Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 20 May 2026
Revised 28 June 2026
Accepted 20 July 2026

Natural Resources for Human Health 2026, Vol. 6 (8s): 1316–1329

KEYWORDS: spinopelvic alignment; sarcopenia; lumbar fusion; Oswestry Disability Index; sagittal vertical axis; paraspinal muscle

Association Between Spinopelvic Alignment, Sarcopenia, and Postoperative Functional Outcomes Among Adults with Lumbar Spine Disorders: A Cross-Sectional Study

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ABSTRACT:

Background: Spinopelvic malalignment and paraspinal muscle degeneration are increasingly recognized as potential contributors to persistent disability after lumbar surgery, but their postoperative relationship is not routinely quantified within the same analytic framework. This study quantified differences in long-term spinopelvic alignment and functional outcomes according to sarcopenia status.

Methods: A secondary cross-sectional analysis was performed using published aggregate data from 213 adults after multilevel posterior lumbar interbody fusion, comprising 69 sarcopenic and 144 nonsarcopenic patients. The final postoperative assessment, obtained at approximately 40 months, was treated as the cross-sectional index visit. Mean differences, Hedges' g with 95% confidence intervals (CIs), and odds ratios for fatty-infiltration categories were reconstructed from reported group summaries. Earlier assessments were used only to describe temporal patterns.

Results: At final follow-up, sarcopenic patients had higher Oswestry Disability Index scores (mean difference [MD], 7.68; 95% CI, 4.96–10.40; g=0.79), greater back-pain VAS scores (MD, 0.70; 95% CI, 0.41–0.99; g=0.71), greater sagittal vertical axis (MD, 14.26 mm; 95% CI, 9.35–19.17; g=0.86), and larger PI–LL mismatch (MD, 6.96°; 95% CI, 3.60–10.32; g=0.64). Lumbar lordosis was 5.60° lower in the sarcopenic group (95% CI, 3.02–8.18°; |g|=0.63). Moderate-to-severe multifidus fatty infiltration was more frequent with sarcopenia (OR, 3.14; 95% CI, 1.60–6.16). Between-group differences were small at baseline and early follow-up and were larger at the final assessment.

Conclusion: Sarcopenia was accompanied by a distinct long-term phenotype of poorer sagittal alignment, greater pain, and greater disability. Because only aggregate data were available, these findings establish group-level association rather than causality or

independent patient-level effects; confirmation with individual-level multivariable data is required.

INTRODUCTION

The degenerative diseases of the lumbar spine, such as degenerative spondylolisthesis, intervertebral disc degeneration, spinal deformity, and spinal stenosis are common sources of pain, decreased function and disability in adults. A large and aging population is affected by lumbar spinal stenosis alone and there are times that decompression or fusion is thought of when neurologic symptoms and functional limitation are present despite proper non-operative treatment (Katz et al., 2022). Post-operative outcomes are variable; while surgery can greatly alleviate pain and improve function. The structure and the degree of correction, frailty of the patient, muscle health, and ability of the patient to keep an efficient upright posture can all play roles in the long-term postoperative functional outcome. As a result, the focus of post-operative assessment is gradually shifting from a local consideration of decompression or fusion status, to one of an integrated assessment of spine alignment and biological reserve.

The spinopelvic alignment is a key component of the economy of standing posture. While pelvic tilt (PT) and sacral slope (SS) indicate the orientation of the pelvis, pelvic incidence (PI) relates to the pelvic morphology and lumbar lordosis (LL) should be assessed in relation to PI and not as an angle per se (Legaye et al., 1998). PI–LL mismatch and sagittal vertical axis (SVA) are commonly employed measures of regional and global sagittal balance, and have been shown to have reproducibility and clinical significance by the SRS–Schwab framework (Schwab et al., 2012). In degenerative lumbar surgery, restoration of lordosis is now becoming more important regarding the distribution of lordosis according to the pelvis as this can affect the residual sagittal imbalance, if not sufficiently restored or distributed appropriately (Diebo et al., 2024). A recent meta-analysis of 23 studies of 1,837 adults also demonstrated that the better the sagittal alignment was in the postoperative state, the lower the risk of disability and persistent pain after lumbar surgery, particularly after fusion and with longer follow-up (Tykocki & Rakasz, 2026).

A complementary biological dimension is muscle health. Traditionally sarcopenia is regarded as a condition of low muscle strength, low muscle mass and/or low muscle quality where low physical performance is present in the most advanced cases (Cruz-Jentoft et al., 2019). In the field of spine research, however, imaging-derived parameters like psoas muscle index (PMI), erector spinae muscle index (EMI), multifidus muscle index (MMI) and fatty infiltration are often used in retrospective datasets. These measurements should therefore not be interpreted as being a full replacement for any consensus clinical diagnosis, but as a marker of radiographic or spine-specific sarcopenia. This is important as there are differences in the action of these muscles, the multifidus and erector spinae having a direct role in segmental control and extension, while the psoas can be used as a convenient measure of overall muscle amount. Recent reviews also highlight that the fatty infiltration measured by MRI brings a qualitative aspect to the degeneration of the paraspinal muscles that could be clinically relevant despite the absence of muscle size reduction (Wang et al., 2024).

There is increased evidence that postsurgical disability is related to the degeneration of the paraspinal muscles. A systematic review and meta-analysis conducted by Han et al. (2023) found that in the literature, higher multifidus fatty infiltration was associated with a higher ODI after surgery and chronic low-back pain. In the study by Chen et al. (2024), which included nine studies and 993 patients, the sarcopenic patients had a lower improvement in ODI, back pain, leg pain, and in the HRQOL scores after undergoing surgical interventions for degenerative lumbar disease. There is further evidence that fatty infiltration of the paraspinal muscles and sarcopenia are linked to worse PROs following lumbar fusion surgery, but associations differ by sex and muscle compartment (Haffer et al., 2024). High lumbar muscularity and low fatty infiltration were indicative of good clinical or radiographic recovery in 206 patients with lumbar interbody fusion (You et al., 2023) and high erector spinae fatty infiltration was associated with poor 1-year patient-reported outcomes (PROs) following lumbar discectomy (Carvalho et al., 2022). The current results indicate that the amount of muscle may not be the best way to reflect the functional implications of paraspinal degeneration.

The relationship between alignment and muscle condition is of utmost importance. Lumbar lordosis (LL) and pelvic tilt (PT) have been correlated with a reduction in multifidus functional cross-sectional area and poorer muscle quality in lumbar spinal stenosis patients (Minetama et al., 2023), suggesting that alignment and muscle degeneration may be interrelated aspects of the same mechanical-biological system. More recent evidence after surgery has revealed that while sarcopenic patients can be corrected fairly well in the early stages, they do have a poorer preservation of LL, PI–LL mismatch, SVA, and patient-reported function following multilevel fusion (Fang et al., 2026). This suggests the intriguing clinical scenario that instrumentation may be able to provide some sagittal correction, but long-term correction may rely in part on the ability of the paraspinal muscular structures to maintain the reconstructed sagittal plane.

The purpose of the present study was thus to estimate the degree of cross-sectional variations of spinopelvic alignment and functional results in sarcopenic and nonsarcopenic adults in long-term postoperative evaluations. The principal goal was to determine the differences in the effect estimates and 95% CIs for the final ODI, SVA, PI – LL mismatch and LL between the groups, instead of just looking at statistical significance. Secondary objectives were to quantify the differences in back-pain VAS, segmental lordosis, paraspinal muscle indices, severity of fatty infiltration between groups and to describe whether differences between groups were present early after surgery or were more pronounced at long-term follow-up. We believed that sarcopenic patients would have higher levels of disability and pain, a larger SVA and PI–LL mismatch, as well as lower LL and segmental lordosis and a worse paraspinal muscle phenotype at the last postoperative evaluation. Due to the nature of the available data (comprising only group-level values not patient–level data), the study was designed to evaluate only group-level associations and the magnitude of effects, but not independent causal effects or statistical interactions.

LITERATURE REVIEW

The biomechanics of spinopelvic assessment involve the functional relationship between the morphology of the pelvis, the curvature of the lumbar spine and the trunk position. The PI is a relatively constant morphological parameter, while PT and SS change with orientation and compensation, and are geometrically related to PI (Legaye et al., 1998). The same applies to LL, which is also dependent on pelvic morphology. To create an efficient sagittal profile, a patient with a high PI typically will need more lordosis than a patient with a low PI. These relationships enabled a change of paradigm from universal angular targets to individualized alignment targets. The SRS–Schwab modifiers: PI–LL mismatch, PT, and SVA are reproducible and thus a useful way to summarize sagittal deformity and its relationship with health-related quality of life (Schwab et al., 2012), and the same concepts have come to increasingly influence planning for degenerative lumbar fusion (Diebo et al., 2024).

Postoperative alignment is not merely radiographic. Tykocki and Rakasz (2026) pooled 23 clinical studies and discovered that patients who were properly aligned had significantly reduced risks for significant disability after surgery and ongoing pain. The relationship between the two was more pronounced after fusion and at follow-up >12 months and the PI–LL-based analyses showed consistently predictive value. The results can be applied to the current study as there were the biggest between-group differences at the long-term follow-up and not directly after surgery. Simultaneously, the procedures and definition of alignment in the meta-analysis were heterogeneous, suggesting that a single threshold should not be taken for granted as it may not mean the same in all degenerative lumbar conditions. Recent prospective short-segment TLIF data also indicate that restoration of the lumbar lordosis may be more patient-specific and related to early pain improvement as opposed to universal radiological targets (Sheidae Mehne & Motlagh Pirooz, 2026). In a multicenter cohort of adult degenerative lumbar deformity (DDLD), further supporting the clinical relevance of the malalignment in appropriately selected populations is the finding that residual immediate postoperative PI – LL mismatch was an independent predictor of an unfavorable postoperative course (Nazarli et al., 2026).

Part of this heterogeneity could be accounted for by muscle degeneration. The recent European consensus refocused the definition of sarcopenia on muscle strength, and muscle quantity or quality used to confirm the diagnosis (Cruz-Jentoft et al., 2019). However, grip strength, gait speed, or chair-rise testing are frequently not performed in spine studies and instead, cross-sectional area or muscle indices are measured via MRI or CT. These imaging measures will have real-world utility, but are more limited phenotypes. The most commonly employed measurement for radiographic sarcopenia is the PMI, with measurements from the multifidus and erector spinae potentially being better markers of local support at the spine. The qualitative aspect of fatty infiltration is added as a muscle may have the same apparent cross-sectional area but lose contractile tissue.

This distinction is backed up by outcome research. Han et al. (2023) found that higher levels of fatty infiltration of the multifidus muscle in the preop period were correlated with a higher pooled standardized mean difference in ODI, while the correlation between fatty infiltration of the psoas and erector spinae was not uniform. Haffer et al. (2024) explored the association between paraspinal fat infiltration and ODI at 12 months in 135 patients who underwent lumbar fusion surgery in a prospective study, and observed differences in the association with sarcopenia between sexes in multivariable analysis. Chen et al. (2024) later reported a larger pooled effect of sarcopenia on ODI improvement (standardized mean difference, 0.53) after degenerative lumbar surgery. Two years after surgery in patients with degenerative lumbar spondylolisthesis, a higher amount of fatty infiltration in the erector spinae muscles correlated with higher overall ODI scores and higher ODI subsections, and multifidus fatty infiltration was related to standing and walking disabilities (Hambrecht et al., 2025). A 2026 meta-analysis of 13 discectomy studies (4,371 patients) also reported that there was a correlation between more severe paraspinal fatty infiltration and recurrence of discectomy, reoperation, the presence of chronic low-back pain (LBP) after surgery, as well as poorer functional recovery (Jin et al., 2026). Taken together, these data indicate that not only is generalized muscle loss important, but so is the quality of muscle in any particular location; however, different populations and operative techniques may be influenced by different extents of muscle loss and muscle quality.

There is also a correlation among muscle morphology, spinal degeneration and alignment prior to surgery in cross-sectional studies. After accounting for demographic factors, Minetama et al. (2023) assessed 70 patients with lumbar spinal stenosis (LSS) and determined that reduced LL and increased PT were correlated with poorer multifidus functional cross-sectional area and muscle quality. This helps to explain an interdependent model whereby sagittal geometry has the ability to alter the mechanical requirements of the trunk musculature, and muscle degeneration could impair the ability to maintain a compensatory posture. A model like this is particularly pertinent after fusion when the number of mobile segments available for compensation has been diminished and the balance needs to be maintained in the reconstructed spine, pelvis and the remaining mobile segments for the long term.

The multilevel fusion cohort in the recent study by Fang et al. (2026) included paraspinal muscle indices, fatty infiltration, serial spinopelvic parameters, ODI, and VAS in the same group of patients. The original authors stated that the clinical outcomes at the beginning of the study were similar between the sarcopenic and nonsarcopenic patients, but that the sarcopenic patients had poorer outcomes at the end of the study in terms of LL, segmental lordosis, PT, PI–LL mismatch, VAS, SVA, and ODI. They also used their patient-level multivariable analysis to assess the associations of pre-operative LL, segmental lordosis, MMI and multifidus fatty infiltration with long-term sagittal imbalance and found that these were all independent factors. It is not possible to repeat that regression in the present study because raw records are not publicly available but, to quantify how large the between-group differences were, group summaries were used to calculate standardized effect magnitudes and CIs.

However, not all the evidence indicates that sarcopenia is always associated with impaired postoperative function. While sarcopenia alone did not discriminate patients at risk of worse outcomes following minimally invasive decompression, lower multifidus fatty infiltration was associated with ODI improvement following this procedure (Regev et al., 2025). However, Kim et al. (2026) determined that hospital stay was longer in sarcopenic fusion patients, but no difference existed in ODI and EQ-5D scores at 12 months in a study of biportal endoscopic decompression and fusion. However, Eryilmaz (2026) found that an increased preoperative paraspinal fatty infiltration was independently associated with the presence of residual back pain and reoperation following lumbar interbody fusion. This seemingly paradoxical result may be due to the different definitions of sarcopenia (either functional or imaging), different surgical invasiveness, different number of fused levels, and different follow-up times. They also help to assess the magnitude of the effect in a number of domains instead of using one or two binary labels to indicate the state of a muscle's health.

Thus, the current literature suggests that an integrated evaluation of the postoperative muscle status, sagittal alignment and function should be performed while paying careful attention to the interpretation of the observational associations. At a given postoperative time point, a cross-sectional comparison of these phenotypes can determine if these phenotypes coexist and the magnitude of the difference, but cannot determine the temporal direction of causality. This distinction is important especially for the same patients who have been measured preoperatively and early postoperatively, since the association measured at the end of the study may be put into perspective by the data measured at different times.

METHODOLOGY

Study design and data source

The present study can be considered a secondary 'aggregate-data' cross-sectional analysis. The published summary tables of the 2026 cohort provided by Fang et al. were used as data sources. The source cohort consisted of adults who had multilevel posterior lumbar interbody fusion performed for degenerative lumbar conditions, had paraspinal muscle imaging, standing spinopelvic radiographs, and patient-reported outcomes. The table-level denominators for all reconstructed analyses were the number of sarcopenic patients (n=69) and nonsarcopenic patients (n=144) reported in the published tables (combined n=213). The original report included a number of repeat visits before and after surgery, but in this primary analysis the last postoperative assessment was used as the single cross-sectional index visit. The mean follow-up was ~40 months in both groups.

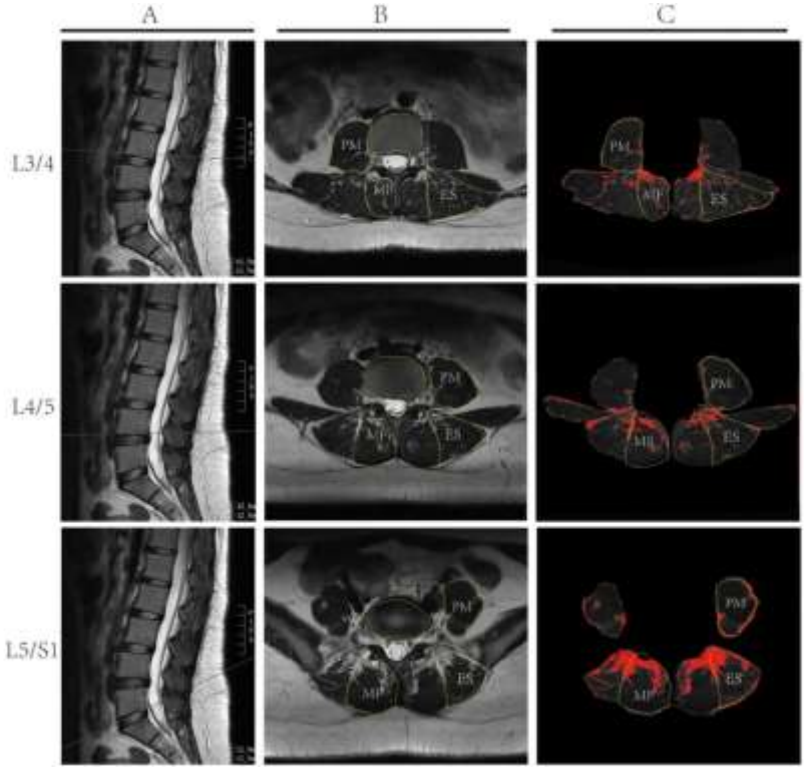
Natural Resources for
Human Health
eISSN: 2583-1194

Population and exposure definition

Patients in the source cohort were divided into sarcopenic and nonsarcopenic groups based on L3 psoas muscle index (psoas area / height²). The published thresholds were <6.36 cm²/m² for men and <3.92 cm²/m² for women (Fang et al., 2026). This definition is imaging-based and does not involve strength or physical-performance testing, so the secondary analysis definition of sarcopenia is taken from the source study's definition of the radiographic classification. Paraspinal muscle measures were: PMI, EMI, MMI, multifidus muscle density (HU), and multifidus and erector spinae fatty infiltration (categorical).

Figure 1 shows a representative example from the literature depicting the delineation of the psoas major, multifidus and erector spinae muscles using MRI, as well as threshold determination of intramuscular fat. It is only provided for the sake of clarity of the imaging constructs in this secondary analysis and is not from the source cohort (Yan et al., 2024).

Figure 1 Illustrative MRI-Based Segmentation of Lumbar Paraspinal Muscles and Fatty Infiltration



Note. Panel A identifies the L3/4–L5/S1 levels on sagittal T2-weighted MRI; Panel B delineates the psoas major (PM), multifidus (MF), and erector spinae (ES) on axial images; Panel C displays threshold-identified fatty tissue in red. Reproduced from Yan et al. (2024), Figure 3, under the Creative Commons Attribution 4.0 International license (CC BY 4.0; https://creativecommons.org/licenses/by/4.0/). The image was cropped to the figure boundary without alteration of scientific content. It is illustrative and is not from the analytic cohort; the present analysis used aggregate measurements reported by Fang et al. (2026).

Spinopelvic variables

The primary spinopelvic parameters included the PT, LL, PI – LL mismatch, segmental lordosis, and SVA. The variables of SS and PI were kept as descriptive variables. In the source study, measurements were taken from the standardized lateral radiographs. PI is a measure of pelvic morphology, PT is a measure of pelvic retroversion, LL is a measure of the L1–S1 lumbar curvature, PI–LL is a measure of the mismatch between the pelvic morphology and lumbar lordosis, and SVA is a measure of global anterior-posterior translation of the trunk (Legaye et al., 1998; Schwab et al., 2012). The sagittal profiles that were more unfavorable for interpretation were characterized by higher SVA and PI–LL mismatch and lower LL and segmental lordosis. PT was interpreted with caution as it is a compensatory parameter and because the reconstructed CI for the final between-group difference contained the null.

Functional outcomes

The primary functional outcome was the Oswestry Disability Index (ODI), which is a validated disease-specific functional measure of low-back-related disability (Fairbank & Pynsent, 2000). The primary clinical secondary outcome was back-pain VAS. Cross-sectional comparisons were done with final follow-up values which were prespecified. A summary at each time point (preoperative, 1-month and 6-month) was created for descriptive temporal visualization only and not analyzed as repeated observations from individuals as covariance across time points was not available.

Statistical analysis

The means of each group were obtained from the published papers and the mean difference (MD) between the sarcopenic and nonsarcopenic groups for each continuous variable was calculated. Standard errors for MDs were computed as sqrt(SD_S²/n_S + SD_NS²/n_NS) and 95% CIs were computed using the Welch–Satterthwaite degrees of freedom approximation. The pooled standard deviation with small-sample correction was used to calculate the standardized effects (Hedges' g). To represent the effect of the figures, values of variables with lower values indicating the poorer status (lower values for LL, segmental lordosis and muscle indices) retained their mathematical sign in tables, whereas the other variables (ODI, back-pain VAS, SVA, PI–LL mismatch, and pelvic tilt) had positive values indicating poorer status in the sarcopenic group. The estimation of the effect size was not interpreted with any set cut points but descriptively with emphasis on the estimate and its CI.

Count data for fatty infiltration were used to recode the data as categorical. Moderate-to-severe vs. mild multifidus fatty infiltration odds ratios (ORs) with 95% confidence intervals (CIs) were calculated as well as the corresponding erector spinae classification ORs with 95% CIs. A secondary comparison of severe vs. nonsevere was also performed. Only aggregate summary data were available and therefore the correlation at the patient level, as well as a multivariable regression model, mediation model, propensity adjustment, and interaction term could not be estimated validly. The multivariable results are from the source study, and these were not duplicated or re-labeled as the results of the present analysis but were used as external contextual evidence.

Temporal visualization

To descriptively compare between-group differences across assessment times, Hedges' g was reconstructed at the preoperative, 1-month, 6-month, and final assessments for ODI, VAS, SVA, PI–LL mismatch, and LL. For LL, the sign was reversed in the trajectory figure so that positive values represented greater lordosis deficit in the sarcopenic group. These plots are descriptive because the absence of participant-level repeated measurements prevents formal longitudinal inference or testing of group-by-time interaction.

Data-quality safeguards and reporting

Values were extracted from the source tables and table-level denominators that totaled the cohort size presented in the source tables (213 persons). The estimates were reconstructed and compared with the directions and significance patterns provided by the source. When the reconstructed effect estimate and CI were different from the summary data, the reconstructed effect estimate and CI were used for interpretation. This occurred for final PT, for which the source reported p=.042 and the reconstructed MD CI just barely contained zero. Thus, the present study does not consider final PT to be a strong between-group difference. No individual-level observations were created, no data from unrelated datasets were combined, and no values were imputed beyond algebraic calculations involving means, SDs, and counts.

Ethical considerations

The present analysis used only publicly available aggregate data and did not access identifiable or individual-level patient information; therefore, no new institutional review board approval or consent procedure was required for this secondary analysis. The original cohort received institutional ethics approval, as reported by Fang et al. (2026).

RESULTS

The analytic cohort comprised 213 patients, including 69 (32.4%) classified as sarcopenic and 144 (67.6%) as nonsarcopenic. Mean age was similar between groups (65.70 vs. 65.06 years; MD, 0.64 years; 95% CI, −1.31 to 2.59). Bone mineral density, hospital stay, and follow-up duration were likewise similar at the aggregate level. BMI was lower in the sarcopenic group by 2.20 kg/m² (95% CI, −2.87 to −1.53; g=−0.98), indicating an important baseline difference that could not be adjusted for without individual-level records. Table 1 summarizes baseline and muscle characteristics.

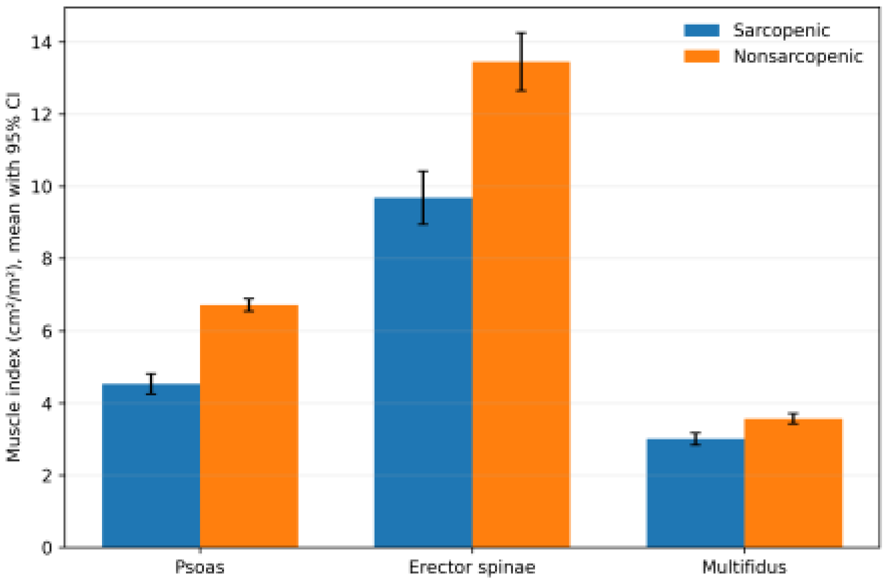
Table 1 *Baseline and Paraspinal Muscle Characteristics by Sarcopenia Status*

Variable	Sarcopenic (n=69)	Nonsarcopenic (n=144)	Mean difference (95% CI)	Hedges' g (95% CI)
Age, years	65.70 ± 6.63	65.06 ± 6.97	0.64 (−1.31, 2.59)	0.09 (−0.19, 0.38)
BMI, kg/m²	23.39 ± 2.38	25.59 ± 2.18	−2.20 (−2.87, −1.53)	−0.98 (−1.28, −0.68)
BMD T-score	−1.10 ± 1.29	−1.11 ± 0.89	0.01 (−0.33, 0.35)	0.01 (−0.28, 0.30)
Follow-up, months	40.51 ± 9.59	39.83 ± 8.84	0.68 (−2.03, 3.39)	0.07 (−0.21, 0.36)
PMI, cm²/m²	4.53 ± 1.19	6.72 ± 1.08	−2.19 (−2.52, −1.86)	−1.95 (−2.30, −1.61)
EMI, cm²/m²	9.68 ± 3.12	13.45 ± 4.91	−3.77 (−4.87, −2.67)	−0.85 (−1.15, −0.55)
MMI, cm²/m²	3.01 ± 0.71	3.57 ± 0.88	−0.56 (−0.78, −0.34)	−0.67 (−0.97, −0.38)
Multifidus density, HU	22.70 ± 18.04	25.53 ± 14.68	−2.83 (−7.77, 2.11)	−0.18 (−0.46, 0.11)

Note. Values are mean ± SD unless otherwise indicated. Mean difference is sarcopenic minus nonsarcopenic. BMD=bone mineral density; PMI=psoas muscle index; EMI=erector spinae muscle index; MMI=multifidus muscle index; HU=Hounsfield units.

As expected from the classification, PMI was substantially lower in the sarcopenic group (4.53±1.19 vs. 6.72±1.08 cm²/m²; MD, −2.19; 95% CI, −2.52 to −1.86; g=−1.95). Lower muscle quantity was not limited to the psoas. EMI was 3.77 cm²/m² lower (95% CI, −4.87 to −2.67; g=−0.85), and MMI was 0.56 cm²/m² lower (95% CI, −0.78 to −0.34; g=−0.67). Multifidus muscle density did not show a clear difference (MD, −2.83 HU; 95% CI, −7.77 to 2.11; g=−0.18). Figure 2 shows the marked separation in muscle indices. Moderate-to-severe multifidus fatty infiltration was more frequent in sarcopenic patients, corresponding to an OR of 3.14 (95% CI, 1.60–6.16). The OR for moderate-to-severe erector spinae fatty infiltration was 2.91 (95% CI, 1.59–5.32). When only severe infiltration was considered, the multifidus association remained pronounced (OR, 3.79; 95% CI, 1.96–7.34), whereas the severe erector spinae estimate was less precise (OR, 1.87; 95% CI, 0.90–3.89).

Figure 2 *Paraspinal Muscle Indices According to Sarcopenia Status*



Note. Bars show group means and 95% confidence intervals reconstructed from published SDs and sample sizes. All three muscle indices were lower in the sarcopenic group.

Table 2 *Association of Sarcopenia Status With Paraspinal Fatty-Infiltration Severity*

Comparison	Sarcopenic event/non-event	Nonsarcopenic event/non-event	Odds ratio (95% CI)
Multifidus: moderate/severe vs mild	55/14	80/64	3.14 (1.60, 6.16)
Multifidus: severe vs nonsevere	28/41	22/122	3.79 (1.96, 7.34)
Erector spinae: moderate/severe vs mild	47/22	61/83	2.91 (1.59, 5.32)
Erector spinae: severe vs nonsevere	16/53	20/124	1.87 (0.90, 3.89)

Note. Odds ratios were reconstructed from published categorical counts. Moderate/severe comparisons use mild infiltration as the reference category.

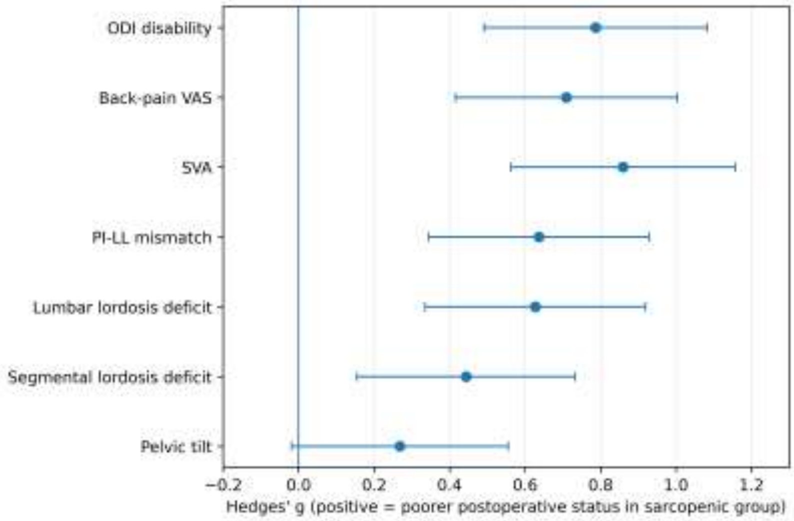
The greatest standardized difference in sagittal dimensions was present for SVA at the final postoperative evaluation. Sarcopenic patients had an SVA of 55.32±17.33 mm compared with 41.06±16.14 mm in nonsarcopenic patients, yielding an MD of 14.26 mm (95% CI, 9.35–19.17) and Hedges' g of 0.86 (95% CI, 0.56–1.16). PI–LL mismatch was also larger in the sarcopenic group (16.33±12.21° vs. 9.37±10.21°; MD, 6.96°; 95% CI, 3.60–10.32; g=0.64). Conversely, LL was lower by 5.60° (95% CI, −8.18 to −3.02; g=−0.63), and segmental lordosis was lower by 2.31° (95% CI, −3.94 to −0.68; g=−0.44). For final SS and PI, there was little evidence of separation between groups. Although PT was 2.30° higher in the sarcopenic group, the reconstructed 95% CI included 0 (−0.04 to 4.64°; g=0.27); as such, PT was not considered to be a robust finding in this secondary analysis. The final postoperative effect estimates are summarized in Table 3 and Figure 3.

Table 3 *Final Postoperative Spinopelvic and Functional Outcomes*

Outcome	Sarcopenic (n=69)	Nonsarcopenic (n=144)	Mean difference (95% CI)	Hedges' g (95% CI)
Pelvic tilt, °	24.13 ± 7.67	21.83 ± 8.93	2.30 (−0.04, 4.64)	0.27 (−0.02, 0.56)
Lumbar lordosis, °	32.91 ± 8.94	38.51 ± 8.88	−5.60 (−8.18, −3.02)	−0.63 (−0.92, −0.33)
PI–LL mismatch, °	16.33 ± 12.21	9.37 ± 10.21	6.96 (3.60, 10.32)	0.64 (0.34, 0.93)
Segmental lordosis, °	14.72 ± 5.96	17.03 ± 4.78	−2.31 (−3.94, −0.68)	−0.44 (−0.73, −0.15)
SVA, mm	55.32 ± 17.33	41.06 ± 16.14	14.26 (9.35, 19.17)	0.86 (0.56, 1.16)
ODI	32.13 ± 9.10	24.45 ± 10.01	7.68 (4.96, 10.40)	0.79 (0.49, 1.08)
Back-pain VAS	3.75 ± 0.99	3.05 ± 0.98	0.70 (0.41, 0.99)	0.71 (0.42, 1.00)
Sacral slope, °	25.12 ± 8.30	26.06 ± 6.71	−0.94 (−3.21, 1.33)	−0.13 (−0.42, 0.16)
Pelvic incidence, °	49.25 ± 8.52	47.88 ± 9.65	1.37 (−1.21, 3.95)	0.15 (−0.14, 0.43)

Note. Mean difference is sarcopenic minus nonsarcopenic. Negative effects for lumbar and segmental lordosis indicate lower lordosis in the sarcopenic group. PI–LL=pelvic incidence minus lumbar lordosis; SVA=sagittal vertical axis; ODI=Oswestry Disability Index; VAS=visual analogue scale.

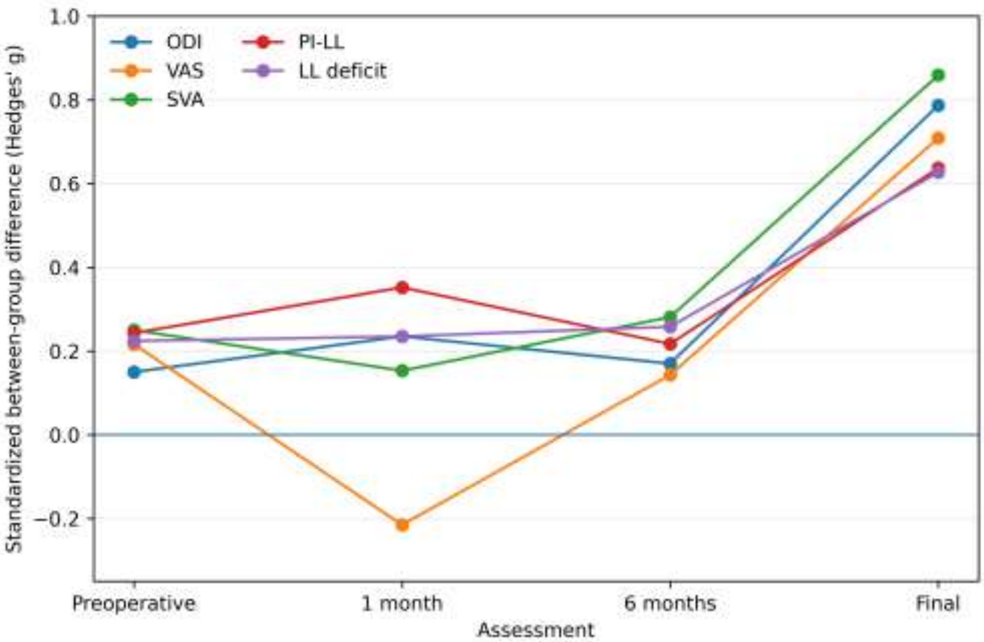
Figure 3 Standardized Differences in Final Postoperative Status



Note. Effects are oriented so that positive Hedges' g indicates a poorer postoperative profile in the sarcopenic group. For lumbar and segmental lordosis, the mathematical sign was reversed in the figure to represent lordosis deficit. The 95% CI for pelvic tilt includes zero.

The results on functional outcomes were also quite consistent. The mean ± SD of final ODI was 32.13±9.10 in the sarcopenic group and 24.45±10.01 in the nonsarcopenic group. The between-group MD was 7.68 points (95% CI, 4.96–10.40), corresponding to Hedges' g=0.79 (95% CI, 0.49–1.08). Final back-pain VAS was 3.75±0.99 versus 3.05±0.98, an MD of 0.70 points (95% CI, 0.41–0.99) and g=0.71 (95% CI, 0.42–1.00). These effects were all in the same direction as the poorer final sagittal profile in the sarcopenic individuals.

Figure 4 Descriptive Between-Group Differences Across Assessment Times



Note. Hedges' g was reconstructed separately at each reported assessment. Positive values indicate poorer status in the sarcopenic group; lumbar lordosis was sign-reversed to represent lordosis deficit. The figure is descriptive and does not constitute a repeated-measures analysis.

Additional descriptive context is provided by the temporal effect pattern reconstructed. The preoperative differences between the groups with respect to ODI, VAS, SVA, PI–LL mismatch, and LL deficit were small, ranging from 0.15 to 0.25. The majority of differences were not large at 1 and 6 months, with a relatively small separation for PI–LL mismatch at 1 month. Standardized effects at the final assessment were 0.79 for ODI, 0.71 for VAS, 0.86 for SVA, 0.64 for PI–LL mismatch and 0.63 for LL deficit. The descriptive differences are shown for each assessment time in Figure 4. This pattern may be viewed descriptively since the analysis was performed on summary data, and the covariance between values within the same persons was not available and therefore could not be accounted for in the analysis.

DISCUSSION

A consistent long-term phenotype emerged from this secondary cross-sectional analysis whereby sarcopenia was associated with suboptimal spinopelvic alignment and higher postoperative disability. Differences between the groups were not limited to the various muscle indices that were used to define sarcopenia. Large standardized differences were observed for the sarcopenic group for SVA at final follow-up (g=0.86) and moderate-to-large differences were observed for PI–LL mismatch and LL deficit (approximately g=0.64 and 0.63), and a substantial difference for ODI (g=0.79). There was also a higher back-pain VAS score (g=0.71). Lower psoas, erector spinae, and multifidus muscle indices were associated with the pattern, and the sarcopenic group also had significantly higher odds of fatty infiltration of the multifidus muscle being moderate to severe. Importantly, the majority of clinical and alignment differences were small prior to surgery and early recovery, and were much greater at the final evaluation.

The overall results of the alignment findings are in line with the literature on lumbar surgery. Tykocki and Rakasz (2026) identified that good postoperative sagittal alignment was correlated with a 67% decrease in the chances of significant disability and a 61% decrease in the likelihood of persistent pain in degenerative lumbar procedures. The same was true for SVA, and the difference in PI–LL mismatch at long-term follow-up was found to be moderate-to-large in the present analysis. The recent prospective cohort of Sheidae Mehne and Motlagh Pirooz (2026), however, showed that significant improvement in symptoms can be seen even if generalized sagittal correction is not performed and that pain improvement is most related to individual lordosis restoration. The apparent contrast lends itself to a nuanced interpretation: Sagittal alignment is clinically relevant, but the value of any single parameter may be dependent upon a range of baseline morphology, procedure, follow-up time, and the patient's compensatory reserve.

Additionally, the PI–LL and LL results are in line with the current surgical-planning concepts. Diebo et al. (2024) stated that degenerative lumbar fusion must restore the lordosis magnitude and distribution in a way that is suitable for the morphology of the pelvis. For the current analysis, the sarcopenic group exhibited a greater long-term mismatch of PI – LL and lower LL despite there being relatively small differences between groups at the outset. In a 2026 multicenter study of adult degenerative lumbar deformity, a residual mismatch between PI–LL was also an independent predictor of a poor postoperative course (Nazarli et al., 2026). All of these observations combined suggest that the residual or recurrent mismatch could be more than a radiographic entity, but the current combined analysis cannot state if muscle degeneration was primary, secondary or concurrent with the mismatch.

The muscle findings are also in line with the meta-analytical and prospective evidence. The pooled SMD for poorer ODI improvement in patients with sarcopenia after undergoing surgery for degenerative lumbar diseases was 0.53 as reported by Chen et al. (2024). In the current analysis, the final cross-sectional ODI effect was greater (g=0.79); however, the numbers cannot be directly compared as one measures improvement and the other measures difference between groups following surgery. In a prospective fusion cohort, Haffer et al. (2024) found that paraspinal fatty infiltration was an independent correlate of 12-month ODI. Hambrecht et al. (2025) also demonstrated that fatty infiltration of the erector spinae was associated with an increased overall ODI and associated with multiple domain-specific disabilities at 2 years postoperatively; Jin et al. (2026) showed that fatty infiltration of erector spinae showed consistent pooled associations with adverse outcomes after lumbar discectomy. All these converging results support the interpretation that local muscle quality is clinically relevant for more than one lumbar procedure.

In relation to the multifidus findings, the PMI effect is quite large and is not as clinically specific. It is not surprising that there was a very large difference between the different sarcopenia groups, since differences were based on PMI, which was used in the groups' definition. Multifidus fatty infiltration, however, was significantly more common while MMI and EMI were not the classification variables but were also lower. This suggests that the sarcopenic phenotype extended beyond the psoas. The multifidus is anatomically located around the spine for segmental stability and fine regulation of lumbar movement and a compartmental proxy of this muscle may be more biomechanically relevant to maintaining lordosis than a simple muscle proxy alone. This interpretation is consistent with the original patient-level analysis by Fang et al. (2026), in which MMI and multifidus fatty infiltration in addition to the preoperative LL and segmental lordosis were reported as independent predictors of long-term sagittal imbalance.

This trend is consistent with a progressive loss of alignment-maintenance function but does not establish longitudinal or causal effects. There were only small differences in ODI, VAS, and SVA between groups in the early postoperative period, and both groups showed improvement after surgery. At final follow-up, however, the sarcopenic group had higher SVA, larger PI – LL mismatch, lower LL and poorer function. A possible explanation is that a satisfactory alignment can be gained after surgery, but the muscle capacity, the sagittal mechanics and intactness of the adjacent segments are required for long-term preservation. A decrease in paraspinal muscle quantity or an increase in fatty infiltration may result in decreased endurance and/or segmental control and more dependence on pelvic/trunk compensation. While this interpretation is biologically plausible, it is still an inference as there are no patient-level longitudinal trajectory data or formal mediation analysis on this secondary dataset.

There is evidence to suggest that there is a reciprocal relationship between muscle morphology and sagittal geometry preoperatively. Minetama et al. (2023) reported associations of reduced LL and increased PT with reduced multifidus morphology in lumbar spinal stenosis, controlling for sex, age, height, and weight. Therefore, muscle degeneration may not just be a consequence of malalignment, but may also be a consequence of chronic malalignment and spinal degeneration which may affect muscle loading and lead to disuse or fatty infiltration. This bidirectionality is a good argument for not using causal language in a cross-sectional analysis. Accordingly, the conclusion is that sarcopenia, paraspinal degeneration and chronic malalignment co-occur and relate to a poorer postoperative function.

Recent research also indicates that the association is procedure-dependent. Interestingly, Regev et al. (2025) showed that multifidus fatty infiltration was actually associated with greater ODI improvement following minimally invasive decompression, although sarcopenia was not associated with poorer outcomes. Kim et al. (2026) also noted no statistically significant differences between the ODI and EQ-5D at 12 months after biportal endoscopic surgery based on sarcopenia status. In contrast, You et al. (2023) found a higher level of muscularity and less fatty infiltration to be associated with better outcomes following lumbar interbody fusion, Carvalho et al. (2022) found that higher erector spinae fatty infiltration was associated with worse postoperative status following discectomy, and Eryilmaz (2026) found fatty infiltration to be an independent predictor of residual pain and reoperation after interbody fusion. The source cohort underwent multilevel PLIF and around 40 months of follow-up, where the duration of mechanical support might be of more significance than following limited decompression. Therefore, variations among studies could be actual effect modification of surgical construct and time, rather than just variation.

The functional results should also be considered in the context and scale. The between-group difference in final ODI was 7.68 points, which was estimated with reasonable precision at the aggregate level and corresponded to a statistically significant standardized effect. A between-group difference (cross-sectional), however, does not represent a Minimal Clinically Important Difference (MCID) for an individual patient. The findings should thus be interpreted as increased disability burden in the sarcopenic group rather than increased disability in all patients as a consequence of sarcopenia. The same holds true for the 0.70-point difference in VAS.

These clinical implications are several. First, normal and abnormal morphology of the paraspinal muscles could prove to be useful pre- and postoperative data, in addition to age and BMI, particularly for multilevel fusion patients. Second, the sagittal alignment should be considered in conjunction with muscle status and not on its own. Patients with apparently acceptable initial alignment with limited paraspinal reserve may require closer follow-up of alignment and function in the future. Third, the results can be used in research studies on prehabilitation, nutritional optimization, resistance exercise and muscle-sparing surgical techniques. While observational evidence that these interventions are effective should not be assumed, these interventions make sense for prospective trials because of the possibility that muscle status may be modifiable while pelvic morphology is not.

This study has a number of strengths. It relied on published summary data for the muscle, alignment, and functional outcomes of interest, provided CIs to quantify the effects instead of re-presentation of source p values, and did not seek to reconstruct patient-level data. Using standardized effects allowed for direct comparisons across effects measured on different scales. It was also apparent that temporal effect sizes were reconstructed showing that the best separation of groups was at long-term follow-up, not apparent from the table comparisons alone. Furthermore, the analysis was done without including consensus clinical sarcopenia, and the multivariable results of the source study were used not as results of reanalysis but as contextual evidence.

The limitations are significant and affect the inference. First, only aggregate group data were available. As a result, the study could not account for confounding, individual-level correlation between muscle and alignment measurements, or nonlinear relationships, nor test the hypothesis that sarcopenia modifies the relationship between alignment and ODI. Nontrivial differences in BMI between groups were observed, which may confound some comparisons. Second, the patients in the analyzed cohort were those undergoing multilevel posterior lumbar interbody fusion from a single source; the generalizability to patients undergoing decompression-only surgery or short-segment fusion, or other diagnoses, or in other health care settings is unknown. Third, sarcopenia was diagnosed using PMI and was not based on a comprehensive consensus evaluation of muscle strength and physical functioning. Fourth, the temporal plots have group summaries at repeated time points and are unable to account for within-person covariance, loss to follow-up, or change-score correlation. Fifth, there was a minor denominator discrepancy in the source narrative, and the tables were consistent in reporting 69 and 144 patients and adding up to the claimed total of 213; thus table denominators were used. Last, as this is a secondary analysis of published summaries it should be considered as a secondary aggregate-data analysis and not as a replacement for a new cohort study at the patient level.

Future studies are needed to collect the original individual-level information or data from a similar registry cohort with standing spinopelvic radiographs, paraspinal muscle measurements, criteria for sarcopenia, and postoperative ODI at a specified index visit. This would allow for multivariable modeling of ODI, direct estimation of the alignment–muscle relationship, and sensitivity analyses by sex, BMI, diagnosis and extent of fusion and assessment of the interaction between sarcopenia and PI–LL/SVA. Possible studies should also include a test for grip strength or ability to rise from a chair to assess both spine and systemic sarcopenia.

CONCLUSION

This secondary cross-sectional analysis of 213 adults with multilevel lumbar fusions had a consistent and long-term pattern of worse sagittal alignment, more disability, more back pain and worse paraspinal muscle morphology in the sarcopenic group. The greatest standardized differences were for SVA, ODI, back-pain VAS, PI – LL mismatch and lumbar lordosis. Multifidus fatty infiltration was also significantly increased in sarcopenic patients, in moderate and severe stages. While there were relatively minor differences early postoperatively, larger discrepancies were seen at the last assessment, indicating that attainment of a good sagittal balance in the long term may be clinically important in patients with limited muscle reserve. These results are similar to recent evidence from meta-analyses and prospective studies that found sagittal alignment and quality of paraspinal muscles to be associated with postoperative function. But the aggregate-data design does not allow for the adjustment of confounding factors, and it is uncertain whether sarcopenia is directly responsible for malalignment or disability. Patient-level studies are needed that combine muscle quantity, muscle quality, spinopelvic parameters, and validated functional outcomes in order to be able to make patient-specific prognostic or treatment decisions.

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