International Orthopaedics (2023) 47:1815–1826
https://doi.org/10.1007/s00264-023-05826-6

ORIGINAL PAPER

Analysis of risk factors for contralateral symptomatic foraminal stenosis after unilateral transforaminal lumbar interbody fusion

Wenjie Lu[1] · Jiaming Zhang[2] · Yuanguo Deng[1] · Lingqiao Wu[1] · Yunlin Chen[3] · Xudong Hu[3] · Chaoyue Ruan[3] · Yang Wang[3] · Weihu Ma[3] · Weiyu Jiang[3]

Received: 12 February 2023 / Accepted: 23 April 2023 / Published online: 8 May 2023

Abstract

Purpose To analyze the risk factors of contralateral symptomatic foraminal stenosis (FS) after unilateral transforaminal lumbar interbody fusion (TLIF) and to guide and standardize the operation process of unilateral TLIF to reduce the occurrence of contralateral symptomatic FS.

Methods A retrospective study was undertaken on 487 patients with lumbar degeneration who underwent unilateral TLIF in the Department of Spinal Surgery of Ningbo Sixth Hospital between January 2017 and January 2021, comprising 269 males and 218 females, with a mean age of 57.1 years (range, 48–77 years). Cases of intraoperative improper operations, such as screw deviation, postoperative hematoma, and contralateral disc herniation, were excluded, and cases of nerve root symptoms caused by contralateral FS were analyzed. Post-surgery, 23 patients with nerve root symptoms caused by contralateral FS were categorized as group A, and 60 patients without nerve root symptoms were randomly selected as group B during the same period. The general data (gender, age, body mass index (BMI), bone mineral density (BMD), and diagnosis) and imaging parameters before and after operation (including contralateral foramen area (CFA), lumbar lordosis angle (LL), segmental lordosis angle (SL), disc height (DH), foramen height (FH), foramen width (FW), fusion cage position, and the difference between postoperative and preoperative) were compared between the two groups. Univariate analysis was performed, and multivariate analysis was undertaken through logistics analysis to determine the independent risk factors. Additionally, the clinical outcomes of the two groups were compared immediately before surgery and one year after surgery, using the visual analogue scale (VAS) score and the Japanese Orthopaedic Association (JOA) score for evaluation.

Results The patients in this study were followed up for a period of 19–25 (22.8atien months. Among them, 23 cases (4.72% incidence) were diagnosed with contralaterally symptomatic FS after the surgery. Univariate analysis indicated significant differences between the two groups in CFA, SL, FW, and cage coronal position. Logistic regression analysis identified preoperative contralateral foramen area (OR = 1.176, 95% CI (1.012, 1.367)), small segmental lordosis angle (OR = 2.225, 95% CI (1.124, 4.406)), small intervertebral foramen width (OR = 2.706, 95% CI (1.028, 7.118)), and cage coronal position not crossing the midline (OR = 1.567, 95% CI (1.142, 2.149)) as independent risk factors for contralateral symptomatic FS after unilateral TLIF. However, there was no statistically significant difference in the pain VAS score between the two groups one year after the operation. In contrast, there was a significant difference in the JOA score between the two groups.

Conclusion The identified risk factors for contralateral symptomatic FS after TLIF include preoperative contralateral intervertebral foramen stenosis, a small segmental lordosis angle, a small intervertebral foramen width, and the coronal position of the cage not crossing the midline. For patients with these risk factors, it is recommended to carefully lock the screw rod during the recovery of lumbar lordosis and ensure that the coronal position of the fusion cage is implanted beyond the midline. If necessary, preventive decompression should also be considered. However, this study did not quantify the imaging data for each risk factor, and further research is needed to improve our understanding of the topic.

Keyword Lumbar spine · Intervertebral fusion · Contralateral symptomatic foramen stenosis · Postoperative complications · Contralateral nerve root symptoms · Risk factors · Prevention

Extended author information available on the last page of the article

Background

TLIF is a refined surgical method that has evolved from the posterior lumbar interbody fusion (PLIF) technique. Blume and Rojas first proposed it in the early 1980s, and it has gradually replaced PLIF as a classic surgical approach for treating lumbar degenerative diseases [1]. The TLIF technique involves using a unilateral transforaminal approach, which avoids excessive traction of the dural sac, nerve roots, and back muscles. It achieves bilateral decompression by retaining the contralateral lamina and facet joints, with little impact on the mechanical structure of the spine's posterior column. This technique also retains bone structures such as the pedicle and lamina, increasing the stability between the upper and lower adjacent vertebral bodies [2]. Long-term clinical studies have shown that TLIF has satisfactory clinical efficacy [3, 4]. However, despite its success, complications can arise during the procedure. A common complication is contralateral symptomatic FS after unilateral TLIF, which can negatively impact the operation's comprehensive efficacy. Previous studies have identified several important risk factors for this complication, including preoperative contralateral intervertebral foramen stenosis, contralateral lateral recess stenosis, large lumbar sagittal plane mobility, and intraoperative fusion device position deviation to one side. Nonetheless, these studies have shortcomings, and the clinical significance of their findings is questionable [5, 6]. Therefore, we conducted a retrospective study of cases of unilateral TLIF in our hospital from January 2017 to January 2021. The study aimed to clarify the risk factors of nerve root symptoms due to contralateral FS after unilateral TLIF and to guide and standardize the operation process of unilateral TLIF to reduce the occurrence of postoperative contralateral symptomatic FS.

Information and methods

Inclusion and exclusion criteria

The inclusion criteria were low back pain with unilateral nerve root symptoms, surgery for unilateral TLIF, the surgical segment between L3 and S1, and lesions involving four segments below, and we excluded patients who had bilateral nerve root symptoms or severe systemic diseases like lumbar trauma, tumors, severe osteoporosis, birth defects or surgeries involving more than four segments, non-unilateral TLIF, or those lacking long-term complete follow-up and clinical data.

General information and case subgroups

In this study, 487 patients (269 males and 218 females) were included with a mean age of 57.1 years (range, 48–77 years). Prior to surgery, all patients underwent lumbar spine X-ray, CT plain scan, and lumbar MRI. Within one week after the operation, patients underwent a reexamination of lumbar spine X-ray and CT plain scan. Additional lumbar MRI was conducted on patients who experienced contralateral nerve root symptoms after surgery, and a nerve root block was performed if needed to identify the cause. Of the total patients, 32 experienced contralateral nerve root symptoms after the operation. The causes were confirmed by imaging and nerve root block examination: 23 cases were attributed to contralateral foraminal stenosis, three cases were due to improper screw position, four cases were caused by postoperative hematoma, and two cases had unknown causes. All 23 cases in which contralateral nerve root symptoms were caused by contralateral foraminal stenosis showed symptoms within one week after the operation, including lower limb pain, hypoaesthesia, paraesthesia, and decreased leg muscle strength. Sixty patients who did not experience contralateral nerve root symptoms after surgery were randomly selected and included in group B using a random number table method.

Among the 23 patients in group A who developed contralateral nerve root symptoms after surgery, immediate conservative measures, including dehydration and steroid therapy, were employed for a period of one to two weeks. Of these patients, 18 exhibited a gradual reduction and improvement of symptoms within two to three days of conservative treatment. However, five patients received revision surgery due to unclear treatment efficacy. The revision surgery was successful, and there was no deterioration of neurological symptoms or changes in muscle strength after surgery. The overall recovery rate was deemed acceptable.

Surgical operation and postoperative management

All patients in this study underwent more than three months of conservative treatment before surgery was considered. Unilateral TLIF was performed by two senior surgeons from the same institution (W-Y.J. and W–H.M.). The patients were positioned prone with abdominal suspension after being given general anaesthesia, and a longitudinal incision of 3–5 cm was made on the affected side of the spine to determine the surgical segment. The skin and fascia were then cut and separated to reveal the outer edge of the lamina and the upper and lower articular processes. On the decompression side, the ligamentum flavum, partial superior, and inferior articular processes were removed, with the extent of resection not exceeding 1/3 of the medial side. After careful preparation of the endplate, an autogenous bone-filling cage was inserted into the intervertebral space, followed by the insertion of the pedicle screw by hand. The pre-bending titanium rod was

placed on the screw, and the screw rod was locked after moderate intervertebral compression. One drainage tube was retained, and the incision was closed in layers after wound haemostasis and irrigation.

Following anaesthesia recovery, patients received non-steroidal anti-inflammatory drugs (NSAIDs) and methylprednisolone to alleviate nerve root pain and inflammation. To prevent deep vein thrombosis, elastic socks and an arteriovenous foot pump were utilized six h after the operation. Once the drainage tube was removed, patients were required to walk with brace protection. In the event that patients experienced contralateral nerve root symptoms after the operation, timely administration of NSAIDs was given. If a single injection of 1% lidocaine 0.5 ml resulted in an improvement of root symptoms by ≥ 80%, the clinical diagnosis was nerve root lesions, and a lumbar MRI was performed to determine the cause.

Imaging evaluation

Within the first week post-operation, all patients underwent a lumbar spine X-ray, lumbar CT scan, and three-dimensional reconstruction to assess the screw position and rule out contralateral nerve root symptoms caused by improper screw placement. Patients with contralateral radicular symptoms underwent additional lumbar MRI to identify the cause of the disease, and a nerve root block was performed if needed to exclude symptoms caused by postoperative haematoma or new disc herniation. The evaluation of screw position was based on the standard of Liu Qingyu et al. [7], while postoperative haematoma was diagnosed according to the presence of an equal or slightly low signal shadow with progressive enlargement on the acute MRI T2WI image. The diagnosis of FS was based on the imaging diagnostic criteria of Widermuth et al. [8].

Measurement of contralateral foramen area CFA (Fig. 1)

CFA was measured using magnetic resonance imaging (MRI) T2-weighted sagittal plane images, and the measurements were obtained using the PACS 3.0 (In-finite, China) irregular surface measurement tool. To account for differences in intervertebral foramen dimensions across different sagittal planes, the paramedian sagittal plane, which can display the pedicle, as well as the superior and inferior articular processes simultaneously, was selected for intervertebral foramen measurement [9, 10].

Measurement of lumbar lordosis angle (LL) and segmental lordosis angle (SL)

LL and SL were assessed both preoperatively and postoperatively. LL was measured as the angle formed by the upper endplates of L1 and S1, while SL was measured using the Cobb method, which involved measuring the angle formed by the vertical lines of the upper and lower endplates of the surgical segment.

Measurement of disc height (DH), foramen height (FH), and foramen width (FW)

DH, FH, and FW were measured using CT sagittal images. DH was defined as the distance between the

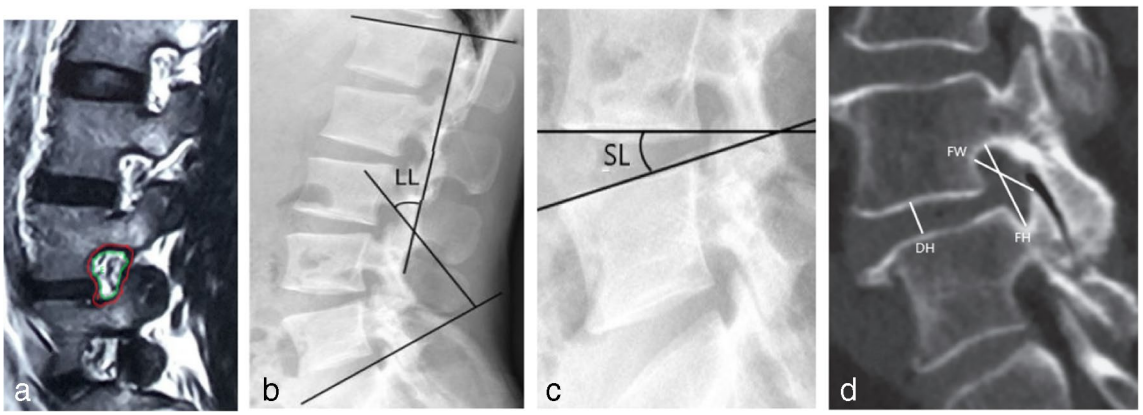

Fig. 1 **a** CFA measurement map of parasagittal MRI reconstruction (red F represents bone structure CFA, green E represents CFA considering soft tissue, F > E). **b** Lumbar lordosis angle LL: the angle between the upper endplates of L1 and S1. **c** Segment lordosis angle SL: the angle between the upper and lower endplates of the surgical segment. **d** Disc height DH: the distance between the upper and lower endplates of the intervertebral space center of the surgical segment; intervertebral space height FH: the distance between pedicles; intervertebral space width FW: The maximum width between the posterior edge of the vertebral body and the anterior edge of the superior articular process of the lower vertebral body

centres of the upper and lower endplates in the median sagittal plane. FH was measured as the distance between the pedicles, while FW was defined as the maximum width between the posterior edge of the vertebral body and the anterior edge of the superior facet of the lower vertebral body.

Description of the position of the fusion cage (Fig. 2)

The position of the fusion cage was assessed using cross-sectional CT scans. The centre of the cage was marked, which was the centre of gravity of the triangle formed by three marked points of the cage (Fig. 2a). The distance from the centre of the cage to the vertebral body was measured as A, and the length of the sagittal diameter of the intervertebral disc was measured as B. The ratio of A to B was calculated to determine the sagittal position of the cage (Fig. 2b). The distance from the centre of the cage to the bisector of the coronal plane of the intervertebral disc was measured as C, which had both positive and negative values. A negative value indicated that the centre of the cage was biased toward the side of the cage, whereas a positive value indicated that it was biased toward the opposite side. The length of the left and right diameters of the intervertebral disc was measured as D, and the ratio of C to D was calculated to determine the coronal position of the cage (Fig. 2c) [11].

The variation before and after the operation was calculated by subtracting the preoperative values from the postoperative values for all the parameters mentioned above. The measurements of all these parameters were performed by a spinal surgeon with over ten years of experience in spinal surgery and a radiologist specialized in musculoskeletal systems. The final results were obtained by averaging two measurements.

Clinical efficacy evaluation

The patients were followed up at one, three, six and 12 months after the operation. The clinical efficacy of the two groups was evaluated using the VAS and the JOA lumbar score. The VAS score and JOA lumbar score were assessed immediately before the operation and at one year postoperatively.

Statistical analysis

All statistical analyses were conducted using SPSS 25.0 software. The normally distributed measurement data were presented as mean ± standard deviation ($X \pm S$), and the independent sample t-test was utilized for analysis. Non-normally distributed measurement data were presented as medians (range from minimum to maximum), and the Mann–Whitney U test was employed. Count data were analyzed using the chi-square (X^2) test. One-way ANOVA was employed to compare the mean difference of each index in different periods, and the LSD method was used for comparison between groups. Univariate intergroup analysis was conducted to screen variables, and logistic regression was utilized to analyze the risk factors of nerve root symptoms caused by contralateral FS after unilateral TLIF. Statistical significance was defined as $P < 0.05$.

Results

General data comparison

A total of 23 patients (14 males and 9 females) who experienced contralateral nerve root symptoms caused by contralateral FS were included in group A, while 60 patients without such symptoms were included in group

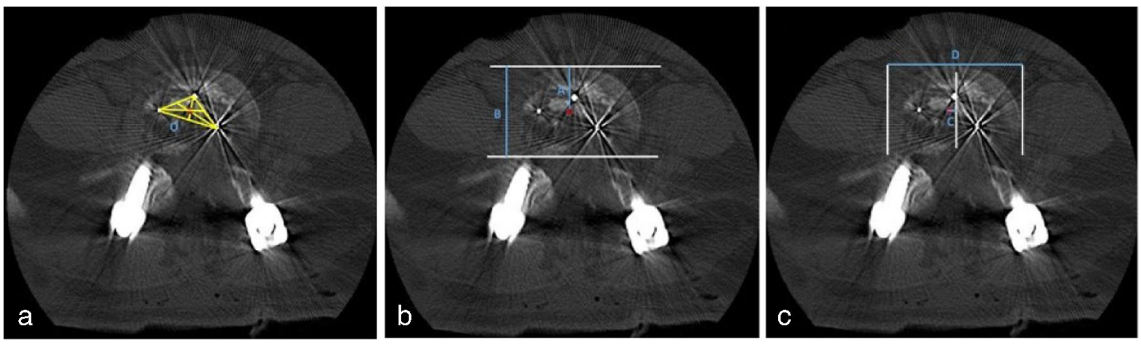

Fig. 2 **a** The center of the marker fuser, i.e., the centre of gravity of the triangle formed by the three marker points of the fuser. **b** Measure the distance A from the centre of the cage to the anterior edge of the vertebral body, measure the sagittal diameter length B of the intervertebral disc, and A/B is the sagittal position of the cage. **c** The distance C from the center of the fusion cage to the coronal bisector of the intervertebral disc is negative when the centre of the fusion cage is deviated from the insertion side of the fusion cage and positive when the centre of the fusion cage is deviated to the opposite side. In this case, the fusion cage is inserted from the left side, so C is positive; left and right disc diameter length D; C/D is the coronal position of the fusion cage

Table 1 Comparison of general data of patients with symptomatic spinal stenosis after unilateral TLIF

Indicators/groups	Symptom group A	Asymptomatic group B	*P* value
Number	23	60	—
Gender (male/female)	9/14	38/22	0.835
Age	55.8 ± 12.7	53.1 ± 15.1	0.544
BMI	23.1 ± 3.5	22.7 ± 2.9	0.665
BMD	−1.8 ± 1.0	−2.0 ± 1.5	0.450
Diagnosis (SS/LS/LDH)	14/4/5	38/9/13	0.962

$P < 0.05$ was considered statistically significant

SS, spinal stenosis; *LS*, lumbar spondylolisthesis; *LDH*, lumbar disc herniation

B (38 males and 22 females). The mean age of group A was 55.8 ± 12.7 years, while that of group B was 53.1 ± 15.1 years. The incidence rate of contralateral nerve root symptoms caused by contralateral FS after unilateral TLIF was found to be 4.72% (23/487). There were no significant differences in gender, age, BMI, BMD, and diagnosis between the two groups, as shown in Table 1.

Surgical related indicators

In this study, there was no statistically significant difference ($P > 0.05$) observed between the two groups in terms of the number of surgical segments involved (1, 2, or 3), the surgical levels involved (L3/4, L4/5, L5/S1, L3/5, L4/S1, L3/S1), and the height of the interbody fusion device (Table 2).

Imaging measurement

The study results indicated that there were no significant differences in LL, DH, and FH between the two groups before and after the operation. However, there was a statistically significant difference in preoperative CFA between group A and group B, with group A having a lower CFA (56.1 ± 15.2) compared to group B (67.1 ± 11.9). Additionally, the difference in postoperative CFA between the two groups was greater, with group A having a lower CFA(42.3 ± 12.0) compared to group B(75.4 ± 14.8), and the change in CFA was less in group A (− 13.8 ± 13.2) compared to group B (8.3 ± 15.2), which was statistically significant ($P < 0.001$). The CFA of group A showed a downward trend, while that of group B showed an upward trend. The difference in SL between the two groups before and after the operation was statistically significant ($P < 0.05$), with values of 10.7 ± 9.8 and 15.6 ± 5.1, 6.3 ± 2.9 and 1.8 ± 2.2, and 21.3 ± 7.9 and 16.7 ± 5.2 for group A and group B, respectively. There were also significant differences in FW between the two groups before and after the operation ($P < 0.05$), with values of 8.1 ± 3.2 and 9.3 ± 1.1, 5.2 ± 3.3 and 8.7 ± 2.0, and 3.6 ± 1.4 and 1.2 ± 1.6 for group A and group B, respectively. No statistically significant difference was found in the sagittal position of the fusion cage between the two groups (44.5 ± 6.8% for group A and 47.2 ± 5.7% for group B), but there was a significant difference in the coronal position (− 6.5 ± 7.8 for group A and 8.2 ± 4.1 for group B) (Table 3).

Clinical observation indicators

The statistical analysis of the preoperative and postoperative VAS and JOA scores between the two groups revealed no significant difference in the preoperative scores ($P = 0.351$). However, the pain VAS score one year after the operation was significantly lower than that before the operation, and the JOA lumbar spine score was significantly higher than that before the operation ($P < 0.05$). There was no significant difference in VAS scores between the two groups ($P = 0.483$). The JOA lumbar score in group B was significantly higher than that in group A ($P < 0.001$, Table 4).

Logistics regression analysis

Four variables with significant differences between the two groups in the single-factor group analysis were included in the logistic regression analysis, and the variables were screened backward stepwise (Wald). The results showed that preoperative contralateral foramen area (OR = 1.176, 95% CI: 1.012–1.367), segmental lordosis angle (OR = 2.225, 95% CI: 1.124–4.406), contralateral intervertebral foramen width (OR = 2.706, 95% CI: 1.028–7.118), and fusion cage coronal position not crossing the midline

Table 2 Comparison of differences in surgical-related indicators between the two groups

Surgical-related indicators/groups	Symptom group A	Asymptomatic group B	*P* value
Surgical segments (1/2/3)	15/6/2	46/11/3	0.559
Surgical level (L3/4, L4/5, L5/S1, L3/5, L4/S1, L3/S1)	2/6/7/2/4/2	4/16/6/7/4/3	0.656
Cage height	8.2e he	8.6e he	0.405

$P<0.05$ was considered statistically significant

Table 3 Comparison of imaging parameters in patients with symptomatic spinal stenosis after unilateral TLIF ($x \pm s$)

Imaging parameters/groups		Symptom group A	Asymptomatic group B	*P* value
CFA (mm^2)	Preoperative	56.1 ± 15.2	67.1 ± 11.9	< 0.001*
	Postoperative	42.3 ± 12.0	75.4 ± 14.8	< 0.001*
	Change	-13.8 ± 13.2	8.3 ± 15.2	< 0.001*
LL (L0	Preoperative	36.8 ± 9.3	35.4 ± 10.8	0.585
	Postoperative	38.2 ± 11.8	38.9 ± 13.4	0.827
	Change	3.1 ± 2.7	2.9 ± 1.8	0.696
SL (L6	Preoperative	10.7 ± 9.8	15.6 ± 5.1	0.004*
	Postoperative	21.3 ± 7.9	16.7 ± 5.2	0.003*
	Change	6.3 ± 2.9	1.8 ± 2.2	< 0.001*
DH (mm)	Preoperative	8.0 ± 2.3	8.3 ± 2.1	0.572
	Postoperative	9.5 ± 1.9	9.8 ± 1.4	0.433
	Change	1.5 ± 0.8	1.6 ± 0.9	0.642
FH (mm)	Preoperative	13.5 ± 3.2	12.9 ± 1.8	0.284
	Postoperative	12.7 ± 4.2	14.1 ± 3.9	0.156
	Change	1.6 ± 3.2	1.9 ± 3.7	0.733
FW (mm)	Preoperative	8.1 ± 3.2	9.3 ± 1.1	0.012*
	Postoperative	5.2 ± 3.3	8.7 ± 2.0	< 0.001*
	Change	3.6 ± 1.4	1.2 ± 1.6	< 0.001*
Cage position (%)	Coronal position	− 6.5 ± 7.8	8.2 ± 4.1	< 0.001*
	Sagittal position	44.5 ± 6.8	47.2 ± 5.7	0.071

$P < 0.05$ was considered statistically significant

(OR = 1.567, 95% CI: 1.142–2.149) were independent risk factors for contralateral symptomatic FS after unilateral TLIF (refer to Figs. 3 and 4). Figures 5 and 6 depict typical cases.

Discussion

TLIF is a surgical procedure that can provide bilateral decompression and sufficient biomechanical stability to promote intervertebral fusion by reaching the intervertebral space through a unilateral intervertebral foramen. TLIF is a widely used technique with excellent curative effects; however, contralateral symptomatic FS often occurs after a unilateral approach. Previous studies have reported the incidence of contralateral root symptoms after microendoscopy-assisted minimally invasive TLIF to be 8.5%, and after open TLIF, it is 4.78%, which is similar to the incidence of 4.72% in this study [12].

Since Hunt et al.'s report of a case of contralateral root symptoms after unilateral TLIF in 2007, several scholars have conducted in-depth research on its incidence and risk factors. Yang et al. [13] found that preoperative contralateral FS was the most common cause of postoperative contralateral symptomatic FS. In the L4-5 segment, the optimal threshold of preoperative CFA was 0.76 cm^2. Cho et al. [14], after studying the morphology of the intervertebral foramen in 33 patients with unilateral TLIF, proposed that the position of the implanted cage played a decisive role in the change in the morphology

Table 4 Comparison of clinical scores of patients with symptomatic spinal stenosis after unilateral TLIF ($x \pm s$)

Clinical indicators/groups		Symptom group A	Asymptomatic group B	*P* value
VAS (leg)	Preoperation	5.5 ± 1.8	6.0 ± 2.3	0.351
	3 months after operation	1.6 ± 1.3	1.8 ± 1.1	0.483
	1 year after operation	1.3 ± 0.8	1.6 ± 1.0	0.201
JOA	Preoperation	11.7 ± 2.6	12.1 ± 3.3	0.603
	3 months after operation	18.7 ± 3.1	22.1 ± 2.8	< 0.001*
	1 year after operation	22.7 ± 2.6	25.1 ± 2.3	< 0.001*

$P < 0.05$ was considered statistically significant

Variables in the equation

Step 1a						95% confidence interval of EXP(B)		
	B	Root Mean Squared Error	Wald	degree of freedom	Statistical significance	Exp(B)	lower bound	upper bound
CFA	0.162	0.077	4.497	1	0.034	1.176	1.012	1.367
SL	0.8	0.348	5.269	1	0.022	2.225	1.124	4.406
FW	0.995	0.494	4.066	1	0.044	2.706	1.028	7.118
Cage	0.449	0.161	7.757	1	0.005	1.567	1.142	2.149
Constant	-26.277	10.465	6.304	1	0.012	0		

a.Variables entered in step one: CFA,SL,FW,Cage.

Fig. 3 Regression analysis results of contralateral symptomatic FS logistics after unilateral TLIF. Note: $P < 0.05$ was considered statistically significant. Hossmer-Lemeshaw test $P = 0.986$, fitting well

of the intervertebral foramen. Hwang et al. [12] conducted a retrospective study of 592 patients undergoing unilateral TLIF and found that the preoperative sagittal range of motion (OR = 1.562; $P = 0.004$) and fuser position (OR = 2.047; $P = 0.015$) were associated with contralateral root symptoms after unilateral TLIF. However, these studies have some limitations. For example, the research data of Hunt et al. were not measured in the same CT sagittal plane, which raises concerns about the reliability of the data. Yang Y et al.'s study was based on L4/5 segment CT image measurement data without taking into account the ligament fat within the intervertebral foramen. Moreover, the lumbar lateral flexion radiographs involved in Hwang et al.'s study are not common and have limited clinical significance. To address these limitations, we combined the anatomical study of the intervertebral foramen [15, 16] and changed the measurement of the CFA from the CT sagittal plane to the MRI (T2W1) sagittal plane. Furthermore, we defined the FW as the maximum width between the posterior edge of the vertebral body and the anterior edge of the superior articular process of the lower vertebral body. The position of the cage is described by the coronal and sagittal plane positions, and the previous experimental research is adjusted and improved to clarify its risk factors and guide clinical prevention and treatment.

Relationship between preoperative contralateral foramen stenosis and contralateral symptomatic FS after unilateral TLIF

Several studies have highlighted the significance of decompressing the intervertebral foramen nerve root during TLIF to improve symptoms [17, 18]. In cases where extensive decompression is unnecessary, bilateral approach decompression can be avoided, and indirect decompression can be used to alleviate contralateral FS. This involves implanting an appropriate cage to increase CFA. However, clinical experience shows that CFA does not always increase as expected. In this study, the preoperative and postoperative

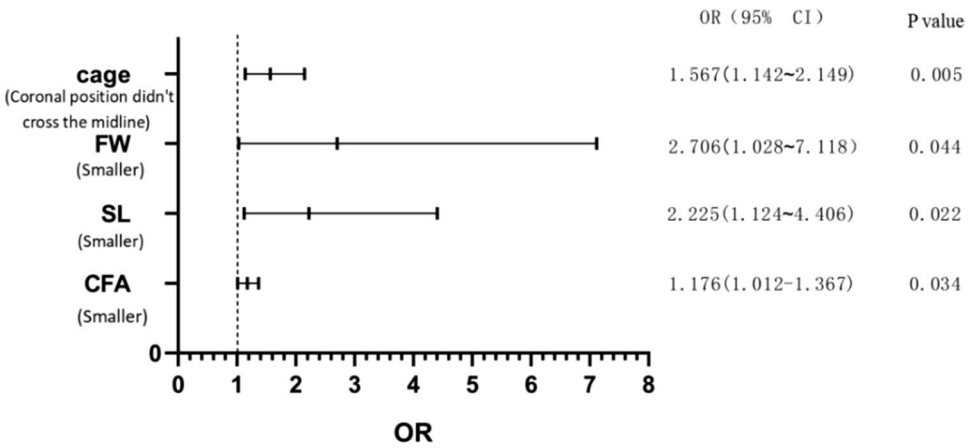

Fig. 4 Forest map of the results of contralateral symptomatic FS logistics regression analysis after unilateral TLIF

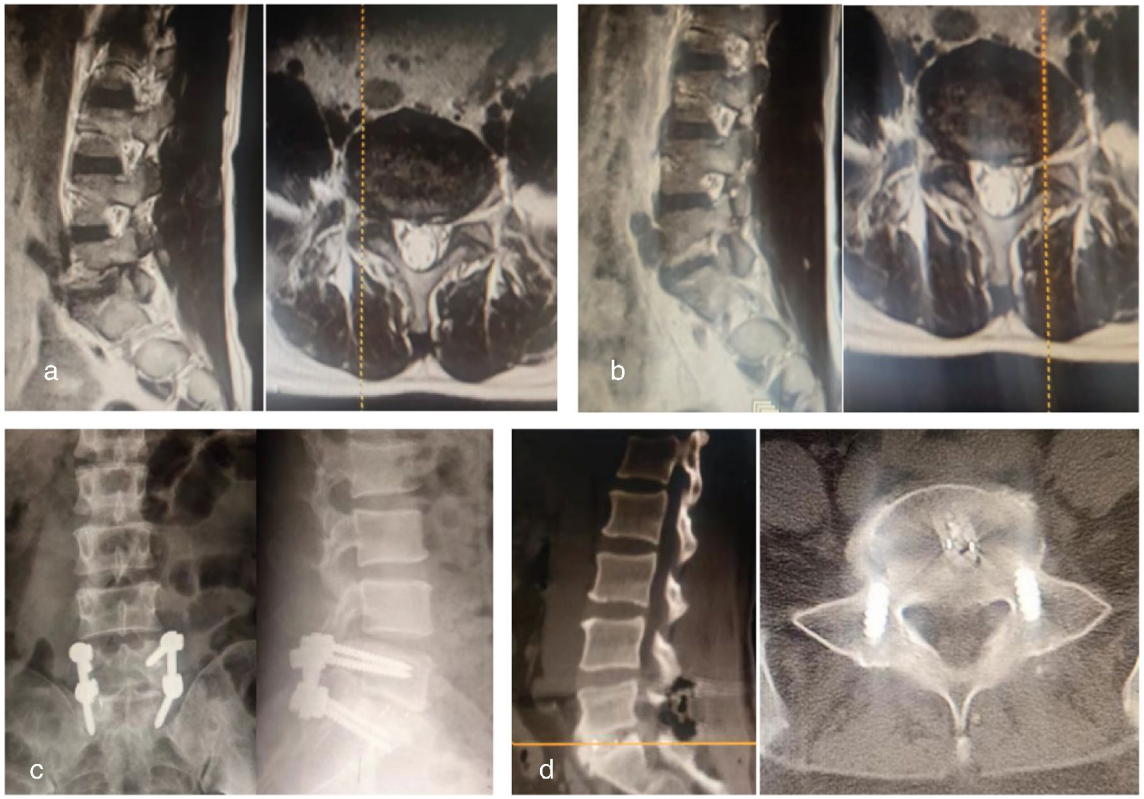

Fig. 5 A 53-year-old male patient with low back pain, intermittent claudication of the right lower limb, numbness, pain, and weakness for more than 1 year aggravated for 1 week. **a**, **b** L5/S1 bilateral lumbar intervertebral foramen stenosis, severe stenosis on the right side, and mild stenosis on the left side. **c** The positive and lateral X-rays of the lumbar spine were reviewed 1 month after the operation, and the decompression and interbody fusion were performed through the right intervertebral foramen of L5/S1. The left side did not undergo preventive decompression, and the screws were in place. **d** One year after lumbar CT review, good intervertebral fusion, fusion position in position (sagittal position slightly ahead of the coronal position according to the middle of the intervertebral space), no endplate collapse, and fusion slip occur

CFA of group A was smaller than that of group B, and the difference was statistically significant. Additionally, the CFA of group A showed a downward trend, while that of group B showed an upward trend. Logistic analysis indicated that preoperative contralateral foramen stenosis was an independent risk factor for postoperative contralateral symptomatic FS.

Relationship between preoperative segmental lordosis angle and contralateral symptomatic FS after unilateral TLIF

The appropriate recovery of lumbar lordosis in lumbar surgery is crucial for improving clinical outcomes and preventing congenital flat back [19]. However, in this study, there were no significant differences in terms of the number of surgical segments, the surgical levels and lumbar lordosis angle LL (preoperative, postoperative, and change) between the two groups, but there were statistical differences in the preoperative, postoperative, and change of segmental lordosis angle SL. Logistic analysis revealed that the preoperative segmental lordosis angle was an independent risk factor for postoperative contralateral symptomatic FS. These results are similar to those reported by Jiang et al. [20], suggesting that excessive pursuit of recovery of lumbar lordosis may contribute to this outcome. Unilateral TLIF only removes one facet joint, and the posterior structure of the lumbar spine experiences less damage. However, the sagittal position of the fusion cage tends to be biased toward the middle and posterior sides, resulting in the hinge fulcrum being moved backward and the force arm becoming smaller, which requires greater stress to recover the lordosis angle. During this process, careless operation may cause the superior articular process of the lower vertebral body to move upward or ventrally, leading to the dislocation of the superior articular process and compression of the intervertebral foramen nerve root.

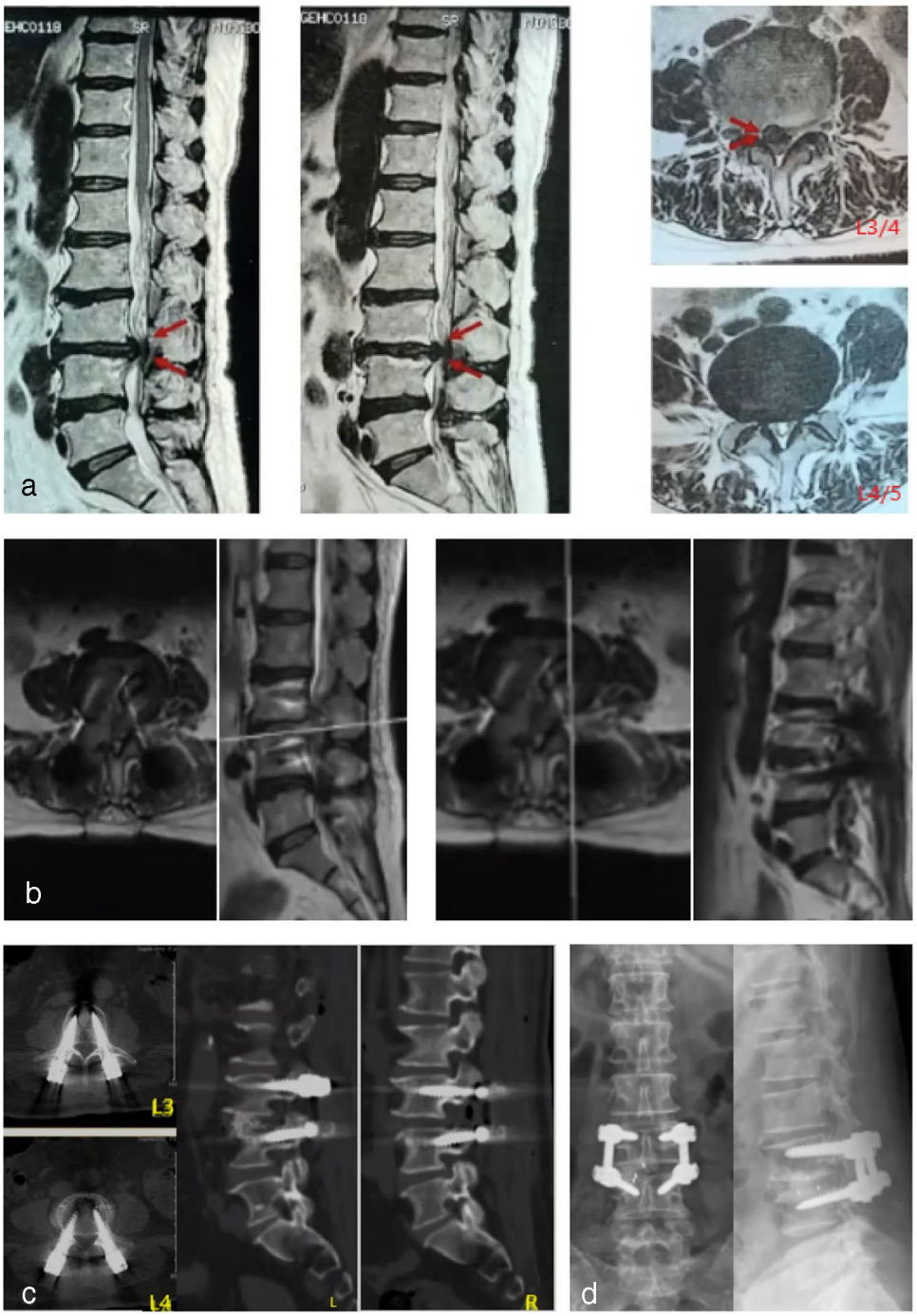

Fig. 6 A 62-year-old female patient with low back pain and numbness of the right lower limb for more than 20 years was admitted to the hospital. Combined with the patient's symptoms, signs, and imaging data, lumbar decompression and interbody fusion were performed through the L3/4 right intervertebral foramen, and no preventive decompression was performed on the left side during the operation. Two days after the operation, the patient developed numbness in the contralateral (left) lower limb, and the anterior tibial muscle strength was grade 0. Conservative treatments such as anti-inflammatory medication, nerve repair, and anti-inflammatory analgesia were given. On the third day, the patient's symptoms improved. **a** Preoperative MRI L3/4 disc herniation, spinal stenosis. **b** Lumbar MRI 2 days after operation showed no contralateral recess stenosis, disc herniation, hematoma, etc. **c** One year after the operation, lumbar CT showed good intervertebral fusion, the position of the fusion cage was in place, no endplate collapse, fusion cage slip, etc. **d** Patients after a 1-month review; screws in place; no broken rods; and no broken nails

Relationship between preoperative contralateral intervertebral foramen width and contralateral symptomatic FS after unilateral TLIF

Studies have indicated that the reduction of the intervertebral foramen width FW is more likely to cause intervertebral foramen nerve root compression than the intervertebral foramen height FH. Intervertebral foramen posterior wall degeneration of hypertrophic ligaments, joint capsule, and the proliferation of facet joints are common causes of nerve root compression [21, 22]. In this study, there were statistical differences in the preoperative and postoperative periods and changes in the width of FW between the two groups. Logistic analysis revealed that a smaller width of the contralateral intervertebral foramen before surgery was an independent risk factor for postoperative symptomatic FS. During the operation, when the screw rod is locked, the superior facet of the lower vertebral body tends to move upward or ventrally. Compared to the intervertebral foramen height, the nerve root has enough buffer space. However,

even a 1–2 mm reduction in the width of the intervertebral foramen can have a significant impact.

Relationship between fusion cage and contralateral symptomatic FS after unilateral TLIF

Clinical studies have demonstrated that intervertebral space and foramen height may not always recover effectively after unilateral TLIF, particularly on the uncompressed side. This may lead to new neurological symptoms [23]. The authors suggest that this could be due to the fusion implant position being biased toward the decompression side. In this study, there was no significant difference in cage height and the sagittal position of the cages between the two groups, but there was a statistical difference in the coronal position. Logistic analysis revealed that the coronal position of the cage, which did not cross the midline, was an independent risk factor for contralateral symptomatic FS after unilateral TLIF. Prior studies have indicated that when the cage height is less than the preoperative intervertebral space height, it is easier to achieve the required SL during surgery, but there is a higher risk of cage slip. Conversely, when the cage height is too high, it is difficult to obtain the required SL during the operation, but slipping is unlikely to occur. Therefore, there is a correlation between cage height and SL [24]. However, in our study, we kept the cage height consistent with DH, avoiding this issue. Thus, cage height did not affect the recovery of SL and was not associated with postoperative symptomatic intervertebral foramen stenosis. Furthermore, when the coronal position of the cage is biased toward the decompression side, the stress distribution inside the intervertebral space becomes unbalanced, causing the intervertebral space to tilt. Consequently, the height of the intervertebral foramen on the decompression side significantly increases, while the height of the intervertebral foramen on the non-decompression side decreases, leading to nerve root compression. A significant amount of bone grafting in the anterior part of the vertebral body near the anterior longitudinal ligament is favorable for vertebral bone fusion. Therefore, the sagittal position of the fusion cage should be located in the middle and posterior sides.

Conclusion

The incidence of contralateral symptomatic FS after unilateral TLIF is relatively low at 4.72%. However, this study found that certain preoperative factors such as contralateral intervertebral foramen stenosis, a smaller segmental lordosis angle, a smaller intervertebral foramen width, and the coronal position of the fusion cage not crossing the midline were independent risk factors for this complication. As a result, for patients with these risk factors, special attention should be given to the locking of the screw rod during lumbar lordosis recovery and the placement of the fusion cage to ensure proper coronal positioning beyond the midline. Additionally, prophylactic decompression may be necessary. It is important to note that this study has some limitations. For instance, it is a single-center study and may not have accounted for other potential risk factors. Furthermore, this study did not provide a quantitative analysis of imaging data, making it difficult to determine when preventive decompression should be performed. Therefore, future multi-centre, large-sample, and high-quality research is necessary to further improve our understanding of the risk factors and appropriate management of contralateral symptomatic FS after unilateral TLIF.

Author contribution All authors contributed to either data collection, analysis, or writing the manuscript. Wenjie Lu wrote the main manuscript text and finished the statistics of the article. Jiaming Zhang prepared the figures. Yuanguo Deng prepared the tables. Lingqiao Wu properly polished the manuscript. Yunlin Chen, Xudong Hu, Chaoyue Ruan, Yang Wang, and Weihu Ma all participated in the operation and collected relevant data. Weiyu Jiang reviewed and revised the manuscript. All authors reviewed the manuscript. The authors read and approved the final manuscript.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval The study was approved by the Ethics Committee of Ningbo Sixth Hospital, and all methods were carried out in accordance with relevant guidelines and regulations. All patient-related data were approved for publication by the patients themselves or their guardians.

Informed consent Written informed consent was obtained from all the participants prior to the publication of this study.

Consent for publication All authors give their consent to publish if accepted by the Editorial Board.

Competing interests The authors declare no competing interests.

References

1. Blume HG, Rojas CH (1981) Unilateral lumbar interbody fusion(posteriorapproach)utilizing dowel aft. J Neurol Orthop Surg 2(2):171–175
2. Wasinpongwanich K, Nopsopon T, Pongpirul K (2022) Surgical treatments for lumbar spine diseases (TLIF vs other surgical techniques): a systematic review and meta-analysis. Front Surg 9:829469. https://doi.org/10.3389/fsurg.2022.829469
3. de Kunder SL, van Kuijk SMJ, Rijkers K, Caelers IJMH, van Hemert WLW, de Bie RA, van Santbrink H (2017)

Transforaminal lumbar interbody fusion (TLIF) versus posterior lumbar interbody fusion (PLIF) in lumbar spondylolisthesis: a systematic review and meta-analysis. Spine J : Off J North Am Spine Soc 17(11):1712–1721. https://doi.org/10.1016/j.spinee.2017.06.018
4. Liu J, Deng H, Long X, Chen X, Xu R, Liu Z (2016) A comparative study of perioperative complications between transforaminal versus posterior lumbar interbody fusion in degenerative lumbar spondylolisthesis. Eur Spine J : Off Publ Eur Spine Soc, Eur Spinal Deform Soc, Eur Sect Cerv Spine Res Soc 25(5):1575–1580. https://doi.org/10.1007/s00586-015-4086-8
5. Bai J, Zhang W, Zhang X, Sun Y, Ding W, Shen Y (2015) A clinical investigation of contralateral neurological symptom after transforaminal lumbar interbody fusion (TLIF). Med Sci Monitor Int Med J Exp Clin Res 21:1831–1838. https://doi.org/10.12659/MSM.894159
6. Chen YL, Hu XD, Wang Y, Jiang WY, Ma WH (2021) Contralateral radiculopathy after unilateral transforaminal lumbar interbody fusion: causes and prevention. J Int Med Res 49(8):3000605211037475. https://doi.org/10.1177/03000605211037475
7. Liu QY, Chen JY, Liang BL, Li JT, Zeng WK (2007) Evaluation of screw position by multi-slice ct after pedicle screw placement. Chin J Med Imag Technol 23(8):1214–1217. https://doi.org/10.3321/j.issn:1003-3289.2007.08.032
8. Wildermuth S, Zanetti M, Duewell S, Schmid MR, Romanowski B, Benini A, Böni T, Hodler J (1998) Lumbar spine: quantitative and qualitative assessment of positional (upright flexion and extension) MR imaging and myelography. Radiology 207(2):391–398. https://doi.org/10.1148/radiology.207.2.9577486
9. Lorenc T, Gołębiowski M, Syganiec D, Glinkowski WM (2022) Associations between patient report of pain and intervertebral foramina changes visible on axial-loaded lumbar magnetic resonance imaging. Diagnostics (Basel, Switzerland) 12(3):563. https://doi.org/10.3390/diagnostics12030563
10. Singh V, Montgomery SR, Aghdasi B, Inoue H, Wang JC, Daubs MD (2013) Factors affecting dynamic foraminal stenosis in the lumbar spine. Spine J : Off J North Am Spine Soc 13(9):1080–1087. https://doi.org/10.1016/j.spinee.2013.03.041
11. Long Z, Li Q, Yan H, Wei W, Tang Y, Yang C (2019) Analysis of the placement of intervertebral fusion device in MISTLIF. J Youjiang Med Univ Natl. https://doi.org/10.3969/j.issn.1001-5817.2019.03.015
12. Hwang SH, Park SW, Kim YB (2020) Risk factors for symptomatic contralateral foraminal stenosis after unilateral transforaminal lumbar interbody fusion. World Neurosurg 133:e452–e458. https://doi.org/10.1016/j.wneu.2019.09.048
13. Yang Y, Liu ZY, Zhang LM, Dong JW, Xie PG, Chen RQ, Yang B, Liu C, Liu B, Rong LM (2018) Risk factor of contralateral radiculopathy following microendoscopy-assisted minimally invasive transforaminal lumbar interbody fusion. Eur Spine J : Off Publ Eur Spine Soc, Eur Spinal Deform Soc, Eur Sect Cerv Spine Res Soc 27(8):1925–1932. https://doi.org/10.1007/s00586-017-5417-8
14. Cho PG, Park SH, Kim KN, Ha Y, Yoon DH, Shin DA (2015) A morphometric analysis of contralateral neural foramen in TLIF. Eur Spine J : Off Publ Eur Spine Soc, Eur Spinal Deform Soc, Eur Sect Cerv Spine Res Soc 24(4):783–790. https://doi.org/10.1007/s00586-015-3783-7
15. Gunasekaran VS, Hejdak D, Meyer B, Klein A, Koch K (2021) Quantitative correlation of lumbar foraminal stenosis with local morphological metrics. Eur Spine J : Off Publ Eur Spine Soc, Eur Spinal Deform Soc, Eur Sect Cerv Spine Res Soc 30(11):3319–3323. https://doi.org/10.1007/s00586-021-06944-8
16. Kim MC, Park JU, Kim WC, Lee HS, Chung HT, Kim MW, Chung NS (2014) Can unilateral-approach minimally invasive transforaminal lumbar interbody fusion attain indirect contralateral decompression? A preliminary report of 66 MRI analysis. Eur Spine J : Off Publ Eur Spine Soc, Eur Spinal Deform Soc, Eur Sect Cerv Spine Res Soc 23(5):1144–1149. https://doi.org/10.1007/s00586-014-3192-3
17. Iwata T, Miyamoto K, Hioki A, Fushimi K, Ohno T, Shimizu K (2015) Morphologic changes in contralateral lumbar foramen in unilateral cantilever transforaminal lumbar interbody fusion using kidney-type intervertebral spacers. J Spinal Disord Tech 28(5):E270–E276. https://doi.org/10.1097/BSD.0b013e318286bb14
18. Yan DL, Pei FX, Li J, Soo CL (2008) Comparative study of PILF and TLIF treatment in adult degenerative spondylolisthesis. Eur Spine J : Off Publ Eur Spine Soc, Eur Spinal Deform Soc, Eur Sect Cerv Spine Res Soc 17(10):1311–1316. https://doi.org/10.1007/s00586-008-0739-1
19. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V (2010) Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. Spine 35(25):2224–2231. https://doi.org/10.1097/BRS.0b013e3181ee6bd4
20. Jang KM, Park SW, Kim YB, Park YS, Nam TK, Lee YS (2015) Acute contralateral radiculopathy after unilateral transforaminal lumbar interbody fusion. J Korean Neurosurg Soc 58(4):350–356. https://doi.org/10.3340/jkns.2015.58.4.350
21. Liu W, Zhao Y, Jia J, Chen X, Mai R, Yuan S, Tian Y, Liu X (2020) Morphologic changes of intervertebral foramen after minimally invasive transforaminal lumbar interbody fusion: a radiographic and clinical study. World Neurosurg 142:e151–e159. https://doi.org/10.1016/j.wneu.2020.06.143
22. Tan J, Li W, Dai ZY, Yan Y, Xia YZ (2021) Anatomical relationship between lumbar disc diameter and intervertebral foraminal diameter with nerve root compression. Chongqing Med 50(10):1737–1740. https://doi.org/10.3969/j.issn.1671-8348.2021.10.027
23. Hawasli AH, Khalifeh JM, Chatrath A, Yarbrough CK, Ray WZ (2017) Minimally invasive transforaminal lumbar interbody fusion with expandable versus static interbody devices: radiographic assessment of sagittal segmental and pelvic parameters. Neurosurg Focus 43(2):E10. https://doi.org/10.3171/2017.5.FOCUS17197
24. Landham PR, Don AS, Robertson PA (2017) Do position and size matter? An analysis of cage and placement variables for optimum lordosis in PLIF reconstruction. Eur Spine J 26(11):2843–2850. https://doi.org/10.1007/s00586-017-5170-z

Authors and Affiliations

Wenjie Lu[1] · Jiaming Zhang[2] · Yuanguo Deng[1] · Lingqiao Wu[1] · Yunlin Chen[3] · Xudong Hu[3] · Chaoyue Ruan[3] · Yang Wang[3] · Weihu Ma[3] · Weiyu Jiang[3]

✉ Weiyu Jiang
weiyujiang1210@163.com

[1] Zhejiang Chinese Medical University, Hangzhou 310053, Zhejiang, China

[2] Huai'an Hospital of Traditional Chinese Medicine, Huaian 223001, Jiangsu, China

[3] Department of Spinal Surgery, Ningbo Sixth Hospital, Ningbo 315040, Zhejiang, China