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Long-segment Fixation with Posterolateral Fusion Versus Short-segment Fixation with Interbody Fusion for Management of High-Grade Lumbar Spondylolisthesis

Neurosurgery

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ABSTRACT

Background: Lumbar spondylolisthesis frequently causes a sagittal imbalance of the spine because it frequently co-occurs with other abnormalities, including forward slip and kyphosis. Spinopelvic sagittal balance is critical in spondylolisthesis assessment and treatment. The traditional fixation placement method, referred to as "short segment fixation," involves placing pedicle screws into the lower and slipping vertebral bodies. The upper vertebrae received additional pedicle screws, resulting in a long segment fixation..

Aim of the work: To to assess the results of long-segment with posterolateral fusion fixation (Long-segment PLF) versus short-segment fixation with interbody fusion (Short-segment PLIF) for the treatment of high-grade lumbar spondylolisthesis.

Patients and methods: Study design: It was designed as a prospective, randomized comparison study.
Setting: Al Azhar university hospitals.
Subjects: According to the used surgical technique, we recruited 60 high-grade lumbar spondylolisthesis patients into 2 independent groups: the long-segment PLF group, including 30 patients, and the short-segment PLIF group, including 30 patients.
Methods: Each patient underwent thorough history-taking, neurological testing, and a VAS for back and leg pain. Pre-operative radiological assessment included (X-rays and MRI) and assessment of the Japanese Orthopedic Association score (JOA score). Posterior decompression with insitu posterior transpedicular screw fixation and posterolateral fusion by long segment [long-segment] fixation; and posterior decompression, reduction, and transpedicular screw fixation [short segment] with interbody fusion were the surgical techniques used. Post-operative outcome measures include VAS scale back and leg pain, post-operative JOA score, complications rate, along with patient satisfaction outcome..

Results: The study population's average age was (47.1 ± 11.2) years, with 63.3 % of females and 36.7 % of males. We found a highly significant decline in VAS ratings (back and leg pain) and a highly significant increase in JOA score in the short and long-segment PLF groups ($p < 0.01$ respectively). A study comparing the two groups discovered that the long-segment PLF group experienced a significantly lower rate of complications compared to the short-segment PLIF group ($p < 0.05$), but there have been no significant differences in postsurgical outcome (patient satisfaction) ($p > 0.05$).

Conclusion: To conclude, both short and long-segment PLF operation techniques were proven to be equally effective regarding improvement of primary clinical outcomes (e.g., success and good satisfaction rates and VAS values for back and leg pain and JOA scores), but the complications rate was greater in the short-segment PLIF patient group.

Keywords: *Long-segment with posterolateral fusion fixation; Short-segment fixation with interbody fusion; High-grade lumbar spondylolisthesis.*

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INTRODUCTION

Complete pars discontinuity is often required to permit such a level of anterior vertebral translation, though it may happen less frequently in other settings. The majority of high-grade spondylolistheses are caused by isthmic and degenerative spondylolistheses. Higher-grade slips may disrupt the patient's overall sagittal balance, altering gait patterns and compensatory posture. [1]

Chronic low back pain patients may experience decreased pain and disability by having their lumbar spondylolisthesis surgically fused, which is a crucial approach to spine stabilization. [2]

Many different techniques have been employed to treat spondylolisthesis, including anterior lumbar interbody fusion, posterior lumbar interbody fusion (PLIF), posterolateral fusion (PLF), and circumferential fusion. [3]

Both techniques aim to enhance fusion rates and clinical satisfaction. But it's not unclear whether the more complicated technique, when combined, results in superior clinical results. [4]

Because lumbar spondylolisthesis is frequently associated with additional abnormalities, including forward slide and kyphosis, it frequently leads to a global sagittal imbalance of the spine. When evaluating and treating patients with spondylolisthesis, spinopelvic sagittal balance is critical. Traditionally, fixation has involved inserting pedicle screws into the slipping and lower vertebral bodies, a technique termed "short segment fixation." Long segment fixation was achieved with the insertion of extra pedicle screws into the slipping vertebra's upper vertebrae. [5]

There have been few studies comparing the lumbar spondylolisthesis sagittal balance of short segment vs. long segment pedicle screw fixation. Considering the importance of sagittal balance in predicting the success of surgery, it is critical to investigate the effects of placing varied numbers of screws on lumbar spondylolisthesis patients' sagittal balance.

This study was conducted to assess the results of long-segment with posterolateral fusion fixation (Long-segment PLF) versus short-segment fixation with interbody fusion (Short-segment PLIF) for the treatment of high-grade lumbar spondylolisthesis.

PATIENTS AND METHODS

PATIENTS:

A total of 60 high-grade lumbar spondylolisthesis patients will be enrolled in the study.

Study design:

Prospective, randomized comparison study.

Setting:

Al Azhar university hospitals.

Target population:

High-grade lumbar spondylolisthesis patients.

Inclusion criteria:

Patients with confirmed high-grade lumbar spondylolisthesis (Meyerding grade III or IV) [6].

Patients with low back pain, intermittent claudication, unilateral/do sciatica symptoms, and who have not improved with conservative treatment for more than six months).

Exclusion criteria:

Patients with intervertebral space infection.

Patients with acute vertebral fractures.

Patients with congenital spinal malformation.

Patients with spinal tumors.

Patients' randomization:

According to the used surgical technique, we recruited 60 high-grade lumbar spondylolisthesis patients into 2 independent groups:

Long-segment PLF group

(30 patients)

Short-segment PLIF group

(30 patients)

METHODS

Patients have been undergoing the following:

Full history taking.

Full neurological examination.

VAS for back pain.

VAS for leg pain.

Pre-operative radiological assessment (X-rays and MRI).

Pre-operative Japanese Orthopedic Association score (JOA score) [7].

Surgical techniques:

Posterior decompression with insitu posterior transpedicular screw fixation and posterolateral fusion by long segment [long-segment] fixation (Long-segment PLF).

Posterior decompression, reduction, transpedicular screw fixation [short segment] with interbody fusion (Short-segment PLIF).

Post-operative outcome measures:

VAS for back pain.

VAS for leg pain.

Post-operative radiological assessment (X-rays and MRI).

Post-operative JOA score.

Rate of complications.

Patients' satisfaction outcome.

Ethical Considerations:

All patients will be included in this study only after giving written consent.

Statistical analysis:

Data entry and statistical analysis have been performed employing MedCalc version 20 (MedCalc, Belgium). We employed significance tests (Mann-Whitney's, Wilcoxon's, Chi-squared tests, factorial ANOVA, and logistic regression analysis).

RESULTS

The average age of the study population was (47.1 ± 11.2) years old, and they weighed an average of (81.9 ± 9) kg. The majority (63.3%) of patients were female, whereas only 36.7% were male, according to the patients' gender.

In terms of preoperative data, leg pain had an average VAS value of (7 ± 1.5) while back pain received an average VAS rating of (5.46 ± 2.3) and the average JOA score was (6 ± 0.94), with (10%) of patients having previous surgery.

Regarding lumbar disc slips, (40%) of patients had L4-5-disc slips, and (60%) had L5-S1 disc slips,

while (85%) had acquired disc slips, and (15%) had developmental disc slips, with Grade-3 slips (78.3%) and Grade-4 slips (21.7%).

Regarding post-operative data, the average VAS rating for back pain was (2.4 ± 1.5), the average VAS rating for leg pain was (1.5 ± 2.3), and the average JOA score was (13.2 ± 2.2), with nobody suffering mortality.

Regarding the complications rate, (28.3%) of patients suffered complications, of which (5%) had Dural tear / CSF leak, (8.3%) had Infection, (3.3%) had Root injury / Foot drop, and (11.7%) had Traction neuropathy / Sciatica.

Regarding outcome (patients' satisfaction); (8.3%) of patients had a poor outcome, (16.7%) had a fair outcome, (46.7%) had a good outcome, and (28.3%) had an excellent outcome.

Comparative analysis:

Regarding comparative studies, according to the surgical technique used, the 60 high-grade lumbar spondylolisthesis patients have been split into two independent groups: the long-segment PLF group (30 patients) and the short-segment PLIF group (30 patients):

Regarding pre-operative data, a comparison study between the two groups indicated that:

Highly significant increase in L5-S1 disc slips in the long-segment PLF group compared to the short-segment PLIF group ($p = 0.0017$).

Non-significant difference in the remaining pre-operative data ($p > 0.05$).

Variable		**Long-segment PLF group (30)**	**Short-segment PLIF group (30)**	**Mann-Whitney's U test**
		Median (IQR)	Median (IQR)	P-value
Age **(years)**		51 (37 – 56)	49 (36 – 57)	= 0.7899
Weight **(kg)**		81.5 (75 – 85)	82.5 (75 – 87)	= 0.5047
VAS score **(back pain)**		6.5 (6 – 7)	6 (5 – 7)	= 0.1636
VAS score **(leg pain)**		7 (7 – 8)	8 (7 – 8)	= 0.1007
Variable		Long-segment PLF group (30)	Short-segment PLIF group (30)	Chi square test (P-value)
Gender	Female	20 (66.7%)	18 (60%)	= 0.5952
	Male	10 (33.3%)	12 (40%)	
Disc level	L4-5	6 (20%)	18 (60%)	= 0.0017**
	L5-S1	24 (80%)	12 (40%)	
Type of slip	Acquired	26 (86.7%)	25 (83.3%)	= 0.7200
	Developmental	4 (13.3%)	5 (16.7%)	
Grade of slip	Grade-3	21 (70%)	26 (86.7%)	= 0.1202
	Grade-4	9 (30%)	4 (13.3%)	
Previous surgery	+ve	2 (6.7%)	4 (13.3%)	= 0.5952

Table 1: Comparison of preoperative data from the two groups employing Mann-Whitney's U and Chi-square tests

Follow up data:

We further compared and analyzed 30 (paired) patients based on pre-and post-surgical serial measurements. The comparison between presurgical and postsurgical measurements showed:

Highly significant decrease in VAS scores (back and leg pain) in the long-segment PLF group ($p < 0.01$ respectively).

Highly significant increase in JOA score in the long-segment PLF group ($p < 0.01$).

Highly significant decrease in VAS scores (back and leg pain) in the short-segment PLF group ($p < 0.01$ respectively).

Highly significant increase in JOA score in the short-segment PLF group ($p < 0.01$) (Fig. **1**, Fig. **2**, Fig. **3**).

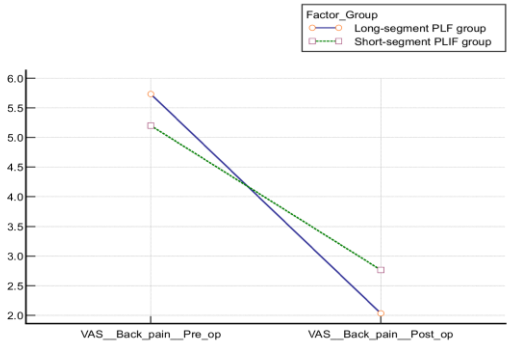


Fig. 1: Comparison of the 2 patient groups regarding serial pre- and post-operative VAS score (back pain) assessments.

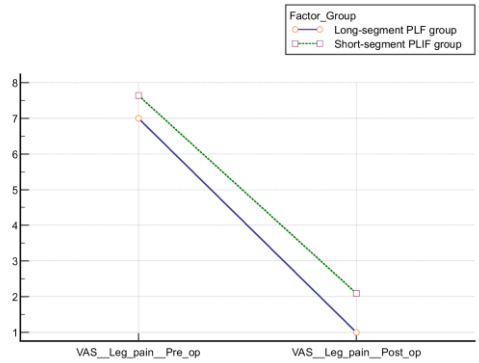


Fig. 2: Comparison of the 2 patient groups concerning serial pre- and post-operative VAS score (leg pain) assessments

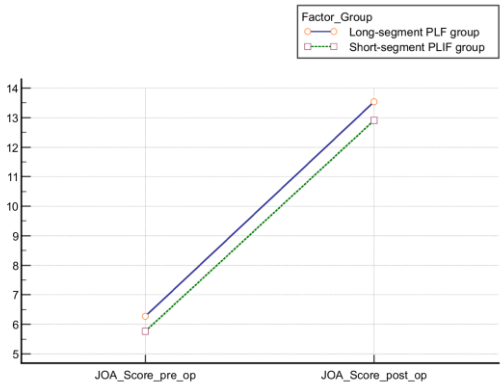


Fig. 3: Comparison of the 2 patient groups concerning serial pre- and post-operative JOA score assessments

Regarding postsurgical data, a comparison study between the two groups indicated that:
Highly significant decrease in complications rate, in Long-segment PLF group; compared to Short-segment PLIF group ($p < 0.05$ respectively).
Non-significant difference as regards postsurgical outcome (patients' satisfaction), VAS scores, and JOA scores ($p > 0.05$) (Fig. **4**).

Variable		**Long-segment PLF group (30)**	**Short-segment PLIF group (30)**	**Mann-Whitney's U test**
		Median (IQR)	Median (IQR)	P-value
VAS score **(back pain)**		1.5 (1 – 3)	2 (1 – 4)	= 0.1203
VAS score **(leg pain)**		0 (0 – 1)	0 (0 – 5)	= 0.1042
JOA score		14 (13 – 15)	13.5 (11 – 14)	= 0.2027
Variable		Long-segment PLF group (30)	Short-segment PLIF group (30)	Chi square test (P-value)
Complications rate	+ve	5 (16.7%)	12 (40%)	= 0.046*
Type of complications	None	25 (83.3%)	18 (60%)	= 0.014*
	Dural tear / CSF leak	3 (10%)	0 (0%)	
	Infection	0 (0%)	5 (16.7%)	
	Root injury / Foot drop	0 (0%)	2 (6.7%)	
	Traction neuropathy / Sciatica	2 (6.7%)	5 (16.7%)	
Outcome (patients' satisfaction)	Poor	3 (10%)	2 (6.7%)	= 0.2148
	Fair	2 (6.7%)	8 (26.7%)	
	Good	15 (50%)	13 (43.3%)	
	Excellent	10 (33.3%)	7 (23.3%)	

Table 2: Comparison of the two groups regarding post-operative data employing Mann-Whitney's U and Chi square tests.

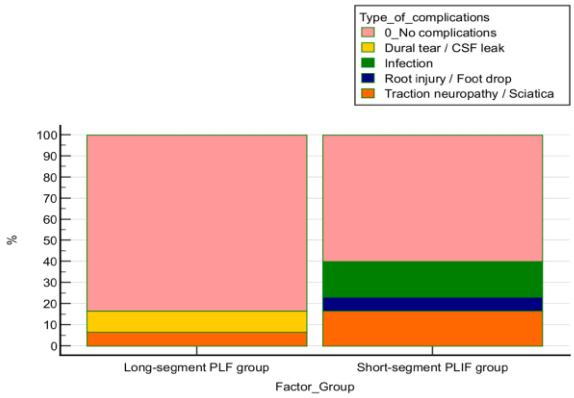


Fig. 4: Comparison of the two groups concerning the rate of complications

Correlation studies:

Studies of correlation between post-operative results and their respective independent predictors (basic clinical, radiological, surgical technique variables) showed the following:

After using the "Forward technique" and adding various predictor factors, a logistic regression analysis reveals that the rise in age, female gender, and short-segment PLF operations all independently increased the likelihood of complications occurring, with significant statistical differences ($p < 0.05$ respectively) .

Predictor Factor	Coefficient	OR	P value
(Constant)	-16.04477		
Age	0.32178	1.3796	0.0013**
Female gender	2.11230	1.1210	0.049*
Short-segment PLF operation	2.55672	1.776	0.0098**

Other factors excluded from the model as (p value > 0.1). OR: odds ratio.

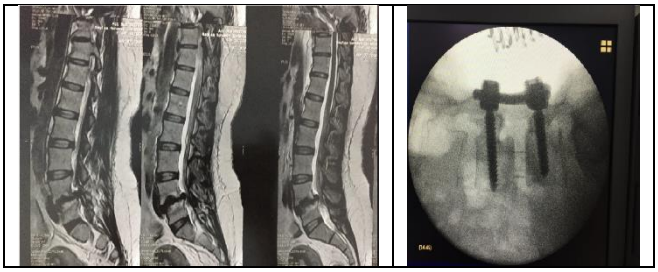
Table 3: Logistic regression model using the Forward approach for variables influencing the occurrence of complications.

Logistic regression analysis reveals that, after using the (Forward technique) and inserting a few predictor factors, the reduction in age had an independent influence on improving the likelihood of a good satisfaction outcome, with statistically significant differences (p = 0.0031) (Table 4).

Predictor Factor	Coefficient	OR	P value
(Constant)	18.55763		
Age	-0.32530	0.7223	0.0031**

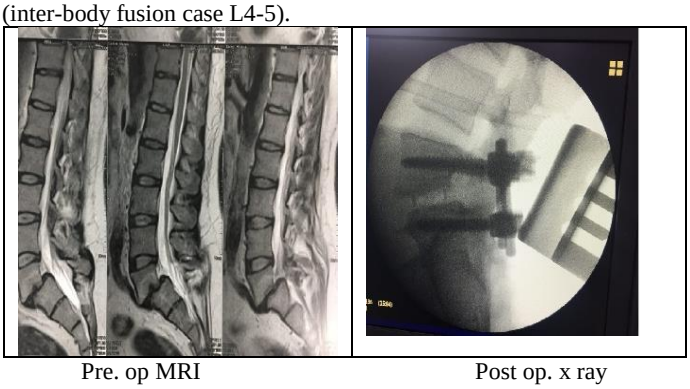
Other factors were omitted from the model as (p value > 0.1). OR: odds ratio.

Table 4: Logistic regression model for variables influencing good satisfaction outcome using the Forward approach.



Pre. op MRI Post op. x ray

Fig. 5: Case example (inter-body fusion case L4-5).



Pre. op MRI Post op. x ray

Fig. 6: Case example (inter-body fusion case L5-S1).

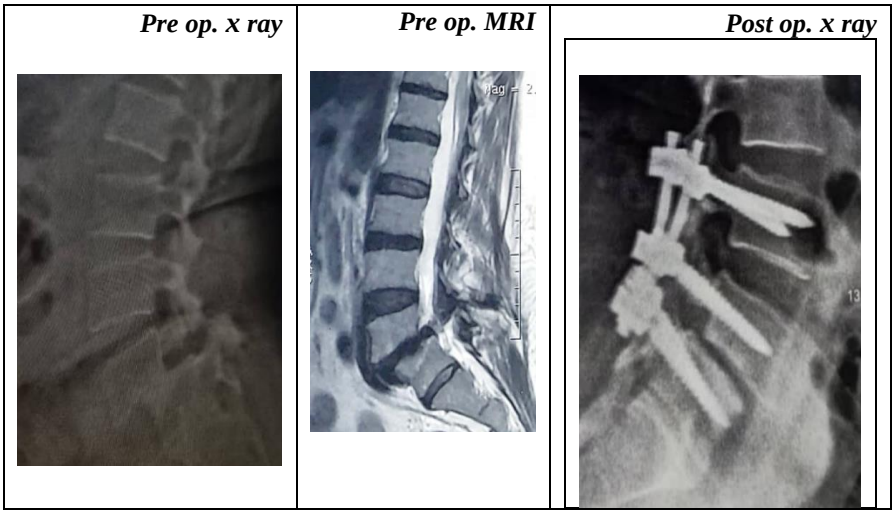


Fig. 7: case example of long segment fixation.

DISCUSSION

This has been a prospective, randomized comparative study with 60 subjects with high-grade lumbar spondylolisthesis to evaluate the outcome of long-segment with posterolateral fusion fixation (Long-segment PLF) versus short-segment fixation with interbody fusion (Short-segment PLIF) for management of high-grade lumbar spondylolisthesis.

The following procedures were performed on the patients: a full history take, a thorough neurological exam, a VAS for leg and back pain, a presurgical radiological assessment (X-rays and MRI), and a Japanese Orthopedic Association score (JOA score).

Measures of the post-operative results comprised the VAS score for back and leg pain, the JOA score, the complications rate, and the patients' satisfaction outcome.

In terms of pre-operative data, we discovered that all participants' average ages were (47.1 ± 11.2) years. In terms of the participants' gender, women made up the majority (63.3%), while men made up 36.7%. This is consistent with Rivollier et al., 2020, and Dawood et al., 2021.[8,9]

Seven individuals with L5-S1 high-grade spondylolisthesis were identified by Rivollier et al., 2020, with an average age of 37 years. Two patients had grades II, four had grades IV, and one had grades V. The mean follow-up period lasted 24 months [8].

Dawood et al., 2021 also reported that the enrolled patients' average age became 53.67 years, and their average BMI became 26.73, and 53.3% of them were women [9].

Regarding post-operative data, nobody suffered mortality, with the mean VAS rating for back pain being (2.4 ±1.5), the mean VAS rating for leg pain being (1.5 ± 2.3), and the mean JOA score being (13.2 ± 2.2). This is consistent with Rivollier et al., 2020, and Dawood et al., 2021.[8,9]

In research by Rivollier et al., 2020, seven people with L5-S1 spondylolisthesis were studied (two patients in grade II, four in grade IV, and one in grade V). From 76 to 94 degrees, the median lumbosacral angle (LSA) increased. After surgery, two cases' Meyerding grades remained stable, while three cases lost two ranks and two cases lost one. Satistically significant differences ($p = 0.036$) have been seen in the postoperative radiological parameters. No significant infection has spread widely. In terms of pain and disability, the median ODI and VAS scores improved. [8]

Dawood et al., 2021 also observed a significant decline in VAS back after operation ($P < .001$) as well as a significant decrease in VAS leg after operation ($P < .001$). [9]

Regarding the complications rate, (28.3%) of patients suffered complications, of which (5%) had Dural tear / CSF leak, (8.3%) had infection, (3.3%) had Root injury / Foot drop, and (11.7%) had Traction neuropathy / Sciatica. This is consistent with Dawood et al., 2021. [9]

In terms of complications, Dawood et al. 2021 concluded that 73.3 % of patients experienced no early complications, while 13.3 % of patients experienced wound infection, and 6.7 % experienced positional neuropathy and postsurgical hematoma. Late complications have been discovered in 33.3% of patients, with adjacent segment disease (13.3%), arthrodesis (13.3%), and fusion failure (6.7%) occurring. [9]

Regarding outcome (patients' satisfaction); (8.3%) of patients had a poor outcome, (16.7%) had a fair outcome, (46.7%) had a good outcome, and (28.3%) had an excellent outcome. This is consistent with DeWald et al., 2005.

DeWald et al., 2005 discovered that, there were 12 excellent clinical outcomes, 7 good clinical outcomes, 1 fair clinical outcome, and 1 poor clinical outcome. The patient who developed complete cauda equina syndrome had a poor outcome (CES). Even though they occasionally experienced back pain, the majority of them had a significant improvement over their presurgical state and had their serious spinal problems resolved. Prior to surgery, the patient, who was rated fair, had bilateral dropped feet. Despite the

significant pain reduction, her disability as a result of her dropped foot remains unresolved. [10]

Regarding comparative studies, according to the surgical technique used, the 60 high-grade lumbar spondylolisthesis patients have been split into 2 independent groups: the Long-segment PLF group (30 patients) and the Short-segment PLIF group (30 patients).

The long-segment PLF group had significantly lower complication rates (fig.7) than the short-segment PLIF group (fig.5,6) (p 0.05). This was in contrast to Farrokhi et al., 2012, and Harada et al., 2021.

However, Farrokhi et al. 2012 showed that at a 1-year follow-up, there had been no significant differences in postsurgical complications. [11]

Also, Harada et al., 2021 disagreed with our results, reporting that multilevel fusions had higher rates of dural tears, reoperation, and facility discharge, as well as lower final VAS-back scores when compared to 1-level fusions. [12]

In our investigation, there have been no statistically significant differences in postsurgical outcome (patients' satisfaction), VAS scores, and JOA scores ($p > 0.05$) (both groups improved). This is consistent with Ekman et al., 2007, Liu et al., 2014, Feng et al., 2015, and Shao et al., 2022.

According to Ekman et al. 2007, PLIF patients' pain indices decreased from 66 to 35 ($P < 0.01$) and their DRIs from 47 to 30 ($P = 0.01$). Compared to the PLF group, the pain and disability rating index (DRI) levels were comparable (not significantly), and the ODI was the same in both groups. In both groups, 74% of patients rated the outcomes as significantly better. [13]

According to Liu et al. 2014, the primary results for PLIF plus PLF and PLF did not differ significantly from one another (OR, 0.88, $P > 0.05$). There have been no statistically significant differences in the complication rates between PLIF and PLF, PLIF plus PLF, and PLF (OR, 2.27; $P > 0.05$; OR, 0.74; $P > 0.05$, respectively). [4]

Feng et al. 2015 also discovered that no differences in preoperative spinopelvic parameters were found in the PLIF and PLF groups. Both surgical groups had significantly higher presurgical pelvic occurrence, pelvic tilt (PT), sacral slope, lumbar lordosis (LL), and L5 incidence (L5I) than in the control group. After the surgery, there had been no significant differences in PT between the PLIF, PLF, and control groups. LL increased in the PLIF group, while in the PLF group it decreased. Both groups significantly restored the slip degree (SD) and L5I. The PLF and PLIF did not significantly differ in terms of short-term clinical results. [14]

Also, Wang et al. 2005 concluded that lumbar interbody fusion is superior to posterolateral fusion in the following: 1) Posterolateral grafts are compressed by 20% of spinal loads, compared to 80% of spinal loads for interbody grafts. 2) Posterolateral grafts only account for 10% of the intervertebral bone surface area, while interbody grafts occupy 90% of it. 3) There is a higher likelihood of fusion because the interbody region is more vascular compared to the posterolateral region. 4) Sagittal and coronal balance are improved by interbody grafts. 5) In the disc region, the application of Rh-BMP-2 (Recombinant Human Bone Morphogenic Protein 2) may promote interbody fusions. 6) An interbody fusion can more easily distinguish between fusion and pseudoarthrosis than a posterolateral fusion. 15

Shao et al., 2022 also concluded that the postsurgical LL, SL, PT, SS, and SD scores in both groups significantly increased as compared to the presurgical scores. The long-segment group corrected more effectively in LL, SL, and PT than the short-segment group at the most recent follow-up. At every time point following surgery, there were significant SD differences between the two groups. The rate of postoperative slip correction was significantly higher in the long-segment group than in the short-segment group. Both groups' postsurgical VAS and ODI scores were significantly higher than their presurgical scores. But, the ODI and VAS scores for the two groups did not differ significantly at all times. [5]

CONCLUSION

To conclude, both short and long-segment PLF operation techniques were proven to be equally effective regarding improvement of primary clinical outcomes (e.g., success and good satisfaction rates, VAS scores for back and leg pain, and JOA score), but the rate of complications was greater in the short-segment PLIF group of patients.

Conflict of interest : none

REFERENCES

1. Beck AW, Simpson AK. High-Grade Lumbar Spondylolisthesis. *Neurosurg Clin N Am*. 2019;30:291–8. https://doi.org/10.1016/j.nec.2019.02.002.
2. Ha K-Y, Na K-H, Shin J-H, Kim K-W. Comparison of posterolateral fusion with and without additional posterior lumbar interbody fusion for degenerative lumbar spondylolisthesis. *Clinical Spine Surgery* . 2008;21:229–34.
3. Kim J-S, Kim D-H, Lee S-H, Park C-K, Hwang J-H, Cheh G, et al. Comparison study of the instrumented circumferential fusion with instrumented anterior lumbar interbody fusion as a surgical procedure for adult low-grade isthmic spondylolisthesis. *World Neurosurgery*. 2010;73:565–71.
4. Liu X-Y, Qiu G-X, Weng X-S, Yu B, Wang Y-P. What is the optimum fusion technique for adult spondylolisthesis—PLIF or PLF or PLIF Plus PLF? A meta-analysis from 17 comparative studies. *Spine*. 2014;39:1887–98.
5. Shao X, Liu H, Wu J, Qian Z, Qu R, Liu T. A retrospective comparative study of postoperative sagittal balance in isthmic L5–S1 spondylolisthesis using single segment or two-segment pedicle screw fixation. *BMC Musculoskeletal Disorders*. 2022;23:1–10.

6. Meyerding H. Spondylolisthesis. *Surg Gynecol Obstet*. 1932;54:371–7.

7. Fukui M, Chiba K, Kawakami M, Kikuchi S, Konno S, Miyamoto M, et al. JOA back pain evaluation questionnaire (JOABPEQ)/JOA cervical myelopathy evaluation questionnaire (JOACMEQ) the report on the development of revised versions April 16, 2007. *Journal of Orthopaedic Science*. 2009;14:348.

8. Rivollier M, Marlier B, Kleiber J-C, Eap C, Litre C-F. Surgical treatment of high-grade spondylolisthesis: Technique and results. *Journal of Orthopaedics*. 2020;22:383–9.

9. Dawood AM, Baky GRA, Soliman HA. Transforaminal lumbar interbody fusion in degenerative spondylolisthesis. *The Scientific Journal of Al-Azhar Medical Faculty, Girls*. 2021;5:198.

10. DeWald CJ, Vartabedian JE, Rodts MF, Hammerberg KW. Evaluation and management of high-grade spondylolisthesis in adults. *Spine.* 2005;30:S49–59.

11. Farrokhi MR, Rahmanian A, Masoudi MS. Posterolateral versus posterior interbody fusion in isthmic spondylolisthesis. *Journal of Neurotrauma*. 2012;29:1567–73.

12. Harada GK, Khan JM, Vetter C, Basques BA, Sayari AJ, Hayani Z, et al. Does the number of levels fused affect spinopelvic parameters and clinical outcomes following posterolateral lumbar fusion for low-grade spondylolisthesis? *Global Spine Journal*. 2021;11:116–21.

13. Ekman P, Möller H, Tullberg T, Neumann P, Hedlund R. Posterior lumbar interbody fusion versus posterolateral fusion in adult isthmic spondylolisthesis. *Spine.* 2007;32:2178–83.

14. Feng Y, Chen L, Gu Y, Zhang Z-M, Yang H-L, Tang T-S. Restoration of the spinopelvic sagittal balance in isthmic spondylolisthesis: posterior lumbar interbody fusion may be better than posterolateral fusion. *The Spine Journal.* 2015;15:1527–35.

15. Wang JC, Mummaneni PV, Haid RW. Current treatment strategies for the painful lumbar motion segment: posterolateral fusion versus interbody fusion. *Spine.* 2005;30:S33–43.