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Prognostic Value of Preoperative Paraspinal, Gluteal and Abdominal Muscle Sarcopenia in Patients Undergoing One-hole Split Endoscopy for Lumbar Disc Herniation: A Retrospective Cohort Study

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Abstract

Background

Sarcopenia and fatty infiltration of spinal and pelvic stabilizing muscles may compromise long-term functional recovery after lumbar spine surgery. One-hole split endoscopy (OSE) is designed to minimize approach-related muscle injury; however, whether preoperative muscle degeneration continues to affect postoperative prognosis remains unclear.

Methods

This retrospective cohort study included 265 consecutive patients with single-level lumbar disc herniation (LDH) who underwent OSE between January 2021 and December 2023 and completed at least 24 months of follow-up. The primary outcome was chronic postoperative low back pain, defined as a final follow-up visual analog scale (VAS) score of ≥ 4. Secondary outcomes included longitudinal VAS and Oswestry Disability Index (ODI) scores and achievement of the minimal clinically important difference (MCID). Patients were classified as having sarcopenia or non-sarcopenia using sex-specific psoas major index thresholds (112 and 153 patients, respectively).

Results

The sarcopenia group had significantly lower psoas major index (PMI), multifidus muscle index (MMI), erector spinae index (EMI), gluteus maximus index (GMaxI) and gluteus medius index (GMedI) values than the non-sarcopenia group, together with more severe fatty infiltration in key paraspinal and gluteal muscles. Both groups showed marked postoperative improvement in VAS and ODI scores. However, at final follow-up, the sarcopenia group had worse VAS (3.21 vs. 2.49, $P < 0.01$) and ODI (24.76% vs. 19.63%, $P < 0.01$) scores and lower MCID achievement rates. In the final multivariable model, higher body mass index (BMI), lower bone mineral density (BMD), lower PMI, lower MMI, GMaxI deficit, lower GMedI, moderate/severe multifidus fatty infiltration and moderate/severe gluteus maximus fatty infiltration were independently associated with chronic postoperative low back pain.

Conclusions

Preoperative degeneration of paraspinal and gluteal muscles, particularly reduced multifidus and gluteal muscle quality and moderate/severe fatty infiltration, was associated with inferior long-term outcomes after OSE. Although OSE is muscle-sparing, it may not fully offset pre-existing spine-pelvis biomechanical impairment caused by sarcopenia. Routine preoperative muscle-quality assessment and targeted prehabilitation may help identify high-risk patients and optimize long-term recovery.

Introduction

Lumbar disc herniation (LDH) is a common cause of low back pain and radicular symptoms and can substantially impair quality of life and work capacity. Surgery is usually considered when neurological symptoms persist despite adequate conservative treatment or when progressive neurological deterioration occurs. Endoscopic lumbar surgery has gained increasing acceptance because it can decompress neural structures with less soft-tissue disruption than conventional open procedures. One-hole split endoscopy (OSE) is a recently developed minimally invasive technique in which the endoscope and instruments are separated within one soft-tissue incision, allowing flexible manipulation without a fixed working cannula. Clinical studies and recent syntheses suggest that OSE can achieve favorable clinical outcomes while reducing approach-related soft-tissue injury [1–5].

Nevertheless, a subset of patients continue to experience persistent or recurrent low back pain after technically successful decompression, suggesting that factors beyond neural compression and surgical trauma may determine long-term recovery. Sarcopenia, characterized by reduced muscle mass, impaired muscle strength and increased fatty infiltration, has been recognized as an important age- and disease-related condition in international and Asian consensus statements [6, 7]. In lumbar degenerative spine disease, sarcopenia has been associated with worse clinical outcomes and delayed functional recovery [8, 9]. Among spinal muscles, degeneration of the multifidus and erector spinae may impair segmental stability and increase abnormal shear stress on the operated segment. The psoas contributes to sagittal balance and pelvic control, whereas gluteal muscles participate in the spine-pelvis-hip kinetic chain by regulating hip extension, posterior pelvic tilt and coronal pelvic stability.

Previous studies have mainly focused on paraspinal muscles or on other endoscopic techniques, such as percutaneous transforaminal endoscopic discectomy and unilateral biportal endoscopy [10, 11]. The prognostic value of a comprehensive preoperative assessment that integrates paraspinal, gluteal and abdominal muscle morphology in patients undergoing OSE has not been fully clarified. We therefore aimed to determine whether preoperative muscle sarcopenia and fatty infiltration influence long-term pain and functional outcomes after OSE and to identify independent predictors of chronic postoperative low back pain.

Methods

Study design and patients

This retrospective cohort study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Xuzhou Central Hospital (approval No. XZXY-LK-20200910-0121). The requirement for informed consent was waived because of the retrospective design. The study followed the STROBE reporting principles for observational studies. Chronic postoperative low back pain at final follow-up (VAS ≥ 4) was prespecified as the primary outcome. Longitudinal VAS/ODI scores and MCID achievement were analyzed as secondary outcomes.

We reviewed consecutive patients who underwent OSE for single-level LDH in the spine surgery department between January 2021 and December 2023. All procedures were performed by the same experienced surgical team. The sample size was determined by consecutive case inclusion during the study period rather than by an a priori power calculation. To reduce selection bias and follow-up heterogeneity, only patients with complete baseline imaging and clinical follow-up of at least 24 months were included.

Inclusion criteria: (1) age 18 years or older; (2) clinical signs and symptoms consistent with LDH; (3) single-level LDH confirmed by CT or MRI corresponding to the clinical presentation; (4) failure of conservative treatment for at least 3 months or progressive neurological symptoms; (5) complete preoperative lumbar MRI and CT obtained within 2 weeks before surgery; and (6) complete postoperative follow-up data.

Exclusion criteria: (1) incomplete clinical records or missing imaging data; (2) lumbar spondylolisthesis, deformity, instability, scoliosis or spinal tumor; (3) multilevel LDH or severe lumbar spinal stenosis requiring extensive decompression; (4) previous lumbar surgery, fracture, infection or malignancy; and (5) severe cardiopulmonary dysfunction or coagulation disorders precluding surgery.

Surgical technique

Patients were placed in the prone position under general anesthesia. The responsible level was confirmed using anteroposterior and lateral fluoroscopy. After routine sterilization and draping, a longitudinal incision approximately 1.5-2.0 cm in length was made, with the center located at the intersection of the target intervertebral space and the spinous process line. The skin, superficial fascia and deep fascia were incised sequentially, and soft tissues were bluntly separated to the laminar surface using serial dilators. The OSE system was then introduced through the same incision. The ligamentum flavum was exposed along the lower margin of the cranial lamina and the upper margin of the caudal lamina and was partially resected using Kerrison rongeurs. When necessary, limited bony trimming of the medial laminar edge was performed to enlarge the operative window. After adequate exposure of the nerve root, the root was gently retracted medially and the herniated or free disc fragment was removed using pituitary rongeurs. The instruments were withdrawn after confirming free nerve-root mobility and adequate hemostasis, and the incision was closed in layers.

Clinical variables and outcomes

Demographic and perioperative variables were extracted from the electronic medical record system, including age, sex, height, weight, body mass index (BMI), bone mineral density (BMD; lowest available T-score from lumbar spine or hip dual-energy X-ray absorptiometry), smoking status, alcohol use, comorbidities, surgical segment, follow-up duration and length of hospitalization (LOS). Smoking was defined as current or previous smoking of at least one cigarette per day for ≥ 1 year. Alcohol use was

defined as regular alcohol consumption at least once per week for ≥ 6 months. Comorbidities included hypertension, diabetes mellitus and coronary artery disease.

Low back pain intensity was evaluated using the VAS (0–10 scale), and functional disability was evaluated using the ODI (0-100%). Assessments were performed preoperatively, at 1 month, at 1 year and at the final follow-up. Chronic postoperative low back pain was defined as a VAS score of ≥ 4 at the final follow-up. MCID achievement was defined as an improvement of at least 1.2 points for VAS back pain and at least 12.8 points for ODI, based on previously published thresholds for lumbar spine surgery [12]. Recurrent disc herniation was defined as the reappearance of radicular symptoms with imaging-confirmed disc herniation at the operated level after an initial period of postoperative symptom relief.

Imaging assessment

Two musculoskeletal radiologists who were blinded to clinical outcomes independently evaluated preoperative lumbar CT and T2-weighted MRI images after a standardized training session and calibration of measurement rules. Images were measured using ImageJ software (National Institutes of Health, Bethesda, MD, USA) or the institutional picture archiving and communication system when DICOM calibration was required.

Cross-sectional areas (CSAs) of the bilateral psoas major, multifidus and erector spinae muscles were measured at the mid-L3 level on axial CT images. CSAs of the gluteus maximus, gluteus medius and gluteus minimus were measured at the mid-S1 level, and CSAs of the rectus abdominis, external oblique, internal oblique and transversus abdominis muscles were measured at the mid-L4 level. Intramuscular fat and visible vessels were carefully excluded from the manually drawn regions of interest. Muscle indices were calculated as bilateral CSA divided by height squared (cm^2/m^2).

Sarcopenia was defined using sex-specific PMI thresholds of < 6.36 cm^2/m^2 in men and < 3.92 cm^2/m^2 in women, consistent with CT-based Asian adult reference criteria [13]. For regression analyses, GMaxI deficit was predefined as a GMaxI value below the sex-specific median of the study cohort and was coded as 1 for deficit and 0 for no deficit; other muscle indices were analyzed as continuous variables per 1 cm^2/m^2 increase.

Fatty infiltration was graded on T2-weighted MRI using the Goutallier system: grade 0, no fat; grade 1, small fatty streaks; grade 2, less fat than muscle; grade 3, approximately equal fat and muscle; and grade 4, more fat than muscle. This qualitative grading method has been used and validated for lumbar paraspinal muscle fatty degeneration on MRI [14, 15]. Because bilateral muscles were assessed independently and then averaged, half-grade values could occur. Average grades ≤ 1 were classified as mild, > 1 and < 3 as moderate, and ≥ 3 as severe fatty infiltration. Moderate and severe grades were combined for regression analyses.

Multifidus muscle density (MMD) was measured in Hounsfield units (HU) at the L3 level on non-contrast CT images by placing a circular region of interest within the muscle belly, avoiding visible fat streaks and

fascial boundaries.

Interobserver reliability was assessed using a two-way mixed-effects intraclass correlation coefficient (ICC) model for absolute agreement for continuous measurements and Cohen's kappa for Goutallier grades. Interobserver reliability was excellent, with ICC values greater than 0.90 for all continuous muscle measurements and kappa values greater than 0.85 for Goutallier-based grading.

Statistical analysis

Continuous variables are presented as mean ± standard deviation or median with interquartile range, as appropriate. Normality was assessed using the Shapiro-Wilk test. Between-group comparisons were performed using independent-samples t tests for normally distributed variables or Mann-Whitney U tests for non-normally distributed variables. Categorical variables are presented as frequencies and percentages and were compared using chi-square tests or Fisher exact tests when expected cell counts were less than 5.

The primary outcome was chronic postoperative low back pain (final follow-up VAS ≥ 4). Univariable logistic regression was first performed for clinically relevant baseline, imaging and preoperative clinical variables. To reduce overfitting and collinearity, only variables with $P < 0.05$ in univariable analysis and without substantial collinearity (variance inflation factor < 5) were entered into the multivariable model. Backward stepwise elimination was then applied, and variables with $P > 0.05$ were removed from the final reduced model. Odds ratios (ORs) are reported with 95% confidence intervals (CIs).

Model calibration was assessed using the Hosmer-Lemeshow test, and discrimination was evaluated using the C-statistic (area under the receiver operating characteristic curve). A two-sided $P < 0.05$ was considered statistically significant. All statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

Results

Baseline characteristics

A total of 265 patients were included: 112 patients in the sarcopenia group and 153 patients in the non-sarcopenia group. All included patients completed at least 24 months of follow-up. Baseline demographic characteristics, BMD, BMI, smoking status, alcohol use, comorbidities, surgical level and LOS were generally comparable between the two groups (Table 1).

Table 1
Comparison of demographic characteristics between patients with and without sarcopenia.

Variable	Sarcopenia group (n = 112)	Non-sarcopenia group (n = 153)	P value
Age, years	51.53 ± 7.26	50.24 ± 6.48	0.287
Sex, male/female	58/54	78/75	0.545
BMI, kg/m²	23.92 ± 3.27	24.58 ± 2.99	0.165
BMD, T-score	-0.74 ± 0.62	-0.66 ± 0.99	0.579
Hypertension/diabetes, n (%)	52 (46.4)	72 (47.1)	0.657
Coronary artery disease, n (%)	31 (27.7)	50 (32.7)	0.630
Smoking, yes/no	28 (25.0)	37 (24.2)	0.713
Alcohol use, yes/no	20 (17.9)	27 (17.6)	0.769
Surgical segment			0.597
L3/4	15	22	
L4/5	64	87	
L5/S1	33	44	
Follow-up, months	26.89 ± 3.15	25.39 ± 2.91	0.268
LOS, days	5.54 ± 1.36	5.20 ± 1.42	0.187

Values are shown as mean ± standard deviation or n (%). BMD, bone mineral density; BMI, body mass index; LOS, length of hospitalization.

Preoperative muscle parameters

The sarcopenia group had significantly lower PMI, MMI, EMI, GMaxI and GMedI values than the non-sarcopenia group (all $P < 0.001$). Moderate/severe fatty infiltration of the multifidus, erector spinae, gluteus maximus and gluteus medius muscles was significantly more frequent in the sarcopenia group. A small between-group difference was also observed for GMinFI; however, gluteus minimus muscle index, abdominal muscle indices, abdominal fatty infiltration grades and MMD showed no consistent between-group differences (Table 2).

Table 2
Comparison of preoperative muscle parameters between groups.

Variable	Sarcopenia group (n = 112)	Non-sarcopenia group (n = 153)	P value
PMI, cm²/m²	5.86 ± 1.14	8.25 ± 1.67	< 0.001
MMI, cm²/m²	2.45 ± 0.79	3.71 ± 0.88	< 0.001
EMI, cm²/m²	9.06 ± 2.83	13.33 ± 3.21	< 0.001
GMaxI, cm²/m²	18.69 ± 3.23	24.57 ± 3.89	< 0.001
GMedI, cm²/m²	10.53 ± 1.94	15.91 ± 2.27	< 0.001
GMinI, cm²/m²	5.86 ± 0.49	6.02 ± 0.73	0.255
RAI, cm²/m²	8.12 ± 1.56	8.35 ± 1.62	0.376
EOI, cm²/m²	6.86 ± 1.43	7.01 ± 1.49	0.428
IOI, cm²/m²	5.63 ± 1.62	5.85 ± 1.71	0.489
TrAI, cm²/m²	3.55 ± 0.53	3.62 ± 0.67	0.512
MFI			
Mild	48	83	0.042
Moderate	28	41	
Severe	36	29	
EFI			
Mild	51	97	0.002
Moderate	27	35	
Severe	34	21	
GMaxFI			
Mild	44	92	< 0.001
Moderate	30	38	
Severe	38	23	
GMedFI			
Mild	41	95	< 0.001

PMI, psoas major index; MMI, multifidus muscle index; EMI, erector spinae index; GMaxI, gluteus maximus index; GMedI, gluteus medius index; GMinI, gluteus minimus index; RAI, rectus abdominis index; EOI, external oblique index; IOI, internal oblique index; TrAI, transversus abdominis index; FI, fatty infiltration; MMD, multifidus muscle density; HU, Hounsfield unit.

Variable	Sarcopenia group (n = 112)	Non-sarcopenia group (n = 153)	P value
Moderate	26	34	
Severe	45	24	
GMinFI			
Mild	49	89	0.034
Moderate	35	42	
Severe	28	22	
RAFI			
Mild	72	98	0.997
Moderate	25	34	
Severe	15	21	
EOFI			
Mild	69	95	0.994
Moderate	27	36	
Severe	16	22	
IOFI			
Mild	70	97	0.995
Moderate	26	35	
Severe	16	22	
TrAFI			0.996
Mild	71	97	
Moderate	26	35	
Severe	15	21	
MMD, HU	28.81 ± 12.01	30.25 ± 12.37	0.619

PMI, psoas major index; MMI, multifidus muscle index; EMI, erector spinae index; GMaxI, gluteus maximus index; GMedI, gluteus medius index; GMinI, gluteus minimus index; RAI, rectus abdominis index; EOI, external oblique index; IOI, internal oblique index; TrAI, transversus abdominis index; FI, fatty infiltration; MMD, multifidus muscle density; HU, Hounsfield unit.

Patient-reported outcomes

Preoperative VAS and ODI scores did not differ significantly between groups, indicating similar baseline symptom severity. Both groups showed substantial improvement in pain and function after surgery. At 1 month and 1 year postoperatively, VAS and ODI scores were similar between groups. At the final follow-up, however, the sarcopenia group had significantly higher VAS (3.21 ± 1.12 vs. 2.49 ± 0.83, P < 0.01) and ODI (24.76 ± 4.95% vs. 19.63 ± 3.71%, P < 0.01) scores than the non-sarcopenia group.

The proportions of patients achieving the MCID for VAS (65.2% vs. 87.6%, P < 0.001) and ODI (80.4% vs. 94.1%, P = 0.001) were also significantly lower in the sarcopenia group (Table 3).

Table 3
Comparison of patient-reported clinical outcomes between groups.

Variable	Sarcopenia group (n = 112)	Non-sarcopenia group (n = 153)	P value
VAS			
Preoperative	6.75 ± 1.19	6.97 ± 1.25	0.213
1 month postoperatively	3.44 ± 0.88	3.53 ± 0.93	0.565
1 year postoperatively	2.92 ± 0.96	2.77 ± 0.87	0.122
Final follow-up	3.21 ± 1.12	2.49 ± 0.83	< 0.01
VAS MCID at final follow-up, n (%)	73/112 (65.2)	134/153 (87.6)	< 0.001
ODI, %			
Preoperative	54.89 ± 8.18	55.84 ± 7.91	0.479
1 month postoperatively	24.81 ± 4.65	25.26 ± 4.40	0.516
1 year postoperatively	19.67 ± 3.37	18.84 ± 3.23	0.174
Final follow-up	24.76 ± 4.95	19.63 ± 3.71	< 0.01
ODI MCID at final follow-up, n (%)	90/112 (80.4)	144/153 (94.1)	0.001

VAS, visual analog scale; ODI, Oswestry Disability Index; MCID, minimal clinically important difference. MCID was defined as an improvement of ≥ 1.2 points for VAS back pain and ≥ 12.8 points for ODI.

Recurrent disc herniation occurred in 13 of 112 patients (11.6%) in the sarcopenia group and 15 of 153 patients (9.8%) in the non-sarcopenia group; this difference was not statistically significant (P = 0.763).

Chronic postoperative low back pain (VAS ≥ 4 at final follow-up) occurred in 52 of 265 patients (19.6%). Specifically, 38 of 112 patients (33.9%) in the sarcopenia group and 14 of 153 patients (9.2%) in the non-sarcopenia group developed chronic postoperative low back pain (P < 0.001).

Predictors of chronic postoperative low back pain

In univariable logistic regression, BMI, BMD, PMI, MMI, EMI, GMaxI deficit, GMedI, multifidus fatty infiltration (MFI), gluteus maximus fatty infiltration (GMaxFI) and gluteus medius fatty infiltration (GMedFI) were significantly associated with chronic postoperative low back pain. EFI showed a borderline association ($P = 0.052$) and was not entered into the final candidate model under the prespecified $P < 0.05$ criterion (Table 4).

Table 4
Univariable logistic regression analysis for postoperative chronic low back pain.

Factor	B value	Odds ratio	95% CI	P value
Age	0.250	1.284	0.785–2.102	0.320
BMI	0.263	1.302	1.098–1.543	< 0.001
BMD	-0.300	0.741	0.629–0.874	< 0.001
PMI	-0.359	0.698	0.552–0.883	0.003
MMI	-0.767	0.462	0.268–0.797	0.006
EMI	-0.114	0.892	0.798–0.997	0.045
GMaxI deficit	0.637	1.892	1.056–3.389	0.032
GMedI	-0.241	0.785	0.692–0.891	< 0.001
GMinI	0.103	1.108	0.785–1.569	0.568
RAI	-0.013	0.987	0.892–1.092	0.774
EOI	-0.008	0.992	0.905–1.087	0.867
IOI	-0.005	0.995	0.901–1.098	0.928
TrAI	-0.011	0.989	0.875–1.118	0.861
MFI (moderate/severe)	1.933	6.925	2.436–19.768	< 0.001
EFI (moderate/severe)	0.096	1.101	0.998–1.216	0.052
GMaxFI (moderate/severe)	0.952	2.587	1.196–5.593	0.015
GMedFI (moderate/severe)	2.036	7.632	2.715–21.448	< 0.001
GMinFI (moderate/severe)	0.103	1.108	0.785–1.569	0.568
RAFI (moderate/severe)	0.028	1.028	0.512–2.064	0.941
EOFI (moderate/severe)	0.015	1.015	0.502–2.052	0.970
IOFI (moderate/severe)	-0.013	0.987	0.475–2.052	0.973
TrAFI (moderate/severe)	0.008	1.008	0.485–2.101	0.984
MMD	-0.008	0.992	0.975–1.009	0.217
Preoperative VAS	0.086	1.090	0.962–1.235	0.120

BMI, body mass index; BMD, bone mineral density; CI, confidence interval; VAS, visual analog scale; ODI, Oswestry Disability Index. Continuous muscle indices are expressed per 1 cm^2/m^2 increase. GMaxI deficit was coded as 1 for GMaxI below the sex-specific median and 0 otherwise. Fatty infiltration variables compare moderate/severe grades with mild grade.

Factor	B value	Odds ratio	95% CI	P value
Preoperative ODI	0.195	1.215	0.978–1.509	0.230

BMI, body mass index; BMD, bone mineral density; CI, confidence interval; VAS, visual analog scale; ODI, Oswestry Disability Index. Continuous muscle indices are expressed per 1 cm^2/m^2 increase. GMaxI deficit was coded as 1 for GMaxI below the sex-specific median and 0 otherwise. Fatty infiltration variables compare moderate/severe grades with mild grade.

After backward stepwise elimination, the final reduced multivariable model retained eight independent predictors: higher BMI, lower BMD, lower PMI, lower MMI, GMaxI deficit, lower GMedI, moderate/severe MFI and moderate/severe GMaxFI (Table 5). EMI and GMedFI were removed because their adjusted P values exceeded 0.05 in the full candidate model.

Table 5
Multivariable logistic regression analysis for postoperative chronic low back pain.

Factor	B value	Odds ratio	95% CI	P value
BMI	0.256	1.293	1.095–1.521	0.002
BMD	-0.277	0.758	0.647–0.889	0.001
PMI	-0.344	0.709	0.561–0.896	0.004
MMI	-0.733	0.481	0.276–0.837	0.010
GMaxI deficit	0.519	1.681	1.417–1.986	0.004
GMedI	-0.427	0.653	0.457–0.932	0.019
MFI (moderate/severe)	1.930	6.892	2.415–19.673	< 0.001
GMaxFI (moderate/severe)	2.066	7.892	2.541–20.698	< 0.001

BMI, body mass index; BMD, bone mineral density; CI, confidence interval; PMI, psoas major index; MMI, multifidus muscle index; GMaxI, gluteus maximus index; GMedI, gluteus medius index; FI, fatty infiltration. Final reduced backward model. GMaxI deficit was coded as 1 for values below the sex-specific median and 0 otherwise.

Among these predictors, moderate/severe multifidus fatty infiltration (OR = 6.892, 95% CI: 2.415–19.673, P < 0.001) and moderate/severe gluteus maximus fatty infiltration (OR = 7.892, 95% CI: 2.541–20.698, P < 0.001) showed the strongest associations with chronic postoperative low back pain.

The final multivariable model demonstrated good calibration (Hosmer-Lemeshow test: $\chi^2 = 6.23$, P = 0.621) and acceptable discriminatory power (C-statistic = 0.782, 95% CI: 0.714–0.850).

Discussion

This study demonstrates that preoperative sarcopenia and fatty infiltration of key stabilizing muscles are associated with inferior long-term outcomes after OSE for LDH. The prespecified primary outcome was

chronic postoperative low back pain, while longitudinal VAS/ODI changes and MCID achievement served as clinically relevant secondary outcomes. Although OSE resulted in early clinical improvement in both groups, the sarcopenia group showed worse final follow-up VAS and ODI scores and lower MCID achievement rates, suggesting that a muscle-sparing surgical approach cannot fully offset pre-existing neuromuscular degeneration of the spine-pelvis stabilizing system [8–11].

Multifidus degeneration appears particularly relevant. The multifidus provides segmental control of rotation and shear forces through short intersegmental fibers, acting as a deep stabilizer that maintains precise segmental alignment during movement. Fatty infiltration reduces contractile fiber content and may impair segmental rotational stiffness, leaving the operated segment vulnerable to repetitive micro-motion during daily activities [14, 15]. This mechanism is clinically important in OSE because the procedure preserves posterior ligamentous and muscular attachments; therefore, postoperative stability depends heavily on the functional reserve of the pre-existing deep stabilizing system rather than on surgical reconstruction or fusion. Our finding that moderate/severe multifidus fatty infiltration was associated with a nearly 7-fold increased odds of chronic low back pain underscores the prognostic significance of this specific muscle.

The gluteal findings emphasize the importance of the spine-pelvis-hip kinetic chain. The gluteus maximus regulates hip extension and posterior pelvic control, whereas the gluteus medius maintains coronal pelvic stability during gait and single-leg stance. When GMaxI deficit or gluteus maximus fatty infiltration is present, the compensatory hip extension mechanism may be weakened [19, 22]. As a result, the already degenerated multifidus must work against a greater lever arm during sitting-to-standing transitions, walking and trunk flexion, which may produce cumulative microtrauma and persistent low back pain. This interaction provides a plausible explanation for why both multifidus-related and gluteus-related parameters remained independent predictors in the reduced model—they represent distinct but complementary components of the overall stabilizing system.

Abdominal muscle parameters were not consistently associated with final outcomes. This does not exclude a role for the abdominal wall in core stability, but it suggests that in single-level LDH treated with posterior endoscopic decompression, long-term symptoms may depend more strongly on the posterior stabilizing system and the hip-pelvic force couple. In addition, the L4 axial plane used for abdominal measurement may not fully represent dynamic abdominal wall activation, and abdominal muscles may compensate through coordinated recruitment even when static CSA differences are small [20, 21]. Future studies using dynamic ultrasound or electromyography may provide additional insights into abdominal muscle function in this context.

The psoas muscle also deserves attention. Although PMI was retained as an independent predictor, its effect size was smaller than that of the multifidus or gluteal muscles. The psoas primarily contributes to sagittal balance and hip flexion, and its CSA may also reflect general systemic sarcopenia and physiological reserve rather than isolated segmental instability [16–18].

Clinically, these results support a more individualized perioperative strategy. Preoperative CT or MRI already obtained for surgical planning can be used to screen for low muscle mass and fatty infiltration without additional cost or radiation exposure. For high-risk patients—particularly those with low BMD, high BMI, severe multifidus fatty infiltration or gluteal muscle degeneration—a 4- to 6-week prehabilitation program may be considered when symptoms and neurological status allow. Such a program should emphasize multifidus activation (e.g., abdominal bracing and bird-dog exercises), core stabilization, gluteus maximus and gluteus medius strengthening (e.g., bridge progression, side-lying hip abduction and clamshell exercises), pelvic control and gait retraining. Nutritional optimization, including adequate protein intake, vitamin D correction when deficient and weight management for patients with high BMI, may further support muscle health and recovery [23–25].

After OSE, rehabilitation should shift from passive rest to active neuromuscular re-education, particularly coordinated activation of the multifidus and gluteal muscles. Rather than relying solely on symptom-based mobilization, a structured rehabilitation program that progressively challenges spine-pelvis control may help patients with pre-existing muscle degeneration achieve better long-term outcomes.

Limitations

This study has several limitations. First, the retrospective single-center design may introduce selection bias and limits generalizability to other populations or surgical techniques. Second, postoperative muscle morphology was not longitudinally assessed, so the effect of OSE and rehabilitation on muscle recovery could not be directly evaluated. Third, objective functional measurements such as grip strength, gait analysis, isokinetic hip strength or electromyographic activation patterns were not available; therefore, radiographic muscle quality was used as a surrogate for muscle function. Fourth, inflammatory biomarkers, detailed nutritional status and rehabilitation adherence were not fully captured, which could have mediated the observed relationships. Fifth, although the model showed good calibration and acceptable discrimination, the events-per-variable ratio was approximately 6.5:1 (52 events for 8 predictors), which is below the commonly recommended threshold of 10:1 for stable logistic regression estimates. Therefore, the multivariable results should be interpreted cautiously and require validation in larger cohorts. Sixth, GMaxI deficit was defined using an internal sex-specific median threshold and therefore requires external validation in independent cohorts.

Conclusions

Preoperative sarcopenia involving paraspinal and gluteal muscles is associated with chronic postoperative low back pain and worse long-term functional recovery after OSE for LDH. Reduced multifidus and gluteal muscle quality, particularly moderate/severe multifidus and gluteus maximus fatty infiltration, may identify patients at increased risk of poor long-term outcomes. Routine preoperative muscle-quality assessment using existing CT or MRI images and targeted perioperative rehabilitation focusing on the spine-pelvis-hip kinetic chain may improve long-term outcomes after OSE.

Abbreviations

BMD
bone mineral density
BMI
body mass index
CI
confidence interval
CSA
cross-sectional area
CT
computed tomography
DICOM
Digital Imaging and Communications in Medicine
DXA
dual-energy X-ray absorptiometry
EFI
erector spinae fatty infiltration
EMI
erector spinae index
EOI
external oblique index
EOFI
external oblique fatty infiltration
FI
fatty infiltration
GMaxFI
gluteus maximus fatty infiltration
GMaxI
gluteus maximus index
GMedFI
gluteus medius fatty infiltration
GMedI
gluteus medius index
GMinFI
gluteus minimus fatty infiltration
GMinI
gluteus minimus index
HU
Hounsfield unit

ICC
intraclass correlation coefficient
IOFI
internal oblique fatty infiltration
IOI
internal oblique index
LDH
lumbar disc herniation
LOS
length of hospitalization
MCID
minimal clinically important difference
MFI
multifidus fatty infiltration
MMD
multifidus muscle density
MMI
multifidus muscle index
MRI
magnetic resonance imaging
ODI
Oswestry Disability Index
OR
odds ratio
OSE
one-hole split endoscopy
PACS
picture archiving and communication system
PMI
psoas major index
RAFI
rectus abdominis fatty infiltration
RAI
rectus abdominis index
ROC
receiver operating characteristic
TrAFI
transversus abdominis fatty infiltration
TrAI
transversus abdominis index

VAS
visual analog scale
VIF
variance inflation factor.

Declarations

Clinical trial number: not applicable.

Ethics approval and consent to participate

This retrospective study was conducted in accordance with the Declaration of Helsinki and was approved by the Biomedical Research Ethics Committee of Xuzhou Central Hospital (Approval No. XZXY-LK-20200910-0121). The requirement for informed consent was waived by the ethics committee because of the retrospective design. All patient data were deidentified before analysis, and no personal identity information was included in the manuscript figures.

Consent for publication

Not applicable. The intraoperative and imaging figures are anonymized and contain no identifiable personal information.

Competing interests

The authors declare no competing interests.

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Author Contribution

Xianyi Zhang, Mustafa Abbas Farhood Sultani and Jie Shang contributed equally to this work and share first authorship. Xianyi Zhang, Mustafa Abbas Farhood Sultani, Jie Shang and Meng Han conceived and designed the study. Xianyi Zhang, Mustafa Abbas Farhood Sultani and Jie Shang performed the statistical analyses and drafted the initial manuscript. Liang Guo and Guizhu Ji were responsible for clinical data collection and follow-up data organization. Ziwei Xia and Chao Ma contributed to imaging

data collection, muscle parameter measurement and data verification. Meng Han supervised the study, provided methodological guidance and critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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None.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to patient privacy and institutional ethical restrictions, but are available from the corresponding author on reasonable request and with permission from the Ethics Committee of Xuzhou Central Hospital.

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Figures

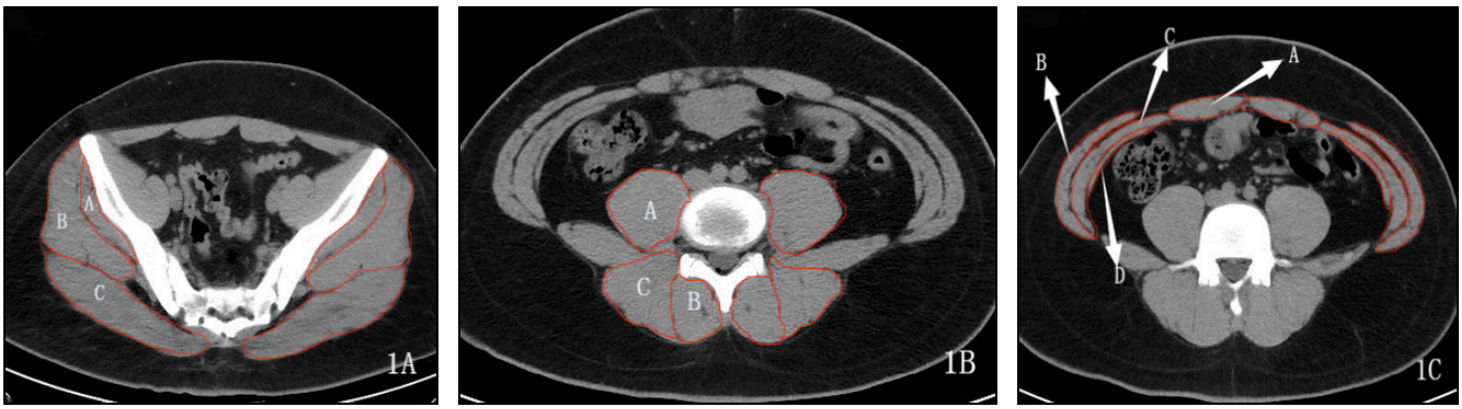


Figure 1

Representative axial CT images showing measurement levels for muscle cross-sectional area. (1A) S1 level for gluteal muscle assessment: labels A, B and C indicate the gluteus minimus, gluteus medius and gluteus maximus, respectively. (1B) L3 level for paraspinal and psoas assessment: labels A, B and C indicate the psoas major, multifidus and erector spinae, respectively. (1C) L4 level for abdominal wall muscle assessment: labels A, B, C and D indicate the rectus abdominis, external oblique, internal oblique and transversus abdominis, respectively. Muscle areas were outlined manually and normalized to height squared to obtain the corresponding muscle indices.

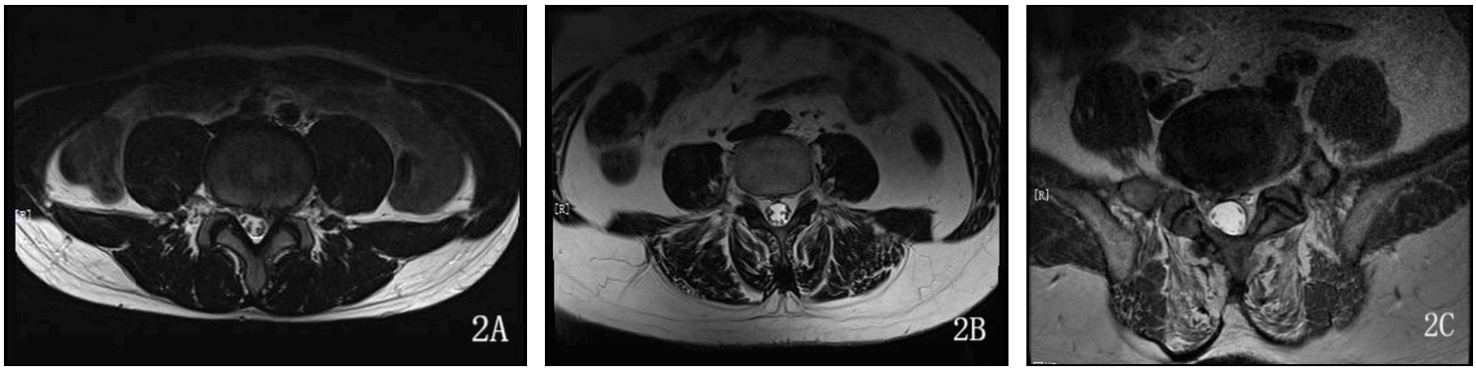


Figure 2

Representative axial T2-weighted MRI images illustrating paraspinal muscle fatty infiltration at lumbar axial levels used for qualitative grading. (A) Mild fatty infiltration; (B) moderate fatty infiltration; (C) severe fatty infiltration according to the modified Goutallier grading approach.

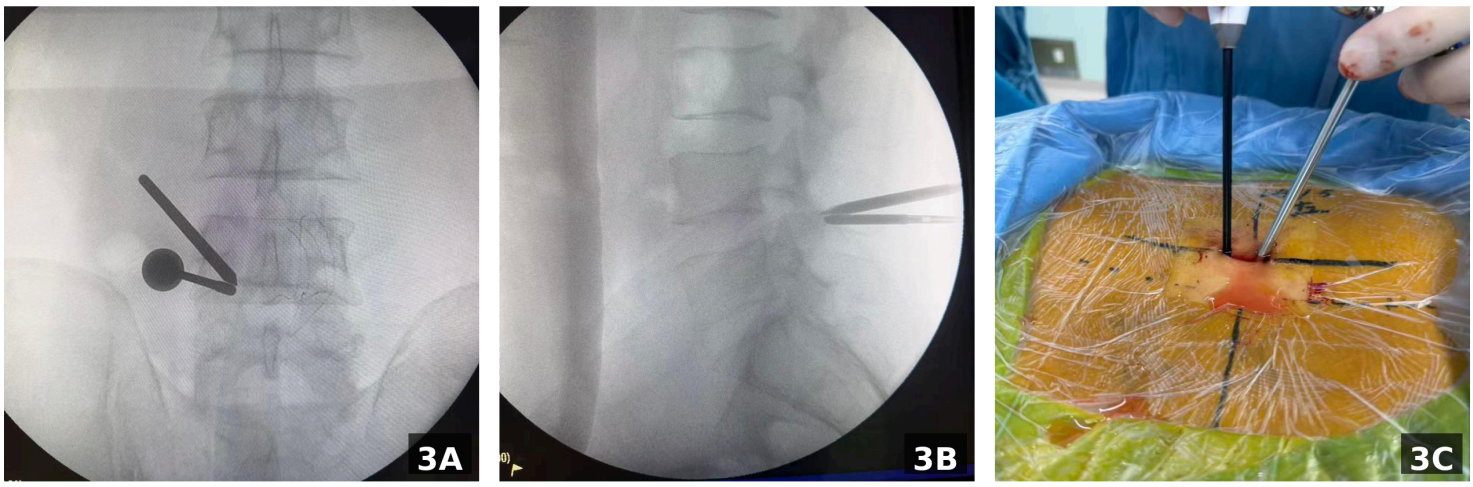


Figure 3

Representative intraoperative views of one-hole split endoscopy. (A) Anteroposterior fluoroscopic localization of the operative level; (B) lateral fluoroscopic confirmation of the working trajectory; (C) intraoperative view showing the one-hole split approach with independent endoscope and instrument manipulation through a small incision.