Journal of Pain Research

Dovepress
Taylor & Francis Group

Open Access Full Text Article

ORIGINAL RESEARCH

Multifidus Muscle Atrophy Predicts Spinal Cage Subsidence After Lumbar Fusion

Cong Zhang[1,2], Chengming Li[1], Xiaotao Wu[1], Xiaozhi Sun[3]

[1]Department of Spine Surgery, Zhongda Hospital, School of Medicine, Southeast University, Nanjing, Jiangsu, People's Republic of China; [2]Division of Sports Medicine and Adult Reconstructive Surgery, Department of Orthopedic Surgery, Nanjing Drum Tower Hospital, Affiliated Hospital of Medical School, Nanjing University, Nanjing, Jiangsu, People's Republic of China; [3]Department of Orthopedics, Yizheng Hospital of Traditional Chinese Medicine, Yizheng, Jiangsu, People's Republic of China

Correspondence: Xiaozhi Sun, Department of orthopedics, Yizheng Hospital of Traditional Chinese Medicine, Yizheng, Jiangsu, 211400, People's Republic of China, Tel +86-15950562358, Email sxz311@126.com

Objective: Degenerative lumbar spondylolisthesis (DLS) is a common degenerative disease that causes low back pain and lower extremity pain. Transforaminal Lumbar Interbody Fusion (TLIF) is an effective surgical method for treating this condition. However, postoperative complications exist, such as cage subsidence, whose causes are complex. This study investigated the characteristics and risk factors of cage subsidence after TLIF in DLS patients.

Methods: A total of 131 TLIF patients were divided into the subsidence group (subsidence group, n=39) and the non-subsidence group (non-subsidence group, n=92). General patient data were collected, including sex, age, body mass index (BMI), surgical time, intraoperative blood loss, hypertension and diabetes. The imaging data collected included the degree of multifidus muscle atrophy (MMA) at the surgical segment preoperatively; the lumbar lordosis angle, segmental lordosis angle, and intervertebral height before surgery, immediately after surgery, and 12 months postoperatively. Univariable analysis and multivariable logistic regression analysis were used to identify independent risk factors for subsidence after TLIF in patients with DLS.

Results: The degree of MMA before surgery in the subsidence group was significantly greater than that in the non-subsidence group ($p < 0.001$). There were statistically significant differences in the final follow-up Visual Analogue Scale (VAS) scores for lower back pain and postoperative Oswestry Disability Index (ODI) scores between the two groups. Intervertebral height correction (OR=11.19, p=0.0001), segmental lordosis angle correction (OR=3.43, p=0.0001), and MMA (OR=0.73, p=0.003) were all independent risk factors for cage subsidence.

Conclusion: Intervertebral height correction, segmental lordosis angle correction and MMA were identified as independent risk factors for cage subsidence after TLIF in patients with DLS. In clinical practice, preoperative physiotherapy and core muscle strengthening training aimed at improving the quality of the multifidus muscle can reduce MMA. Meanwhile, selecting an appropriate height for the interbody fusion cage and avoiding excessive correction of the lordotic angle can be used to reduce the incidence of interbody fusion cage subsidence after TLIF and improve patients' clinical outcomes.

Keywords: lumbar vertebrae, spondylolysis, degenerative lumbar spondylolisthesis, osteoporosis, multifidus muscle

Introduction

DLS patients often experience varying degrees of lower back pain, leg pain, and neurogenic claudication. The prevalence in the general population ranges from 4.1% to 11.1%, with an increased incidence after the age of 45, and a higher occurrence in females, with a sex ratio of approximately 1:4 to 1:5.[1,2] For those with milder symptoms, conservative treatments can be considered early on, such as bed rest, the use of analgesics, and strengthening exercises for the back muscles.[3,4] When conservative treatment is ineffective or symptoms recur or worsen, surgical intervention becomes the primary treatment option. Currently, the main surgical treatment method is lumbar fusion surgery, for which there are various techniques: anterior lumbar interbody fusion (ALIF), posterior lumbar interbody fusion (PLIF), extreme lateral interbody fusion (XLIF), and transforaminal lumbar interbody fusion (TLIF).[5] These procedures effectively decompress

https://doi.org/10.2147/JPR.S534086
Received: 12 April 2025
Accepted: 14 January 2026
Published: 20 January 2026

the spinal canal and restore the correct sagittal and coronal alignment of the spine by realigning the affected vertebrae and encouraging interbody fusion; screw fixation is often applied for robust support.

Each of these surgical methods has its own advantages and disadvantages. For example, the traditional TLIF technique requires extensive dissection of the paravertebral muscle tissue, particularly the innermost multifidus muscle, leading to direct damage and denervation of this muscle.[6] Applying this approach via the natural space between the multifidus and longissimus muscles (applying the Wiltse approach) involves resecting a portion of the facet joint on one side during the procedure.[7] This reduces the traction on and stimulation of the nerve roots and dural sac, while preserving the ligamentous complex structure at the back of the spine, thereby minimising the impact on spinal stability to some extent.[8] At the same time, this strategy reduces the dissection and retraction of the multifidus muscle, thereby lowering the risk of damaging it and preserving its function as much as possible. This method is minimally invasive and has become an ideal method for treating degenerative lumbar diseases.[9]

Previous studies have reported that cage subsidence after lumbar fusion surgery can lead to weakened anterior column support, loss of intervertebral height, decreased local segmental lordosis, laxity of ligament folds, non-fusion of the grafts at the surgical segment, and the formation of pseudarthrosis, all of which can affect surgical efficacy and even lead to revision surgery.[10–12] The incidence of cage subsidence following TLIF ranged from 15.43% to 32.12%. There is significant variability in these rates and no consensus has been reached.[13–16] In addition, many factors influence subsidence, including age, BMI, surgical technique, implant type, and many other factors. There is considerable debate regarding the factors that influence subsidence, and the results of interventions have often been unsatisfactory, necessitating further investigation.[17–20]

There is a close association between MMA and DLS. However, it remains unclear whether atrophy of the multifidus muscle at the surgical segment prior to surgery in DLS patients impacts cage subsidence. At the same time, considering that subsidence can have a very adverse effect on the postoperative outcomes of TLIF, it is clinically important to explore the independent risk factors for this phenomenon as well as preventive measures from the perspective of muscular imbalance and atrophy.

Data and Methods

Collection of General Information

A retrospective analysis was conducted on patients with DLS who underwent surgical treatment in the Department of Spine Surgery of Zhongda Hospital, Southeast University, Nanjing, China, from September 2020 to January 2022. To exclude the potential influence of cage subsidence after TLIF in different segments of DLS, we only collected cases of single-segment DLS at the L4/5 level, where the incidence of spondylolisthesis is highest. We excluded cases who experienced significant damage to the bony endplate during surgery and those lost to follow-up after surgery. Ultimately, 131 DLS patients were included in the study. Among these patients, there were 32 males and 99 females, resulting in a male-to-female ratio of approximately 1:3, with ages ranging from 51 to 82 years and a mean age of 63.8 years.

All patients underwent TLIF surgery using the Wiltse approach and were divided into two groups based on whether the cage subsided at 12 months postoperatively: the subsidence group (loss of intervertebral height ≥ 2 mm) and the non-subsidence group (loss of intervertebral height < 2 mm). General patient information was collected, including age, sex, BMI, and the presence/absence of osteoporosis (DXA T-score and clinical history), hypertension, and diabetes. Imaging data were used to record each patient's intervertebral space height, lumbar lordosis angle, segmental lordosis angle, MMA, surgical duration, and intraoperative blood loss at various preoperative and postoperative time points. The incidence of cage subsidence were followed up at 12 months postoperatively. All subjects were informed of the specifics of this study and provided consent. The study complied with the principles outlined in the Declaration of Helsinki and was approved by the Ethical Committee of the Zhongda Hospital, Southeast University (NO.2019ZDSYLL101-P01).

Intervertebral space height was measured as the average height of the anterior and posterior edges of the intervertebral space at the surgical segment (see Figure 1). Segmental lordosis (SL) was measured as the angle between the tangent lines of the upper endplate of the upper vertebra and the lower endplate of the lower vertebra at the treatment segment.

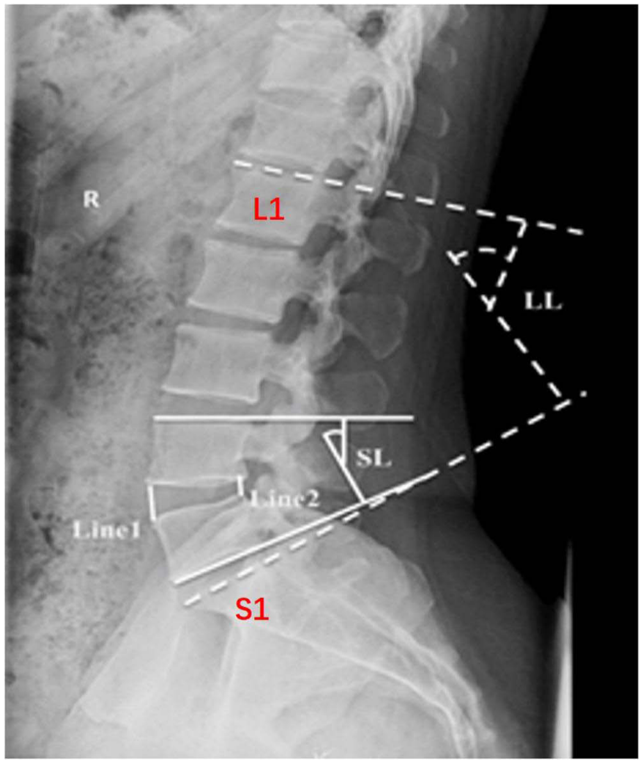

Figure 1 Parameter measurements. Lumbar lordosis (LL, dotted lines), the angle formed by the extended lines of the upper endplate of the L1 vertebra and the upper endplate of the S1 vertebra; segmental lordosis (SL, solid lines), the angle between the tangent lines of the upper endplate of the upper vertebra and the lower endplate of the lower vertebra at the fused segment; intervertebral space height, the average of the anterior height of the intervertebral space (Line 1) and the posterior height of the intervertebral space (Line 2).

Lumbar lordosis (LL) was taken as the angle formed by the extended lines of the upper endplate of the L1 vertebra and the upper endplate of the S1 vertebra.

For MMA measurements, all patients with spondylolisthesis underwent standardised scanning using a 3.0 T Siemens MRI scanner (Siemens Healthcare, Erlangen, Germany). T2-weighted images were obtained at the L3/4, L4/5, and L5/S1 intervertebral disc levels, corresponding to the maximal cross-sectional area of the paravertebral muscles. The cross-sectional area of the multifidus muscle on both sides of the lumbar spine was measured at the specified levels using ImageJ software (National Institutes of Health, Bethesda, MD, USA) and summed to determine the gross cross-sectional area (GCSA). Click on the threshold button of Image J software and adjust it until the fat infiltration area in the image is completely covered. Similarly, the lean cross-sectional area (LCSA) of the multifidus muscle on both sides was measured and summed to represent the total LCSA (Figure 2). The degree of MMA was calculated as the ratio of LCSA to GCSA (LCSA/GCSA), with a higher ratio indicating milder atrophy and a lower ratio indicating more severe atrophy.

Cage subsidence was determined as follows. For the surgical fusion segment, if postoperative X-rays in the standing lateral, flexion and extension positions, or three-dimensional reconstructed CT scans of the lumbar spine at 12 months after surgery, showed that the metal marker of the cage had sunk into the adjacent upper and lower endplates with a total displacement $\geq$ 2 mm, it was considered cage subsidence; if the displacement was $<$ 2 mm, it was not considered subsidence[21,22] (Figure 3).

Inclusion and Exclusion Criteria

Patients presenting with single-segment degenerative spondylolisthesis at the L4/5 level who were over the age of 45 years were included. All participants were required to have complete imaging data available both before and after their surgical intervention. Furthermore, only those with a postoperative follow-up period of at least 12 months were eligible. Patients associated with the following were excluded: insufficient follow-up time or incomplete imaging data; individuals

 https://doi.org/10.2147/JPR.S534086

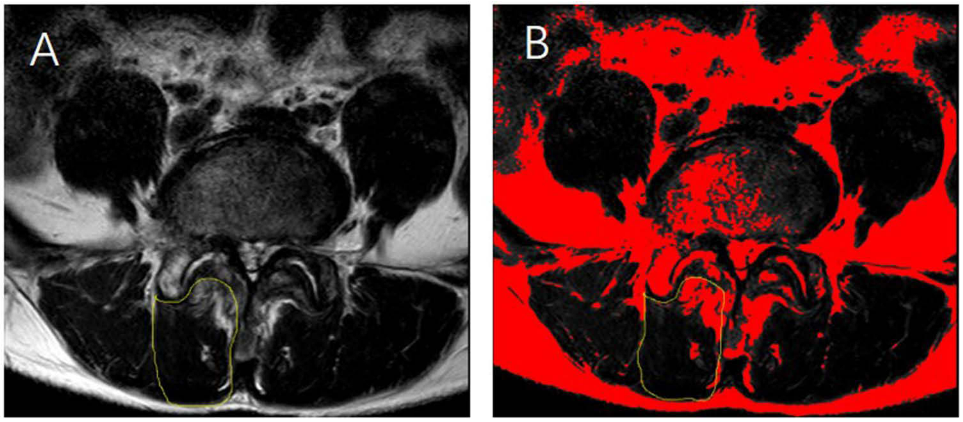

Figure 2 Axial T2-weighted magnetic resonance imaging (MRI) of a 65-year-old female patient, illustrating (**A**) the area of the multifidus muscle at the L4/5 level, outlined in yellow and (**B**) the area of fat infiltration within the multifidus muscle highlighted in red. The MMA ratio (LCSA/GCSA) is calculated by summing the measured areas on both sides of the lumbar spine.

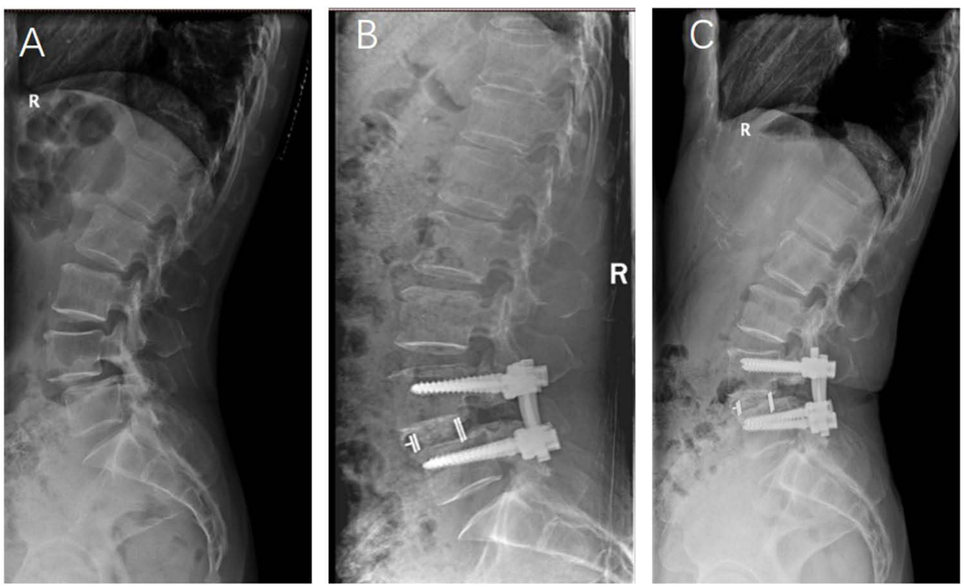

Figure 3 A 62-year-old female patient. (**A**) Preoperative lateral X-ray of the lumbar spine indicating degenerative spondylolisthesis at the L4 vertebra; (**B**) postoperative X-ray of the lumbar spine 1 week after TLIF surgery showing recovery of the intervertebral space height at the surgical segment, with good positioning of the screws and rods, and no anteroposterior sliding or subsidence of the cage; (**C**) X-ray of the lumbar spine at the last follow-up indicating significant loss of intervertebral height at the surgical segment, with notable cage subsidence.

with a history of trauma to the lumbar spine or previous lumbar spine surgery, with isthmic spondylolisthesis or a history of primary or metastatic tumours of the spine, with severe spinal deformity, significant bony endplate destruction, Modic changes or Schmorl's nodes at the surgical segment, or a history of ankylosing spondylitis, rheumatoid arthritis, or spinal tuberculosis. Finally, any patient who experienced injury to the upper and lower cartilaginous endplates of the vertebrae during the surgery was also excluded.

Operative Method

After successful anaesthesia, the patient was placed in the prone position. A C-arm X-ray machine was used for fluoroscopic localisation of the spondylolisthesis segment. The surgical area was routinely disinfected and draped, and a midline vertical incision was made to cut through the skin and subcutaneous fascia, reaching the lumbar fascia. The space between the multifidus and longissimus muscles was palpated approximately 2.5–3.0 cm lateral to the spinous process and then blunt dissection was performed. Then the bilateral natural interval between the multifidus and longissimus muscles was exposed to reveal the facet joints and the screw entry points (applying the Wiltse approach) where pedicle screws are inserted. An ultrasound osteotome was used to remove part of the bilateral laminae, allowing exploration of the dural sac and nerve roots, followed by discectomy. The spondylolisthesis vertebra was reduced carefully, to avoid pulling the screws out in patients with severe osteoporosis. After irrigating the intervertebral space with saline, autologous bone was implanted, and a straight PEEK cage (Medtronic Sofamor Danek) filled with autologous bone was inserted, along with a titanium rod, which was locked into place. During the procedure, the C-arm X-ray machine was used to confirm satisfactory positions of the screws and cage. The incision was closed in layers and bandaged. All surgeries were performed by the same experienced attending physician and team.

Postoperative Care and Rehabilitation

All patients received an intravenous infusion of 1 g cefazolin sodium before and after surgery. Routine postoperative treatments included analgesia and neuro-nutritional therapy. During bed rest, patients performed straight leg raises to prevent venous thrombosis in the lower limbs. If the drainage amount was less than 50 mL within 48 h after surgery, the drainage tube was removed, and lumbar X-rays in both the anteroposterior and lateral views were repeated. After the drainage tube was removed, patients could wear a lumbar support brace and start ambulating. Patients with osteoporosis were given fundamental anti-osteoporosis treatment postoperatively (calcium tablet and vitamin D).

Observation Indicators

We recorded the following general data of patients with DLS: surgical-related data, including operation time and intraoperative blood loss; preoperative and postoperative parameters (12 months after surgery) of lumbar vertebrae in the sagittal sequence, such as preoperative intervertebral height, intervertebral height correction, preoperative lumbar lordosis angle, lumbar lordosis angle correction, loss of lumbar lordosis angle at last follow-up, preoperative segmental lordosis angle of the surgical segment, correction of the segment lordosis angle, and loss of segment lordosis angle; the degree of atrophy of multifidus muscles in the surgical segment preoperatively; the incidence of cage subsidence at follow-up.

Statistical Analysis

Quantitative data are expressed as mean ± standard deviation. Between-group comparisons were conducted using t-tests or rank-sum tests depending on whether the variables met the assumptions of normal distribution and homogeneity of variance (Shapiro–Wilk test and Kolmogorov–Smirnov test). Qualitative data are expressed as frequency and percentage, and between-group comparisons were conducted using χ^2 tests or Fisher's exact probability method. A P value < 0.05 was considered statistically significant. Statistical analyses were performed using SPSS 20.0 software (IBM Corporation, Armonk, NY, USA).

Univariable and multivariable logistic regression analyses were employed to identify the risk factors for cage subsidence. The dependent variable was the occurrence of cage subsidence (a binary outcome: yes or no). Independent variables included in the initial univariable analysis were selected based on clinical relevance and previous literature, encompassing general patient data (eg, age, sex, BMI, osteoporosis, hypertension, diabetes), surgical parameters (eg, operation time, blood loss), and radiographic measurements (eg, preoperative intervertebral height, intervertebral height correction, segmental lordosis angle correction, multifidus muscle atrophy (MMA)). Variables that showed a significance level of P < 0.05 in the univariable analysis were included in the initial multivariable logistic regression model. A backward stepwise selection method (likelihood ratio test, with a removal criterion of P > 0.05) was used to identify independent risk factors by eliminating non-significant variables sequentially. The results are presented as odds ratios (OR) with 95% confidence intervals (CI). The basic assumptions of logistic regression were checked. The continuous independent variables were assessed for linearity with the logit of the dependent variable using the Box-Tidwell test. No significant non-linear relationships were found.

https://doi.org/10.2147/JPR.S534086

Multicollinearity among the independent variables was diagnosed using the variance inflation factor (VIF); a VIF value of less than 10 was considered to indicate no substantial multicollinearity.

Results

Comparison of General Data

There were no statistically significant differences between the two groups in terms of BMI, operation time, intraoperative blood loss, and the presence/absence of diabetes and hypertension. However, there were statistically significant differences (P < 0.05) in age, sex, and osteoporosis between the two groups (Table 1).

Comparison of Imaging Indicators

There were no statistically significant differences in the preoperative disc height, lumbar lordosis angle, or segmental lordosis angle of the surgical segment between the groups. However, at the last follow-up, there were statistically significant differences (P < 0.001) in intervertebral height correction, lordosis angle correction and loss of lumbar lordosis angle, and lordosis angle correction and loss of segment lordosis angle. The MMA was significantly (P < 0.001) greater in the subsidence group than in the non-subsidence group (Table 2).

Table 1 Comparison of General Data

Variable	Subsidence Group (n=39)	Non-Subsidence Group (n=92)	*P*
Age	66.15±7.90	62.80±7.83	0.027
Male, n (%)	4 (10.26%)	28 (30.43%)	0.014
BMI (kg/m^2)	25.85±3.43	24.87±3.03	0.104
Osteoporosis, n (%)	31 (79.49%)	47 (51.09%)	0.002
Diabetes, n (%)	14 (35.90%)	22 (23.91%)	0.16
Hypertension, n (%)	17 (43.59%)	47 (51.09%)	0.432
Intraoperative blood loss (mL)	219.74±98.50	233.15±99.80	0.482
Follow-up time	13.05±1.19	12.99±1.09	0.773

Notes: The value is presented as mean ± SD, and n (%). p-value corresponds to independent *t*-test or Mann–Whitney *U*-test and chi-square test or Fisher exact test.
Abbreviations: BMI, body mass index.

Table 2 Comparison of Imaging-Related Indicators

Variable	Subsidence Group (n=39)	Non-Subsidence Group (n=92)	P
Preoperative intervertebral height (mm)	7.46±0.93	7.63±0.82	0.313
Intervertebral height correction (mm)	3.99±0.92	3.31±0.83	0.001
Preoperative lumbar lordosis angle (°)	37.49±3.28	38.41±3.16	0.132
Lordosis angle correction (°)	7.21±1.64	6.16±1.36	0.001
Loss of lumbar lordosis angle (°)	4.59±1.86	2.68±1.56	0.001
Preoperative segmental lordosis angle (°)	11.54±3.69	12.33±3.22	0.223
Lordosis angle correction (°)	5.54±1.90	3.85±1.62	0.001
Loss of segment lordosis angle (°)	2.79±1.38	2.02±1.28	0.003
MMA ratio	0.43±0.09	0.62±0.06	0.001

Notes: The value is presented as mean ± SD, and n (%). p-value corresponds to independent *t*-test or Mann–Whitney *U*-test and chi-square test or Fisher exact test.
Abbreviations: MMA, multifidus muscle atrophy.

Clinical Efficacy

Neither group of patients experienced severe complications such as nerve or vascular injury during surgery. Three patients had cerebrospinal fluid leaks during the procedure, which resolved with conservative treatment before discharge. Within 1 week postoperatively, the patients underwent re-examinations with lumbar X-rays, which showed satisfactory reduction of the spondylolisthesis and good restoration of spinal alignment. During the follow-up period, there were no significant signs of rod or screw loosening or breakage. In all, 39 patients experienced cage subsidence, while 92 did not, a subsidence rate of 29.77%. There were no statistically significant differences between the two groups in preoperative VAS and ODI scores for lower back pain or leg pain. In addition, there were statistically significant differences in the final follow-up VAS scores for lower back pain and postoperative ODI scores between the two groups ($P < 0.05$; Table 3). Although the final scores differed, it cannot be concluded that the cage subsidence caused worse clinical outcomes, as there were no significant differences in baseline scores or degree of improvement.

Univariable Analysis of Factors Affecting Cage Subsidence

In univariable logistic regression analyses, age, osteoporosis, intervertebral height correction, lumbar lordosis angle correction, loss of lumbar lordosis angle at the last follow-up, segment lordosis angle correction, and loss of segment lordosis angle were all risk factors for cage subsidence after TLIF in patients with DLS ($P < 0.05$; Table 4).

Multivariable Logistic Regression Analysis of Independent Risk Factors for Cage Subsidence

In multivariable logistic regression analyses, MMA ratio (OR=0.73, 95% CI: 0.64–0.82, p=0.012), intervertebral height correction (OR=11.19, 95% CI: 3.56–48.85, p=0.0001), and lordosis correction at the surgical segment (OR=3.43, 95% CI: 1.82–6.45, p=0.0001) were independent risk factors for cage subsidence after TLIF in patients with DLS (Table 5).

Table 3 Comparison of Clinical Efficacy

Variable	Subsidence Group (n=39)	Non-Subsidence Group (n=92)	*P*
Preoperative VAS scores for lower back pain	7.43±0.71	7.11±0.93	0.465
VAS score for lower back pain at the last follow-up	2.46±0.68	2.04±0.80	0.005
Preoperative VAS scores for leg pain	6.36±1.28	6.49±1.16	0.616
VAS scores for leg pain at the last follow-up	1.79±0.74	1.82±0.68	0.837
Preoperative ODI score	59.23±9.84	56.30±9.91	0.124
Postoperative ODI score at the last follow-up	27.22±5.70	23.75±6.81	0.006

Notes: The value is presented as mean ± SD, p-value corresponds to independent *t*-test.
Abbreviations: VAS, Visual Analogue Scale; ODI, Oswestry Disability Index.

Table 4 Results of Univariable Logistic Regression Analysis

Variable	OR value	95% CI	*P*
Age	1.06	1.01–1.11	0.029
Osteoporosis	3.71	1.54–8.93	0.0034
MMA ratio	0.72	0.64–0.82	0.001
Intervertebral height correction	2.34	1.49–3.68	0.0002
Lumbar lordosis angle correction (°)	1.62	1.23–2.13	0.0006
Loss of lumbar lordosis angle (°)	1.87	1.44–2.42	< 0.0001
Segment lordosis angle correction (°)	1.69	1.33–2.13	< 0.0001
Loss of segment lordosis angle (°)	1.52	1.15–2.02	0.0037

Abbreviation: MMA, multifidus muscle atrophy.

 https://doi.org/10.2147/JPR.S534086

Table 5 Multivariable Logistic Regression Analysis

Variable	OR value	95% CI	*P*
MMA ratio	0.73	0.64–0.82	0.012
Intervertebral height correction	11.19	3.56–48.85	0.0001
Segment lordosis angle correction	3.43	1.82–6.45	0.0001

Abbreviation: MMA, multifidus muscle atrophy.

Considering potential multicollinearity during multivariable modelling, we performed a collinearity diagnosis for the continuous variables mentioned above. The variance inflation factor values for each variable were all less than 10, indicating no collinearity among the factors. The final results are shown in Table 5.

Discussion

Cage subsidence may occur after TLIF surgery, with an average time of 7.2 months postoperatively.[13] In the case of XLIF, it generally occurs within the first 1.5 months after surgery, with few new occurrences after 3 months.[23] For ALIF, most cases occur within 3 months after surgery. Over time, the incidence does not significantly increase.[24] A follow-up period of 12 months was selected for the assessment of cage subsidence to ensure sufficient time for interbody fusion to mature and to capture late-onset subsidence events, as previous literature suggests that most subsidence occurs within the first year postoperatively.[13,23–25]

Our multivariable logistic regression analyses indicated that MMA, intervertebral height correction, and segment lordosis correction are independent risk factors for cage subsidence after TLIF surgery in patients with DLS.

Intervertebral height correction is a risk factor for cage subsidence. There are several possible reasons for this. To improve a patient's intervertebral stenosis and nerve root symptoms, the surgeon might excessively increase the height of the intervertebral space during surgery. This can also occur due to incorrect placement of the fusion cage. Furthermore, a large amount of bone graft material might be implanted in the intervertebral space to promote a better bone fusion rate. The chosen size of the fusion cage itself might also be unsuitable These factors can all lead to an overcorrection of the intervertebral height, resulting in increased pressure on the surgical segment, which in turn can cause the fusion cage to sink or collapse. In addition, overcorrection of the intervertebral height can damage the vertebral endplates during surgery, further suggesting that intervertebral height correction is a risk factor for cage subsidence.[26]

Correcting the lordosis angle at the surgical segment too much is also a risk factor for subsidence. Achieving the correct segmental lordosis angle is crucial for restoring the natural curve of the lower lumbar spine, as it normally accounts for around 60% of the total physiological lumbar lordosis.[27] Patients with DLS often have significant degeneration of the intervertebral disc, with a notable decrease in intervertebral height and loss of the segmental lordosis angle. In their efforts to restore the original segmental lordosis angle, surgeons may sometimes overcorrect it.

In a study of patients undergoing minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) using a banana-shaped cage, the correction of intervertebral height and segmental lordosis angle was significantly greater than that of a straight-shaped cage, and the incidence of subsidence was also significantly increased.[28] Less invasive surgery can reduce systemic inflammatory index and systemic inflammatory response index, but there is a lack of relevant research on whether it affects the cage subsidence in TLIF.[29]

If doctors excessively pursue angle correction to restore lumbar lordosis, it can lead to more endplate damage than anticipated, resulting in corresponding clinical complications, such as cage subsidence. Such findings indicate that correction of segmental lordosis angle is a risk factor for cage subsidence. Clinically, effective intervention to correct intervertebral height and segmental lordosis angle can reduce the rate of subsidence after TLIF for lumbar spondylolisthesis.[30]

The degree of atrophy of the multifidus muscle is also an independent risk factor for subsidence; the greater the degree of atrophy, the higher the incidence of subsidence.[31,32] This muscle plays an important role in maintaining the sagittal alignment of the lumbar spine and lumbar lordosis. Theoretically, in patients with severe multifidus atrophy, the role of this muscle weakens.[32] Due to the strong fixation provided by the posterior column of the spine, the supporting role of the anterior column is diminished in patients with severe multifidus atrophy, leading to a loss of intervertebral height and subsequent subsidence. Our results validate this hypothesis, indicating that the degree of multifidus atrophy does have an impact on subsidence after fusion surgery. Weerasak et al found that the correlation between multifidus atrophy and cage subsidence was the strongest following MIS-TLIF; patients with severe multifunction atrophy had a subsidence rate of 76.0% compared to normal patients.[33] In addition, subsidence can lead to exacerbation of pain symptoms in the back and leg during the early postoperative period (3 months).[34] The atrophy of the multifidus muscle leads to decreased stability of the lumbar segment, which in turn results in subsidence. Therefore, these patients may require additional pedicle screw fixation to avoid severe subsidence.[35] Clinicians should pay attention to protecting the MMA in their work to help reduce cage subsidence, such as through surgical techniques, surgical methods, and back muscle exercises. In our study, there was a significant correlation between cage subsidence and at the last follow-up for lower back pain and also for ODI scores. Furthermore, subsidence was closely related to the decrease in the cross-sectional area of the multifidus muscle and the increase in fat infiltration rate before surgery.

Considering these results, there is reason to speculate that MMA is an independent risk factor for cage subsidence after TLIF. Prehabilitation training and postoperative physiotherapy regimen can be implemented to alleviate post-operative low back pain and enhance quality of life following TLIF surgery. This can include: (1) Educational booklet and video; (2) An in-person physical therapy (PT) session; and (3) A telemedicine visit with a physiatrist.[36,37] In the future, clinical intervention aimed at addressing MMA may reduce the subsidence rate following TLIF for lumbar spondylolisthesis, which could improve clinical outcomes such as lower back pain and ODI scores.

Osteoporosis is closely associated with cage subsidence after lumbar interbody fusion. In one study, osteoporosis was an important risk factor for both cage position migration and backward movement.[38] In addition, in MIS-TLIF, osteoporosis is a significant risk factor for postoperative subsidence.[33] These findings indicate that osteoporosis is a critical risk factor and effective treatments for osteoporosis could help prevent subsidence.[39] We initially employed a two-factor modelling approach and found that the degree of intervertebral height correction, lumbar lordosis correction, and lordosis correction at the surgical segment achieved during surgery did not show statistically significant differences in relation to outcomes in osteoporosis patients. Thus, we hypothesised that osteoporosis might act as a mediating factor.

This study had some limitations. Due to the significantly higher incidence of DLS in females compared to males, and the relatively low rate of smoking among middle-aged and older women, we did not include smoking as a potential factor influencing cage subsidence. The imaging data measurements were performed manually, which inherently introduces some error and is time-consuming. Currently, most rod-screw systems are made of titanium implants, and metallic artifacts in postoperative MRI and CT scans significantly interfere with the measurement of paravertebral muscles. Therefore, we were unable to measure the degree of multifidus atrophy postoperatively. The subsidence group exhibits a lower prevalence of male patients. Further sample collection is required to facilitate the inclusion of more male subjects to the study. We also did not compare subsidence between cages from different manufacturers and with different specifications.

Conclusion

Intervertebral height correction, segment lordosis angle correction and MMA are all independent risk factors for cage subsidence after TLIF for DLS. When selecting TLIF as a treatment for patients with L4/5 DLS, these factors should be considered. In clinical practice, preoperative physiotherapy and core muscle strengthening programs aimed at improving multifidus muscle quality can reduce multifidus muscle atrophy. Meanwhile, selecting an appropriate cage height and avoiding excessive correction of the lordotic angle can be used to reduce the rate of cage subsidence after TLIF and improve patient clinical outcomes.

Data Sharing Statement

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

The study complied with the principles outlined in the Declaration of Helsinki and was approved by the Ethical Committee of the Zhongda Hospital, Southeast University (NO.2019ZDSYLL101-P01). Written informed consent was obtained from all patients.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

The research was supported by grants from the National Natural Science Foundation of China (82202768), Zhongda Hospital Affiliated to Southeast University, Jiangsu Province High-Level Hospital Construction Funds (GSP-LCYJFH20) , the Fundamental Research Funds for the Central Universities (2242020K40156), Open Project Programme of the Key Base for Standardized Training for General Physicans, Zhongda Hospital, Southeast University (ZDZYJD-QK-2022-16), Jiangsu Entrepreneurship and Innovation Doctors (202030338).

Disclosure

The authors report no conflicts of interest in this work.

References

1. Randall RM, Silverstein M, Goodwin R. Review of pediatric spondylolysis and spondylolisthesis. *Sports Med Arthroscopy Rev*. 2016;24 (4):184–187. doi:10.1097/JSA.0000000000000127
2. Tebet MA. Current concepts on the sagittal balance and classification of spondylolysis and spondylolisthesis. *Revista brasileira de ortopedia*. 2014;49(1):3–12. doi:10.1016/j.rbo.2013.04.011
3. Nambu K, Numata H, Yoshitani J, et al. Ten-year clinical outcomes of endoscope-assisted minimally invasive surgical decompression for lumbar spinal stenosis with degenerative spondylolisthesis and comparison with conservative treatment. *Spine Surg Relat Res*. 2024;8(1):73–82. doi:10.22603/ssrr.2023-0093
4. Austevoll IM, Hermansen E, Fagerland MW, et al. Decompression with or without FUSION IN DEGENERATIVE LUMBAR SPONDYLOLISTHESis. *N Engl J Med*. 2021;385(6):526–538. doi:10.1056/NEJMoa2100990
5. Rathbone J, Rackham M, Nielsen D, et al. A systematic review of anterior lumbar interbody fusion (ALIF) versus posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), posterolateral lumbar fusion (PLF). *Eur Spine J*. 2023;32(6):1911–1926. doi:10.1007/s00586-023-07567-x
6. Asada T, Zhao ER, Ehrlich AM, et al. Distinct recovery patterns after transforaminal lumbar interbody fusion: comparing minimally invasive and open approaches using mixed-effects segmented regression. *Neurospine*. 2025;22(1):3–13. doi:10.14245/ns.2550096.048
7. Bahir AW, Daxing W, Jiayu X, Bailian L, Shao G. Comparative efficacy and fusion outcomes of unilateral bi-portal endoscopic transforaminal lumbar interbody fusion versus minimally invasive transforaminal lumbar interbody fusion in treating single-segment degenerative lumbar spondylolisthesis with lumbar spinal stenosis: a two-year retrospective study. *J Orthop Surg Res*. 2024;19(1):835. doi:10.1186/s13018-024-05315-5
8. Quraishi NA, Konig M, Booker SJ, et al. Access related complications in anterior lumbar surgery performed by spinal surgeons. *Eur Spine J*. 2013;22(Suppl 1):S16–20. doi:10.1007/s00586-012-2616-1
9. Zhang Q, Yuan Z, Zhou M, Liu H, Xu Y, Ren Y. A comparison of posterior lumbar interbody fusion and transforaminal lumbar interbody fusion: a literature review and meta-analysis. *BMC Musculoskelet Disord*. 2014;15:367. doi:10.1186/1471-2474-15-367
10. Le TV, Baaj AA, Dakwar E, et al. Subsidence of polyetheretherketone intervertebral cages in minimally invasive lateral retroperitoneal transpsoas lumbar interbody fusion. *Spine*. 2012;37(14):1268–1273. doi:10.1097/BRS.0b013e3182458b2f
11. Marchi L, Abdala N, Oliveira L, Amaral R, Coutinho E, Pimenta L. Stand-alone lateral interbody fusion for the treatment of low-grade degenerative spondylolisthesis. *The Scientific World J*. 2012;2012:456346. doi:10.1100/2012/456346
12. Hou Y, Luo Z. A study on the structural properties of the lumbar endplate: histological structure, the effect of bone density, and spinal level. *Spine*. 2009;34(12):E427–433. doi:10.1097/BRS.0b013e3181a2ea0a
13. Kim MC, Chung HT, Cho JL, Kim DJ, Chung NS. Subsidence of polyetheretherketone cage after minimally invasive transforaminal lumbar interbody fusion. *J Spinal Disord Tech*. 2013;26(2):87–92. doi:10.1097/BSD.0b013e318237b9b1
14. Zhao L, Zeng J, Xie T, Pu X, Lu Y. Advances in research on Cage subsidence following lumbar interbody fusion]. Zhongguo xiu fu chong jian wai ke za zhi = Zhongguo xiufu chongjian waike zazhi =. *Chin J Reparative Reconst Surg*. 2021;35(8):1063–1067. doi:10.7507/1002-1892.202104036
15. Yao YC, Chou PH, Lin HH, Wang ST, Liu CL, Chang MC. Risk factors of cage subsidence in patients received minimally invasive transforaminal lumbar interbody fusion. *Spine*. 2020;45(19):E1279–E1285. doi:10.1097/BRS.0000000000003557

16. Lee HJ, Kim JS, Ryu KS. Minimally Invasive TLIF Using unilateral approach and single cage at single level in patients over 65. *Biomed Res Int*. 2016;2016:4679865. doi:10.1155/2016/4679865
17. Labrom RD, Tan JS, Reilly CW, Tredwell SJ, Fisher CG, Oxland TR. The effect of interbody cage positioning on lumbosacral vertebral endplate failure in compression. *Spine*. 2005;30(19):E556–561. doi:10.1097/01.brs.0000181053.38677.c2
18. Choi JY, Sung KH. Subsidence after anterior lumbar interbody fusion using paired stand-alone rectangular cages. *Eur Spine J*. 2006;15(1):16–22. doi:10.1007/s00586-004-0817-y
19. Grant JP, Oxland TR, Dvorak MF. Mapping the structural properties of the lumbosacral vertebral endplates. *Spine*. 2001;26(8):889–896. doi:10.1097/00007632-200104150-00012
20. Lin GX, Quillo-Olvera J, Jo HJ, et al. Minimally invasive transforaminal lumbar interbody fusion: a comparison study based on end plate subsidence and cystic change in individuals older and younger than 65 years. *World Neurosurg*. 2017;106:174–184. doi:10.1016/j.wneu.2017.06.136
21. Oh KW, Lee JH, Lee JH, Lee DY, Shim HJ. The correlation between cage subsidence, bone mineral density, and clinical results in posterior lumbar interbody fusion. *Clin Spine Surg*. 2017;30(6):E683–E689. doi:10.1097/BSD.0000000000000315
22. Xi Z, Mummaneni PV, Wang M, et al. The association between lower Hounsfield units on computed tomography and cage subsidence after lateral lumbar interbody fusion. *Neurosurg Focus*. 2020;49(2):E8. doi:10.3171/2020.5.FOCUS20169
23. Marchi L, Abdala N, Oliveira L, Amaral R, Coutinho E, Pimenta L. Radiographic and clinical evaluation of cage subsidence after stand-alone lateral interbody fusion. *J Neurosurg Spine*. 2013;19(1):110–118. doi:10.3171/2013.4.SPINE12319
24. Cheung KM, Zhang YG, Lu DS, Luk KD, Leong JC. Reduction of disc space distraction after anterior lumbar interbody fusion with autologous iliac crest graft. *Spine*. 2003;28(13):1385–1389. doi:10.1097/01.BRS.0000067093.47584.CA
25. Williams AL, Gornet MF, Burkus JK. CT evaluation of lumbar interbody fusion: current concepts. *AJNR Am J Neuroradiol*. 2005;26(8):2057–2066.
26. Wu H, Shan Z, Zhao F, Cheung JPY. Poor bone quality, multilevel surgery, and narrow and tall cages are associated with intraoperative endplate injuries and late-onset cage subsidence in lateral lumbar interbody fusion: a systematic review. *Clin Orthop Relat Res*. 2022;480(1):163–188. doi:10.1097/CORR.0000000000001915
27. Kim CH, Chung CK, Park SB, Yang SH, Kim JH. A change in lumbar sagittal alignment after single-level anterior lumbar interbody fusion for lumbar degenerative spondylolisthesis with normal sagittal balance. *Clin Spine Surg*. 2017;30(7):291–296. doi:10.1097/BSD.0000000000000179
28. Choi WS, Kim JS, Hur JW, Seong JH. Minimally invasive transforaminal lumbar interbody fusion using banana-shaped and straight cages: radiological and clinical results from a prospective randomized clinical trial. *Neurosurgery*. 2018;82(3):289–298. doi:10.1093/neuros/nyx212
29. Moldovan F. Correlation between peripheric blood markers and surgical invasiveness during humeral shaft fracture osteosynthesis in young and middle-aged patients. *Diagnostics*. 2024;14(11):1112. doi:10.3390/diagnostics14111112
30. Wang D, Chen X, Han D, Wang W, Kong C, Lu S. Radiographic and surgery-related predictive factors for increased segmental lumbar lordosis following lumbar fusion surgery in patients with degenerative lumbar spondylolisthesis. *Eur Spine J*. 2024;33(7):2813–2823. doi:10.1007/s00586-024-08248-z
31. Kotheeranurak V, Jitpakdee K, Lin GX, et al. Subsidence of interbody cage following oblique lateral interbody fusion: an analysis and potential risk factors. *Global Spine J*. 2023;13(7):1981–1991. doi:10.1177/21925682211067210
32. Chen J, Li J, Sheng B, Li L, Wu S. Does preoperative morphology of multifidus influence the surgical outcomes of stand-alone lateral lumbar interbody fusion for lumbar spondylolisthesis? *Clin Neurol Neurosurg*. 2022;215:107177. doi:10.1016/j.clineuro.2022.107177
33. Singhatanadgige W, Sukthuayat A, Tanaviriyachai T, et al. Risk factors for polyetheretherketone cage subsidence following minimally invasive transforaminal lumbar interbody fusion. *Acta Neurochir (Wien)*. 2021;163(9):2557–2565. doi:10.1007/s00701-021-04923-y
34. Kotheeranurak V, Jitpakdee K, Lin GX, et al. Subsidence of interbody cage following oblique lateral interbody fusion: an analysis and potential risk factors. *Global Spine J*. 2021;21925682211067210.
35. Moser M, Adl Amini D, Jones C, et al. The predictive value of psoas and paraspinal muscle parameters measured on MRI for severe cage subsidence after standalone lateral lumbar interbody fusion. *Spine J*. 2023;23(1):42–53. doi:10.1016/j.spinee.2022.03.009
36. Eubanks JE, Cupler ZA, Gliedt JA, et al. Preoperative spinal education for lumbar spinal stenosis: a feasibility study. *Pm r*. 2024;16(9):992–1000. doi:10.1002/pmrj.13140
37. Hoffman H, Bennett SS, Li CH, Haakana P, Lu DC. Minimally invasive decompression and physiotherapy for lumbar spinal stenosis in geriatric patients. *Cureus*. 2018;10(6):e2785. doi:10.7759/cureus.2785
38. Park MK, Kim KT, Bang WS, et al. Risk factors for cage migration and cage retropulsion following transforaminal lumbar interbody fusion. *Spine J*. 2019;19(3):437–447. doi:10.1016/j.spinee.2018.08.007
39. Jin H, Suk KS, Lee BH, et al. Antiosteoporosis medication in patients with posterior spine fusion: a systematic review and meta-analysis. *Spine J*. 2025;25(9):1877–1898. doi:10.1016/j.spinee.2025.04.018