Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Radiographic Measurement of Psoas Muscle Width as a Predictor of Cage Subsidence Following Transforaminal Lumbar Interbody Fusion

Xingyu Shao
West China Hospital of Sichuan University
Wenxue Wang
Sichuan University
Youwei Ai
West China Hospital of Sichuan University
Qian Chen
Affiliated Hospital of North Sichuan Medical College
Ce Zhu
West China Hospital of Sichuan University
Hong Ding
West China Hospital of Sichuan University
Zhuojie Xiao
West China Hospital of Sichuan University
Yongdi Wang
West China Hospital of Sichuan University
Lechuan Zhu
West China Hospital of Sichuan University
Limin Liu
liulimin_spine@163.com
West China Hospital of Sichuan University

Research Article

Keywords: PMW, TLIF, Cage subsidence, Psoas muscle, Paraspinal muscles

Posted Date: November 14th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11303573/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Radiographic Measurement of Psoas Muscle Width as a Predictor of Cage Subsidence Following Transforaminal Lumbar Interbody Fusion

Authors: Xingyu Shao, MD,[1#] Wenxue Wang, MD,[3#] Youwei Ai, MD,[1] Qian Chen[1,2], Ce Zhu, MD,[1] MD, Hong Ding, MD[1], Zhuojie Xiao, MD[1], Yongdi Wang, MD[1], Lechuan Zhu, MD[1], Limin Liu, MD[1*]

Affiliations:

[1] Department of Orthopedic Surgery and Orthopedic Research Institute, West China Hospital, Sichuan University, Chengdu 610041, Sichuan, China;

[2] Department of Orthopedic and Laboratory of Biological Tissue Engineering and Digital Medicine, Affiliated Hospital of North Sichuan Medical College, Nanchong, Sichuan, China;

[3] Sichuan University, Chengdu, China, Anesthesia Operation Center of West China Hospital / West China School of Nursing;

[#]First Authors:

Xingyu Shao, Wenxue Wang

***Corresponding Authors:**

Limin Liu, MD.

Department of Orthopedic Surgery and Orthopedic Research Institute, West China Hospital, Sichuan University, Chengdu 610041, Sichuan, China

Email: liulimin_spine@163.com

Abstract

Objective Cage subsidence is a common complication after transforaminal lumbar interbody fusion (TLIF). We evaluated whether preoperative radiographic psoas muscle width (PMW), measured on routine lumbar radiographs, is independently associated with cage subsidence after single-level TLIF.

Methods This retrospective single-center study included 262 patients undergoing single-level TLIF between 2018 and 2023. PMW was measured at the L3 inferior endplate on preoperative standing anteroposterior radiographs. Multivariable logistic regression assessed the independent association between PMW and subsidence; a PMW-by-sex interaction term was tested and sex-stratified receiver operating characteristic (ROC) analysis was performed, with bootstrap internal validation.

Results Cage subsidence occurred in 58 patients (22.14%). Patients with subsidence had significantly lower PMW (98.33±9.24 mm vs. 112.72±10.42 mm, $p<0.001$) and volumetric bone mineral density (105.36±19.98 mg/cm³ vs. 134.34±29.80 mg/cm³, $p<0.001$). In the multivariable model, PMW remained an independent predictor (OR 0.815, 95% CI 0.765, 0.869; $p<0.001$), as did sex and vBMD. Sex-stratified ROC analysis demonstrated good discriminatory performance: AUC 0.870 for males (cutoff 112.25 mm; sensitivity 0.842, specificity 0.798) and AUC 0.886 for females (cutoff 101.05 mm; sensitivity 0.846, specificity 0.820). Interobserver reliability was excellent (ICC=0.914).

Conclusion Lower preoperative radiographic PMW was independently associated with cage subsidence after single-level TLIF. PMW may help identify patients at low risk, but the sex-specific cutoff values are exploratory and require external validation.

Keywords: PMW; TLIF; Cage subsidence; Psoas muscle; Paraspinal muscles

Introduction

Lumbar degenerative disease is a leading cause of chronic low back pain, radiculopathy, and functional disability, often resulting in a significant reduction in quality of life [1, 2]. In cases where conservative management does not yield adequate symptomatic relief, surgical intervention is indicated as an essential therapeutic modality. Among the available fusion techniques, transforaminal lumbar interbody fusion (TLIF) effectively stabilizes degenerative segments, restores disc height, and achieves indirect neural decompression [3-5]. Despite these advantages, cage subsidence remains a common postoperative complication following TLIF [6, 7]. This complication has become a major cause of surgical revision and symptom recurrence [8-11]. Therefore, early identification of modifiable and non-

modifiable risk factors for cage subsidence, coupled with the implementation of targeted preventive strategies, is essential to ensuring optimal surgical outcomes and reducing healthcare costs.

Previous studies have demonstrated that atrophy of the psoas major and paraspinal muscles is an important predictor of cage subsidence following TLIF [12, 13]. Dual energy X-ray absorptiometry (DEXA) is commonly used to estimate appendicular lean mass in sarcopenia assessment but cannot reliably quantify individual deep trunk muscles [14, 15]. Computed tomography (CT) and magnetic resonance imaging (MRI) provide more detailed regional assessment of psoas and paraspinal muscle morphology, although image segmentation requires additional time and expertise [16-18]. This renders the measurement process highly cumbersome; consequently, clinicians rarely assess the psoas major and paraspinal muscles in routine practice, thereby limiting the routine incorporation of muscle parameters into preoperative risk assessment.

In an effort to bridge this gap, alternative imaging modalities have been explored. It has been demonstrated that radiographic thigh muscle measurements serve as robust predictors of psoas muscle area (PMA) and sarcopenia [19]. Recent investigation has further established that psoas muscle width (PMW) measured on plain anteroposterior radiographs demonstrates moderate-to-strong correlation with cross-sectional imaging and serves as a reliable, reproducible method for predicting sarcopenia [20]. Given that plain radiographs are universally available, inexpensive, and standard in preoperative evaluation, PMW measurement offers a practical screening tool without additional cost or radiation exposure. Despite these advantages, few studies have investigated PMW's predictive value for cage subsidence after TLIF. This study aimed to determine whether preoperative radiographic PMW is independently associated with cage subsidence following single-level TLIF and to assess its sex-specific discriminatory performance. We hypothesized that reduced preoperative PMW would be significantly

associated with increased cage subsidence risk and would serve as an independent predictor. Incorporating this readily accessible parameter into routine preoperative evaluation may facilitate identification of high-risk patients, guide counseling, and optimize surgical decision-making.

Methods

Patient Selection

This retrospective study included patients who underwent single-level TLIF at the Department of Orthopedics of our institution between 2018 and 2023. The inclusion criteria were as follows: (1) patients who underwent single-level TLIF for lumbar degenerative disease at our institution; and (2) availability of complete preoperative and postoperative imaging and clinical data. Patients were excluded if they had a history of previous lumbar surgery, metabolic bone disease, ankylosing spondylitis, tumor history, history of radiotherapy or chemotherapy, spinal infection, spinal trauma, or radiographs in which the bilateral psoas margins at the L3 level could not be reliably identified. All patients were followed for at least 12 months, and all surgical procedures were performed by a single senior spine surgeon.

Data Collection

Comprehensive clinical data were retrieved from the hospital's electronic medical records. Patients were divided into No Subsidence and Subsidence groups according to whether cage subsidence occurred. Demographic data included patient age, sex, body mass index (BMI), hypertension, diabetes, Charlson co-morbidity index (CCI), diagnosis, surgical level, cage type and cage size (length, height, and width). Radiographic data included disc height, v-BMD, PMW, and cage subsidence.

Measurement of Psoas Muscle Width

The PMW was measured on standing anteroposterior lumbar spine radiographs at the level of the inferior endplate of the L3 vertebral body, where the psoas major is typically most developed (**Figure 1.**)[20]. The transverse distance between the lateral borders of the bilateral psoas muscles was obtained. Due to the natural radiographic contrast provided by adjacent fat tissue, the psoas muscles are usually clearly visualized on plain radiographs. When the muscle margins were poorly delineated, image brightness and contrast were adjusted to facilitate accurate identification. The PMW was measured twice for each patient, and the mean value of the two measurements was used for subsequent statistical analysis. Interobserver reliability was assessed using the intraclass correlation coefficient (ICC) based on measurements independently performed by two observers who were blinded to the patients' clinical outcomes.

Measurement of BMD

Preoperative lumbar spine CT scans served as the basis for determining the standard volumetric bone mineral density (vBMD) at the L1/2 level. A Mindways calibration phantom (Mindways Software Inc., Austin, USA) was employed to ensure measurement accuracy. By converting Hounsfield unit (HU) values obtained from the L1 and L2 vertebral bodies through phantom-based standardization, vBMD was quantified in mg/cm^3 [21, 22]. When vBMD>120 mg/cm^3, the patient is classified as having normal bone mineral density; a vBMD of 80-120 mg/cm^3 indicates low bone mass; and a vBMD <80 mg/cm^3 is diagnostic of osteoporosis.

Measurement of cage subsidence and disc height.

In accordance with the most commonly used definition in the TLIF literature, cage subsidence was defined as the cage sinking more than 2 mm into the adjacent vertebral endplate on lateral radiographs, as described in previous systematic reviews [9]. Radiographic evaluation was performed immediately postoperatively and at 3, 6, and 12 months, as well as at the final follow-up. Disc height was calculated using Farfan's index with the formula: DH=[(a+b)/c] * 100%, (a is the anterior disc height, b is the posterior disc height, and c is the sagittal width of the disc)[23].

Statistical Analysis

Statistical analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality and compared using the independent-samples t test or Mann–Whitney U test, as appropriate. Categorical variables were compared using the chi-square test or Fisher's exact test. Variables that were statistically significant in univariate analysis ($p<0.05$) **or** variables of clinical relevance from previous studies were entered into a multivariable logistic regression model to evaluate the independent association between PMW and cage subsidence. To assess potential effect modification by sex, PMW was mean-centered and a PMW-by-sex interaction term was tested. Because absolute PMW values differed between sexes, sex-stratified receiver operating characteristic (ROC) analyses were subsequently performed, and optimal cutoff values were determined using the Youden index. Interobserver reliability was assessed using the intraclass correlation coefficient. Results are reported as odds ratios or area under the curve (AUC) with 95% confidence intervals. A two-sided p value <0.05 was considered statistically significant.

Results

Patient Characteristics

A total of 262 patients who underwent single-level TLIF were included in the study. Among them, 123 were male and 139 were female. The mean age of all patients was 55.99 ± 12.79 years. Cage subsidence occurred in 58 patients (22.14%). There was a statistically significant difference between the no subsidence and subsidence groups in terms of age, sex, QCT-vBMD, and PMW. No significant differences were observed between the two groups in other variables (**Table 1.**).

Multivariable Analysis

Given sex-specific differences in baseline PMW and the higher subsidence rate in females (28.06% vs. 15.45%), an interaction term (PMW-C*Sex) was tested but was non-significant (OR 1.067, 95% CI: 0.939, 1.213; p=0.322) (**Table 3.**) and removed from the final model. In the reduced multivariable model, PMW remained an independent predictor of cage subsidence (OR 0.815, 95% CI: 0.765, 0.869; p<0.001). The other independent predictors were sex (OR 0.837, 95% CI: 0.755, 0.929; p<0.001) and QCT-vBMD (OR 0.965, 95% CI: 0.947, 0.983; p<0.001) (**Table 4**.).

Discriminatory Performance of PMW

In our statistical analysis, we observed that the distribution of PMW differed between male and female patients. Accordingly, we performed sex-stratified analyses and sex-specific ROC analyses. In the sex-stratified subgroup analysis, PMW was significantly lower in the subsidence group than in the no subsidence group among male patients (105.50 ± 9.19 mm vs. 119.94 ± 9.19 mm, p<0.001). Similarly, among female patients, PMW was significantly lower in the subsidence group compared with the no subsidence group (94.84 ± 7.05 mm vs. 105.21 ± 4.81 mm, p<0.001) (**Table 2**).

ROC curve analysis demonstrated that PMW had good predictive value for cage subsidence. In male patients, the AUC was 0.870, with a cut-off value of 112.25 mm, a sensitivity of 0.842, and a specificity of 0.798. In female patients, the AUC was 0.886, with a cut-off value of 101.05 mm, a sensitivity of 0.846, and a specificity of 0.820 (**Figure 2**.). The interobserver reliability of PMW measurement was excellent (ICC=0.914). Bootstrap internal validation with 1,000 resamples yielded optimism-corrected AUCs of 0.873 in male patients and 0.888 in female patients, indicating minimal optimism in discrimination. However, the sensitivity at the derived cut-off was overestimated in the apparent analysis: the corrected sensitivity was 0.779 (vs. 0.842 apparent) in male and 0.812 (vs. 0.846 apparent) in female, while specificity remained stable (corrected 0.790 in male and 0.811 in female).

Discussion

The principal finding of this study was that lower preoperative radiographic psoas muscle width was independently associated with cage subsidence after single-level TLIF. Patients who developed subsidence had substantially lower PMW and QCT-derived vBMD than those without subsidence, and the association between PMW and subsidence remained significant after adjustment for relevant clinical variables and bone mineral density. PMW also showed good discriminatory performance in both male and female patients. Although absolute PMW values and the corresponding cutoff values differed between sexes, no significant PMW-C*Sex interaction was observed. Collectively, these findings suggest that radiographic PMW may provide a simple estimate of musculoskeletal vulnerability that complements, rather than replaces, the assessment of bone quality. In the present cohort, 58 of 262 patients developed cage subsidence, and both PMW and QCT-vBMD remained significant in the adjusted model.

Previous studies have linked degeneration of the psoas and paraspinal muscles with mechanical complications after lumbar fusion. CT- and MRI-based measurements, including muscle cross-sectional area, functional cross-sectional area, and fatty infiltration, provide detailed information on muscle morphology and composition and have been associated with cage subsidence, screw loosening, and other postoperative mechanical complications [12, 13, 24, 25]. However, these measurements generally require manual or semiautomated segmentation, dedicated software, and additional interpretation time, which limits their routine application in preoperative assessment. Kataoka et al. introduced radiographic PMW as a simple measurement obtained from standard anteroposterior radiographs and demonstrated a correlation between PMW and CT-based psoas muscle area [20]. The present study extends the potential application of this measurement from sarcopenia screening to the assessment of cage subsidence after lumbar fusion. Nevertheless, PMW should not be considered equivalent to CT- or MRI-based evaluation. It reflects a single transverse dimension and cannot directly quantify muscle composition, fatty infiltration, or strength. Its principal value may therefore lie in rapid preliminary screening rather than comprehensive muscle assessment.

Several mechanisms may account for the association between reduced PMW and cage subsidence. First, lower PMW may reflect reduced regional muscle mass and broader musculoskeletal vulnerability. The psoas and paraspinal muscles contribute to trunk control, dynamic stabilization, and load sharing across the lumbar spine. Reduced muscle reserve may be associated with less favorable load distribution after fusion, potentially increasing mechanical demand at the cage–endplate interface [12, 26]. This explanation remains biomechanically plausible but was not directly evaluated in the present study because muscle strength, electromyographic activity, and segmental loading were not measured. In addition, muscle loss and impaired bone quality frequently coexist. Aging, physical inactivity, endocrine

alterations, inadequate nutritional status, and metabolic dysfunction may contribute simultaneously to reductions in muscle mass and deterioration of bone strength [27, 28]. Patients with lower PMW may therefore have a broader phenotype of musculoskeletal frailty rather than isolated psoas atrophy. Importantly, both PMW and QCT-vBMD remained associated with cage subsidence in the multivariable analysis. This suggests that muscle status and bone mineral density may represent complementary components of susceptibility to cage–endplate failure. QCT-vBMD primarily reflects trabecular bone mineral density, whereas PMW may capture aspects of regional muscle reserve and general physical condition that are not fully represented by bone density alone[20].

Age was significantly greater in patients with subsidence in the unadjusted comparison but was not independently associated with subsidence in the multivariable model. This finding suggests that the apparent influence of age may be mediated, at least in part, through age-related deterioration in bone and muscle status. Older patients commonly exhibit both lower vBMD and greater muscle atrophy or fatty infiltration [18, 29, 30]. Thus, chronological age alone may be less informative than direct assessment of the underlying musculoskeletal characteristics that accompany aging.

This study also observed significant sex differences: the incidence of cage subsidence was significantly higher in female patients compared to male patients (28.06% vs. 15.45%, p=0.014), and the baseline PMW level was generally lower in females. This disparity may be explained by several factors. First, postmenopausal elderly women experience accelerated bone loss due to hormonal changes, resulting in lower bone mineral density compared with men [31, 32]. Second, previous studies have shown that women tend to have lower psoas major muscle content and more pronounced paraspinal muscle degeneration than men of the same age [33, 34]. Consequently, they are more likely to fall into the high-risk category characterized by low PMW combined with low BMD. To avoid confounding by

sex, we mean-centered PMW and tested the PMW-C*Sex interaction in the multivariable model. The interaction was not statistically significant (OR 1.067, 95% CI 0.939, 1.213; p=0.322). This indicates that the protective effect of PMW against cage subsidence did not differ between men and women, and that no evidence of significant effect modification by sex was observed. We therefore dropped the interaction term in favor of parsimony. Nevertheless, because baseline PMW distributions differ between sexes, a single cutoff would introduce bias into risk estimation. We accordingly performed sex-specific ROC analyses and identified optimal cutoffs of 112.25 mm for men and 101.05 mm for women. These findings suggest that sex differences influence the distribution of PMW and the resulting ROC thresholds, but not the underlying association between PMW and cage subsidence. In clinical practice, sex-specific cutoffs prevent underestimation or overestimation of risk in either group. The sex-specific cutoff values identified in this study should nevertheless be regarded as exploratory because they were derived and evaluated in the same cohort and have not undergone external validation.

From a clinical perspective, radiographic PMW may serve as an initial screening marker rather than a direct indication for treatment. Because anteroposterior lumbar radiographs are routinely obtained before TLIF, PMW can be measured without additional imaging acquisition or specialized muscle-segmentation software. A low PMW value may prompt more detailed assessment of bone health, nutritional status, physical function, and muscle condition. It may also encourage greater attention to modifiable surgical factors that influence subsidence, including preservation of the vertebral endplate, appropriate cage footprint and position, and avoidance of excessive disc-space distraction. However, the current findings do not demonstrate that psoas strengthening, nutritional supplementation, or other prehabilitation strategies reduce the risk of subsidence. Such interventions should not be recommended solely on the basis of the present observational data.

Study limitations

Several limitations should be acknowledged. First, this was a retrospective study conducted at a single center, and the results may be influenced by selection bias, residual confounding, and institution-specific surgical practice. Second, PMW reflects only the transverse width of the psoas region and does not directly measure muscle cross-sectional area, fatty infiltration, tissue composition, or strength. Third, radiographic PMW may be affected by magnification, patient positioning, lumbar rotation, body size, and bowel gas, and a normalized measurement such as PMW relative to vertebral body width was not evaluated. Fourth, cage subsidence was assessed on lateral radiographs rather than CT, which may have resulted in underestimation of mild endplate penetration. Fifth, potentially relevant technical factors, including intraoperative endplate injury, cage position, cage–endplate footprint, were not comprehensively analyzed. Sixth, the study did not evaluate fusion status, patient-reported outcomes, symptomatic subsidence, or revision surgery; therefore, the clinical consequences of radiographic subsidence could not be determined. Finally, the sex-specific cutoff values were derived and evaluated in the same cohort. Although bootstrap internal validation suggested minimal optimism in discrimination, the cutoffs remain preliminary and require external validation before clinical use.

Conclusion

Lower preoperative radiographic PMW was independently associated with cage subsidence after single-level TLIF, even after adjustment for QCT-vBMD and relevant clinical covariates. PMW may provide a simple screening marker of musculoskeletal vulnerability from routine lumbar radiographs. Because absolute PMW differed by sex, sex-specific interpretation is appropriate; however, the derived cutoff values should be considered exploratory rather than definitive clinical thresholds.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the Ethics Committee on Biomedical Research West China Hospital of Sichuan University (IRB number: 2023-250). For this type of study (retrospective study), formal consent is not required in China.

Consent for publication

Not applicable.

Availability of data and materials

Data are available upon reasonable request from the corresponding author.

Competing Interests

Authors are required to disclose financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

Funding

No funding was obtained for this study

Authors' contributions

X.S., W.W, Y.A., and Q.C. contributed to the conception of the study;

X.S., W.W, L.L, Y.W., Y.A., Z.X., and L.Z. performed Acquisition and data;

X.S., W.W, Y.A., and H.D. contributed significantly to analysis and manuscript preparation;

X.S., W.W, Y.A., Q.C., and C.Z. performed the data analyses and wrote the manuscript;

Q.C., Y.A., H.D., L.L. helped perform the analysis with constructive discussions.

L.L. contributed to the supervision

All authors reviewed the manuscript.

Acknowledgements

Not applicable.

Table 1. Baseline characteristics of all the patients (n=262)

	All (n=262)	No subsidence (n=204)	Subsidence (n=58)	p
Age, years	55.99±12.79	54.2±13.11	62.31±9.20	**<0.001**
Sex, n (%)				**0.014**
Male	123 (46.9)	104 (51)	19 (32.8)	
Female	139 (53.1)	100 (49)	39 (67.2)	
BMI, (kg/m²)	24.31±3.08	24.26±3.07	24.29±3.02	0.955
Hypertension, n (%)	70 (26.7)	52 (25.5)	18 (31)	0.400
Diabetes, n (%)	38 (14.5)	26 (12.7)	12 (20.7)	0.129
Smoking, n (%)	62 (23.7)	50 (24.5)	12 (20.7)	0.546
Alcohol consumption, n (%)	46 (17.6)	36 (17.6)	10 (17.2)	0.943
CCI, n (%)				0.380
0	24 (9.2)	16 (7.8)	8 (13.8)	
1	84 (32.1)	66 (32.4)	18 (31)	
2 and over	154 (58.8)	122 (59.8)	32 (55.2)	
Diagnosis, n (%)				0.467
Lumbar stenosis	160 (61.1)	128 (62.7)	32 (55.2)	
Degenerative spondylolisthesis	56 (21.4)	40 (19.6)	16 (27.6)	
Spondylolytic spondylolisthesis	32 (12.2)	26 (12.7)	6 (10.3)	
Herniated intervertebral disc	14 (5.3)	10 (4.9)	4 (6.9)	
Surgical level, n (%)				0.963
L1-2	4 (1.5)	4 (2)	0 (0)	
L2-3	8 (3.1)	6 (2.9)	2 (3.4)	
L3-4	10 (3.8)	8 (3.9)	2 (3.4)	
L4-5	138 (52.7)	106 (52)	32 (55.2)	
L5-S1	102 (38.9)	80 (39.2)	22 (37.9)	
Cage type, n (%)				0.354
PEEK	135 (51.5)	102 (50)	33 (56.9)	
n-HA/PA66	127 (48.5)	102 (50)	25 (43.1)	
Cage length, n (%)				0.975
22mm	86 (32.8)	66 (32.4)	20 (34.5)	
24mm	28 (10.7)	22 (10.8)	6 (10.3)	
26mm	148 (56.5)	116 (56.9)	32 (55.2)	
Cage height, n (%)				0.525
10mm	60 (22.9)	46 (22.5)	14 (24.1)	
12mm	196 (74.8)	152 (74.5)	44 (75.9)	
14mm	6 (2.3)	6 (2.9)	0 (0)	
Cage width, n (%)				0.414
8mm	50 (19.1)	38 (18.6)	12 (20.7)	
10mm	110 (42.0)	90 (44.1)	20 (34.5)	
12mm	102 (38.9)	76 (37.3)	26 (44.8)	
Preop disc height	52.50±15.01	53.44±14.76	49.21±15.54	0.058

Postop disc height	66.94±13.38	67.13±13.03	66.25±14.63	0.657
Change of disc height	1.39±0.52	1.36±0.48	1.48±0.65	0.130
QCT-vBMD (mg/cm³)	127.93±30.39	134.34±29.80	105.36±19.98	**<0.001**
PMW (mm)	109.53±11.78	112.72±10.42	98.33±9.24	**<0.001**

BMI, body mass index; CCI, Charlson co-morbidity index; PEEK polyetheretherketone; n -HA/PA66. nano-hydroxyapatite/polyamide66; QCT-vBMD, volumetric bone mineral density measured by quantitative computed tomography; PMW, psoas muscle width

Bold font indicates statistically significant.

Table 2. Comparison of baseline characteristics between no subsidence and subsidence stratified by sex

	Male			Female		
	No subsidence (n=104)	**Subsidence (n=19)**	**p**	**No subsidence (n=100)**	**Subsidence (n=39)**	**P**
Age, years	54.52±12.78	61.21±11.78	**0.036**	53.86±13.50	62.85±7.76	**<0.001**
BMI, (kg/m²)	24.11±3.24	25.55±3.24	0.073	24.67±2.89	23.67±2.92	0.173
Hypertension, n (%)	30 (28.8)	7 (36.8)	0.485	22 (22)	11 (28.2)	0.440
Diabetes, n (%)	16 (15.4)	4 (21.1)	0.511	10 (10)	8 (20.5)	0.097
Smoking, n (%)	26 (25)	7 (36.8)	0.284	24 (24)	5 (12.8)	0.145
Alcohol consumption, n (%)	18 (17.3)	4 (21.1)	0.746	18 (18)	6 (15.4)	0.714
CCI, n (%)			0.496			0.187
0	10 (9.6)	2 (10.5)		6 (6)	6 (15.4)	
1	36 (34.6)	9 (47.4)		30 (30)	9 (23.1)	
2 and over	58 (55.8)	8 (42.1)		64 (64)	24 (61.5)	
Diagnosis, n (%)			0.181			0.430
Lumbar stenosis	66 (63.5)	8 (42.1)		62 (62)	24 (61.5)	
Degenerative spondylolisthesis	24 (23.1)	6 (31.6)		16 (16)	10 (25.6)	
Spondylolytic spondylolisthesis	10 (9.6)	3 (15.8)		16 (16)	3 (7.7)	
Herniated intervertebral disc	4 (3.8)	2 (10.5)		6 (6)	2 (5.1)	
Surgical level, n (%)			0.086			0.228
L1-2	2 (1.9)	0 (0)		2 (2)	0 (0)	
L2-3	2 (1.9)	0 (0)		4 (4)	2 (5.1)	
L3-4	4 (3.8)	2 (10.5)		4 (4)	0 (0)	
L4-5	44 (42.3)	13 (68.4)		62 (62)	19 (48.7)	
L5-S1	52 (50)	4 (21.1)		28 (28)	18 (46.2)	
Cage type, n (%)			0.803			0.226
PEEK	57 (54.8)	11 (57.9)		45 (45)	22 (56.4)	
n-HA/PA66	47 (45.2)	8 (42.1)		55 (55)	17 (43.6)	
Cage length, n (%)			1.000			0.961
22mm	32 (30.8)	6 (31.6)		34 (34)	14 (35.9)	
24mm	12 (11.5)	2 (10.5)		10 (10)	4 (10.3)	
26mm	60 (57.7)	11 (57.7)		56 (56)	21 (53.8)	
Cage height, n (%)			1.000			1.000
10mm	20 (19.2)	4 (21.1)		26 (26)	10 (25.6)	
12mm	80 (76.9)	15 (78.9)		72 (72)	29 (74.4)	
14mm	4 (3.8)	0 (0)		2 (2)	0 (0)	
Cage width, n (%)			0.494			0.436
8mm	14 (13.5)	4 (21.1)		24 (24)	8 (20.5)	
10mm	46 (44.2)	6 (31.6)		44 (44)	14 (35.9)	
12mm	44 (42.3)	9 (47.4)		32 (32)	17 (43.6)	

Preop disc height	53.90·±14.09	47.14±14.93	0.079	52.95±15.49	50.21±15.92	0.361
Postop disc height	67.74±13.14	63.87±11.00	0.248	66.50±12.95	67.40±14.93	0.598
Change of disc height	1.43±0.52	1.41±0.62	0.705	1.30±0.42	1.52±0.67	0.062
QCT-vBMD (mg/cm³)	139.33±29.96	100.54±12.54	**<0.001**	129.17±28.88	107.71±22.52	**<0.001**
PMW (mm)	119.94±9.19	105.50±9.19	**<0.001**	105.21±4.81	94.84±7.05	**<0.001**

BMI, body mass index; CCI, Charlson co-morbidity index; PEEK polyetheretherketone; n -HA/PA66. nano-hydroxyapatite/polyamide66; QCT-vBMD, volumetric bone mineral density measured by quantitative computed tomography; PMW, psoas muscle width

Bold font indicates statistically significant.

Table 3. Multivariable logistic regression analysis with interaction between PMW-C and Sex

	B	SE	Wald	Odds ratio	95% Confidence interval	p
Age	0.023	0.022	1.120	1.023	0.981, 1.067	0.097
Sex	-0.210	0.064	10.743	0.811	0.715, 0.919	**0.001**
BMI	-0.047	0.072	0.425	0.954	0.828, 1.099	0.514
Hypertension	0.225	0.533	0.178	1.252	0.441, 3.558	0.673
Diabetes	1.061	0.567	3.499	2.889	0.951, 8.781	0.061
QCT-vBMD	-0.035	0.010	13.069	0.965	0.947, 0.984	**<0.001**
PMW-C	-0.239	0.051	22.321	0.787	0.713, 0.869	**<0.001**
PMW-C*Sex	0.065	0.065	0.979	1.067	0.939, 1.213	0.322

QCT-vBMD, volumetric bone mineral density measured by quantitative computed tomography; PMW-C, psoas muscle width centering;

Bold font indicates statistically significant.

Table 4. Multivariable logistic regression analysis of patients

	B	SE	Wald	Odds ratio	95% Confidence interval	p
Age	0.024	0.021	1.329	1.024	0.983, 1.067	0.249
Sex	-0.178	0.053	11.230	0.837	0.755, 0.929	**<0.001**
BMI	-0.056	0.071	0.610	0.946	0.822, 1.088	0.435
Hypertension	0.315	0.519	0.369	1.371	0.496, 3.791	0.543
Diabetes	1.021	0.560	3.317	2.775	0.965, 8.321	0.069
QCT-vBMD	-0.036	0.010	13.792	0.965	0.947, 0.983	**<0.001**
PMW	-0.204	0.032	40.016	0.815	0.765, 0.869	**<0.001**

QCT-vBMD, volumetric bone mineral density measured by quantitative computed tomography; PMW, psoas muscle width

Bold font indicates statistically significant.

Figure 1. PMW measured on anteroposterior lumbar spine radiographs of L3

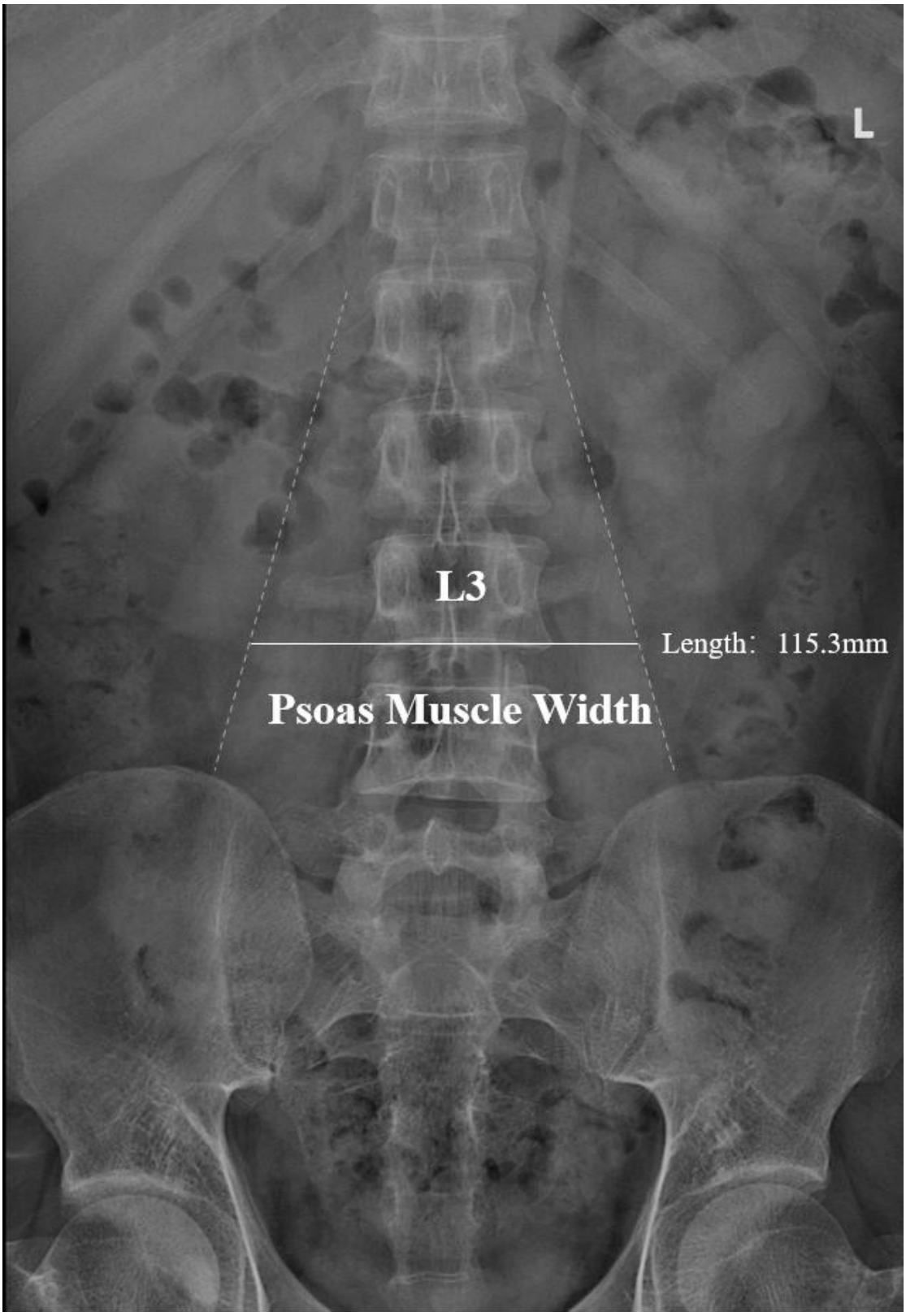


Figure 2. Receiver operating characteristic curves to assess the ability of PMW to predict cage subsidence in male patients (A) and female patients (B).

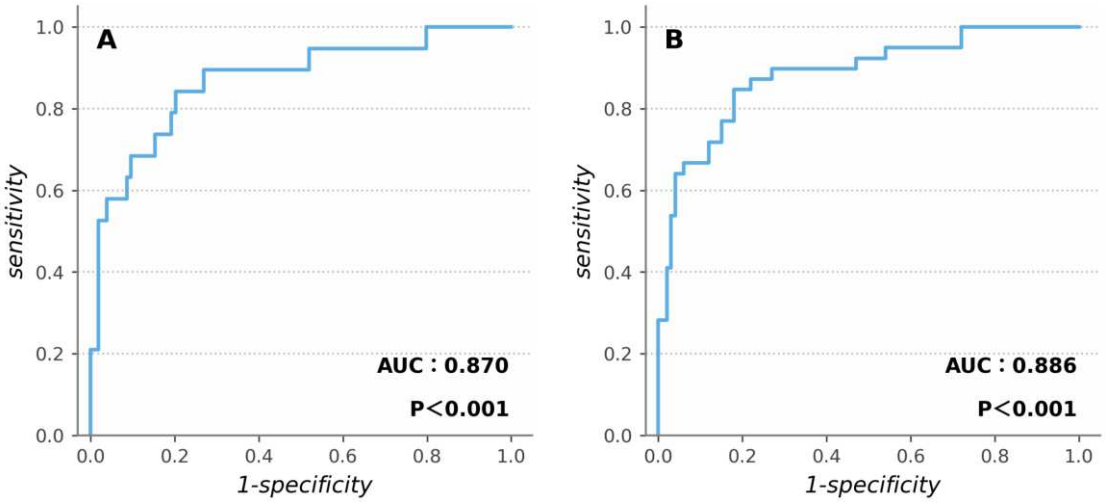
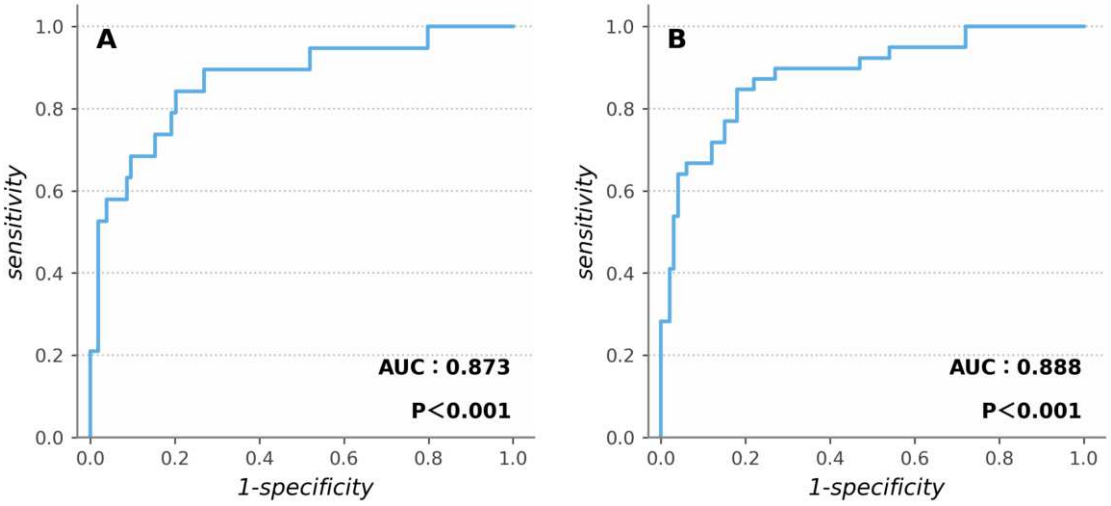


Figure 3. Receiver operating characteristic curves with bootstrap internal validation (1,000 resamples) to assess the ability of PMW to predict cage subsidence in male patients (A) and female patients (B).



References

1. Hicks GE, Morone N, Weiner DK. Degenerative lumbar disc and facet disease in older adults: Prevalence and clinical correlates. Spine. 2009;34(12):1301-6. https://doi.org/10.1097/BRS.0b013e3181a18263.

2. Weiler C, Lopez-Ramos M, Mayer HM, Korge A, Siepe CJ, Wuertz K, et al. Histological analysis of surgical lumbar intervertebral disc tissue provides evidence for an association between disc degeneration and increased body mass index. BMC Research Notes. 2011;4. https://doi.org/10.1186/1756-0500-4-497.

3. Wasinpongwanich K, Nopsopon T, Pongpirul K. Surgical Treatments for Lumbar Spine Diseases (TLIF vs. Other Surgical Techniques): A Systematic Review and Meta-Analysis. Frontiers in surgery. 2022;9:829469. https://doi.org/10.3389/fsurg.2022.829469.

4. Drossopoulos PN, Ononogbu-Uche FC, Tabarestani TQ, Huang CC, Paturu M, Bardeesi A, et al. Evolution of the Transforaminal Lumbar Interbody Fusion (TLIF): From Open to Percutaneous to Patient-Specific. Journal of clinical medicine. 2024;13(8). https://doi.org/10.3390/jcm13082271.

5. Bartlett AM, Shabana S, Folz CC, Paturu M, Shaffrey CI, Quist P, et al. Optimizing TLIF Approach Selection: An Algorithmic Framework with Illustrative Cases. Journal of clinical medicine. 2025;14(12). https://doi.org/10.3390/jcm14124209.

6. Li Q, Long X, Shi L, Wang Y, Guan T, Lv J, et al. Prevalence and risk factors for cage subsidence after lumbar interbody fusion: A protocol for systematic review and meta-analysis. Medicine. 2021;100(49):e28085. https://doi.org/10.1097/md.0000000000028085.

7. Dinh HTP, Ushirozako H, Hasegawa T, Ebata S, Ohba T, Oba H, et al. Risk Factors and Consequences of Cage Subsidence after Single-level Posterior or Transforaminal Lumbar Interbody Fusion: A Retrospective Multicenter Study. Spine surgery and related research. 2025;9(3):339-49. https://doi.org/10.22603/ssrr.2024-0241.

8. Parisien A, Wai EK, ElSayed MSA, Frei H. Subsidence of Spinal Fusion Cages: A Systematic Review. International journal of spine surgery. 2022;16(6):1103-18. https://doi.org/10.14444/8363.

9. Ali Baig R, Quiceno E, Soliman MAR, Aguirre AO, Okai BK, Kuo CC, et al. Definition of cage subsidence in transforaminal lumbar interbody fusion (TLIF) approach and posterior lumbar interbody fusion (PLIF) approach – A systematic review. Journal of Clinical Neuroscience. 2025;133:111048. https://doi.org/https://doi.org/10.1016/j.jocn.2025.111048.

10. Tempel ZJ, McDowell MM, Panczykowski DM, Gandhoke GS, Kojo Hamilton D, Okonkwo DO, et al. Graft subsidence as a predictor of revision surgery following stand-alone lateral lumbar interbody fusion. Journal of Neurosurgery: Spine. 2018;28(1):50-6. https://doi.org/10.3171/2017.5.SPINE16427.

11. Amorim-Barbosa T, Pereira C, Catelas D, Rodrigues C, Costa P, Rodrigues-Pinto R, et al. Risk factors for cage subsidence and clinical outcomes after transforaminal and posterior lumbar interbody fusion. European Journal of Orthopaedic Surgery & Traumatology. 2022;32(7):1291-9. https://doi.org/10.1007/s00590-021-03103-z.

12. Han G, Fan Z, Yue L, Zou D, Zhou S, Qiu W, et al. Paraspinal muscle endurance and morphology (PMEM) score: a new method for prediction of postoperative mechanical complications after lumbar fusion. The Spine Journal. 2024;24(10):1900-9. https://doi.org/10.1016/j.spinee.2024.05.010.

13. Gengyu H, Jinyue D, Chunjie G, Bo Z, Yu J, Jiaming L, et al. The predictive value of preoperative paraspinal muscle morphometry on complications after lumbar surgery: a systematic review. European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society. 2022;31(2):364-79. https://doi.org/10.1007/s00586-021-07052-3.

14. Weng SE, Huang YW, Tseng YC, Peng HR, Lai HY, Akishita M, et al. The Evolving Landscape of Sarcopenia in Asia: A Systematic review and meta-analysis following the 2019 Asian working group for sarcopenia (AWGS)

diagnostic criteria. Archives of gerontology and geriatrics. 2025;128:105596. https://doi.org/10.1016/j.archger.2024.105596.
15. Petermann-Rocha F, Balntzi V, Gray SR, Lara J, Ho FK, Pell JP, et al. Global prevalence of sarcopenia and severe sarcopenia: a systematic review and meta-analysis. Journal of cachexia, sarcopenia and muscle. 2022;13(1):86-99. https://doi.org/10.1002/jcsm.12783.
16. Gebrewold Y, Tesfaye B. Does lumbar MRI predict degree of disability in patients with degenerative disc disease? A prospective cross-sectional study at University of Gondar comprehensive specialized hospital, North West Ethiopia, 2020. BMC medical imaging. 2022;22(1):138. https://doi.org/10.1186/s12880-022-00866-7.
17. Lee SH, Park SW, Kim YB, Nam TK, Lee YS. The fatty degeneration of lumbar paraspinal muscles on computed tomography scan according to age and disc level. The Spine Journal. 2017;17(1):81-7. https://doi.org/10.1016/j.spinee.2016.08.001.
18. Si F, Wang T, Zang L, Yuan S, Du P, Fan N, et al. Characteristics of paraspinal muscle fat infiltration in asymptomatic Chinese adults: a cross-sectional study. Quantitative imaging in medicine and surgery. 2023;13(7):4526-39. https://doi.org/10.21037/qims-22-1131.
19. Nassar JE, Farias MJ, Hostin R, Gupta MC, Klineberg EO, Mundis GM, et al. Full-Body Radiographic Imaging-Based Thigh Muscle Measurement for Sarcopenia. 2026. https://doi.org/10.1097/brs.0000000000005777.
20. Kataoka T, Okamoto T, Matsuda SJJOB, SURGERY J. Radiographic Measurement of Psoas Muscle Width: A Simple and Reliable Screening Tool for Sarcopenia. 2026. https://doi.org/10.2106/jbjs.25.01094.
21. Kalender WA, Klotz E, Suess C. Vertebral bone mineral analysis: an integrated approach with CT. Radiology. 1987;164(2):419-23. https://doi.org/10.1148/radiology.164.2.3602380.
22. Weir VJ. Bone Densitometry Imaging. In: Zhang J, editor. Quality and Patient Safety in Medical Imaging: A Modality-Based Approach. Cham: Springer Nature Switzerland; 2025. p. 65-75.
23. Pfirrmann C, Metzdorf A, Zanetti M, Hodler J, Boos N. Magnetic Resonance Classification of Lumbar Intervertebral Disc Degeneration. Spine. 2001;26:1873-8. https://doi.org/10.1097/00007632-200109010-00011.
24. Han G, Zou D, Li X, Zhang S, Li Z, Zhou S, et al. Can fat infiltration in the multifidus muscle be a predictor of postoperative symptoms and complications in patients undergoing lumbar fusion for degenerative lumbar spinal stenosis? A case-control study. Journal of orthopaedic surgery and research. 2022;17(1):289. https://doi.org/10.1186/s13018-022-03186-2.
25. Choi MK, Kim SB, Park CK, Malla HP, Kim SM. Cross-Sectional Area of the Lumbar Spine Trunk Muscle and Posterior Lumbar Interbody Fusion Rate: A Retrospective Study. Clin Spine Surg. 2017;30(6):E798-e803. https://doi.org/10.1097/bsd.0000000000000424.
26. Wilke HJ, Wolf S, Claes LE, Arand M, Wiesend A. Stability increase of the lumbar spine with different muscle groups. A biomechanical in vitro study. Spine. 1995;20(2):192-8. https://doi.org/10.1097/00007632-199501150-00011.
27. Yang Q, Yan D, Wang L, Li K, Liang W, Zhang W, et al. Muscle fat infiltration but not muscle cross-sectional area is independently associated with bone mineral density at the lumbar spine. The British journal of radiology. 2022;95(1134):20210371. https://doi.org/10.1259/bjr.20210371.
28. Sun G, Dai Y, Liu L, Du Y, Jiang P, Li X, et al. Fatty infiltration and cross-sectional area as indicators of muscle mass in osteoporosis: a meta-regression study. Frontiers in endocrinology. 2025;16:1651505. https://doi.org/10.3389/fendo.2025.1651505.
29. Goodpaster BH, Park SW, Harris TB, Kritchevsky SB, Nevitt M, Schwartz AV, et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. The journals of gerontology Series A, Biological sciences and medical sciences. 2006;61(10):1059-64. https://doi.org/10.1093/gerona/61.10.1059.

30. Crawford RJ, Filli L, Elliott JM, Nanz D, Fischer MA, Marcon M, et al. Age- and Level-Dependence of Fatty Infiltration in Lumbar Paravertebral Muscles of Healthy Volunteers. AJNR American journal of neuroradiology. 2016;37(4):742-8. https://doi.org/10.3174/ajnr.A4596.
31. Alswat KA. Gender Disparities in Osteoporosis. Journal of clinical medicine research. 2017;9(5):382-7. https://doi.org/10.14740/jocmr2970w.
32. Davis SR, Pinkerton J, Santoro N, Simoncini T. Menopause—Biology, consequences, supportive care, and therapeutic options. Cell. 2023;186(19):4038-58. https://doi.org/10.1016/j.cell.2023.08.016.
33. Wang W, Li W. [Radiographic parameters and influencing factors of paraspinal muscle degeneration in healthy people]. Zhongguo xiu fu chong jian wai ke za zhi = Zhongguo xiufu chongjian waike zazhi = Chinese journal of reparative and reconstructive surgery. 2024;38(7):880-8. https://doi.org/10.7507/1002-1892.202402060.
34. Schlaeger S, Inhuber S, Rohrmeier A, Dieckmeyer M, Freitag F, Klupp E, et al. Association of paraspinal muscle water-fat MRI-based measurements with isometric strength measurements. European radiology. 2019;29(2):599-608. https://doi.org/10.1007/s00330-018-5631-8.