

# Clinical Significance of PLIF in Restoring L4-S1 Segmental Lordosis of 2-level Isthmic Spondylolisthesis

Jing-Yu Wang

Second Xiangya Hospital

Fu-Sheng Liu

Second Xiangya Hospital

Jing Li (✉ [jingli1969@csu.edu.cn](mailto:jingli1969@csu.edu.cn))

Second Xiangya Hospital

Xiao-Bin Wang

Second Xiangya Hospital

---

## Research article

**Keywords:** 2-level spondylolisthesis, PLIF, L4-S1 SL, LDI, sagittal plane parameters

**Posted Date:** February 12th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-198135/v1>

**License:** © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

---

# Abstract

**Background:** Spinal and pelvic sagittal plane balance is closely related to good clinical prognosis, so in the treatment of 2-level isthmic spondylolisthesis, attention should be paid not only to adequate nerve decompression, but also to the correction of lumbosacral sagittal plane parameters. The purpose of this study was to observe the clinical prognosis and sagittal parameters of patients with isthmic spondylolisthesis treated with PLIF, and to find out the risk factors leading to poor prognosis.

**Methods:** From January 2006 to August 2018, the clinical data of patients with 2-level isthmic spondylolisthesis treated with PLIF in the Second Xiangya Hospital of Central South University were retrospectively collected. The clinical symptoms (JOA score and VAS score) and the sagittal parameters of lumbosacral segment (PI, PT, LL, L4-S1 SL, LDI, PI-LL, LL and L4-S1 SL) were recorded before operation, immediately after operation and at the last follow-up. According to the improvement rate of JOA score, the patients were divided into two subgroups, poor(P) group and good(G) group. The parameters within and between the two subgroups were compared. Meanwhile, Pearson correlation analysis was conducted between sagittal parameters and JOA score improvement rate.

**Results:** A total of 52 patients were enrolled in this study, the average age was  $(59.96 \pm 9.11)$  years, and the mean follow-up time was  $(31.88 \pm 8.37)$  months. Group G ( $n = 37$ ) and group P ( $n = 15$ ). In terms of clinical symptom improvement and sagittal plane parameters, except PI, the other parameters of the patients were improved compared with those before operation, and the difference was statistically significant. In the intra-group comparison, except PI, other indexes in group G were significantly improved, while in group P, there was no significant difference in PI, LL, L4-S1 SL, LDI, PI-LL before and after operation. In the comparison between groups, there was no significant difference in baseline data between group G and group P; postoperative VAS score(back pain) in group G was lower than that in group P, but there was no significant difference in VAS score(leg pain); in terms of JOA score and JOA score improvement rate, group G was significantly better;  $\Delta$ L4-S1 SL, L4-S1 SL and LDI were larger in group G, and the proportion of patients with normal LDI was higher than that in group P. Pearson correlation analysis showed that postoperative  $\Delta$ L4-S1 SL, LDI and L4-S1 SL were positively correlated with JOA improvement rate. 2 patients with failed internal fixation occurred in group P, and the postoperative LDI was less than 50%.

**Conclusion:** PLIF is an effective method for the treatment of 2-level isthmic spondylolisthesis.  $\Delta$ L4-S1 SL, L4-S1 SL and good LDI may be important sagittal parameters affecting the clinical prognosis of L4 and L5 isthmus spondylolisthesis.

## Introduction

Isthmic spondylolisthesis is one of the most common types of lumbar spondylolisthesis in adults [1]. It refers to the displacement of the upper vertebral body relative to the lower vertebral body caused by unilateral or bilateral interarticular fractures, resulting in low back pain, lower limb radiation pain, neurogenic claudication and other clinical symptoms. Lumbosacral 2-segmental isthmic spondylolisthesis is rare, with an incidence of 0.3-1.48% [2, 3]. When conservative treatment fails, decompression, reduction and fusion are required to relieve nerve compression and correct deformity.

The safety and efficacy of transforaminal lumbar interbody fusion (TLIF) and posterior lumbar interbody fusion (PLIF) in the treatment of single-segmental spondylolisthesis have been confirmed. However, compared with single-segmental lesions, the sagittal deformities of double-segmental spondylolisthesis are more serious[4]. The sagittal balance of spine and pelvis is closely related to good clinical prognosis[5-7]. When the sagittal plane is out of balance, it will lead to compensatory mechanisms, such as cervicothoracic overextension, pelvic retroversion and knee flexion, causing muscle fatigue and leading to chronic back pain and dysfunction[8, 9]. Therefore, in the treatment of 2-level spondylolisthesis, we should not only pay attention to adequate nerve decompression, but also pay more attention to the correction sagittal deformity.

In this study, the clinical data of 52 patients with L4 and L5 isthmic spondylolisthesis treated with PLIF in our department were analyzed retrospectively in order to find out the risk factors leading to poor prognosis.

## Methods

### *Study population*

With consent of the ethics committee of the Second Xiangya Hospital of Central South University and informed consent of patients, we retrospectively collected the clinical data of 52 cases of L4 and L5 double-segmental isthmic spondylolisthesis who underwent surgical treatment in our hospital from January 2006 to August 2018. Inclusion criteria: (1) the diagnosis was confirmed as continuous L4 and L5 double-segmental isthmic spondylolisthesis; (2) there were definite indications for surgery; (3) surgical treatment using PLIF technique and only L4-S1 internal fixation and fusion. Exclusion criteria: (1) incomplete imaging data; (2) follow-up time < 24 months; (4) previous history of lumbar surgery, trauma, pelvis or lower limb disease, lumbar tumor, inflammation and coronal deformity (Cobb angle >10 °).

### *Surgical Procedures*

All patients underwent PLIF by senior spinal surgeons. The patient was placed in prone position under general anesthesia. Along the posterior median incision, skin and fascia were incised in turn, paravertebral muscles were separated, and bilateral screw entry points were exposed. Then the L4 and L5 floating lamina, spinous process and facet joints connected with them were removed, and the soft tissue on the bone surface was removed as a subsequent bone graft material. Appropriate pedicle screws were implanted on both sides of L4-S1, and the L4/5 and L5/S1 disc spaces were treated with distraction and pull reduction, followed by the removal of L4/5 and L5/S1 discs, and the nerve roots of L4, L5 and S1 were released. Intervertebral bone grafting was performed using autogenous bone or cage combination. Finally, the posterior compression operation was performed at the L4/5 and L5/S1 segments, and the bone graft surface was held tightly.

## ***Radiological Evaluation***

The imaging parameters were measured independently by two spinal surgeons with the software of surgimap ver.2.3.2.1 software (New York, USA). The average measured by the two surveyors as the final result. The indexes of preoperative, postoperative and final follow-up included: L4 slippage percentage, L5 slippage percentage, lumbar lordosis (LL), L4-S1 SL (segmental lordosis), LDI:  $100(L4-S1\ SL/LL)\%$ , pelvic identity (PI), peptic tilt (PT), sacral slope (SS). Slippage percentage: the ratio of the sliding distance of the upper vertebral body relative to the caudal vertebral body to the length of the superior endplate of the caudal vertebral. LL: the angle between L1 upper endplate and S1 upper endplate. L4-S1 SL: the angle between L4 upper endplate and S1 upper endplate.  $\Delta LL$  and  $\Delta L4-S1\ SL$  were defined as postoperative values minus preoperative values.

## ***Data Collection and Clinical Evaluation***

The clinical data of the patients were obtained from the medical records department and outpatient follow-up. Demographic data and Perioperative Parameters included age, gender, Body Mass Index (BMI), operation time, intraoperative blood loss, follow-up time, and fusion status.

The standard of bone fusion was that X-ray showed the formation of continuous bone bridge between adjacent vertebral bodies, or there was no obvious light transmission area between adjacent vertebral bodies on CT, or there was no abnormal activity on dynamic X-ray film. VAS score and JOA score were used to quantify the clinical efficacy, JOA score improvement rate =  $100/100$  (postoperative score – preoperative score) / (29-preoperative score).

In order to facilitate statistical analysis, according to the literature standard [10,11], we divided the LDI into two groups: the normal group (50% - 80%) and the abnormal group (not within 50% - 80%), and divided the improvement rate of JOA score into two subgroups: poor (P) group (<50%) and good (G) group (>50%).

## **Statistical Analysis**

All statistical analysis was performed by SPSS 23.0 (SPSS, Chicago, Illinois, USA). The measurement data were expressed by mean  $\pm$  standard deviation, the difference between groups was analyzed by independent sample t test, and the data before and after operation was analyzed by paired sample t test. The count data were expressed by frequency or constituent ratio, and the statistical analysis was performed by chi square test. Pearson's correlation coefficient was used to determine the correlation between imaging parameters and JOA score improvement rate. All tests were two-sided, and a  $P < 0.05$  was considered statistically significant.

## **Results**

### ***Demographic data and Perioperative Parameters***

A total of 52 consecutive L4 and L5 isthmic spondylolisthesis cases were included in this study, including 38 females (73.08%). The age of the patients was ( $59.96 \pm 9.11$ ) years and the BMI was ( $23.12 \pm 1.64$ ) kg/m<sup>2</sup>. (Table 1)

Among the perioperative parameters, the operation time was ( $216.00 \pm 24.62$ ) min, the blood loss was ( $810.38 \pm 197.23$ ) ml, and the follow-up time was ( $31.88 \pm 8.37$ ) months. The fusion rate was 86.54% at the last follow-up. (Table 1)

In terms of clinical symptom improvement and sagittal parameters, except that PI was comparable before and after surgery, other parameters were improved compared with that before surgery, and the differences were statistically significant ( $P < 0.05$ ) (Table 2 and 3).

### ***Subgroup analysis according to JOA score improvement rate***

According to the improvement rate of JOA score, there were no significant differences in demographic data such as age, gender, BMI, preoperative sagittal parameters and symptom scale scores, and fusion rate between the two groups (Table 1,2,3).

In self-comparison before and after surgery, it was found that all the other indexes except PI in group G were significantly improved, and the differences were statistically significant ( $P < 0.05$ ), while in group P, in addition to PI, we also found that there was no significant difference in LL, L4-S1 SL, LDI, PI-LL before and after operation (Table 3).

After operation at the last follow up, there were differences in the improvement of clinical symptoms and sagittal parameters between group P and group G. We found that the VAS score of low back pain in group G was lower than that in group P (2.03 vs 4.60,  $P < 0.001$ ), but there was no significant difference in VAS score of leg pain ( $P = 0.744$ ); In the JOA score and JOA score improvement rate, group G was significantly better ( $P < 0.001$ ). In terms of imaging parameters, L4-S1 SL and LDI were larger in group G ( $36.00^\circ$  vs  $29.33^\circ$ ,  $P = 0.033$  and  $63.26\%$  vs  $52.51\%$ ,  $P = 0.015$ ), and the proportion of normal LDI in group G was higher than that in group P;  $\Delta L4-S1\ SL$  was larger in group G, and the difference was statistically significant ( $11.89^\circ$  vs  $5.80^\circ$ ,  $P = 0.029$ ). Other parameters such as LL, PI-LL, PT, SS were not significantly different between group P and group G, but we can still find that the improvement of parameters in group G is more obvious (Table 1,3).

### ***Correlation Analysis of JOA improvement rate***

In the correlation analysis, we found no correlation between JOA score improvement rate and preoperative imaging parameters. After operation, we found that L4-S1 SL, LDI and  $\Delta L4-S1\ SL$  were positively correlated with JOA score improvement rate ( $r = 0.371$ ,  $P = 0.042$ ;  $r = 0.348$ ,  $P = 0.011$ ;  $r = 0.468$ ,  $P = 0.035$ ). Other parameters such as LL, PI, PT, SS were not significantly correlated with JOA score improvement rate (Table 4).

### *Complication of internal fixation*

No internal fixation failure occurred in group G, while 2 cases in the P group had postoperative internal fixation failure, and their postoperative LDI was less than 50%. During the follow-up, 1 case had the phenomenon that the top screw migrated and cut the upper endplate (figure 2), the patient refused to undergo reoperation and was under close follow-up. Revision operation was performed in 1 case of sacral screw fracture.

## **Discussion**

The causes of isthmus spondylolisthesis are complex, including genetic, traumatic, mechanical and hormonal factors [12,13]. Among them, the abnormality of spine and pelvis parameters is an important factor in the occurrence and development of spondylolisthesis [14]. Therefore, for the surgical principles of spondylolisthesis, in addition to decompression, reduction, fixation and fusion, attention should be paid to the reconstruction of lumbosacral sagittal balance. Zhou et al. [4] found that patients with isthmus spondylolisthesis have larger PI and L5I than asymptomatic healthy people, while patients with multi-segmental spondylolisthesis have larger SVA, PT and smaller LL, L4-S1 SL than single-segmental spondylolisthesis, which means that surgery is more challenging in correcting sagittal deformities of 2-level spondylolisthesis.

Du et al. [15] treated 58 cases of L4 and L5 spondylolisthesis with TLIF. The postoperative PT, SS, LL, L4-S1 SL, SVA and other parameters were significantly improved as compared with those before operation, it was found that 2-level TLIF was more effective in restoring local and global sagittal balance. Song et al. [1] treated 32 cases of 2-level isthmus spondylolisthesis with PLIF, the excellent and good rate of JOA score recovery was 84.3%, and the fusion rate was 87.5%, which was similar to our results. In this study, the JOA score, VAS score and sagittal plane parameters were significantly improved compared with those before operation through more than 2 years follow-up, which once again demonstrated the effectiveness of PLIF in the treatment of 2-level spondylolisthesis.

We believe that the advantage of PLIF in the treatment of 2-level spondylolisthesis lies in [13, 15-19]: 1. after spondylolisthesis, the posterior lamina is almost floating, and is usually accompanied by severe articular process hyperplasia and osteophyte formation, removal of posterior structure is beneficial to the reduction; 2. fully enlarge the spinal canal and nerve root foramen to avoid squeezing the nerve root after reduction; 3. laminectomy can obtain more autogenous bone, which avoids the rejection of allogeneic bone and the complications of iliac bone removal, which is beneficial to the interbody fusion. 4. double-segmental interbody fusion is beneficial to the restoration of intervertebral foramen height and lumbosacral sagittal plane; 5. discectomy, intervertebral height and sagittal plane reconstruction, fusion and internal fixation can be completed in one stage.

In this study, the overall improvement rate of JOA after operation was  $(64.81 \pm 27.83) \%$ . We divided the patients into two groups according to the threshold of 50% improvement rate of JOA score. Through comparative analysis, it was found that poor reconstruction of L4-S1 SL and LDI was an important factor affecting prognosis. Kuhta et al. [20] treated 57 cases of single-segment degenerative spondylolisthesis with TLIF and found that insufficient correction of SL during operation would lead to forward shift of center of gravity and affect clinical prognosis. Takahashi et al. [21] found that the insufficient increase of L3-L5 SL in the treatment of L3 and L4 double-segment degenerative spondylolisthesis by PLIF was related to the poor clinical prognosis. He et al. [22] believe that in the treatment of degenerative spondylolisthesis with PLIF, the recovery of SL and PT is related to the clinical effect, and the increase of SL and the decrease of PT may play a positive role in relieving low back pain after operation. In this study,  $\Delta$  L4-S1 SL, L4-S1 SL in group G was higher than that in group P, and positively correlated with the improvement rate of JOA score, indicating the importance of reconstruction of L4-S1 SL in double-segmental spondylolisthesis for improving clinical prognosis. According to the concept of the "core economic cone" [23], when the body is within the smallest cone, the muscle consumes the least energy, when the radius of the cone increases, the muscles of the back and buttocks must be activated to maintain body balance. L4-S1 is the base of the spine, when it is not properly corrected, it may lead to overall imbalance, to compensate for torso tilt, extension of the remaining segments and pelvic retroversion may be the cause of low back pain.

In order to reconstruct L4-S1 SL, we think the following can be done during the operation: 1. the hip joint should be properly extended before operation; 2. the posterior hyperplastic structures should be removed completely, which is beneficial to the shortening of the rear and the opening of the front during compression; 3. a moderate-sized cage should be anterior placed within disc space[22, 24, 25]; 4. in order to avoid the difficulty of compression, the anterior part of disc space can be grafted first, and then the remaining bone can be implanted after compression; 5. the ideal range of L4 – S1 SL is 2/3 of LL, and LL is related to PI [11,26, 27], so individual bending should be performed; 5. L4 and L5 screws toward the lower endplate is more beneficial to the compression and the recovery of segmental lordosis[28].

LDI is the ratio of L4-S1 SL to LL, which is an important parameter of lumbosacral. Janik et al. [29] Considered that the ideal LDI in asymptomatic population should be 2/3. Relevant studies have shown that small LDI in adult spinal deformity may lead to postoperative proximal junctional kyphosis [30]. Zheng et al. [10] found that patients with abnormal LDI after PLIF were more likely to have adjacent segment degeneration (ASD) than those with normal LDI, and patients with low LDI were more likely to have ASD than those with high LDI. In this study, the LDI of the 2 cases of internal fixation failure was less than 50%, indicating that abnormal LDI will increase the incidence of mechanical complications. We found that the mean LDI and proportion of LDI within the normal range in the G group were higher than those in group P, and there was a positive correlation between LDI and JOA score improvement rate, indicating that for double level spondylolisthesis, increasing L4-S1 SL appropriately and paying attention to its matching with LL can improve the clinical prognosis of patients to a certain extent.

The shortcomings of this study are: 1. the limitations of single center retrospective analysis, the incidence rate of 2-level isthmus spondylolisthesis is low, and the number of cases is relatively small, some parameters may not get statistical difference.

Therefore, relevant conclusions need to be verified by prospective, multi-center, long-term follow-up of large sample of cases; 2. taking JOA score improvement rate as the basis for grouping has some subjectivity; 3. there are many reasons that affect the prognosis of patients, we only discuss the radiological parameters as the risk factors of clinical prognosis. However, as far as we know, this is one of the few clinical and sagittal follow-up studies of PLIF in the

treatment of 2-level isthmic spondylolisthesis, and it is the first time to explore the relationship between  $\Delta L4-S1$  SL,  $L4-S1$  SL, LDI and the clinical prognosis of L4 and 5 isthmic spondylolisthesis.

## Conclusion

PLIF is an effective treatment for L4 and L5 isthmic spondylolisthesis,  $\Delta L4-S1$  SL,  $L4-S1$  SL and good LDI may be important sagittal parameters that affect the clinical prognosis.

## Abbreviations

LL: Lumbar lordosis; SL: segmental lordosis; JOA: Japanese Orthopaedic Association; PI: Pelvic incidence; PT: Pelvic tilt; SS: Sacral slope; PLIF: posterior lumbar interbody fusion; VAS: Visual analog scale; LDI: lordosis distribution index.

## Declarations

### Ethics approval and consent to participate:

The study protocol was approved by the Institutional Review Board at the Second Xiangya Hospital, Central South University, Hunan, P.R. China. Written informed consent was obtained from each patient for publication of this study.

### Consent for publication:

Not applicable.

### Availability of data and material:

All data relevant to the study are included in the article.

### Competing interests:

Jing-Yu Wang; Fu-Sheng Liu; Xiao-Bin Wang and Jing Li declare that they have no conflict of interest.

### Authorship:

All authors participated in data acquisition. JL and XBW conceived and designed the study. JYW and FSL collected the data, performed the statistical analysis and wrote the manuscript. XBW and JL contributed to revision of the manuscript. All authors read and approved the final manuscript.

### Funding:

This work was supported by the National Natural Science Foundation of China (Grant No. 81871821 to JL).

### Acknowledgements:

None.

## References

1. Song D, Song D, Zhang K, et al. Double-level isthmic spondylolisthesis treated with posterior lumbar interbody fusion: A review of 32 cases. *Clinical neurology and neurosurgery*. 2017;161:35-40.
2. Liu X, Wang L, Yuan S, et al. Multiple-level lumbar spondylolysis and spondylolisthesis. *Journal of neurosurgery Spine*. 2015;22(3):283-287.
3. Sakai T, Sairyo K, Takao S, et al. Incidence of lumbar spondylolysis in the general population in Japan based on multidetector computed tomography scans from two thousand subjects. *Spine*. 2009;34(21):2346-2350.
4. Zhou Q, Sun X, Chen X, et al. How does sagittal spinopelvic alignment of lumbar multisegmental spondylolysis differ from monosegmental spondylolysis? *Journal of neurosurgery Spine*. 2020;1-8.
5. Tempel Z, Gandhoke G, Bolinger B, et al. The Influence of Pelvic Incidence and Lumbar Lordosis Mismatch on Development of Symptomatic Adjacent Level Disease Following Single-Level Transforaminal Lumbar Interbody Fusion. *Neurosurgery*. 2017; 80(6):880-886.
6. Sebaaly A, Grobost P, Mallam L, et al. Description of the sagittal alignment of the degenerative human spine. *European spine journal*. 2018; 27(2):489-496.
7. Harroud A, Labelle H, Joncas J, et al. Global sagittal alignment and health-related quality of life in lumbosacral spondylolisthesis. *European spine journal*. 2013; 22(4):849-856.
8. Le Huec J, Faundez A, Dominguez D, et al. Evidence showing the relationship between sagittal balance and clinical outcomes in surgical treatment of degenerative spinal diseases: a literature review. *International orthopaedics*. 2015; 39(1):87-95.
9. Barrey C, Roussouly P, Le Huec J, et al. Compensatory mechanisms contributing to keep the sagittal balance of the spine. *European spine journal*. 2013;S834-841.

10. Zheng G, Wang C, Wang T, et al. Relationship between postoperative lordosis distribution index and adjacent segment disease following L4-S1 posterior lumbar interbody fusion. *Journal of orthopaedic surgery and research*.2020;15(1):129.
11. Yilgor C, Sogunmez N, Boissiere L, et al. Global Alignment and Proportion (GAP) Score: Development and Validation of a New Method of Analyzing Spinopelvic Alignment to Predict Mechanical Complications After Adult Spinal Deformity Surgery. *The Journal of bone and joint surgery*. 2017; 99(19):1661-1672.
12. Ogawa H, Nishimoto H, Hosoe H, et al. Clinical outcome after segmental wire fixation and bone grafting for repair of the defects in multiple level lumbar spondylolysis. *Journal of spinal disorders & techniques*. 2007; 20(7):521-525.
13. Zhang S, Ye C, Lai Q, et al. Double-level lumbar spondylolysis and spondylolisthesis: A retrospective study. *Journal of orthopaedic surgery and research*. 2018; 13(1):55.
14. Labelle H, Mac-Thiong J, Roussouly P. Spino-pelvic sagittal balance of spondylolisthesis: a review and classification. *European spine journal* .2011;641-646.
15. Du C, Li S, Xu L, et al. Sagittal reconstruction of lumbosacral contiguous double-level spondylolytic spondylolisthesis: a comparison of double-level and single-level transforaminal lumbar interbody fusion. *Journal of orthopaedic surgery and research*. 2019; 14(1):148.
16. Simmons J. Posterior lumbar interbody fusion with posterior elements as chip grafts. *Clinical orthopaedics and related research*. 1985;(193):85-89.
17. Song D, Chen Z, Song D. Surgical treatment of double-level isthmic spondylolisthesis. *Journal of neurosurgery Spine*. 2014; 20(4):396-399.
18. Song D, Chen Z, Song D, et al. Comparison of posterior lumbar interbody fusion (PLIF) with autogenous bone chips and PLIF with cage for treatment of double-level isthmic spondylolisthesis. *Clinical neurology and neurosurgery*. 2015; 138:111-116.
19. Sudo H, Oda I, Abumi K, et al. Biomechanical study on the effect of five different lumbar reconstruction techniques on adjacent-level intradiscal pressure and lamina strain. *Journal of neurosurgery Spine*. 2006;5(2):150-155.
20. Kuhta M, Bošnjak K, Vengust R. Failure to maintain segmental lordosis during TLIF for one-level degenerative spondylolisthesis negatively affects clinical outcome 5 years postoperatively: a prospective cohort of 57 patients. *European spine journal* .2019;28(4):745-750.
21. Takahashi Y, Okuda S, Nagamoto Y, et al. Effect of segmental lordosis on the clinical outcomes of 2-level posterior lumbar interbody fusion for 2-level degenerative lumbar spondylolisthesis. *Journal of neurosurgery Spine*.2019;1-6.
22. He S, Zhang Y, Ji W, et al. Analysis of Spinopelvic Sagittal Balance and Persistent Low Back Pain (PLBP) for Degenerative Spondylolisthesis (DS) following Posterior Lumbar Interbody Fusion (PLIF). *Pain research & management*. 2020;2020:5971937.
23. Haddas R, Sambhariya V, Kosztowski T, et al. Cone of economy classification: evolution, concept of stability, severity level, and correlation to patient-reported outcome scores. *European spine journal*. 2021.
24. Ould-Slimane M, Lenoir T, Dauzac C, et al. Influence of transforaminal lumbar interbody fusion procedures on spinal and pelvic parameters of sagittal balance. *European spine journal* .2012;21(6):1200-1206.
25. Rice J, Sedney C, Daffner S, et al. Improvement of Segmental Lordosis in Transforaminal Lumbar Interbody Fusion: A Comparison of Two Techniques. *Global spine journal* .2016; 6(3):229-233.
26. Pan C, Wang G, Wang X, et al. Predictive formulae of ideal lumbar lordosis determined by individual pelvic incidence and thoracic kyphosis in asymptomatic adults. *Journal of orthopaedic science*. 2021.
27. Pan C, Wang G, Sun J. Correlation between the apex of lumbar lordosis and pelvic incidence in asymptomatic adult. *European spine journal* .2020;29(3):420-427.
28. Kong L, Zhang Y, Wang F, et al. Radiographic Restoration of Sagittal Spinopelvic Alignment After Posterior Lumbar Interbody Fusion in Degenerative Spondylolisthesis. *Clinical spine surgery*. 2016; 29(2):E87-92.
29. Janik T, Harrison D, Cailliet R, et al. Can the sagittal lumbar curvature be closely approximated by an ellipse? *Journal of orthopaedic research* .1998; 16(6):766-770.
30. Ohba T, Ebata S, Oba H, et al. Correlation Between Postoperative Distribution of Lordosis and Reciprocal Progression of Thoracic Kyphosis and Occurrence of Proximal Junctional Kyphosis Following Surgery for Adult Spinal Deformity. *Clinical spine surgery*. 2018;31(9):E466-E472.

## Tables

**Table 1** Demographic, perioperative and clinical follow-up parameters

Variable	Total	Group P	Group G	<i>P</i>
Number of patients	52	15	37	
Age (years)	59.96±9.11	62.06±10.72	59.11±8.39	0.294
Gender				0.364
Female	38	12	26	
Male	14	3	11	
BMI (kg/m <sup>2</sup> )	23.12±1.64	23.40±1.79	23.00±1.58	0.433
Operative time (min)	216.00±24.62	223.33±24.98	213.03±24.18	0.174
Blood loss (ml)	810.38±197.23	831.33±227.50	801.89±186.34	0.630
Follow up (months)	31.88±8.37	34.53±8.68	30.81±8.12	0.148
Fusion situation				0.680
Non fusion	7	2	5	
Fusion	45	13	32	
JOA IR (%)	64.81±27.83	28.52±10.44	81.15±10.21	<b>&lt;0.001</b>
ΔLL	1.75±4.74	1.73±4.64	1.80±5.13	0.962
ΔL4-S1 SL	10.13±9.20	5.80±10.14	11.89±8.31	<b>0.029</b>
LDI subgroup				<b>0.024</b>
Normal	42	9	33	
Abnormal	10	6	4	

*P*-value for the comparison between group G and the group P JOA IR: JOA score improvement rate

**Table 2** Clinical effect and non-spinal pelvic parameters of preoperative and final follow-up

Variable	Total(n=52)			group P(n=15)			group G(n=37)			<i>P</i> 1	<i>P</i> 2
	Pre-op	Latest-fu	<i>P</i>	Pre-op	Latest-fu	<i>P</i> value	Pre-op	Latest-fu	<i>P</i>		
JOA score	12.35±2.67	23.13±4.70	<b>&lt;0.001</b>	12.40±2.75	16.53±2.42	<b>&lt;0.001</b>	12.32±2.68	25.81±1.90	<b>&lt;0.001</b>	0.927	<b>&lt;0.001</b>
VAS score											
back	6.81±1.12	2.77±1.81	<b>&lt;0.001</b>	6.73±1.28	4.60±1.18	<b>&lt;0.001</b>	6.83±1.17	2.03±1.46	<b>&lt;0.001</b>	0.777	<b>&lt;0.001</b>
leg	7.29±1.32	1.19±0.82	<b>&lt;0.001</b>	7.27±1.28	1.13±0.92	<b>&lt;0.001</b>	7.30±1.35	1.22±0.79	<b>&lt;0.001</b>	0.940	0.744
L4 slippage percentage [%]	29.46±11.53	3.06±1.90	<b>&lt;0.001</b>	30.87±10.91	3.40±1.84	<b>&lt;0.001</b>	28.89±11.87	2.92±1.93	<b>&lt;0.001</b>	0.581	0.414
L5 slippage percentage [%]	23.25±11.31	2.46±1.70	<b>&lt;0.001</b>	22.67±12.79	2.27±1.87	<b>&lt;0.001</b>	23.49±10.84	2.54±1.64	<b>&lt;0.001</b>	0.815	0.603

Pre-op: Pre-operation, Post-op: Post-operation, Latest-fu: Latest follow-up;

*P*: Latest-fu vs Pre-op, *P*1, *P*2: Pre-op vs Pre-op and Latest-fu vs Latest-fu between group P and the group G.

**Table 3** Sagittal plane parameters of spine and pelvis

Variable	Total			Group P			Group G				
	Pre-op	Post-op	Latest-fu	Pre-op	Post-op	Latest-fu	<i>P</i> 1	<i>P</i> 2	Pre-op	Post-op	<i>P</i> 3
LL	53.37±7.50	55.12±7.67	56.23±7.49	52.87±4.22	54.67±5.14	55.60±5.93	0.196	0.099	53.57±8.52	55.30±8.54	0.001
L4-S1SL	23.79±3.58	33.77±10.54	34.08±10.27	23.40±1.99	28.67±11.69	29.33±11.46	0.078	<b>0.044</b>	23.95±4.06	35.84±9.43	0.001
LDI (%)	44.60±2.76	60.79±15.18	60.16±14.69	44.37±3.22	52.04±19.45	52.51±19.12	0.124	0.099	44.70±2.60	64.34±11.60	0.001
PI	63.56±7.42	63.48±7.21	63.65±7.24	63.27±8.51	63.27±8.11	63.33±8.35	1.000	0.885	63.68±7.06	63.57±6.93	0.001
PT	33.08±5.09	24.46±4.03	25.60±4.33	33.40±5.60	26.73±3.13	27.27±3.81	<b>0.001</b>	<b>0.002</b>	32.95±4.60	23.35±4.37	0.001
SS	30.48±9.51	35.54±8.46	34.65±8.75	29.87±12.45	35.53±8.36	33.07±9.00	<b>0.005</b>	<b>0.016</b>	30.73±8.23	36.54±8.62	0.001
PI-LL	10.19±7.29	8.37±6.11	7.42±6.00	10.40±7.02	8.60±4.88	7.73±5.38	0.217	0.106	10.11±7.48	8.07±6.61	0.001

Compared with preoperative parameters, *P* values were all less than 0.05 except PI in total parameters;

*P*1, *P*2: Post-op vs Pre-op, Latest-fu vs Pre-op in Group P;

*P*3, *P*4: Post-op vs Pre-op, Latest-fu vs Pre-op in Group G;

*P*5, *P*6, *P*7: Pre-op vs Pre-op, Post-op vs Post-op, Latest-fu vs Latest-fu between 2 groups.

**Table 4** Correlation analysis between sagittal balance parameters and clinical outcomes

Parameters (Pre-operation)	JOA score improvement rate		Parameters (Post-operation)	JOA score improvement rate	
	Correlation coefficient	<i>P</i>		Correlation coefficient	<i>P</i>
LL	0.000	1.000	LL	0.005	0.974
L4-S1 SL	0.158	0.685	L4-S1 SL	0.371	<b>0.042</b>
LDI	0.215	0.416	LDI	0.348	<b>0.011</b>
PI	0.007	0.961	PI	0.007	0.959
PT	-0.038	0.787	PT	-0.055	0.697
SS	0.026	0.855	SS	0.066	0.643
PI-LL	-0.007	0.961	PI-LL	-0.003	0.984
			ΔLL	0.007	0.959
			ΔL4-S1 SL	0.468	<b>0.035</b>

## Figures





**Figure 1**

A 66 years old female presented with isthmic spondylolisthesis at L4 / 5 and L5 / S1. (a) Preoperative PI = 68.6 °, PT = 35.8 °, SS = 32.8°, LL = 55.3 °, L4-S1 SL = 25.5 °, LDI = 46.11%, PI-LL = 13.3 °, JOA score = 13, VAS score(back) = 7, VAS score(leg) = 6. (b) The sagittal plane of the lumbosacral obtained well reconstruction after double-segment PLIF combined with autologous bone grafting, PI = 68.1°, PT = 26.1°, SS = 42.0°, LL = 65.6°, L4-S1 SL = 42.2°, LDI = 64.33%, PI-LL = 2.5°. (c) After 36 months of follow-up, sagittal parameters maintained satisfactory, internal fixation position was well, interbody fusion was achieved, JOA score was 26, VAS score(back) was 1, VAS score(leg) was 1, JOA score improvement rate was 81.25%.



## Figure 2

Female, 48 years old, L4 and L5 isthmic spondylolisthesis. (a) Preoperative PI = 70.8 °, PT = 30.5 °, SS = 40.3 °, LL = 59.5 °, L4-S1 SL = 21.8 °, LDI = 36.64%, PI-LL = 11.3 °, JOA score=11, VAS score(back) = 6, VAS score(back) = 6. (b) The sagittal parameters of lumbosacral after two segment PLIF: PI = 70.1 °, PT = 22.4 °, SS = 47.7 °, LL = 55.8°, L4-S1 SL = 27.3 °, LDI = 48.92%, PI-LL = 14.3 °. (c) 6 months after operation, it was found that the upper screw migrated to the adjacent disc space, the patient refused to undergo reoperation and was under close follow-up. d 2 years after operation, PI= 71.9 °, PT = 32.7 °, SS = 39.2 °, LL = 54.2 °, L4-S1 SL = 8.9 °, LDI = 16.42%, PI-LL = 17.7 °, JOA score= 18, VAS score(back) = 4, VAS score(leg) = 1, JOA score improvement rate = 38.89%.