.96 (0.92–0.99) 0.0208
Expectation of reduced limitations (10 points)		1.29 (1.03–1.61) 0.0289	1.46 (1.10–1.94) 0.0090	1.51 (1.15–1.98) 0.0031
Moderate stenosis vs. none/mild			14.9 (1.91–116) 0.0100	17.4 (2.32–130) 0.0055
Severe stenosis vs. none/mild			17.0 (2.47–116) 0.0040	14.4 (2.29–90.6) 0.0045
AUROC	0.753	0.753	0.836	0.777

Odds ratio (95% confidence interval) *p*-value. BMI, body mass index; BSS, Brigham Spinal Stenosis questionnaire; CPSE, chronic pain self-efficacy; AUROC, area under the receiver operating characteristic.

Multivariable models showed that a combination of several preoperative biopsychosocial factors could be used to predict the likelihood of 4-year surgical success (Table 4). CPSE pain management [adjusted OR or AOR for 10 points 0.81 (0.66–0.98); 0.0316], symptom duration [AOR for 12 months 0.96 (0.92–0.99); $p = 0.0208$], expectation of reduced limitations [AOR for 10 points 1.51 (1.15–1.98); $p = 0.0031$], and moderate or severe stenosis (AOR 14.4–17.4; $p = 0.0045$–0.0055) constituted a parsimonious subset of predictors of overall surgical success with an accuracy of 0.777 as indicated by the area under receiver operator characteristic curve (AUROC). Other criteria for improvement had similar levels of accuracy (AUROC 0.753–0.836).

Discussion

In United States Veterans with symptomatic LSS, 63% of participants demonstrated sustained DL success at 4 years, similar to the success rate at 1 year (3). Noteworthy preoperative characteristics associated with a higher likelihood of sustained, 4-year, surgical success included lower self-efficacy for pain management, shorter duration of symptoms, greater treatment credibility, and having moderate to severe anatomical stenosis.

Similar to the 1-year success rate, only about 50% of participants experienced significant functional improvement, a key outcome for older adults. Having worse baseline physical function and higher baseline self-efficacy for function were associated with a higher likelihood of significant functional improvement. Studies have highlighted the potential benefits of cognitive and physical prehabilitation prior to and immediately following spinal surgery (35–39), although heterogeneous methods prevent definitive conclusions from being drawn. Our findings suggest the potential value of future studies designed to evaluate the impact on DL outcomes of prehabilitation focused on enhancing self-efficacy.

Four-year improvements in symptom severity (e.g., pain and paresthesias) mirrored those at 1 year (3). Approximately 2/3 of participants had sustained a reduction in symptom severity. Significant predictors of 4-year symptom severity reduction were greater preoperative symptom severity, shorter symptom duration, and greater treatment credibility.

Satisfaction at 4 years post-DL also mirrors those reported at 1 year post-DL (3), with approximately 69% reporting satisfaction at 1 year and 72% reporting satisfaction at 4 years. Approximately 13% of participants at 1 year and 12% at 4 years post-DL reported being satisfied despite experiencing no significant improvement in pain or function. Predictors of significant satisfaction included lower BMI, lesser preoperative symptom severity, greater treatment credibility, and having moderate to severe anatomical stenosis. It has been highlighted in non-surgical patients with chronic pain that symptomatic improvement and satisfaction are not necessarily correlated and that the patient–provider relationship plays a prominent role in determining satisfaction with care (40). Future studies should include such contextual factors as a part of preoperative assessment.

Our findings suggest the importance of preoperative counseling that emphasizes personalized goals. If functional improvement is the patient's main goal, then preoperative efforts to optimize self-efficacy for function may be important. If reduction of symptoms is the patient's main goal, encouraging patients with more severe symptoms and anatomical pathology toward surgery may need to be considered. Future studies that include more participants are needed to validate our observations and evaluate the impact on patient outcomes of a personalized approach to care.

We note that approximately 20% of participants who demonstrated surgical success at 1 year did not demonstrate success at 4 years and vice versa. Despite most revision surgeries for simple DL being performed prior to 1 year (41), our data suggest that continued observation (vs. operative intervention) may be prudent for some participants with potentially delayed improvement. Factors that predict deterioration following initial success also require identification. While a more detailed analysis of participants with delayed improvement and delayed deterioration is beyond the scope of the present study, further investigation is warranted.

The main strength of our study was the rigorous assessment of a comprehensive set of biopsychosocial predictors, and additional preoperative factors, relevant to older adults. To our knowledge, we included the most comprehensive set of preoperative factors

that have been studied in patients with LSS undergoing DL. Several study limitations also should be noted. The 4-year cohort represented approximately 57% of the original 1-year cohort, and there were some differences in baseline characteristics as noted earlier. However, the direction of the differences does not indicate the same informative censoring in typical longitudinal studies on aging, where the frailest participant dropout. In addition, our study participants were predominantly male veterans; thus, our findings may not generalize to the larger community of individuals undergoing DL for LSS. Although we observed acceptable predictive accuracy in multivariable models, there are very likely key extra-skeletal predictive factors that we did not collect such as muscle health, genetic profiles, and other biological parameters. Future studies should be conducted on a larger cohort with an even more comprehensive set of preoperative factors to optimize predictive accuracy. Estimates of predictive accuracy from an independent validation sample are more credible and necessary before definitive prediction rules can be considered.

Conclusion

Preoperative characteristics may predict long-term DL surgical success at 4 years. Further study is needed to not only establish predictive accuracy but also the impact of modifying presurgical risk factors on surgical outcomes.

Data availability statement

Due to a patient protection of veterans, the authors are limited in their capacity to provide raw data.

Ethics statement

The studies involving humans were approved by the Department of Veterans Affairs (VA) Central Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DF: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal Analysis, Data curation. KH: Writing – review & editing, Investigation, Formal Analysis. EL: Writing – review & editing, Investigation. HK: Writing – review & editing, Investigation. SN: Writing – review & editing, Investigation. SK: Writing – review & editing, Investigation, Funding acquisition, Formal Analysis. AG: Writing – review & editing, Investigation. JK: Writing – review & editing, Investigation, Formal Analysis. SP: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal Analysis, Data curation, Conceptualization. DW: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal Analysis, Data curation, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The authors declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmscd.2024.1493642/full#supplementary-material

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