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Preoperative Multifidus Activation During Movement and Recurrent Low Back Pain at 6 to 12 Months After Lumbar Spinal Stenosis Surgery: A Prospective Observational Study

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Abstract

Purpose

Although lumbar spinal stenosis (LSS) surgery improves pain and function, some patients experience recurrent low back pain (LBP). This exploratory study examined whether the preoperative lumbar multifidus (LMF) to lumbar erector spinae (LES, specifically the longissimus muscle) activity ratio on surface electromyography (sEMG) is associated with recurrent LBP and pain outcomes 6–12 months after LSS surgery.

Methods

Seventy patients with LSS undergoing surgery were enrolled and followed for 12 months. Preoperative sEMG of back extensor muscles was recorded during a trunk flexion–return task. The primary outcome was the postoperative change in LBP visual analog scale (VAS) from 6 to 12 months (ΔLBP 6–12M). The secondary outcome was LBP VAS at 12 months. Recurrent LBP was defined as a ≥ 20-mm VAS increase between 6 and 12 months. The main exposure was the LMF/LES activity ratio; multivariable linear regression adjusted for prespecified covariates.

Results

Recurrent LBP occurred in 9 of 70 patients (12.9%). These patients had a lower LMF/LES ratio than those without recurrence. This ratio was significantly associated with ΔLBP 6–12M (β=−22.9, 95% CI − 44.6 to − 1.3, p = 0.038) and 12-month LBP VAS (β=−20.6, 95% CI − 40.2 to − 0.9, p = 0.041). However, the latter association was attenuated after body mass index adjustment (β=−18.8, 95% CI − 38.7 to 1.1, p = 0.064).

Conclusion

Lower preoperative LMF activation during movement is associated with mid-term postoperative LBP worsening after LSS surgery. Therefore, preoperative assessment of LMF activation patterns may identify patients at risk for postoperative LBP recurrence.

Introduction

Lumbar spinal stenosis (LSS), a common degenerative disorder in older adults, causes low back pain (LBP) and lower extremity symptoms. Surgery for LSS generally improves pain and function [1]. However, postoperative outcomes vary, with some patients experiencing persistent or recurrent LBP despite neural symptom relief. Approximately one-third of patients report clinically relevant LBP during long-term follow-up [2]. Persistent LBP correlates with reduced satisfaction, functional impairment, and poorer

health-related quality of life [3]. Therefore, identifying predictors of postoperative LBP is a key challenge in LSS surgery.

Although several patient-related and surgical factors have been linked to postoperative LBP [4–8], these largely reflect static characteristics and do not address dynamic spinal function. Given the heterogeneity of postoperative pain trajectories, additional functional factors may underlie inter-individual variability. One potential mechanism is impaired segmental stabilization of the lumbar spine, in which the lumbar multifidus (LMF) plays a central role [9]. Morphological and functional LMF alterations in patients with lumbar disorders and LBP can affect spinal loading and control, potentially perpetuating postoperative LBP [10]. However, morphology alone fails to assess LMF recruitment and coordination during movement. As muscle activation reflects movement control, evaluating patterns during functional tasks could elucidate spinal support mechanisms related to postoperative pain.

To complement morphological assessments, surface electromyography (sEMG) measures muscle activity during functional tasks in patients with LSS and derives indices of activation magnitude and timing. Existing studies found inconsistent associations between electromyographic indices and LBP outcomes, with some reporting no correlation and others reporting concurrent improvements in longissimus muscle activity and reduced LBP [11, 12]. This inconsistency stems partly from postoperative-only assessments, which limit causal inference because activation patterns may reflect preoperative characteristics, surgical effects, or recovery adaptations. Consequently, the association between preoperative, movement-related LMF activation and postoperative LBP remains underexplored.

In this exploratory prospective observational study, we examined whether preoperative sEMG-assessed muscle activation patterns were associated with postoperative LBP after LSS surgery.

Methods

We hypothesized that preoperative activation patterns of the LMF muscle, assessed via sEMG during a functional task, would correlate with worsening LBP from 6 to 12 months postoperatively in patients undergoing surgery for LSS. This study was conducted and reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

Study Design

This single-center prospective observational study consecutively enrolled patients with clinical and radiological LSS diagnoses scheduled for surgery from July, 2020 to August, 2024. Preoperative assessments included detailed clinical evaluations and sEMG. LBP intensity and functional disability were evaluated at 6 and 12 months postoperatively. This study was approved by the institutional ethics committee (approval no. 20A042) and conducted in accordance with the Declaration of Helsinki.

Participants

Patients were included if they completed preoperative assessments, including functional-task sEMG, and a 12-month follow-up. Exclusion criteria comprised age ≥ 85 years, chronic inflammatory diseases, severe comorbidities that limited activities of daily living, such as malignancy, active infection, or severe cardiovascular or respiratory disease, neurological disorders, cognitive impairment or psychiatric conditions, and coexisting musculoskeletal disorders substantially impairing daily activities or motor assessments. Additional exclusions for analysis applied if preoperative assessments were incomplete due to intercurrent illness (e.g., acute infection) or logistics, consent was lacking, preoperative data were missing, sEMG was not performed, or 12-month data were unavailable.

Outcomes

The primary outcome was postoperative change in LBP intensity from 6 to 12 months (ΔLBP 6–12M), selected to capture post-recovery pain trajectories potentially indicating recurrence or worsening [5]. LBP and leg pain intensities were assessed separately using a 0–100 mm visual analog scale at baseline and 6 and 12 months postoperatively. ΔLBP 6–12M was calculated as the 12-month LBP VAS score minus the 6-month score, with positive values denoting worsening. The secondary outcome was 12-month LBP intensity. Exploratory analysis defined recurrent LBP as a ≥ 20-mm VAS increase from 6 to 12 months, corresponding to the minimal clinically important difference [14]. LBP-related disability was assessed using the Oswestry Disability Index (ODI) at the same time points.

Motor Tasks

Motor tasks included a prone maximal trunk extension for sEMG normalization [15] and a standing trunk flexion–return from upright posture [16]. For the standing task, participants adopted a comfortable upright posture and, upon verbal cue, flexed the trunk maximally forward before extending back to upright (Fig. 1).

Participants bent forward from an upright standing position to their maximal flexion position and then returned to upright standing. The movement was conceptually divided into the start position, maximum flexion phase, return phase, and end position

Tasks were performed at self-selected speeds. After sufficient practice, one trial per participant was recorded under standardized instructions for pace and motion range.

Surface Electromyography Acquisition and Derived Measure

Preoperative sEMG was recorded from the LMF and lumbar erector spinae (LES; specifically the longissimus muscle) at a 500-Hz sampling frequency using the TS-MYO system (Trunk Solution Co., Japan), which features bipolar electrodes in a fixed configuration, with a 10-mm center-to-center interelectrode distance.

Skin was prepared with conductive gel (Skinpure; Nihon Kohden, Japan) before sensor placement, which followed standardized SENIAM recommendations [17]. Placement was confirmed by palpation, signal stability was visually confirmed, and data acquisition was initiated using the manufacturer's software. Derived measures were computed from recorded signals.

Signal Processing and EMG Normalization

Raw sEMG signals underwent 50–450-Hz band-pass filtering without a notch filter. Filtered signals were converted to root mean square (RMS) amplitudes using a 50-ms moving window. Representative values for each analysis segment were the mean RMS amplitudes excluding segments with artifacts.

For EMG normalization, the mean RMS amplitude from the central 3 s of a 5-s sustained maximal contraction during prone maximal trunk extension was calculated for each muscle. In the standing trunk flexion–return task, LMF and LES amplitudes increased minimally near maximal flexion compared with quiet standing; thus, the analysis focused on the return phase for clearer activation.

The return phase was identified by visual inspection using synchronized video and sEMG waveforms in the manufacturer's software. One assessor selected the peak activation time point, extracting a 1.2-s centered window (0.6 s before and after). Maximal activity from prone trunk extension defined as 100% maximal voluntary contraction (MVC) per muscle. Mean normalized return-phase activity was expressed as %MVC. The LMF/LES activity ratio during the return phase was used to reflect the relative contribution of the segmental stabilizer LMF and the more superficial extensor LES during movement. This ratio was calculated by dividing normalized LMF activity (%MVC) by normalized LES activity (%MVC).

Clinical Variables and Potential Confounders

Clinical, surgical, imaging, functional, and psychosocial variables were collected to address potential confounding. Preoperative baseline variables encompassed demographics (age, sex, and body mass index [BMI]), disease-related factors (diagnosis, symptom duration, baseline pain intensity, and functional disability), comorbidities (e.g., hypertension, dyslipidemia, and Charlson Comorbidity Index, based on medical records), and surgical details (procedure type, number of operated levels, operative time, and intraoperative blood loss, based on operative records).

Physical performance included maximal back extensor strength [15], five-times sit-to-stand test for lower-limb strength, and straight-leg raise angle for flexibility, assessed per prior methods. Pain-related psychosocial factors were measured via validated questionnaires, including the Pain Catastrophizing Scale (PCS) [18]. Imaging variables from magnetic resonance imaging were used to quantify multifidus muscle mass and fatty degeneration as per established methods [13]. Spinal alignment used the sagittal vertical axis on standing radiographs.

Statistical Analysis

Continuous variables are summarized as median (interquartile range [IQR]); categorical variables are summarized as counts (percentages). Clinical characteristics were compared between patients with and without recurrent LBP using Mann–Whitney U tests for continuous variables and Fisher's exact tests for categorical variables.

For the primary analysis, multivariable linear regression was performed with ΔLBP 6–12M as the dependent variable. The primary independent variable was the log-transformed LMF/LES activity ratio during the return phase, serving as a relative indicator of multifidus activation.

Covariates, selected a priori based on literature and clinical relevance, included age, sex, BMI [5], surgical procedure [6], number of operated levels [7], PCS score [8], and 6-month LBP VAS [19, 20]. Covariates were entered simultaneously in all models, assessing associations between preoperative sEMG characteristics and pain worsening, adjusting for early postoperative pain.

For the secondary analysis, multivariable linear regression used LBP VAS at 12 months as the dependent variable, with the same independent variable and covariates.

Missing data were handled via complete-case analysis without imputation. Model assumptions were assessed using residual diagnostics. All tests were two-sided with significance set at $p < 0.05$. All analyses were conducted using EZR (version 1.70; Saitama Medical Center, Jichi Medical University, Saitama, Japan).

Results

During the study period, 192 patients underwent surgery for LSS. Among these, 122 were excluded due to chronic inflammatory disease (n = 5), coexisting musculoskeletal disorders interfering with activities of daily living (n = 5), age ≥ 85 years (n = 3), neurological disorders (n = 11), psychiatric disorders (n = 10), inability to complete motor assessments (n = 11), severe comorbidities that limited activities of daily living (n = 9), inability to complete preoperative assessments due to hospitalization scheduling constraints (n = 12), lack of informed consent (n = 3), coronavirus disease 2019 infection (n = 8), missing preoperative assessment data (n = 12), absence of preoperative sEMG assessment (n = 31), or inability to complete 12-month postoperative follow-up (n = 2). Consequently, 70 patients were analyzed.

Recurrent LBP occurred in 12.9% (9/70) of patients. LBP VAS worsened significantly more in patients with recurrent LBP than in those without recurrent LBP (Fig. 2a). However, changes in leg pain VAS and ODI scores did not differ between groups (Fig. 2b–c).

Low back pain visual analog scale (VAS) (a), leg pain VAS (b), and Oswestry Disability Index (ODI) (c) are shown from preoperative baseline to 6 and 12 months after surgery. Values are shown as medians. In the figure, "recurrence" and "no recurrence" denote patients with recurrent low back pain and those without recurrent low back pain, respectively.

The change in low back pain VAS from 6 to 12 months differed between groups; patients with recurrent low back pain showed a 42.4-mm greater increase than those without recurrent low back pain (95% CI, 31.7 to 53.0). In the longitudinal mixed-effects model, the group-by-time interaction for the 6–12-month change was significant ($p < 0.001$). In contrast, no significant between-group differences were observed in longitudinal changes in leg pain VAS or ODI.

Baseline symptom duration was significantly longer in patients with recurrent LBP, with no differences in demographics, baseline pain and disability, or perioperative characteristics (Table 1).

Table 1
Patient characteristics by low back pain recurrence status

Variable	Overall (n = 70)	LBP recurrence (n = 9)	LBP no recurrence (n = 61)	P-value
Age, years	72.0 [66.0–75.0]	71.0 [66.0–75.0]	73.0 [67.0–75.0]	0.853
Female sex, n (%)	37 (52.9)	5 (55.6)	32 (52.5)	1.000
BMI, kg/m^2	24.9 [22.8–26.5]	26.3 [23.0–26.7]	24.4 [22.8–26.3]	0.326
Symptom duration, months	20.0 [9.0–59.0]	36.0 [20.0–120.0]	19.0 [8.0–57.0]	0.044
CCI	0.0 [0.0–1.0]	0.0 [0.0–1.0]	0.0 [0.0–1.0]	0.381
Coexisting musculoskeletal disorder, n (%)	27 (38.6)	2 (22.2)	25 (41.0)	0.466
Preoperative ODI, %	42.2 [30.0–53.3]	44.4 [24.4–46.7]	42.2 [31.1–53.3]	0.374
Preoperative LBP VAS, mm	48.0 [25.0–71.0]	39.0 [24.0–79.0]	49.0 [25.0–71.0]	0.944
Preoperative leg pain VAS, mm	52.0 [27.0–78.0]	68.0 [39.0–83.0]	51.0 [26.0–77.0]	0.636
Fusion surgery, n (%)	52 (74.2)	5 (55.6)	47 (77.0)	0.667
Number of operated levels	1.0 [1.0–2.0]	2.0 [1.0–2.0]	1.0 [1.0–2.0]	0.174
Operative time, min	158.0 [116.0–189.0]	147.0 [108.5–156.8]	163.5 [120.8–194.2]	0.130
Blood loss, mL	155.0 [70.0–282.0]	175.0 [65.0–372.5]	150.0 [78.8–278.8]	0.796
Maximal back extensor strength, kgf	7.1 [4.5–9.3]	7.1 [5.0–10.0]	7.0 [4.6–9.3]	0.868
Five-times sit-to-stand test, s	9.3 [7.7–12.6]	9.6 [8.4–12.3]	9.2 [7.7–12.3]	0.833
Straight leg raise, °	60 [45.0–72.5]	60.0 [60.0–70.0]	60.0 [45.0–70.0]	0.909
PCS	33.0 [25.5–41.0]	40.0 [35.0–41.0]	32.0 [25.0–40.0]	0.124
Multifidus muscle area, cm^2	626.2 [467.0–1052.2]	512.0 [369.7–640.4]	657.0 [468.5–1092.5]	0.081
Multifidus fatty area, %	34.4 [23.7–53.3]	33.0 [30.7–61.7]	34.1 [22.4–48.7]	0.452

Variable	Overall (n = 70)	LBP recurrence (n = 9)	LBP no recurrence (n = 61)	P-value
SVA, mm	47.6 [30.6–77.1]	53.2 [43.3–65.0]	49.1 [29.3–80.2]	0.622

Data are presented as medians [interquartile range] or number (%) of patients.

LBP, low back pain; BMI, body mass index; CCI, Charlson Comorbidity Index; ODI, Oswestry Disability Index; VAS, visual analog scale; PCS, Pain Catastrophizing Scale; SVA, sagittal vertical axis.

Preoperative sEMG revealed a significantly lower LMF/LESactivity ratio during the trunk flexion return phase in patients with recurrent LBP than in those without recurrent LBP (0.84 [0.71–0.97] vs 1.10 [0.85–1.55]; p = 0.022). Absolute muscle activity levels (%MVC) at rest and during the return phase showed no between-group differences (Table 2).

Table 2
Comparison of EMG variables between groups

Variable	LBP recurrence (n = 9)	LBP no recurrence (n = 61)	P-value
LES activity at rest, %MVC	34.0 [18.7–40.4]	30.1 [16.9–48.8]	0.861
LMF activity at rest, %MVC	34.1 [27.5–36.3]	33.2 [22.6–58.9]	0.539
LES activity during the return phase, %MVC	69.5 [55.8–74.7]	61.9 [42.7–94.4]	0.972
LMF activity during the return phase, %MVC	64.8 [33.9–76.8]	67.8 [46.1–110.1]	0.171
LMF/LES activity ratio during the return phase	0.84 [0.71–0.97]	1.10 [0.85–1.55]	0.022

Data are presented as medians [interquartile range].

LBP, low back pain; MVC, maximum voluntary contraction; LMF, lumbar multifidus; LES, lumbar erector spinae [longissimus].

In the primary multivariable linear regression, the log-transformed preoperative LMF/LES activity ratio was inversely associated with ΔLBP 6–12M across all models (Models 1–3: β = −22.9 to − 24.4; all $p < 0.05$; Table 3).

Table 3
Linear regression analyses for postoperative change in low back pain between 6 and 12 months (ΔLBP 6–12M)

Variable	Model 1 β (95% CI)	P-value	Model 2 β (95% CI)	P-value	Model 3 β (95% CI)	P-value
Log LMF/LES activity ratio	−24.4 (− 45.0, − 3.7)	0.022	−24.3 (− 45.5, − 3.2)	0.025	−22.9 (− 44.6, − 1.3)	0.038
PCS total	0.1 (− 0.3, 0.5)	0.648	0.1 (− 0.3, 0.5)	0.656	0.1 (− 0.4, 0.5)	0.748
6-month LBP VAS	−0.5 (− 0.6, − 0.3)	< 0.001	−0.5 (− 0.7, − 0.2)	< 0.001	−0.4 (− 0.7, − 0.2)	< 0.001
Female sex	1.3 (− 7.7, 10.3)	0.774	1.3 (− 8.0, 10.6)	0.779	1.8 (− 7.6, 11.2)	0.706
Age	−0.5 (− 1.1, 0.1)	0.132	−0.5 (− 1.1, 0.2)	0.144	−0.5 (− 1.1, 0.2)	0.144
Number of operated levels	—	—	0.0 (− 9.6, 9.6)	0.998	−0.1 (− 9.7, 9.5)	0.985
Fusion procedure	—	—	0.0 (− 11.2, 11.1)	0.994	−0.2 (− 11.5, 11.0)	0.967
BMI	—	—	—	—	−0.5 (− 2.1, 1.0)	0.475
R^2	0.330		0.330		0.336	

PCS, Pain Catastrophizing Scale; LBP, low back pain; VAS, visual analog scale;

BMI, body mass index; CI, confidence interval.

Unstandardized regression coefficients (β) with 95% confidence intervals are shown.

Model 1 adjusted for age, sex, 6-month low back pain VAS, and PCS.

Model 2 further adjusted for surgical procedure and the number of operated levels.

Model 3 additionally adjusted for BMI.

Variance inflation factors ranged from 1.02 to 1.16 across all models.

In the secondary analysis, the log-transformed LMF/LES ratio was inversely associated in Models 1 and 2 (Model 1: β = −20.5, 95% CI − 39.7 to − 1.3, p = 0.037; Model 2: β = −20.6, 95% CI − 40.2 to − 0.9, p = 0.041). After BMI adjustment, the association persisted directionally but lost significance (Model 3: β = −18.8, 95% CI − 38.7 to 1.1, p = 0.064; Table 4).

Table 4
Linear regression analyses for 12-month low back pain VAS

Variable	Model 1 β (95% CI)	P-value	Model 2 β (95% CI)	P-value	Model 3 β (95% CI)	P-value
Log LMF/LES activity ratio	−20.5 (− 39.7, − 1.3)	0.037	−20.6 (− 40.2, − 0.9)	0.041	−18.8 (− 38.7, 1.1)	0.064
PCS total	0.2 (− 0.2, 0.6)	0.303	0.2 (− 0.2, 0.6)	0.354	0.2 (− 0.3, 0.6)	0.455
6-month LBP VAS	0.7 (0.5, 0.9)	< 0.001	0.7 (0.5, 0.9)	< 0.001	0.7 (0.5, 0.9)	< 0.001
Female sex	−0.5 (− 8.9, 7.9)	0.902	−0.8 (− 9.4, 7.9)	0.857	−0.2 (− 8.9, 8.5)	0.962
Age	−0.3 (− 0.9, 0.3)	0.270	−0.3 (− 0.9, 0.3)	0.314	−0.3 (− 0.9, 0.3)	0.311
Number of operated levels	—	—	0.0 (− 8.7, 8.7)	0.998	−0.1 (− 8.8, 8.6)	0.978
Fusion procedure	—	—	2.0 (− 8.5, 12.5)	0.711	1.8 (− 8.8, 12.3)	0.739
BMI	—	—	—	—	−0.7 (− 2.1, 0.7)	0.308
R^2	0.479		0.463		0.464	

PCS, Pain Catastrophizing Scale; LBP, low back pain; VAS, visual analog scale;

BMI, body mass index; CI, confidence interval; LMF, lumbar multifidus;

LES, lumbar erector spinae [longissimus].

Unstandardized regression coefficients (β) with 95% confidence intervals are shown.

Model 1 adjusted for age, sex, 6-month low back pain VAS, and PCS.

Model 2 further adjusted for surgical procedure and the number of operated levels.

Model 3 additionally adjusted for BMI.

Variance inflation factors ranged from 1.0 to 1.14 across all models.

Variance inflation factors indicated minimal multicollinearity in both models (ΔLBP 6–12M: range 1.05–1.16, maximum 1.16; 12-month LBP VAS: range 1.04–1.14, maximum 1.14). Diagnostic plots showed

minor deviations from linearity assumptions (Online Resources 1 and 2), including mild residual structure, limited heteroscedasticity, small Q–Q plot tail deviations, elevated leverage in some observations (up to approximately 0.30), and no influential points by Cook's distance.

Discussion

In this prospective observational cohort of 70 patients undergoing surgery for LSS, we examined whether preoperative sEMG measures were associated with recurrent LBP between 6 and 12 months postoperatively. Recurrent LBP was defined as a ≥ 20-mm increase in LBP VAS from 6 to 12 months and occurred in 9 patients (12.9%). Patients with recurrent LBP had longer symptom duration and a lower preoperative LMF/LES activity ratio during the movement task. In multivariable models, the log-transformed LMF/LES activity ratio remained associated with ΔLBP 6–12M and 12-month LBP after adjustment for prespecified covariates, including 6-month LBP. These findings suggest that movement-related relative LMF activation, which may accompany prolonged symptoms, is linked to mid-term LBP worsening beyond early postoperative pain.

Although LSS surgery generally improves LBP at the group level, postoperative LBP trajectories are heterogeneous and may diverge from leg symptoms or disability [2]. In our study, recurrent LBP occurred without parallel changes in leg pain or disability. This pattern is partly influenced by our operational definition. However, it supports the interpretation that postoperative LBP may follow a partially independent course. Studies in patients with LSS show altered LMF and LES activation patterns during walking or loading tasks compared with healthy controls, though overall muscle activity magnitude does not consistently correlate with LBP or ODI scores [21]. Accordingly, absolute LMF and LES activity (%MVC) at rest and during the return phase did not differ between groups with and without recurrent LBP. Conversely, the preoperative LMF/LES ratio during movement was lower in the recurrent LBP group and inversely associated with postoperative pain outcomes in multivariable models, including worsening from 6 to 12 months and LBP at 12 months. This supports use of the LMF/LES ratio as an index of local-to-global extensor recruitment, which may help explain postoperative LBP beyond early pain alone.

Modeling studies propose that reduced LMF function redirects segmental stabilization demands to other extensors, fostering superficial muscle dominance [22]. In LSS, postoperative LMF activity reductions with relative superficial extensor increases (e.g., iliocostalis) have been reported [23]. Mechanical analyses reveal that extensor imbalances elevate spinal anterior shear and compression, heightening disc and endplate shear strain and contact pressure [24]. Hence, reduced relative LMF contribution may signify a muscle activation pattern linked to increased lumbar mechanical loading.

However, the inverse association between the preoperative LMF/LES activity ratio and 12-month LBP VAS scores was attenuated after additional BMI adjustment. BMI may reflect spinal mechanical loading [25] and affect compressive and shear forces. These findings suggest that mid-term postoperative LBP worsening is multifactorial, particularly through the interplay between body weight–related loading and relative trunk extensor activation. Longitudinal studies after decompression report unchanged trunk

muscle activation and motor control in response to sudden loading for up to 24 months postoperatively, despite improvements in pain and function [11]. This indicates that preoperative activation patterns persist partially after surgery, influencing the postoperative mechanical environment. Therefore, preoperative or early postoperative interventions targeting movement-related LMF activation may mitigate recurrent LBP risk.

This study had some limitations. First, the small sample size, the substantial number of exclusions related to study procedures, and the observational design may have introduced bias, limited generalizability, and prevented causal inference about the association between preoperative muscle activation and postoperative LBP recurrence. Second, the limited number of sEMG trials cannot exclude measurement error from electrode placement, skin condition, or technical factors. However, consistent directional associations in the primary and secondary analyses imply that random variability alone is unlikely to explain the findings. Lastly, since sEMG was not repeated postoperatively and recurrent LBP was defined only by VAS change, we could not assess postoperative activation changes or outcomes beyond pain. Future longitudinal studies should incorporate repeated sEMG and broader outcomes to test whether modifying movement-related LMF activation can alter mid-term postoperative pain trajectories.

Conclusion

In patients with LSS, lower preoperative LMF activation during movement tasks was associated with recurrent LBP 6–12 months after surgery. This exploratory analysis suggests that preoperative LMF activation patterns may be linked to isolated postoperative LBP without worsening of leg symptoms or disability. Preoperative and early postoperative assessment of LMF and trunk muscle function may help identify patients at risk of recurrent LBP after LSS surgery and guide targeted interventions.

Declarations

Declarations

Competing Interests

The authors declare that, except for Dr. Hideki Nagashima, they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Dr. Hideki Nagashima, a co-author of this manuscript, is a member of the Editorial Board of the European Spine Journal.

Author Contribution

Yuki Kitsuda: Conceptualization, Methodology, Investigation, Writing - Review & Editing. Takashi Wada: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Project

administration. Shinji Tanishima: Supervision, Writing - Review & Editing. Daiki Takemori: Investigation, Writing - Review & Editing. Chikako Takeda: Supervision, Writing - Review & Editing. Mari Osaki: Supervision, Writing - Review & Editing. Hideki Nagashima: Supervision, Writing - Review & Editing.

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Data Availability

Data statementThe datasets generated and/or analyzed in the current study are available from the corresponding author upon reasonable request.

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Figures

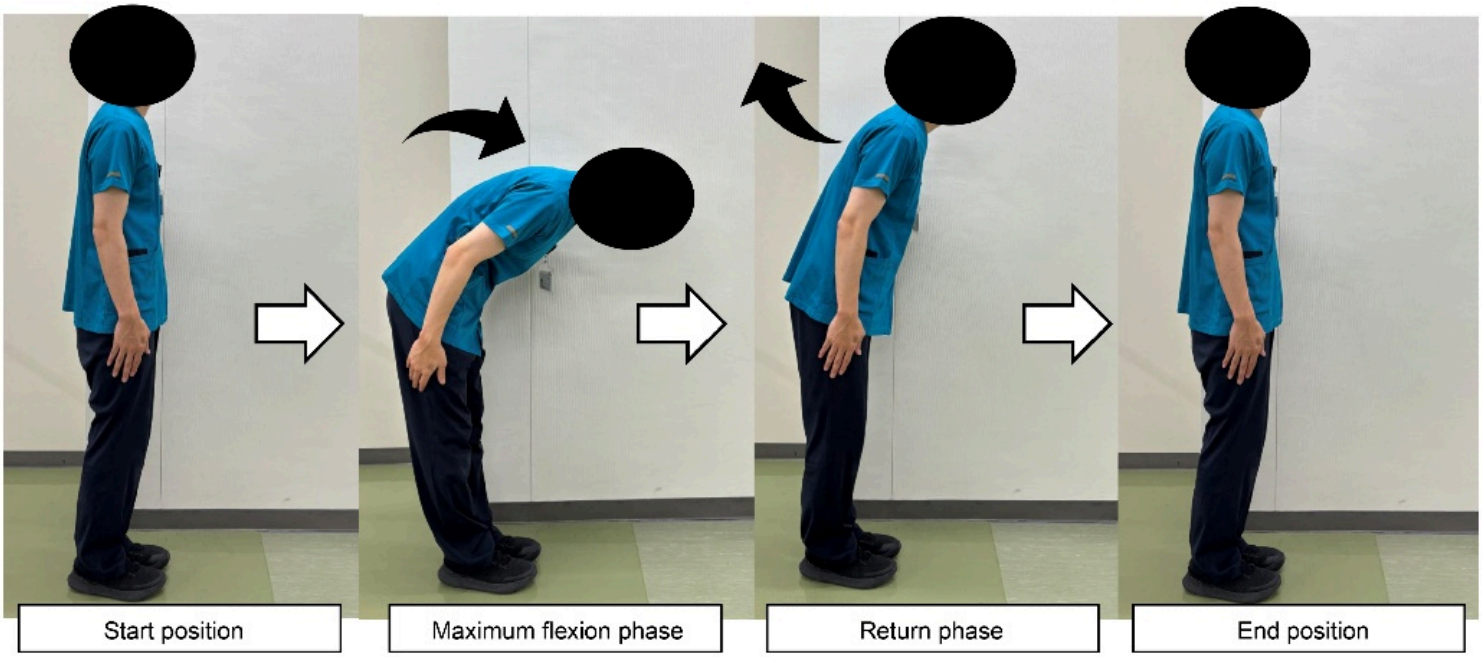


Figure 1

Standing trunk flexion–return task

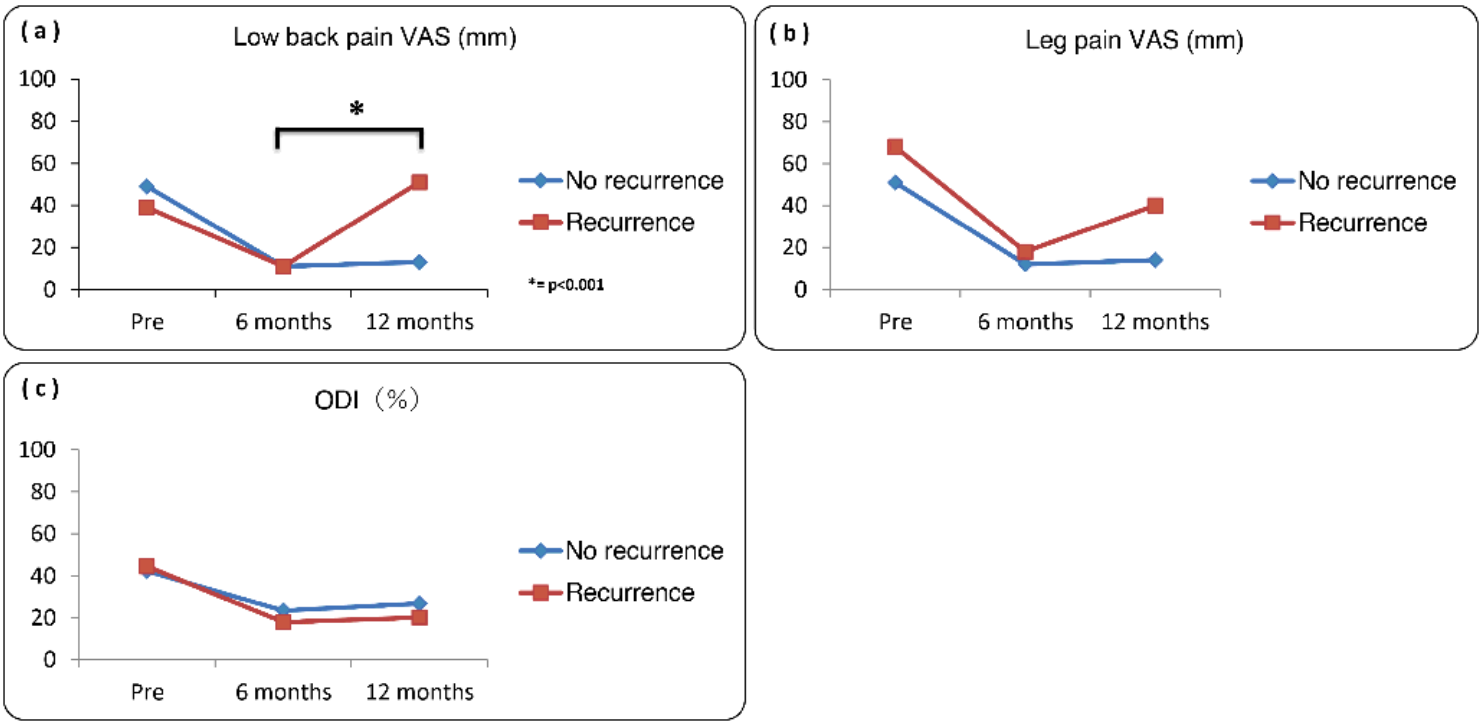


Figure 2

Changes in low back pain, leg pain, and disability according to recurrent low back pain status

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