ORIGINAL STUDY

Lumbar Pedicle Screws Fixation Before Versus After Posterior Lumbar Interbody Fusion: A Comparative Study and Technical Insight

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Abstract

Background data: **The order of steps for lumbar spine pedicle screw fixation (PSF) and posterior lumbar interbody fusion (PLIF) may differ from one surgeon to another, which may affect the surgical outcomes.**

Purpose: **To evaluate the difference between PSF before and after PLIF in patients with degenerative lumbar spine diseases.**

Study design: **A comparative retrospective clinical study.**

Patients and methods: **This study reported patients who underwent lumbar PSF and PLIF from January 2018 to March 2022. The patients were allocated into two groups: group A (PSF before PLIF) and group B (PSF after PLIF).**

A total of 567 patients, 264 in group A and 303 in group B, were recruited for this study. Outcome parameters included operative time, operative blood loss, operative blood transfusion, and operative complications.

Results: **No significant differences were found between the two groups when comparing surgical time and intraoperative complications ($P > 0.05$). However, compared with group B, a significant decrease was found in intraoperative blood loss and the need for intraoperative blood transfusion in group A ($P < 0.05$).**

Conclusion: **This study suggests that the lumbar PSF is preferred before rather than after PLIF as it significantly reduces operative blood loss and the need for blood transfusion.**

Keywords: Intraoperative blood loss, Pedicle screw fixation, Posterior lumbar interbody fusion

Introduction

Posterior lumber interbody fusion (PLIF) can successfully treat various disorders, including degenerative lumbar disc disease, spinal canal stenosis, and spondylolisthesis. PLIF may be supported with posterior instrumentation, either the standard pedicle screws fixation or the trans-laminar screws [1]. The greatest advantage of PLIF is the decompression of the neural elements and fusion of the two vertebral bodies into a single motion segment [2]. Multiple studies supported that PLIF was superior to posterior lateral fusion (PLF) in clinical outcome and fusion rate but equal in blood loss and postoperative complications [3]. In comparison between PLIF alone and PLIF combined with pedicle screw fixation (PSF), the group treated by PLIF and PSF showed significantly more blood loss and longer operative time. However, the duration for obtaining bone union was significantly shorter than that in the PLIF alone. The advantages of PSF are early bone fusion, shorter postoperative bed rest

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duration, and better correction of spondylolisthesis [4]. Patients undergoing spinal surgery are at risk of significant blood loss, requiring blood and fluid replacement. One of the keys to enhanced recovery in spinal surgery is reducing intraoperative blood loss and its hazards [5].

As surgeries are complex harmonic processes that involve steps and technical actions, surgeries of the same type can be done with different sequences of steps and/or technical actions to get the same surgical target [6]. A standardized model that describes the surgical workflow is important for training, education, and quality evaluation [7].

Some surgeons prefer doing the step of PSF before rather than after PLIF to avoid neural exposure during this step with expected hazards. However, others prefer the step of PSF to be after PLIF with neural exposure to be a guide for screw insertion. This debate highlights the increasing need to ensure optimal patient safety, quality of intraoperative care, and better surgical outcomes.

This study aims to detect the best technical model during PLIF and PSF by comparing PSF before versus after PLIF in patients with degenerative lumbar spine disease in a single center.

Patients and methods

This comparative retrospective (from January 2018 to March 2022) study was conducted on patients who underwent PLIF and PSF at the neurosurgery department of our university hospital. The patients were randomly allocated into two groups according to surgeon preference: group A, patients submitted to PSF before PLIF; Group B, patients submitted to PSF after PLIF.

Written informed consent was obtained from every patient for surgery and publication, and the study was approved by the institutional review board (IRB#: 9429). This study was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans. The team for each operative list (four elective operative lists per week) consists of at least one professor or assistant professor and lecturers (consultants) of neurosurgery, assisted by specialists and residents of neurosurgery with similar anesthetic team qualifications. Our neurosurgery department has 80 beds for elective and emergency cases. We perform more than 500 spinal surgeries per year.

Inclusion criteria were patients subjected to lumbar PSF and PLIF and having spondylolysis, spondylolisthesis, spondylosis, lumber canal stenosis, or lumber disc prolapses, with the main clinical presentations of low back pain, sciatica, claudication, and/or neurological deficits.

Exclusion criteria included patients with recurrent lumbar surgeries, fractures, infections, or tumors, patients receiving medications affecting blood clotting or coagulation (antiplatelet, anticoagulants), patients suffering from blood diseases affecting operative bleeding, and patients presenting with anemia.

All patients were fully assessed before scheduled surgeries: clinical evaluation of the general and the neurological condition by detailed history and general and neurological examination. This step was routinely done before hospital admission at the outpatient clinics with other specialties consultation such as internal medicine, cardiology, and anesthesiology. Routine laboratory investigations included complete blood pictures, liver function tests, kidney function tests, blood sugars, viral markers for hepatitis C and B, and bleeding profile and other investigations according to the patient's condition. The radiographic study included preoperative lumbosacral MRI, lumbosacral plain X-rays, and multislice computed tomography (MSCT) scans in some selected cases.

Reported outcome parameters

Operative time: This means the time from the skin incision until the closure of the surgical wound.

Operative blood loss: The visual method for blood loss calculation was used in all surgeries. This method depends on calculating the amount of blood in the suction container with adjustment for the used irrigating saline and the blood-soaked gauze and cottoned pieces [4 × 4-soaked gauze piece = 10 ml blood and 30 × 30 cm = 100 ml blood] [8].

Blood transfusion: According to The American Society of Anesthesiologists Task Force, the trigger for blood transfusion was hemoglobin concentration between 6 and 10 g/dl and hematocrit of less than 30% based on intraoperative measurement. Moreover, blood loss (loss of 30–40% of patient's blood volume) and hemodynamics of the patients were estimated [9]. Complete blood pictures and arterial blood gases were routinely assessed during our surgeries. The submuscular drain was removed within 24 h in all patients after assessment of its blood content. Preoperative confirmation of blood reserve is routine work for every patient in the form of packed red blood cells (each unit = 250 ml).

Accuracy of screw purchase: operative lateral and anteroposterior fluoroscopy, intraoperative exploration, and a routine postoperative lumbosacral MSCT scan for each patient.

Operative complications: They included durotomy, root injury, and screw malposition.

Surgical procedure

All patients were operated on under general anesthesia in the prone position. The order of steps during lumbar PSF and PLIF surgeries differed in our university hospital according to the surgeon's preference. In group A, pedicle screws were inserted before PLIF, while in group B, pedicle screws were inserted after PLIF. The main surgeon followed the standard guidelines of spinal surgeries such as patient position, intraoperative vital signs, use of diathermy and bipolar, use of hemostatic materials, and subperiosteal muscle dissections.

The common steps for screw insertion under the fluoroscopy guide were as follows: entry point exposure, decortication of the entry site, use of the spinal hole open awl instrument to make the entry pit, the pedicle finder instrument (straight or curved types) passing through the pedicle for about 30 mm, then use of the feeler instrument to assess the boundaries of the pathway, followed by use of the serrated tap to make the final screw pathway, which was tested by the feeler before the screw was driven in. The rods were adjusted to the screw heads at the end of the operation before the step of closure.

Statistical analysis

All data were collected, tabulated, and statistically analyzed using SPSS 20.0 for Windows (SPSS Inc., Chicago, IL, USA, 2011). Quantitative data were expressed as the mean ± SD, and qualitative data were expressed as numbers and percentages. The *t*-test was used to compare two groups of normally distributed variables. Percentages of categorical variables were compared using the χ^2 test. All tests were two-sided. A *P* value of >0.05 was considered statistically significant.

Results

In total, 567 patients who were eligible for our inclusion criteria were recruited for this study and included two groups. Group A: patients submitted to PSF before PLIF, including 264 patients, group B: patients submitted to pedicle screw fixation after PLIF, including 303 patients.

The mean ages were 50 ± 12 (42–66) years and 50 ± 10 (38–59) years in groups A and B, respectively, with nonsignificant differences between the two groups. There were no significant differences between the groups regarding sex distribution, main clinical presentations, medical comorbidities, or pathological data, including the number of operated lumbar segments and the type of spinal pathology (discogenic, spondylosis, spondylolysis, and spondylolisthesis) (Table 1).

The mean operative time was 207.7 ± 35 (120–340) minutes versus 213 ± 48 (120–380) minutes in groups A and B, respectively, which showed no significant difference between the two groups. Group B showed significant operative blood loss of 972 ± 26 (500–1800) ml compared to group A 809 ± 22 (400–1800) ml ($P = 0.0001$) and this was also reported in one-, two-, and three-level surgeries (Table 2).

Group B showed significant operative blood transfusion compared to group A ($P = 0.002$) and this was also reported in two-level surgeries, while there was no significant difference in one- and three-level surgeries. In one-level surgeries, no patient received a blood transfusion in both groups. In two-level surgeries, eight patients received blood transfusions (two units of packed red blood cells) in group B, while no patients in group A received blood transfusions, which was statistically significant ($P = 0.0036$). In three-level surgeries, 15 patients received blood transfusions in group B (15 out of 75, 20%), while in group A, six patients received blood transfusions (6 out of 58, 10.3%) without statistical significance ($P = 0.065$), the number of transfused units of packed red blood cell ranged from 2 to 3 units per patient. Routine postoperative care includes a complete blood picture and all our patients were stable without needing a postoperative blood transfusion (Table 2).

Operative complications showed no significant difference between the two groups, including screw malposition ($P = 0.17$), dural injury ($P = 0.44$), and root injury ($P = 0.49$). However, there was a higher incidence of screws malposition percentages and dural and nerve root injuries during screw insertions in group A (3.5%, 3.8%, and 1.9%) versus group B (2.9%, 3.3%, and 1.65%) (Table 2).

Discussion

This retrospective study compared outcomes in patients with degenerative lumbar spinal diseases who received PSF before versus after PLIF. A total of 356 male and 211 female patients were enrolled. There was a significant difference in our study between the two groups regarding intraoperative blood loss volume and the need for intraoperative blood transfusion in favor of group A. However, the two groups had no significant differences when comparing surgical time and intraoperative complications.

Briggs and Milligan described the PLIF technique in 1944 [10], and then the fusion results improved due to the development of interbody implants and

Table 1. Demographic and pathological data of study patients (n = 567).

Parameters	Group A (*n* = 264)	Group B (*n* = 303)	T	*P* value
Age/years	50 ± 12 (42–66)	50 ± 10 (38–59)	0	1
Sex				
Male	163 (61.7%)	193 (63.7%)	0.5	
Female	101 (38.3%)	110 (36.3%)		0.3
Clinical presentation				
Low back pain	240 (91%)	280 (92%)	0.43	0.33
Sciatica	230 (87%)	255 (84%)	−1	0.16
Claudication	180 (68%)	191 (63%)	−1.2	0.1
Motor deficit	84 (32%)	92 (30%)	−0.5	0.3
Sensory deficit	190 (72%)	209 (69%)	−0.78	0.21
Segmental pathology				
1 segment	120 (45%)	131 (43%)	−0.48	0.32
2 segments	86 (33%)	97 (32%)	−0.25	0.4
3 segments	58 (22%)	75 (25%)	0.84	0.2
Spinal pathology				
Discogenic	102 (39%)	118 (39%)	0	0.5
Spondylosis	98 (37%)	115 (38%)	0.25	0.4
Spondylolysis	15 (5.7%)	21 (7%)	0.63	0.26
Spondylolisthesis	49 (18.6%)	49 (16%)	−0.82	0.21
Medical comorbidity				
Diabetes	36 (14%)	42 (13%)		0.73
Hypertension	53 (20%)	66 (22%)		0.56

Data expressed as mean ± SD or number (%). n = patients' number; P > 0.05 = nonsignificant.

Table 2. Operative data of the study patients (n = 567).

Parameters	Group A	Group B	t	*P* value
Operative time/min				
All	207.7 ± 35 (120–340)	213 ± 48 (120–380)	1.51	0.065
1-level surgery	154 ± 22 (120–230)	158 ± 24 (120–240)	1.4	0.17
2-level surgery	202 ± 27 (160–300)	209 ± 30 (170–300)	1.7	0.1
3-level surgery	267 ± 38 (200–340)	272 ± 48 (180–380)	0.7	0.52
Operative blood loss/ml				
All	809 ± 22 (400–1800)	972 ± 26 (500–1800)	8.2	0.0001
1-level surgery	621 ± 18 (400–1200)	706 ± 23 (500–1400)	3.3	0.001
2-level surgery	766 ± 20 (500–1300)	1024 ± 27 (550–1700)	7.3	0.0001
3-level surgery	1040 ± 28 (700–1800)	1187 ± 28 (800–1800)	3	0.003
Operative blood transfusion				
All	6 (2.3%)	23 (7.6%)	2.85	0.002
1-level surgery	0	0	0	0
2-level surgery/RBC units	0	8 (8.2%) {2}	2.7	0.0036
3-level surgery/RBC units	6 (10.3%) {2–3}	15 (20%) {2–3}	1.5	0.065
Screws malposition				
Total	52 (3.5%)	55 (2.9%)	−0.9	0.17
Mediolateral malposition	30 (2%)	33 (1.7%)	−0.6	0.27
Operative correction	18/30	27/33	−0.7	0.23
Craniocaudal malposition	22 (1.5%)	22 (1.2%)		
Operative correction	11/22	14/22		
Incidental durotomy				
Total	11 (4.2%)	12 (3.96%)	−0.14	0.44
-During screwing	10 (3.8%)	10 (3.3%)	−0.32	0.37
-During PLIF	1 (0.4%)	2 (0.66%)	0.42	0.34
Root injury				
Total	6 (2.27%)	7 (2.3%)	0.024	0.49
-During screwing	5 (1.9%)	5 (1.65%)	−0.23	0.41
-During PLIF	1 (0.4%)	2 (0.66%)	0.42	0.34

Data expressed as mean ± SD or number (%); n = patients' number; P > 0.05 = nonsignificant; min: minute; mm: milliliter; RBCs: red blood cells.

PSF for posterior instrumentation [11]. The steps of spinal fusion surgeries may differ according to the pathological picture of the spine, the type of fusion, the approach, and the concepts of the surgeon.

The operative time duration showed no significant difference between the two groups in our study. In Group A, mean time durations were 154 ± 22 min for one-level surgeries, 202 ± 27 min for two levels, and 267 ± 38 min for three levels versus 158 ± 24, 209 ± 30, and 272 ± 48 min in group B. So the different step sequences do not affect the operative time duration, as the main time consumed is in the preparation and decompression steps.

The present study showed significant differences between the two groups regarding blood loss and the need for blood transfusion, as group A with the PSF step before PLIF correlated with less blood loss and blood transfusion.

One-level surgery showed significant blood loss in group B, but no patients received blood transfusions in both groups. Two-level surgery showed significant blood loss in group B, with eight patients receiving blood transfusions from group B, which was statistically significant. Three-level surgery showed significant blood loss in group B, with six patients receiving blood transfusions from group A and 15 patients from group B, which was statistically insignificant.

Estimating intraoperative blood loss is one of the challenges for doctors. Despite the inaccuracy of visual estimation by anesthesiologists and surgeons, this is still the mainstay for estimating intraoperative blood loss [12]. Intraoperative blood loss is one of the most challenging issues for all surgeons, with the sequences of excessive blood loss in patients and the quality of the operation outcome in some situations. Blood transfusions has a lot of known hazards, including disease transmission, allergic reactions, acute lung injury, volume overload, infections, hemolytic transfusion reactions, febrile reactions, hypotension reactions, dyspnea, and others [13]. Lei et al. [14] reported a transfusion rate of 11% (11/58, 19%) in their study on PLIF, which included 37 patients with one level, 19 patients with two levels, and three patients with three levels of degenerative spine diseases. The transfusion rates in our study were 2.3% and 7.6% for groups A and B, respectively.

The statistically significant blood loss in group B in comparison with group A may be explained by that in group B: the early decompression by laminectomy and dealing with the pathological findings inside the spinal canal, such as fibrocartilaginous masses, disc material, or bony and soft tissue removal during foraminotomy, will lead to bleeding from many sources, such as the bone and peridural vasculature. Despite the hemostatic maneuvers by bipolar cauterization, bone wax, and gel foam, there are two main reasons for increasing blood loss in this group: (1) long period of exposure of injured vessels during PLIF, even with small blood ooze, as after the step of PLIF, the step of fixation will start and take time (2); the mechanical effect during screws insertion will cause some movements of the spinal segment, which may affect the hemostatic effect on the exposed tissues of the previous step. These factors were avoided in group A as the decompression, and interbody fusion steps will be late after screw insertion.

Because the volume and complexity of spinal surgeries are increasing, intraoperative blood loss management has become a pivotal research topic within the field. There are many tools for minimizing blood loss in patients undergoing spine surgery, either in preoperative preparations or during surgery [15].

In addition to the previous results, we can confirm some technical insights during this study, the pedicle screws when inserted before PLIF, allow the use of the rods for disc distraction that helps curettage of the disc space, especially in collapsed discs. Also, this allows insertion of the cage and then compression on the cage utilizing the pedicle screws and the rod. These are the arguments for those who insert pedicle screws before fusion. However, narrow disc space management during PLIF before pedicle screw insertion may need more effort with intervertebral reamers, curettes, bone chisels, and hammers.

Concerning surgical complications, our results revealed no significant difference between groups regarding screws malposition ($P = 0.17$), dural injury ($P = 0.44$) or root injury ($P = 0.49$); but there was a slight increase in screws malposition percentages and also dural and nerve root injuries during screw insertions in group A (group A; 3.5%, 3.8% and1.9% versus group B; 2.9%, 3.3% and 1.65% respectively), which can be explained by the fact that dural exposure before screws insertion may give more orientation for screw manipulations, especially when the facet joints are eroded or extensively hypertrophied, which mask the exact mediolateral entry point localization and trajectory.

Malposition of pedicle screws can cause damage to the dural sac or the nerve roots when the pedicle wall is broken mediocaudally [dangerous zone]. Screw malposition was recorded at 8.1% and nerve injuries at 5%. Different modalities can be used to attain the best screw pathway to avoid neural complications, such as intraoperative fluoroscopy and computed tomography navigation [16,17]. Whitecloud et al. [18] reported 15% of neurologic complications, 5% of which were caused by incorrect screw placement.

In our study, dural and root injuries occurred more often than decompression due to instrumentation. In contrast, Katones et al. [19] reported that seven cases (6.3%) of dural tears occurred during the decompression step and none during instrumentation. Surgeons adapted to one specific posterior lumbar fusion technique will tend to prefer that technique, whatever the pathology being treated, or the number of segments performed [20].

Being a retrospective study design of a single institution work is the limitation of this study; thus, a large prospective multicenter study is highly recommended to validate the best step sequences during PLIF and PSF surgery.

Conclusion

The data of this study suggest that the lumbar PSF is preferred before rather than after PLIF as it significantly reduces operative blood loss and the need for blood transfusion.

Ethics Information

The article does not contain information about medical device(s)/drug(s).

Conflict of Interest

The authors report no conflicts of interest.

Author declaration of funding statement

No funds were received in support of this work.

Abbreviations

IRB	Institutional review board
MSCT	Multislice computerized tomography
PLF	Posterior lateral fusion
PLIF	Posterior lumbar interbody fusion
PSF	Pedicle screw fixation
RBCS	Red blood cells

References

[1] Periasamy K, Shah K, Wheelwright EF. Posterior lumbar interbody fusion using cages, combined with instrumented posterolateral fusion: a study of 75 cases. Acta Orthop Belg 2008;74:240–8. PMID: 18564483.

[2] Lin PM, Cautilli RA, Joyce MF. Posterior lumbar interbody fusion. Clin Orthop Relat Res 1983;180:154–68.

[3] Li Y, Wu Z, Guo D, You H, Fan X. A comprehensive comparison of posterior lumbar interbody fusion versus posterolateral fusion for the treatment of isthmic and degenerative spondylolisthesis: A meta-analysis of prospective studies. Clin Neurol Neurosurg 2020;188:105594. https://doi.org/10.1016/j.clineuro.2019.105594. Epub 2019 Nov 11. PMID: 31751844.

[4] Nakai S, Yoshizawa H, Kenmotsu K, Nishimoto S, Morita T. Posterior lumbar interbody fusion: with and without pedicle screw fixation. In: Yonenobu K, Ono K, Takemitsu Y, editors. Lumbar fusion and stabilization. Tokyo: Springer; 1993. https://doi.org/10.1007/978-4-431-68234-9_21.

[5] Theusinger OM, Spahn DR. Perioperative blood conservation strategies for major spine surgery. Best Pract Res Clin Anaesthesiol 2016;30:41–52.

[6] Padoy N, Blum T, Feussner H, Berger M-O, Navab N. Online Recognition of Surgical Activity for Monitoring in the Operating Room. AAAI, 2008, p. 1718–24.

[7] Carrillo F, Esfandiari H, Müller S, von Atzigen M, Massalimova A, Suter D, et al. Surgical process modeling for open spinal surgeries. Front. Surg 2022;8:776945.

[8] Ali AE, Aleisa AA, Alsubaie HI, Buhlaiqah NR, Algadeeb JB, Alsneini HA. Blood loss estimation using gauze visual analogue. Trauma Mon 2016;21:e34131. https://doi.org/10.5812/traumamon.34131. PMID: 27626017; PMCID: PMC5003499.

[9] American Society of Anesthesiologists Task Force on Perioperative Blood Management. Practice guidelines for perioperative blood management: An updated report by the American Society of Anesthesiologists Task Force on Perioperative Blood Management. Anesthesiology 2015;122:241–75.

[10] Briggs H, Milligan PR. Chip fusion of the low back following exploration of the spinal canal. J Bone Joint Surg Am 1944;26: 125–30.

[11] Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg 2015;1:2–18. https://doi.org/10.3978/j.issn.2414-469X.2015.10.05. PMID: 27683674; PMCID: PMC5039869.

[12] Gerdessen L, Meybohm P, Choorapoikayil S, Herrmann E, Taeuber I, Vanessa Neef V, et al. Comparison of common perioperative blood loss estimation techniques: a systematic review and meta-analysis. J Clin Monit Comput 2021;35:245–58.

[13] Clevenger B, Kellehe A. Hazards of blood transfusion in adults and children Continuing Education in Anaesthesia. Critical Care Pain J 2014;14:112–6.

[14] Lei F, Li Z, He W, Tian X, Zheng L, Kang J, et al. Total and hidden blood loss between open posterior lumbar interbody fusion and transforaminal lumbar interbody fusion by Wiltse approach. Medicine 2020;99:e19864.

[15] Mikhail C, Pennington Z, Arnold PM, Brodke DS, Chapman JR, Chutkan N, et al. Minimizing blood loss in spine surgery. Global Spine J 2020;10(1S):71S–83S.

[16] Suess O, Schomacher M. Control of pedicle screw placement with an electrical conductivity measurement device: initial evaluation in the thoracic and lumbar spine. Adv Met Med 2016.

[17] Fan Y, Du J, Zhang J, Liu S, Xue X, Huang Y, et al. Comparison of accuracy of pedicle screw insertion among 4 guided technologies in spine surgery. Med Sci Mon Int Med J Exp Clin Res 2017;23:5960–8.

[18] Whitecloud IIITS, Butler JC, Cohen JL, Candelora PD. Complications with the variable spinal plating system. Spine 1989;14:472–6.

[19] Katonis P, Christoforakis J, Aligizakis AC, Papadopoulos C, Sapkas G, Hadjipavlou A. Complications and problems related to pedicle screw fixation of the Spine. Clin Orthop 2003;411:86–94.

[20] Kowalski RJ, Ferrara LA, Benzel EC. Biomechanics of bone fusion. Neurosurg Focus 2001;10:E2.