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Clinical and biomechanical outcomes of single-position anterior fixation in anterior lumbar interbody fusion

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Abstract

Background Anterior lumbar interbody fusion (ALIF) is an effective treatment for lumbar degenerative diseases, but it usually requires combined posterior fixation. Currently, Currently, there is no high-strength fixation technique for single-position anterior approach. This study aimed to introduce L5 vertebral body screws combined with S1 vertebral body-pedicle screw fixation (BPSF) as a novel single-position anterior fixation technique for ALIF, and to evaluate its clinical and biomechanical outcomes.

Methods Sixty-three patients with L5/S1 degenerative disease undergoing ALIF were divided into BPSF ($n=22$) and posterior pedicle screw fixation (PPSF, $n=41$) groups. Clinical outcomes, radiographic parameters, and complications were collected and compared between groups. Biomechanically, an adult lumbar spine model was used to simulate two ALIF fixation configurations under normal and osteoporotic conditions. Each construct was loaded with 500N compression and 10N·m torque to simulate flexion/extension, lateral bending, and axial rotation. Kinematic analyses included ROM, interbody cage stress, and fixation device strain.

Results The BPSF group showed significantly shorter operative duration (152.5 min (127.5, 173.1) vs. 165.0 min (140.0, 262.5), less intraoperative blood loss (115.0 ± 56.9 ml vs. 160.0 ml (110.0, 222.5) mL), and lower postoperative low back pain scores (1.6 ± 0.8 vs. 2.2 ± 0.7) compared to the PPSF group. And there were no statistically significant differences between the two groups in JOA improvement rate (49.9 ± 14.2% vs. 54.7 ± 18.1%), lumbar lordosis correction (6.9 ± 7.3° vs. 7.6 ± 7.1°), fusion rate (90.9% vs. 92.7%), or complication rate (27.3% vs. 19.5%). Biomechanically, BPSF reduced ROM during flexion (12% reduction) and axial rotation (63% reduction) compared to PPSF, with higher interbody cage stress but lower posterior fixation device stress under most loading conditions.

Conclusion BPSF provides safe anterior fixation for ALIF, reducing operative time and early postoperative pain. Its biomechanical stability, especially in rotational resistance, supports it as an alternative to PPSF for L5/S1 fusion.

Keywords Anterior lumbar interbody fusion, Pedicle screw fixation, Biomechanical assessment, Finite element analysis

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Introduction

Anterior lumbar interbody fusion (ALIF) provides direct visualization of the disc space and enables implantation of larger interbody cages at lower lumbar segments. This approach achieves effective neural decompression while restoring lumbar spinal alignment [1–3]. Despite its widespread use of ALIF in lumbar degenerative disease treatment, the procedure involves resection of a significant portion of the anterior longitudinal ligament during cage implantation, which may compromise anterior tension band integrity and increase risks of fusion failure or cage migration [4, 5].

To enhance the stability of the spine and the fusion rate, ALIF usually requires the combination of posterior pedicle screw fixation (PPSF) [6]. However, this inevitably prolongs the operation time and increases complication risks [7]. Consequently, alternative anterior fixation strategies have emerged over the evolution of ALIF, including low-profile anterior plating systems and self-stabilizing cages. These innovations aim to improve construct rigidity, prevent anterior graft protrusion, and eliminate reliance on secondary posterior procedures [8–10]. Subsequent biomechanical evaluations, however, demonstrate that these anterior-only Instrumentations exhibit inferior strength compared to PPSF, particularly during lateral bending movements [11, 12].

In this study, we applied L5 vertebral body screws combined with S1 vertebral body-pedicle screw fixation (BPSF) as supplementary fixation under a single-position setup for ALIF. By comparing clinical and biomechanical outcomes with PPSF, we aimed to evaluate its clinical value and safety.

Materials and methods

Patient population

A retrospective study was performed in the Second Affiliated Hospital of Dalian Medical University from January 2021 to December 2023. This study was approved by the Ethics Review Committee of the Second Affiliated Hospital of Dalian Medical University and obtained the unique identification number of research registration (KY2025-106–01). This study met guidelines of the responsible local governing agency and complied with the principles of the Declaration of Helsinki. Each patient signed a written informed consent form. The inclusion criteria include: (i) Age over 18 years old; (ii) Degeneration of the L5/S1 segment, including lumbar disc herniation, lumbar spinal stenosis, and spondylolisthesis. The exclusion criteria include: (i) Multilevel degeneration and severe spinal stenosis; (ii) Lumbar spondylolisthesis of grade II and above or with posterior fusion; (iii) History of diseases that cause peritoneal adhesions; (iii) Inflammation, pathologic fracture or neuromuscular origin.

All consecutive cases meeting the inclusion criteria were recruited without selection bias during the study period. For the control group, patients who underwent anterior bone graft fusion combined with PPSF between January 2019 and January 2021 by the same surgical team were enrolled using matching inclusion and exclusion criteria.

Surgical technique

The patient was placed in a supine position on a radiolucent operating table. A standard transperitoneal ALIF was performed in L5-S1 intervertebral space. Following complete discectomy and neural decompression, a polyetheretherketone (PEEK) interbody fusion cage packed with artificial bone graft was positioned within the prepared disc space under direct visualization. The entry point for S1 pedicle screw insertion was localized 1 cm lateral to the midline at the sacral promonitory level, under fluoroscopic guidance, Kirschner wires were punctured into the bilateral pedicles of S1. When approaching the posterior edge of the vertebral body, it was ensured that the K-wire tip was maintained lateral to the medial pedicular boundary to prevent spinal canal encroachment (Fig. 1). Then, the K-wire was advanced further to the posterior edge of the pedicle, K-wires were replaced with cannulated pedicle screw guidewires. After that, polyaxial Pedicle Screw (6.0×55 mm or 6.0×60 mm) were inserted over the guidewires. The appropriate length was typically measured using a depth probe, and the posterior cortex of the pedicle was intentionally penetrated to achieve bicortical screw fixation, thereby optimizing the pullout resistance. Similarly, two additional polyaxial pedicle screws (6.0×40 mm) were inserted into the L5 vertebra via an oblique trajectory, extending from the anteroinferior margin to the posterosuperior margin, capitalizing on the vertebral body's anatomical geometry. After confirming the correct position of the screws, a connecting rod was installed. If necessary, the spondylolisthesis could be reduced through the internal fixation system. Finally, the posterior peritoneal layer was reapproximated with a running 3–0 absorbable suture to prevent visceral herniation, and a layered abdominal closure was performed.

Data collection and analysis

The patient's clinical and radiological information obtained by accessing the electronic record system, compared this information with that of patients who underwent ALIF and PPSF. The standard demographics were collected, including age, sex. Surgical data including operative time and estimated blood loss (EBL). The radiologic Outcomes include Lumbar lordosis (LL) and lumbar spine fusion rate six months after the surgery. On computed tomography (CT) sagittal bone window

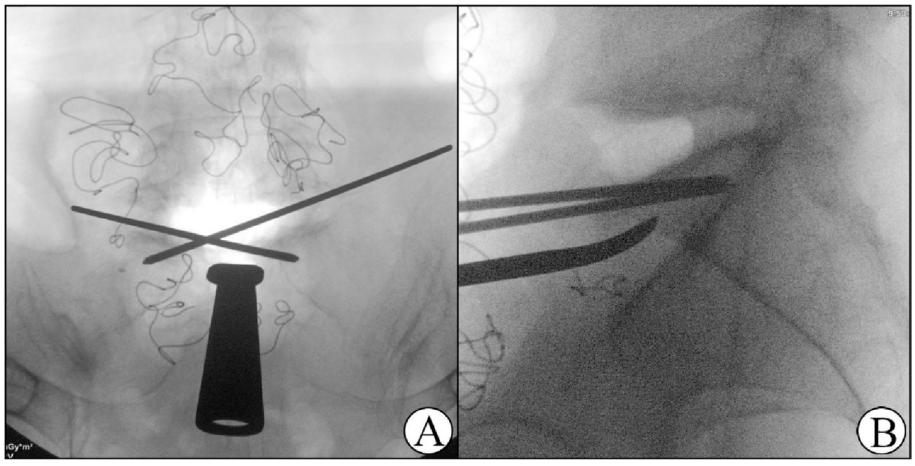


Fig. 1 Anteroposterior and lateral images taken by C-arm fluoroscopy during the operation. When approaching the posterior edge of the vertebral body, it was ensured that the K-wire tip was maintained lateral to the medial pedicular boundary to prevent spinal canal encroachment

images, the formation of continuous bridging bone between the superior and inferior vertebral endplates was defined as the criterion for bony fusion. Clinical Outcomes evaluated by the Visual Analog Scale (VAS) and Japanese Orthopedic Association (JOA) score.

Statistical analysis was performed using SPSS 27.0 software. Continuous variables were presented as mean ± standard deviation (SD) or median with interquartile range (IQR). Normality of variables was evaluated via the Kolmogorov–Smirnov test. For normally distributed data, independent samples t-tests were used to compare clinical and radiological outcomes between groups, while the Wilcoxon rank-sum test was applied for non-normally distributed variables. Categorical variables were analyzed using Pearson's chi-square test. Statistical significance was defined as $P < 0.05$.

Construction of the finite element lumbar spine model

High-resolution computed tomography data of a 30-year-old healthy male were collected, the DICOM data were imported into Mimics (Materialise, Leuven, Belgium) for segmentation to resulting in volumetric bodies with a 3-mm tetrahedral mesh model. This model was loaded into Geomagic Studio 12 (Geomagic, USA) for smoothing treatment, a NURBS surface and an osteoporosis model were constructed. Then, the smoothed model was processed using SolidWorks 2016 (Dassault Systèmes, USA) software to construct the intervertebral disc, vertebral body, cartilaginous parts of the facet joints, annulus fibrosus, and nucleus pulposus, and the internal fixation screws were assembled. Subsequently, the 3D skeletal model was loaded into Ansys 10.0 (Ansys Mechanical, USA), and the contact relationships and ligament models were established according to the anatomical structure. The contact characteristics of the facet articulation were simulated by three-dimensional frictionless contact elements. The gap of the facet joint was < 0.1 mm. while ligaments are modeled as nonlinear spring elements that are only affected by tension. The finite element model of the entire spine was validated by comparing it with the results of previously published finite element models [13] (Fig. 2).

Construction of surgical models

The anterior longitudinal ligament (ALL) and the nucleus pulposus (NP) were removed at the L5-S1 segment, while the posterior structures were kept intact. The intervertebral fusion cage (37 × 28 × 14 mm, 12°) (Double medical, China) was filled with allogeneic cancellous boneto simulate the implanted allogeneic bone graft, and then it was placed in the center of the intervertebral space. Then, the model was applied to two different fixation techniques: (1) Bilateral traditional pedicle screw fixation (L5: 6.0 × 45 mm; S1: 6.5 × 40 mm); (2) Percutaneous pedicle screw fixation (L5: 6.0 × 40 mm; S1: 6.0 × 55 mm). The diameter of the connecting rod is 4.5 mm (Fig. 3).

Material properties and load conditions

The properties of all elements are shown in (Table 1) according to previous literatures [14]. It is assumed that the posterior joint space is 0.5 mm, and the Coulomb friction coefficient is defined as 0.3, with the thickness of the cortical bone being 1 mm. In the defined osteoporosis model, the Young's modulus and density of the cancellous bone are reduced by 66%, and the cortical bone and posterior structures are decreased by 33% [15].

A pre-compressive load of approximately 500 Newtons, which is equivalent to two-thirds of the human body mass, is applied to the upper surface of the L4 lumbar vertebra. An additional moment of 10 N*m is applied in each direction to simulate six physiological activities, including flexion, extension, left and right lateral

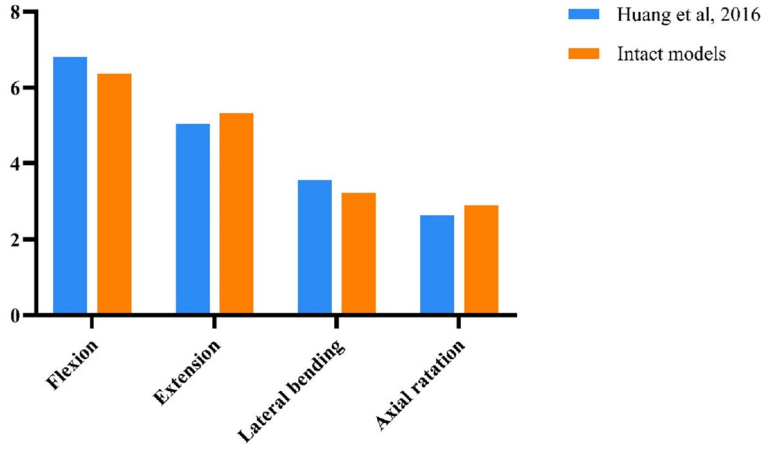


Fig. 2 The range of motion (ROM) of the complete lumbar spine model was compared with the previous experimental results. The comparison results show that the ROM is consistent with the values measured in previous experiments

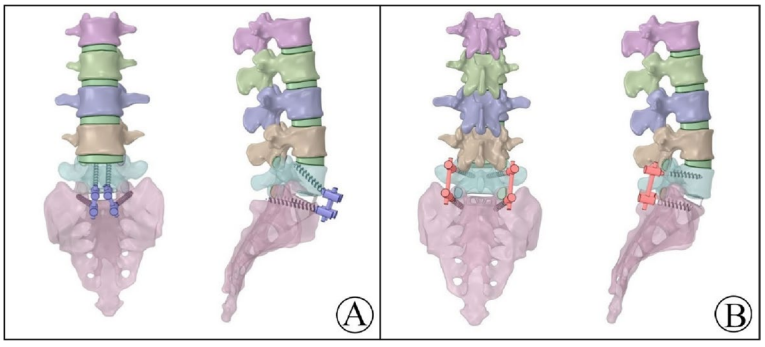


Fig. 3 Schematic diagrams of models of anterior lumbar interbody fusion using two different fixation methods: A. L5 vertebral body screws combined with S1 body-pedicle screw fixation (BPSF). B. Posterior pedicle screw fixation (PPSF)

Table 1 Material properties of the finite element model

Component	Young's modulus (MPa)	Poisson ratio	Cross-Sectional Area (mm^2)
Vertebral body			
Cortical bone	12,000(osteoporosis:8040)	0.3	/
Cancellous bone	100(osteoporosis:34)	0.2	/
Endplate	1000(osteoporosis:670)	0.3	/
Posterior bone	3500 (osteoporosis:2345)	0.3	/
Screws and rods	110,000	0.29	/
PEEK cage	3600	0.49	/
Nuclear pulposus	1	0.45	/
Annulus fibrosus	4.2	0.3	/
Facet joints	1000	0.3	/
Ligaments			
ALL	20	0.3	63.7
PLL	20	0.3	20
IPL	11.6	0.3	40
SPL	15	0.3	30
ITL	58.7	0.3	3.6
Capsular ligament	32.9	0.3	60
Flavum ligamentum	19.5	0.3	40

bending, and left and right axial torsion. The range of motion (ROM), the stress of the fusion cage, and fixation instrument are measured to evaluate the biomechanical characteristics of two models.

Results

Patient characteristics

A total of 22 patients undergoing ALIF with BPSF were enrolled. Their mean age was 58.5 ± 14.4 years, and the follow-up period was 20.6 ± 4.9 months. Comparative analysis with 41 patients receiving ALIF combined with PPSF revealed no statistically significant differences in baseline demographics (Table 2). All procedures were successfully completed without major intraoperative complications.

Operative efficiency

The BPSF group demonstrated significantly shorter operative time (152.5 (127.5, 173.1) vs. 165.0 (140.0, 262.5) min; $P = 0.037$) and reduced intraoperative blood loss (115.0 ± 56.9 vs. 160.0 (110.0, 222.5) mL; $P = 0.001$), compared to the ALIF + PPSF group.

Table 2 Comparative outcomes of BPSF Group vs. PPSF Group

Parameter	BPSF Group ($n=22$)	PPSF Group ($n=41$)	*p*-Value	Cohen's d
Demographics				
Age (years, mean ± SD)	58.5 ± 14.4	63.6 ± 8.5	0.135	0.472
Sex (male, %)	12(54.5%)	20(48.8%)	0.663	
Surgical Data				
Operative time (min)	152.5 (127.5, 171.3)	165.0 (140.0, 262.5)	0.037	
Blood loss (mL)	115.0 ± 56.9	160.0 (110.0, 222.5)	0.001	0.853
Clinical Outcomes				
Preoperative VAS	6.5 ± 1.9	7.0 ± 1.4	0.180	0.358
Postoperative VAS	1.9 ± 0.7	2.2 ± 0.7	0.200	0.342
VAS for lumbago (POD 3)	1.6 ± 0.8	2.1 ± 0.8	0.019	0.634
Preoperative JOA score	11.1 ± 2.7	10.7 ± 3.4	0.633	0.127
Postoperative JOA score	20.1 ± 2.5	20.7 ± 3.5	0.507	0.176
Improvement rate of JOA(%)	49.9 ± 14.2	54.7 ± 18.1	0.280	0.288
Radiological Outcomes				
Preoperative LL (°)	33.9 ± 10.1	32.3 ± 7.6	0.493	0.182
Postoperative LL (°)	40.7 ± 6.5	38.5 (34.7, 42.5)	0.254	0.118
Improvement of LL(°)	6.9 ± 7.3	7.6 ± 7.1	0.686	0.108
Fusion rate at 6 months (%)	20(90.9%)	38(92.7%)	0.804	

Clinical outcomes

Both groups achieved effective neural decompression with comparable improvements in postoperative limb pain VAS scores and JOA scores. The JOA improvement rates were 49.9 ± 14.2% vs 54.7 ± 18.1%; $P=0.280$). Notably, the ALIF + BPSF group exhibited superior early postoperative pain control, with significantly lower back VAS scores on postoperative day 3 (1.6 ± 0.8 vs 2.1 ± 0.8, $P=0.019$).

Radiological outcomes

All patients underwent imaging examinations at 6 months postoperatively. Diagnosis of bony fusion was based on sagittal bone window CT imaging, where the presence of continuous trabecular bone bridging between the superior and inferior vertebral endplates was considered diagnostic. The fusion rates of the two groups were 90.9% and 92.7%, while the LL corrections on standing radiographs were (6.9 ± 7.3)° and (7.6 ± 7.1)°, respectively. There were no statistical differences in fusion rate ($P=0.804$) or LL correction ($P=0.686$) between the two groups.

Complication

In our study, a total of 6 patients developed one or more complications, and there was no statistically significant difference in the complication rates between the two groups of patients (27.3% vs 19.5%; $P=0.480$). Among them, 4 patients experienced transient abdominal discomfort and ileus, but all of whom resolving spontaneously within 7 postoperative days. A postoperative MRI of an asymptomatic patient showed a large amount of fluid in the left tissue space, and a lymphocele was suspected. One patient developed muscle weakness in the right ankle joint after the operation (muscle strength grade 4 before the operation and grade 2 after the operation), and the muscle strength recovered to grade 4 after 3 months of rehabilitation treatment. At the same time, in one patient who had postoperative abdominal discomfort, postoperative nerve root irritation occurred due to the screw being inserted into the lateral recess, but the condition improved after three nerve root blocks. None of the patients had screw breakage or displacement of the intervertebral fusion cage within 1 year after the operation. Only 2 cases had endplate collapse, but it also met the criteria for bone fusion.

Range of motion

Under normal bone mineral density conditions, the BPSF construct manifested segmental mobility values as follows: 0.94° for flexion, 0.29° for extension, 0.33°/0.39° for left/right lateral bending, and 0.25°/0.24° for clockwise/counterclockwise axial rotation (Fig. 4). Kinematic analysis disclosed that, in comparison with the PPSF, the BPSF construct exhibited a significantly reduced ROM during flexion (a 12% reduction) and axial rotation (a 63% reduction). In the context of osteoporotic conditions, the mobility of both constructions increased across all motion modes, with a 12% increment for BPSF and a 14% increment for PPSF.

The stress of the cages fixation instrument

The stress values of the fusion cage under various loads are shown in Fig. 5. Whether under normal bone mass conditions or in the osteoporosis model, the stress of the cage in different motion states is basically the same. During extension and lateral bending movements, the PPSF fixation shows a good fixation effect and can significantly reduce the stress of cage. However, in rotational movements, the BPSF fixation model seems to be smaller.

The stress of the fixation instrument under various loads are shown in Figs. 6 and 7. Whether under normal bone mass conditions or in the osteoporosis model, the BPSF model shows a good fixation effect and can significantly reduce the screw stress. Especially during lateral bending and rotational movements, the screw stress can be reduced by 49% approximately.

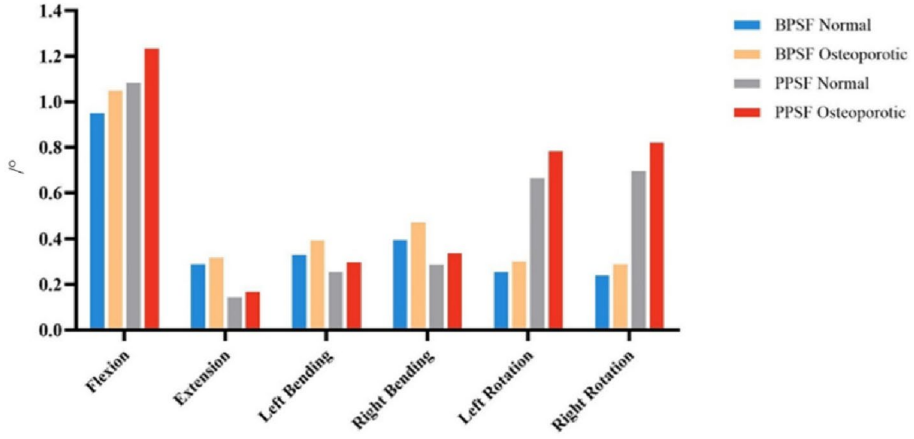


Fig. 4 ROM (°) of L5/S1 fusion segment in two internal fixation models under normal and osteoporosis conditions

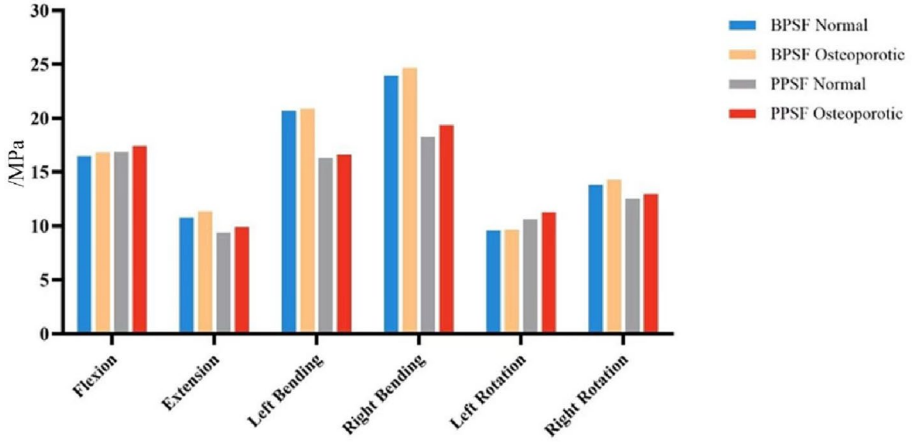


Fig. 5 Cage stress (MPa) in two internal fixation models under normal and osteoporosis conditions

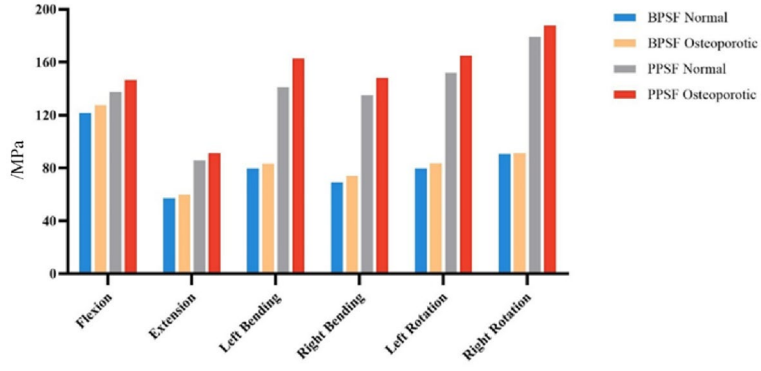


Fig. 6 Fixation instrument stress (MPa) in two internal fixation models under normal and osteoporosis conditions

Case presentation

A 55-year-old female patient presented with lower extremity pain and numbness. She received ALIF combined with BPSF (Fig. 8). Postoperatively, her VAS score improved from 8 to 2, while the JOA score increased from 6 to 18, yielding a JOA improvement rate of 52.2%. LL was restored from 35.7° preoperatively to 40.2° postoperatively.

Discussion

The historical origins of anterior lumbar surgery can be traced back to the surgical management of tuberculosis, modern ALIF was first introduced by Mercer in 1936,

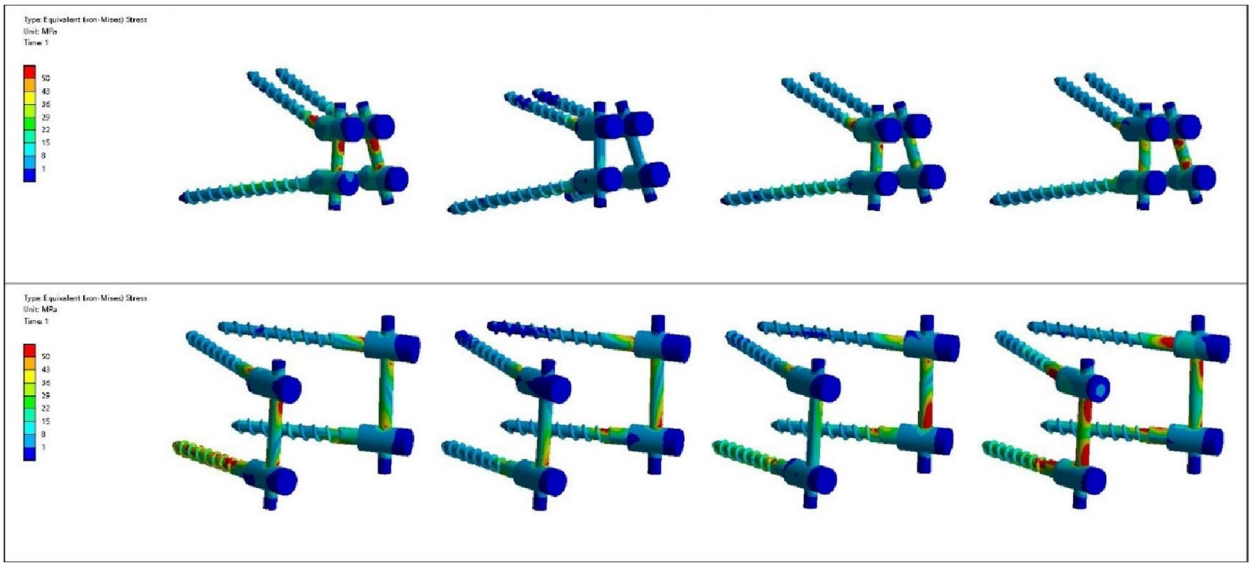


Fig. 7 Stress nephogram of two fixation systems under normal bone quality conditions

involving discectomy and interbody bone graft placement [16]. However, the lack of mechanical stability in standalone ALIF procedures necessitated adoption of extremely conservative postoperative protocols during its early clinical application. Including early immobilization and subsequent plaster braces, until radiographic evidence of early arthrodesis or callus formation emerged [17].Given the steep learning curve and variable clinical outcomes associated with this technique, ALIF remained a controversial procedure throughout the 1960 s and 1970s. During this period, its use was limited to salvage scenarios for patients with failed posterior spinal surgeries [18].

Advances in surgical techniques have solidified ALIF's role through its unique advantages, including thorough intervertebral decompression, large-scale graft placement, and preservation of paravertebral musculature and posterior osseous structures [1]. Today, this procedure is broadly adopted across diverse spinal pathologies. Despite these advancements, posterior instrumentation remains the only validated method to enhance arthrodesis rates by augmenting construct stability [19]. While anterior plating systems and integrated stand-alone cages offer stability enhancement without requiring posterior exposure, their ability to provide sufficient stiffness in cases of significant spinal instability has been consistently suboptimal [12, 20, 21]. In contrast, both anterior screw-plate constructs and pedicle screw-rod systems confer a marked reduction in spinal mobility and a significant increase in segmental rigidity. No statistically significant difference was identified between these two adjunctive fixation devices with respect to their capacity to restrict spinal flexion, extension, axial rotation, or anteroposterior shear forces. However, the pedicle screw-rod system demonstrates superior efficacy in limiting lateral bending of the spinal segment [11]. Additionally, the incidence of subsidence and displacement during the fusion period is significantly lower with the posterior pedicle screw-rod system than with anterior plating systems (2% vs. 22.1%) [22].

However, the necessity of a second surgical approach for posterior fixation introduces additional operative time and associated complications. Firstly, in contrast to the lumbar spine's dense cortical bone, sacral pedicles demonstrate shorter dimensions and wider morphology, providing limited cortical purchase for fixation [23]. This anatomical feature predisposes to common failure modes at L5/S1, including periscrew sacral cortical fractures and implant loosening [24]. To address this, bicortical fixation, in which the pedicle screws traverse the anterior sacral cortex, has been demonstrated to provide superior stability compared to unicortical fixation techniques [25–31]. Notwithstanding, in select patient populations, iliac crest obstruction imposes limitations on achievable medial trajectory angles [32–34], increasing risks of pedicle medial wall violation and resultant L5 nerve root injury [35, 36].

The S1 "pedicle" is uniquely composed of cancellous bones converging from the sacral ala to the vertebral body, differing from true lumbar pedicles. This broadened osseous structure enables safe placement of reverse pedicle screws. Cadaveric studies report S1 pedicle dimensions of 22.6–35.1 mm in height and 18.9–31.7 mm in width [37, 38]. This robust morphology provides an extensive safe corridor for screw trajectory planning. Meanwhile, degenerative changes within the anterior longitudinal ligament complex and osteophyte formation contribute to cortical thickening at the sacral

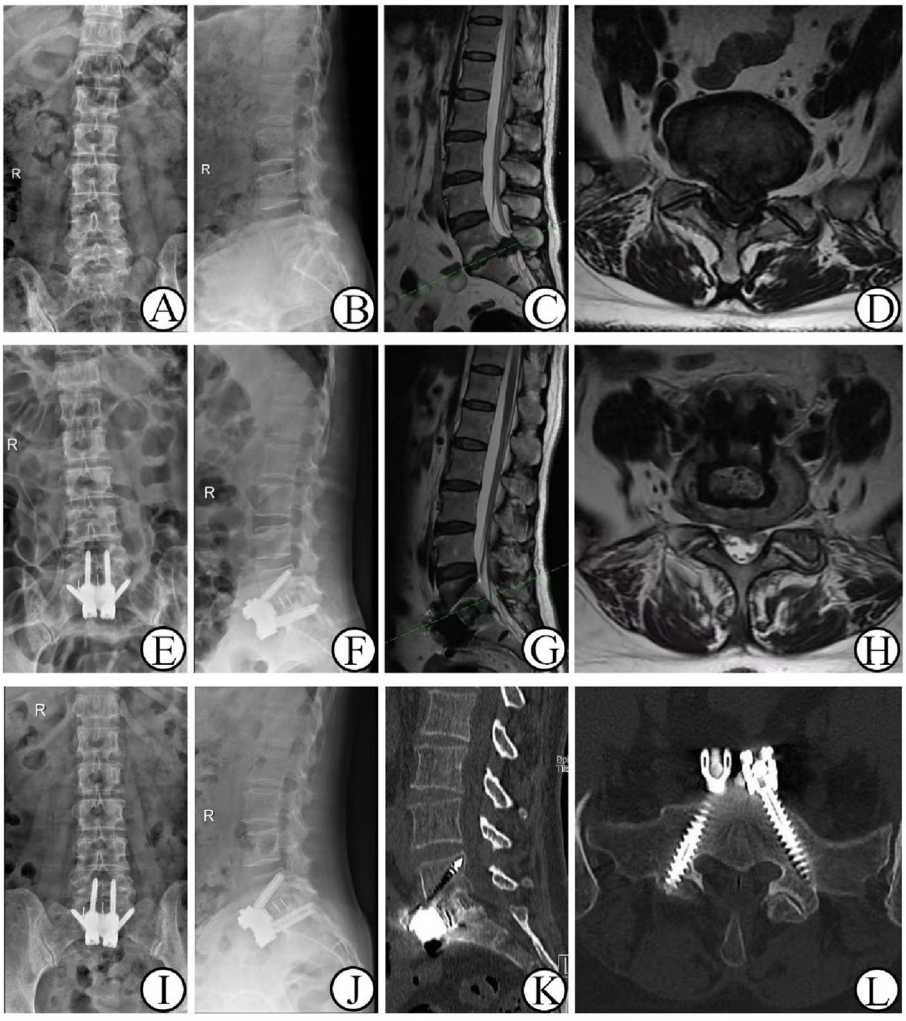


Fig. 8 A 55-year-old female patient with lower extremity pain and numbness. The patient underwent ALIF combined with BPSF. **A-D** Preoperative X-ray films and magnetic resonance imaging (MRI) showed that the Loss of lumbar lordosis and a severe protrusion of the L5/S1 intervertebral disc. **E–H** Immediate postoperative X-ray films and MRI demonstrated that the Intervertebral height and lordosis was restored, and the spinal canal was effectively decompressed **I-L** X-ray films and computed tomography (CT) scans at 6-Month follow-up showed that continuous trabecular bone bridging the fusion site

promontory, reaching up to 2.3 mm. Screws anchored at the promontory with bicortical purchase demonstrate up to 99% improvement in pull-out strength compared to traditional bicortical fixation techniques [27, 39, 40]. These findings validate the theoretical feasibility and biomechanical superiority of sacral screws placed via the promontory entry point with posterior pedicle cortex penetration.

Vascular structures anterior to L5 present an insurmountable obstacle for anterior pedicle screw fixation. Anatomical investigations reveal the aortic bifurcation resides superior to inferior endplate of L4, with mean apex-to-promontory distances of 36.9 mm in males and 35.2 mm in females [41]. And the transverse diameter between the left common iliac vein and right common iliac artery at the L5/S1 disc level measures 33.5 mm^{28}. This can provide an operative field of 14.6 cm^2 [42], sufficient for intervertebral decompression and inferoanterior L5 screw placement. To optimize screw length, an oblique trajectory from anteroinferior to posterosuperior vertebral margins may be employed. This cranially directed technique not only enhances fixation stability but also minimizes construct stress while improving bone-screw interface integrity [43, 44].

Fusion rate as a critical metric for evaluating internal fixation failure. Published data demonstrate ALIF combined with PSF achieves fusion rates of 88%–100% [6, 45, 46]. In the current study, 90.9% fusion was observed at 6 months postoperatively, progressing to 100% at 1 year, comparable to posterior fusion outcomes and consistent with previously reported PSF results. Biomechanical testing revealed BPSF provided equivalent fixation strength to PPSF, and with superior rotational stability. This rationale is highly consistent with clinical biomechanical

principles. First, bicortical anchorage at S1 improves screw fixation stability. Second, anterior surgery resects portions of the anterior longitudinal ligament and intervertebral discs, thereby impairing the anterior spinal column stability; however, the posterior column stability remains intact. BPSF can provide effective anterior column control, and this combined anterior–posterior stabilization achieves a rigid and stable spinal fixation construct. Additionally, unlike the parallel screw alignment in PPSF, the angled configuration of L5 and S1 screws in this construct also limits rotational displacement of the adjacent vertebral segments. Meanwhile, the unique screw trajectory at L5 markedly mitigated implant-associated stress. Prior biomechanical and clinical studies have established that the predominant load borne by pedicle screws acts along the craniocaudal axis. Non-axial loading on pedicle screws is known to induce screw subsidence and plowing within the vertebral bone, which subsequently precipitates screw loosening [47]. Thus, the adoption of a cephalad-oriented pedicle screw trajectory can effectively attenuate the risk of implant loosening, particularly in patients with osteoporosis who exhibit compromised bone quality [48].

ALIF carries inherent risks of operative approach-related complications, with reported complication rates of 11%–24% [49, 50]. In the present study, the overall complication rate was 27.3%, though the majority involved transient abdominal distension without serious sequelae or permanent injuries. All complications were common surgical sequelae except for one case of lymphocele. Lymphocele is a cystic fluid accumulation formed in the retroperitoneal or surgical area due to continuous leakage of lymph fluid caused by damage to lymph nodes or blood vessels during surgery. According to research data, the incidence of lymphocele after ALIF is approximately 2.1% [51]. This condition typically presents abdominal pain, distension, and/or wound-related issues. Symptomatic cases were managed via drainage/sclerotherapy, while asymptomatic patients can be followed up until the imaging findings show regression.

This investigation encompasses several limitations. First, BPSF is a novel fixation technique. The learning curve may exert a certain impact on the initial research outcomes. Moreover, the current sample size is limited, and future studies should enroll larger cohorts with extended follow-up durations to comprehensively evaluate the clinical efficacy of this technique. Second, inclusion of initial surgical cases may introduce inherent bias in metrics such as operative time and clinical efficacy. Third, the current biomechanical model omits musculature simulation, with ligaments modeled as nonlinear tension-only spring elements, potentially altering lumbar kinematics and stress distribution. In addition, posterior pedicle screws are adopted in the present study, and the screw caps inevitably exert a certain mass effect. In future research, we will develop an internal fixation system suitable for anterior approaches. Notwithstanding these limitations, this study validates the clinical utility of BPSF fixation, offering valuable guidance for spine surgeons.

Conclusion

The unique S1 anatomy provides a secure corridor for anterior pedicle screw placement, combined with L5 vertebral screws, this approach offers robust supplementary fixation for ALIF in both clinical and biomechanical contexts. Meanwhile, BPSF demonstrates efficacy in reducing operative duration, minimizing intraoperative blood loss, and avoiding postoperative lumbago, positioning it as a viable routine adjunct for ALIF procedures.

Abbreviations

ALIF	Anterior lumbar interbody fusion
PPSF	Posterior pedicle screw fixation
BPSF	Body-pedicle screw fixation
ROM	Range of motion
JOA	Japanese Orthopedic Association score
VAS	Visual analogue scale
LL	Lumbar lordosis

Acknowledgements

None.

Authors' contributions

Z.W.L. and D.P.F. conceptualized and designed the study. M.Q.L, X.B.Y., and M.D.Z. collected and processed the data. M.Q.L. and X.B.Y. analyzed and interpreted the data. M.Q.L., X.B.Y., and M.D.Z. wrote the manuscript. Z.W.L. and D.P.F. revised the manuscript. All authors read and approved of the final manuscript.

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Data availability

Please contact the corresponding author with data access requests. All other datasets generated during the study will be made available at reasonable request to the corresponding author.

Declarations

Ethics approval and consent to participate

Human study was approved by the Ethics Committee of The Second Affiliated Hospital of Dalian Medical University (KY2025-106–01). Each patient signed a written informed consent form. In this study, all methods were performed in accordance with the Declaration of Helsinki relevant guidelines and regulations.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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