Comparison of Posterior Pedicle Screw Fixation and Lateral Fixation in the Extreme Lateral Interbody Fusion in Lumbar Degenerative Disease Patients with Osteopenia or Osteoporosis

Xianzheng Wang, MM, Huanan Liu, MM, Weijian Wang, MM, Yapeng Sun, MD, Fei Zhang, MM, Lei Guo, MM, Jiaqi Li, MM, Wei Zhang, MD

Department of Spinal Surgery, The Third Hospital of Hebei Medical University, Shijiazhuang, China

Objective: Nowadays, with the increasing proportion of osteoporosis in patients with lumbar degenerative diseases, doctors are facing the choice of intraoperative internal fixation methods. The purpose of this study was to compare and assess the clinical results of posterior bilateral pedicle screw fixation and lateral fixation in the extreme lateral interbody fusion (XLIF) in patients with osteopenia or osteoporosis.

Methods: The retrospective review was performed on 67 degenerative lumbar diseases patients with osteopenia or osteoporosis who underwent XLIF in our hospital from January 2018 to July 2021. Patients in this study were classified into lateral screw (LS) group, lateral self-locking plate (LP) group, and bilateral pedicle screw (BPS) group. The functional evaluation factors containing Japanese Orthopaedic Association (JOA) score, visual analogue scale (VAS) of leg pain, and VAS of low back pain, radiological factors such as disc height (DH), lumbar lordotic (LL) angle, segmental lordotic (SL) angle, cage subsidence degree and interbody fusion degree were compared.

Results: Primary outcomes: no differences were observed with regards to the incidence of complications among LS, LP and BS group (P < 0.05). The JOA and leg pain VAS were significantly improved after operation (P < 0.05) and all groups demonstrated similar improvements in the leg pain VAS and JOA score (P > 0.05). When comparing VAS of leg pain and JOA scores, no differences were identified among LS, LP and BPS groups (P > 0.05). There are four thigh sensory complaint, one hip flexor weakness and one thigh pain occurred and no death was observed. There were significantly better DH, LL angle, SL angle, cage subsidence degree and interbody fusion degree in the BPS group than in LS and LP groups 1 year after surgery (P < 0.05). The DH loss ratio, LL angle loss ratio, SL angle loss ratio in the BPS group was significantly lower than in the LP and LS groups (P < 0.05). The 12-month SL angle improvement rate in the BPS group was significantly higher than in the LP and LS groups (20.20 ± 14.69, 0.73 ± 4.68, 6.20 ± 12.31, P < 0.05). Secondary outcomes: the BPS patients had significantly worse intraoperative blood loss and operation time than LS and LP patients (P < 0.05).

Conclusion: In lumbar diseases patients with osteopenia or osteoporosis, the bilateral pedicle screw fixation has better orthopedic effect than lateral internal fixation, and can better maintain the stability of the spine in the long-term follow-up, which is a better choice in XLIF surgery.

Key words: Cage subsidence; Extreme lateral interbody fusion; Fusion; Internal fixation

Author for Address for correspondence: Jiaqi Li and Wei Zhang, Department of Spinal Surgery, The Third Hospital of Hebei Medical University, Shijiazhuang 050000, Hebei Province, China Phone: 86-0311-88602382; Email: lijiaqiat430@163.com; zhangweiat430@sina.com

Xianzheng Wang is the first author.

Received 24 March 2022; accepted 6 September 2022

Orthopaedic Surgery 2022;14:3283-3292 • DOI: 10.1111/os.13540

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.
Introduction

Extreme lateral interbody fusion (XLIF) has been an effective minimally invasive operation for the treatment of degenerative lumbar diseases, such as lumbar spondylolisthesis, lumbar disc herniation, spinal stenosis and lumbar scoliosis through indirect decompression. When comparing the clinical effect with traditional posterior lumbar surgery, it has the advantages of avoiding injury of the venous plexus in the spinal canal, the invasion of nerve root and sheath sac, which greatly reduces the amount of intraoperative bleeding and low back muscle damage, and can improve the curvature of spine to some extent. However, once the fusion failure and disc space collapse occur after XLIF, it may seriously worsen the decompression and orthopedic effect, and lead to the reappearance of nerve symptoms.

Degenerative lumbar disease occurs mostly in elderly patients, with varying degrees of osteopenia or osteoporosis, which has become more widely recognized as a concern in spinal surgery. Meanwhile, osteopenia or osteoporosis as a disorder due to the decline of bone mineral density and bone quality, the destruction of bone microstructure and the increase of bone brittleness, often leads to slow prognosis of postoperative bone fusion. Meanwhile, the fragile bone can make reduced disc height, intervertebral fusion failure, cage collapse, and pseudojoint formation, which greatly affects the surgical orthopedic effect and long-term spinal stability, and even lead to reoperation.

Nowadays, posterior pedicle screws, lateral screws and lateral self-locking plates or other fixation methods are commonly used in lumbar surgery. But for the intraoperative internal fixation methods, different surgeons have different choices. Moreover, some surgeons choose to perform stand-alone XLIF. It is of great importance to choose an appropriate fixation apparatus, especially for osteopenia or osteoporosis patients, for it can better correct spinal curvature, improve neurological symptoms more effectively, and maintain the stability of the spine.

This experiment has the following purposes: (i) to explore the effect of different internal fixation methods on intervertebral fusion, such as disc height, interbody fusion and cage subsidence, which will indirectly affect the recovery of neural function; (ii) to explore the influence of different internal fixation methods on spinal curvature, such as lumbar lordotic angle and segmental lordotic angle at various stages after operation, which can reflect the ability of the procedure and maintaining curvature; (iii) to explore the recovery of neurological function after operation, such as Japanese Orthopaedic Association (JOA) score, and visual analogue scale (VAS); and (iv) to explore surgical risk factors such as operation time, blood loss and complications, which is important for elderly patients.

Method

Patient Population
All surgery procedures were performed by the same surgeon. Sixty-seven degenerative lumbar disease patients who underwent XLIF at the Hebei Medical University Third Hospital from January 2018 to June 2021 were included. The patients in this study were divided into the lateral screw (LS) group (n = 22), the lateral self-locking plate (LP) group (n = 21), and the bilateral pedicle screw (BPS) group (n = 24) according to the fixation method. All patients underwent follow-up for at least 1 year.

Inclusion criteria for this study included age ≥ 18 years, imaging examination showing that L3-4 or L4-5 segment was responsible for the clinical symptoms, patients who were suitable for LS, LP and BPS fixation, patients who underwent invalid conservative treatment for at least 3 months, in the dual energy X-ray absorptiometry, the T-score was less than or equal to −1 and greater than −2.5. Exclusion criteria for this study included bone fracture, bone tumor, lumbar tuberculosis, spinal cord injury, bone deformity, surgical contraindications such as severe respiratory, cerebral, and cardiovascular disease, reoperation of lumbar spine, patients who were followed up for <1 year.

Surgical Procedure

Lateral Screw or Lateral Self-locking Plate
All the patients were treated with general anesthesia. After the patient was placed in lateral position, lateral fluoroscopy was used to find the target level. The skin was incised and the subcutaneous tissue and dorsal fascia were divided. Then the retroperitoneal space was reached and we used a dilator to split the psoas muscle bluntly. After we found the target disc, we chose to use a retractor to maintain the operation area, and the decompression work was performed. After the disc was removed, a cage inserted with bone fragments was placed in the intervertebral area. After the discectomy, we used a lateral self-locking plate or lateral screws to fix the vertebral body (Figs. 1 and 2).

Bilateral Pedicle Screw
All the patients were treated with general anesthesia. After the patient was placed in lateral position, we then used lateral fluoroscopy to find the target level. The skin was incised and the subcutaneous tissue and dorsal fascia were divided. Then the retroperitoneal space was reached and we used a dilator to split the psoas muscle bluntly. After we found the target disc, we chose to use a retractor to maintain the operation area, and the decompression work was performed. After the disc was removed, a cage inserted with bone fragments was placed in the intervertebral area. After the incision was sutured, the position of patient was altered to prone. We used lateral fluoroscopy to locate the incision site, and made four longitudinal incisions. We then placed the puncture needles at the inferior outer edge of the vertebral pedicle, and inserted them into the vertebra through the pedicle. After confirming the proper location, the pedicle screws were inserted and the connecting rods were passed through each end of the screws (Fig. 3).
Fig. 1  One case of lateral screw method. Preoperative lateral position X-ray radiograph indicate the bone structure of lumbar vertebrae (A); postoperative X-ray radiograph indicate the fixation position (B, C); the postoperative sagittal CT at 3- and 12-month show the cage subsidence and dissatisfied fusion situation (D, E)

Fig. 2  One case of lateral self-locking plate method. Preoperative lateral position X-ray radiograph indicate the bone structure of lumbar vertebrae (A); postoperative X-ray radiograph indicate the fixation position (B, C); the postoperative sagittal CT at 3- and 12-month show the mild cage subsidence and fusion situation (D, E)

Fig. 3  One case of bilateral pedicle screw method. Preoperative lateral position X-ray radiograph indicate the bone structure of lumbar vertebrae (A); postoperative X-ray radiograph indicate the fixation position (B, C); the postoperative sagittal CT at 3- and 12-month show the fusion situation (D, E)
Baseline and Efficacy Evaluation
Baseline index includes age, sex, body mass index and follow-up time. Surgery related factors including operation time, intraoperative blood loss, and perioperative complications were captured. The dual energy X-ray absorptiometry was used to test the bone mineral density (BMD) of lumbar spine. The patients with T-score less than or equal to −1 and greater than −2.5 were diagnosed as osteopenia. The patients with T-score less than or equal to −2.5 were diagnosed as osteoporosis.

Radiographic Index
The anterior–posterior and lateral X-ray, lumbar CT scan and MRI were taken before the surgery and 3-months and 1 year after surgery to assess imaging related outcomes.

Disc Height
The disc height (DH) was calculated as: the distance between the center of the upper and lower endplates. Rate of the DH improvement was calculated as: \((12 \text{ months } DH - \text{ preoperative } DH) / \text{preoperative } DH \times 100\)%, which was used to observe the improvement of DH at the time point of 1 year after operation compared to the postoperative DH. Loss ratio of DH was calculated as: \((3 \text{ months } DH - 12 \text{ months } DH) / 3 \text{ months } DH \times 100\)%, which was used to indicate the DH loss between 3 and 12 months after surgery.

Interbody Fusion Degree
The interbody fusion degree was assessed by the CT scan captured 3 and 12 months after surgery. Complete fusion was defined as: bone bridge formed in the intervertebral space connecting adjacent endplate. Incomplete fusion was defined as: partial nonunion was found at only one endplate at fusion segment. Failed fusion was defined as: there were no bone graft material found in the fusion segment.

Cage Subsidence Degree
The cage subsidence degree was assessed by the CT scan. Subsidence was evaluated and classified into four grades according the degree of cage subsidence into the endplates: grade I (0%–12%), grade II (13%–24%), grade III (25%–36%), grade IV (37%–50%), and grade V (51%–100%, indicating intervertebral space collapse).

Lumbar Lordotic Angle
The lumbar lordotic angle (LL) was an angle between the upper endplate of the L1 and the inferior endplate of S1 on the lateral radiograph. Rate of the LL angle improvement was calculated as: \((12 \text{ months } LL \text{ angle} - \text{ preoperative } LL \text{ angle}) / \text{preoperative } LL \text{ angle} \times 100\)%, which was used to observe the improvement of LL angle at the time point of 1 year after operation compared to the postoperative LL angle. Loss ratio of LL angle was calculated as: \((3 \text{ months } LL \text{ angle} - 12 \text{ months } LL \text{ angle}) / 3 \text{ months } LL \text{ angle} \times 100\)%, which was used to indicate the LL angle loss between 3 and 12 months after surgery.

Segmental Lordotic Angle
The segmental lordotic angle (SL) was an angle between cranial and caudal endplates of the fusion segment. Rate of the SL angle improvement was calculated as: \((12 \text{ months } SL \text{ angle} - \text{ preoperative } SL \text{ angle}) / \text{preoperative } SL \text{ angle} \times 100\)%, which was used to observe the improvement of SL angle at the time point of 1 year after operation compared to the postoperative SL angle. Loss ratio of SL angle was calculated as: \((3 \text{ months } SL \text{ angle} - 12 \text{ months } SL \text{ angle}) / 3 \text{ months } SL \text{ angle} \times 100\)%, which was used to indicate the SL angle loss between 3 and 12 months after surgery.

Functional Evaluation
The visual analog scale (VAS) and Japanese Orthopaedic Association (JOA) score were recorded before surgery, 3, 6 and 12 months after the operation.

Visual Analog Scale
The VAS was used to evaluate the degree of pain. The scores are recorded by degree from 0 to 10. 0, 1–3, 4–6, 7–9, 10 indicates “no pain,” “mild pain,” “moderate pain,” “severe pain,” and “the worst imaginable pain” respectively.

VAS Improvement Rate
The VAS improvement rate was calculated to evaluate the relief of pain: \((12 \text{ months score} - \text{ preoperative score}) / \text{preoperative score} \times 100\)%

Japanese Orthopaedic Association Score
The JOA score is a disease-specific and physician-oriented scale which was designed to assess the neurological status of patients. This scale consists of four domain scores (subjective symptoms, clinical signs, activity of daily living scale, bladder function), scaled from 0 to 9, 6, 14, and −6, respectively. The score range was 0–29.

JOA Score Improvement Rate
The JOA score rate improvement was calculated to assess the functional improvement: \((12 \text{ months score} - \text{ preoperative score}) / (29 - \text{ preoperative score}) \times 100\)%

Statistical Methods
The Student’s t test, one-way analysis of variance and post hoc test, repeated-measures analysis of variance, Pearson chi-square and Fisher’s exact test were used when appropriate to test the significance of the differences within and among the groups. We analyzed the data with the SPSS Statistics 25.0 (IBM, Armonk, NY, USA). Statistical significance was set at \(P < 0.05\). All the outcomes are shown as mean values and standard deviation.
Results

Baseline and Clinical Outcomes (Secondary Outcome)
The baseline characteristics were shown in Table 1. Sixty-seven patients (48 men) were included for analysis, in which 22 (32.83%) underwent LS, 21 (31.34%) underwent LP and 24 underwent BPS (35.83%). The average age at baseline was 56.71 years. There were no significant differences in sex, age, body mass index, bone mineral density, and follow-up time ($P > 0.05$). The intraoperative blood loss was higher in the BPS group than in the LS and LP groups ($107.83 \pm 20.75$ ml vs $81.90 \pm 21.40$ ml, $85.95 \pm 27.58$ ml, $F = 8.298$, $P < 0.05$). The operation time of BPS patients was longer than LS and LP patients ($152.50 \pm 33.9$ min vs $120.59 \pm 33.98$ min, $115.66 \pm 21.18$ min, $F = 10.207$, $P < 0.05$). No patients were reoperated upon during follow-up.

Radiographic Evaluation Outcomes (Primary Outcome)
The radiographic outcomes were shown in Tables 2 and 3.

Disc Height
When comparing DH, no significant difference was identified among the groups before and 3 months after operation ($P > 0.05$). There was significantly better DH in BPS group than in LS and LP group 12 months after surgery ($8.298 \pm 2.83$ mm vs $7.94 \pm 2.83$ mm, $F = 8.298$, $P < 0.05$). No significantly difference was identified in 12-month DH improvement rate among LS, LP and BPS group ($8.298 \pm 2.83$ mm vs $7.94 \pm 2.83$ mm, $F = 8.298$, $P < 0.05$). The DH loss ratio of BPS patients was significantly lower than that of LP and LS patients ($11.12 \pm 9.64$% vs $13.19 \pm 9.29$%, $11.12 \pm 9.64$%, $P < 0.05$).

LL Angle
The LL angle demonstrated similar results among the groups before and 3 months after operation ($P > 0.05$). The LL angle in BPS patients showed significantly larger results than LS and LP patients 12 months after surgery ($34.28 \pm 2.83$° vs $30.92 \pm 2.73$°, $30.59 \pm 2.35$°, $F = 13.522$, $P < 0.05$). No differences were observed in 12-month LL improvement rate among the LS, LP and BPS groups ($3.50 \pm 13.12$%, $0.17 \pm 21.42$%, $5.86 \pm 11.30$%, $F = 2.114$, $P > 0.05$). The BPS patients had significantly better LL angle loss ratio than the LS and LP groups ($0.19 \pm 12.00$% vs $7.94 \pm 12.56$%, $8.32 \pm 8.95$%, $F = 3.525$, $P < 0.05$).

SL Angle
Regarding LL angle, there was no difference among groups before and 3 months after operation ($P > 0.05$). There was significantly larger SL angle in the BPS group than in the LS and LP groups 12 months after surgery ($21.42 \pm 3.52$° $10.60 \pm 2.10$°, $10.38 \pm 2.88$°, $F = 62.845$, $P < 0.05$). The 12-month SL angle improvement rate in the BPS group was significantly higher than in the LS and LP groups ($23.96 \pm 21.01$%, $0.33 \pm 19.62$%, $1.60 \pm 17.63$, $F = 8.411$, $P < 0.05$). The SL angle loss ratio of BPS patients was significantly lower than LP and LS patients ($1.74 \pm 18.86$% vs $13.96 \pm 13.48$%, $14.33 \pm 13.50$%, $F = 4.844$, $P < 0.05$).

Cage Subsidence Degree
All groups demonstrated similar results of cage subsidence degree 3 months after operation ($P > 0.05$). The BPS group showed significantly better cage subsidence result than LS and LP group 12 months after operation ($P < 0.05$).

Interbody Fusion Degree
There was significantly better interbody fusion degree result in the BPS group than in the LS and LP groups 12 months after operation ($P < 0.05$). When comparing interbody fusion degree, no significant difference was found among groups 3 months after surgery ($P > 0.05$).

Functional Evaluation Outcomes (Primary Outcome)
The functional outcomes of the patients are shown in Table 4.

### Table 1: Patient demographic and surgery-related data

| Variable                          | LS               | LP               | BPS              | Statistical value | p-value |
|-----------------------------------|------------------|------------------|------------------|-------------------|---------|
| Patients, n                       | 22               | 21               | 24               |                   |         |
| Age, years                        | 56.54 ± 1.22     | 56.85 ± 0.91     | 56.75 ± 1.11     | $F = 0.454$       | 0.637*  |
| Sex (male, female)                | 18.6             | 13.8             | 19.5             | $F = 1.662$       | 0.440*  |
| BMD, T-score                      | $-2.18 \pm 0.25$ | $-2.16 \pm 0.28$ | $-2.19 \pm 0.36$ | $F = 0.064$       | 0.938*  |
| Osteoporosis/osteopenia           | 4/18             | 4/17             | 5/19             |                   | 1b      |
| BMI, kg/m²                        | 24.80 ± 4.81     | 25.27 ± 2.83     | 23.56 ± 3.73     | $F = 1.186$       | 0.312*  |
| Follow-up, months                 | 14.00 ± 0.97     | 13.90 ± 1.09     | 13.95 ± 1.12     | $F = 0.043$       | 0.958*  |
| L3-4/L4-5                         | 8/14             | 9/12             | 10/14            | 0.217             | 0.905*  |
| Blood loss, ml                    | 81.90 ± 21.40    | 85.95 ± 27.58    | 107.83 ± 20.75f  | $F = 8.298$       | 0.001*  |
| Operation time, min               | 120.59 ± 33.98   | 115.66 ± 21.18   | 152.50 ± 33.98f  | $F = 10.207$      | <0.001* |

Abbreviations: Blood loss, intraoperative blood loss; BMD, bone mineral density; BMI, body mass index; BPS, bilateral pedicle screw; LP, lateral self-locking plate; LS, lateral screw.; *Notes: One-way analysis of variance.; **Fisher’s exact test.; †Pearson Chi-square test.; ‡P < 0.05, compared with other groups using post hoc tests.
The VAS of leg pain improved significantly after operation in all groups (all \(P < 0.05\)). No difference was identified among the three groups at all time points (all \(P > 0.05\)).

**JOA Score**

The JOA score improved significantly after operation in all groups (all \(P < 0.05\)). No difference was found among the three groups at all time points (all \(P > 0.05\)).
The complications are shown in Table 5. In the LS group, three patients had postoperative complications (13.63%), which included thigh sensory complaint (two cases) and hip flexor weakness (one case). Among the LP patients, two patients developed postoperative complications (9.52%), which included thigh sensory complaint (one case) and thigh (one case). In the BPS group, two patients developed thigh sensory complaint (8.33%). No significant difference in the incidence rate of complications was found among the groups. All the complications were relieved within 1 month.

**Complications (Primary Outcome)**

The study of Phillips et al. demonstrated that pseudarthrosis and pseudo-joint and reoperation in osteopenia patients were nearly 2–3 times higher than those in patients with normal bone mass. Internal fixation devices can increase the stability in patients’ early activities and functional exercise. The study of Phillips et al. showed that the combined usage of posterior pedicle screw has more advantages in preventing cage subsidence and long-term spinal correction loss. This experiment aimed to explore the suitable fixation methods in degenerative lumbar patients with osteopenia or osteoporosis by comparing different internal fixation methods (Fig. 2).

**Background**

In XLIF, we enter the operation site through a small retroperitoneal incision, which can avoid the injury of abdominal organs, large blood vessels and sympathetic nerve chain, leading to less intraoperative blood loss. Meanwhile, the subsidence and displacement of fusion cage are serious complications of lumbar interbody fusion. The rates of pseudo-joint and reoperation in osteopenia patients were nearly 2–3 times higher than those in patients with normal bone mass. Internal fixation devices can increase the stability in patients’ early activities and functional exercise. The study of Phillips et al. showed that the combined usage of posterior pedicle screw has more advantages in preventing cage subsidence and long-term spinal correction loss. This experiment aimed to explore the suitable fixation methods in degenerative lumbar patients with osteopenia or osteoporosis by comparing different internal fixation methods (Fig. 2).

**Intervertebral Fusion**

**Disc Height.** XLIF achieved good results by indirect decompression of nerve through intervertebral traction and fusion. However, the postoperative disc height loss may limit the

### Table 4: Functional outcomes

| Variable               | LS (n = 18)         | LP (n = 17)         | BPS (n = 21)        | Statistical value | P value |
|------------------------|---------------------|---------------------|---------------------|-------------------|---------|
| JOA preoperative       | 11.05 ± 1.98        | 11.34 ± 1.84        | 11.00 ± 2.15        | F = 0.187         | 0.830*  |
| 1 day                  | 20.04 ± 1.90b       | 20.90 ± 0.95b       | 19.77 ± 1.84b       | F = 0.857         | 0.429*  |
| 3 months               | 20.69 ± 0.96c       | 21.29 ± 1.04c       | 21.10 ± 1.64c       | F = 0.999         | 0.374*  |
| 6 months               | 20.99 ± 0.84c       | 21.34 ± 0.87c       | 20.57 ± 0.91c       | F = 0.913         | 0.407*  |
| 12 months              | 21.73 ± 0.78d       | 21.36 ± 0.88d       | 21.73 ± 1.07d       | F = 1.158         | 0.320*  |
| p value                | <0.001b             | <0.001b             | <0.001b             |                   |         |
| 12 months IR (%)       | 103.97 ± 44.90      | 93.10 ± 32.55       | 107.19 ± 54.26      | F = 0.528         | 0.561*  |

**Notes:** One-way analysis of variance; *P < 0.05, compared with preoperative variable within group using Paired t test.

### Table 5: Complications

| Variable                      | LS (n = 22) | LP (n = 21) | BPS (n = 24) | Statistical value | P value |
|-------------------------------|------------|------------|-------------|-------------------|---------|
| Thigh sensory complaint       | 2          | 1          | 2           | 0.513             | 1.000*  |
| Hip flexor weakness           | 1          | 0          | 0           | 1.822             | 0.647*  |
| Thigh pain                    | 0          | 1          | 0           | 1.975             | 0.313*  |

**Notes:** Fisher’s exact test.
maintenance of initial decompression, leading to the recurrence of symptoms. Intervertebral disc height can predict the long-term effect of patients to a certain extent. According to our research, the loss rate of disc height among BPS patients was significantly lower than lateral fixation patients. Consistent with our study, Marchi’s study showed that in patients who underwent stand-alone XLIF, the disc height loss occurred 6 months postoperatively and in the next 6 months, there was still a small decrease in disc height. The posterior instrumentation can decrease segmental range of motion and increased segmental stiffness. Cappuccino et al.’s biomechanical analysis showed that bilateral pedicle screw–supplemented constructs demonstrated greater reduction in range of motion than lateral plate. For patients with osteopenia or osteoporosis, segmental stability is of great importance to the promotion for fusion. Compared with bilateral pedicle screw–supplemented constructs, lateral plate can only provide unilateral stiffness and less resistance to rotation, which could be detrimental to spinal stability and intervertebral fusion progress.

**Interbody Fusion Degree.** Among patients who underwent lumbar fusion, osteopenia or osteoporosis may lead to poor prognosis, pseudoarthrosis and other complications related to fusion. After lumbar fusion, bone resorption, formation and remodeling would begin at the bone graft area to form a sturdy and reliable bone fusion. The metabolic imbalance in osteopenia or osteoporosis is adverse to the formation of bone fusion. In our study, the interbody fusion degree of BPS patients was significantly higher than lateral fixation patients. At 1-year follow-up, reports about the fusion rate of XLIF ranged from 85% to 93%. Malham et al. reported fusion rate of 46% at 6 months, 58% at 9 months and 85% at 12 months. Aiming to improve the fusion rate in our surgery, we used bone paste to promote bone growth. In Gao et al.’s study, the rhBMP-2 combined with allogenic bone and autologous bone marrow combined with allogenic bone showed better fusion rate than allogenic bone, and combination use of bone graft material showed good clinical and fusion results in XLIF. Although autogenous bone graft, the gold standard, is still recommended for bone defect repair, the acquisition of iliac bone grafts may lead to chronic donor site pain, infection, fracture and hematoma. Therefore, we recommend the use of bone substitutes instead of autologous bone in surgery.

**Cage Subsidence.** Intervertebral disc degeneration and osteopenia are associated with cartilage endplate damage, and the coxeness of which can induce more serious destruction to the endplate. Cage subsidence would decrease the disc height, reduce indirect decompression effect of neural foramen, increase sagittal dislocation and the disorder of adjacent segments. In our study, the cage subsidence degree in BPS group was significantly better than that in lateral fixation group. The occurrence of subsidence is closely related to bone mineral density, the choice of internal fixation instruments and implants. There was a strong correlation of stability of screw fixation and cancellous bone density, which is most affected by osteopenia. Pisano et al.’s study showed that patients with low bone density were more likely to suffer subsidence after lumbar surgery and if the cage height was more than 1.3 mm higher than the intervertebral space, the possibility of cage subsidence would be greater. Luís’s study showed that wider cages can lead to lower cage subsidence incidence and more effective segmental lordosis improvement in XLIF. The wide implants can span the apophyssial ring, which can effectively resist subsidence under compressive loads. In addition, some experts hold the view that the fusion rate and clinical outcomes at the final follow-up would not be influenced by subsidence shown in radiographic test, which is still controversial and needed to be further studied.

**Spinal Curvature**

*Curvature Recovery.* Secondary to disc space asymmetry and collapse, sagittal and coronal deformities usually occur in the degenerative spine, which often leads to kyphosis, low back pain, and injury of the nervous system due to reduced foraminal height. The XLIF showed no damage to the adjacent tissue such as anterior and posterior longitudinal ligament, lamina and facet joints, which is beneficial to the preservation of local stability. In our study, the BPS group showed significantly better SL angle improvement rate and SL angle loss ratio than lateral fixation group. Compared with lateral fixation, posterior pedicle screw combined with rod has stronger orthopedic ability and better biomechanical support, which is particularly important in elderly patients with osteopenia or osteoporosis. Inconsistent with our study, Sharma et al.’s study showed that there was a mean correction of 1.5 degrees in SL angle in the posterior and lateral fixation method. The reason why we had better orthopedic effect may be due to that we selected larger cages in operation, and posterior pedicle screw fixation was more advantageous for maintaining intervertebral space stability. In our experiment, at 3 months after operation, the SL and LL angle of all groups significantly improved. However, the loss ratio of SL and LL angle in the LS and LP groups was significantly higher than in the BPS group.

**Recovery of Neural Function**

The VAS of leg pain and JOA score improved significantly after operation in all groups and no difference was identified among the three groups at all time points, which showed the good effect of XLIF operation on nerve decompression. Consistent with our research, Pojskic et al.’s experiment showed that the VAS improved after XLIF, which dropped from 8.8 to 2.8. In Chen’s research, the JOA score increased from 12 to 18.9, showing the same trend as our report. It can be seen that XLIF is an effective operation for the treatment of lumbar degenerative diseases.
Surgery Related Factors
The length of operation needs to be minimized for elderly patients with complex diseases and relative contraindications of operation. In Lamartina et al.’s study, the intraoperative blood loss was 105 ml, which was similar to our result. In Mu’s research, the average operation time ranged from 51 to 160, which was close to the results in our study. For the operation period, because of the need to change the posture during operation, the operation time in the posterior internal fixation group was significantly longer than that in the lateral internal fixation group. Moreover, due to the back incisions, the posterior fixation group showed worse blood loss compared with lateral fixation group, which could not be avoided. However, considering that the stability of the intervertebral disc is related to the success or failure of the operation and prognostic efficacy, we believe that the appropriate extension of the operation time and the increase of intraoperative blood loss are acceptable.

Complications
It is generally believed that elderly patients would be more likely to suffer postoperative complications after conventional lumbar arthrodesis. Among all patients in this study, the incidence of thigh sensory complaint was 7.14%, the incidence of hip flexor weakness was 1.7%, and the incidence of thigh pain was 1.7%, which were lower than the previous studies. And no significant difference was observed in the incidence of complications among the groups. All the patients recovered from complications within 1 month. Lumbar plexus injury is a serious complication, which should be paid enough attention during surgery. Therefore, for beginners, we recommend using intraoperative EMG monitoring, which can effectively avoid nerve injury.

Limitations
There are some limitations in this study. First, the follow-up time in this study, which is more than 1 year, was relatively short, but we think that 1 year is long enough for patients to recover, at which time all the patients should obtain complete interbody fusion after surgery. However, a prospective study with larger sample size and longer term follow up should be conducted in the future. Second, the details of fusion procedure were mostly based on the operating surgeon, thus leading to the likelihood of bias, although all surgery was by the same surgeon. Third, the cages we used in the surgery came from different device manufacturers, which may bring about bias. In addition to avoid that, we carefully selected the peek cage with the same length-width-height ratio, which insured that the difference of cage wound not affect the final results. As for the advantages, our experiments can help doctors to select appropriate instruments for treatment to a certain extent, and contribute to the long-term stability of the patient’s spine.

Conclusion
For lumbar diseases patients with osteopenia or osteoporosis, the posterior bilateral pedicle screw fixation can promote intervertebral fusion, correct and maintain the spinal curve in the long-term follow-up, and effectively alleviate the neurological symptoms of patients, which shows that bilateral pedicle screw fixation is a better choice in XLIF surgery.

As for the future research in this field, the long-term effects of different fixation methods combined with different anti-osteopenia drugs to explore better treatment methods for patients with osteopenia and degenerative lumbar disease can be explored.

Acknowledgments
I would like to thank the medical imaging department of our hospital for their support in image analysis.

Author Contributions
Xianzheng Wang: acquisition of data, writing manuscript. Huan Liu, Weijian Wang, Fei Zhang, Lei Guo, Jiaqi Li, Yapeng Sun: analysis and interpretation of data. Wei Zhang: substantial contribution in design and conception of the study. All authors read and approved the final manuscript.

Ethical Approval
This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study protocol was approved by the Ethics Committee of The Third Hospital of Hebei Medical University (Hebei, China).

References
1. Li R, Li X, Zhou H, Jiang W. Development and application of oblique lumbar interbody fusion. Orthop Surg. 2020;12(2):355–65.
2. Quante M, Halm H. Extreme lateral interbody fusion. Indication, surgical technique, outcomes and specific complications. Der Orthopadie. 2015;44(2):138–45.
3. Wang TY, Nayar G, Brown CR, Pimenta L, Karikari IO, Isaacs RE. Bony lateral recess stenosis and other radiographic predictors of failed indirect decompression via extreme lateral interbody fusion: multi-institutional analysis of 101 consecutive spinal levels. World Neurosurg. 2017;106:819–26.
4. Aspray TJ, Hill TR. Osteoporosis and the ageing skeleton. Subcell Biochem. 2019;91:453–76.
5. Ehresman J, Ahmed AK, Lubelski D, et al. Vertebral bone quality score and postoperative lumbar lordosis associated with need for reoperation after lumbar fusion. World Neurosurg. 2020;140:e247–e52.
6. Soldozy S, Montgomery SR Jr, Sarathy D, et al. Diagnostic, surgical, and technical considerations for lumbar interbody fusion in patients with osteopenia and osteoporosis: a systematic review. Brain Sci. 2021;11(2):241. doi: 10.3390/brainsci11020241.
7. Hiyama A, Kato H, Sakai D, Tanaka M, Sato M, Watanabe M. Facet joint violation after single-position versus dual-position lateral interbody fusion and percutaneous pedicle screw fixation: a comparison of two techniques. J Clin Neurosci. 2020;78:47–52.
8. Li XH, She LJ, Zhang W, Cheng XD, Fan JP. Biomechanics of extreme lateral interbody fusion with different internal fixation methods: a finite element analysis. BMC Musculoskelet Disord. 2022;23(1):134.
9. Khalid SI, Nuna RS, Maasarani S, et al. Association of osteopenia and osteoporosis with higher rates of pseudarthrosis and revision surgery in adult patients undergoing single-level lumbar fusion. Neurosurg Focus. 2020;49(2):E6.
10. Phillips FM, Isaacs RE, Rodgers WB, et al. Adult degenerative scoliosis treated with XLIF: clinical and radiographical results of a prospective multicenter study with 24-month follow-up. Spine. 2013;38(21):E533-E61.
11. Marchi L, Abdala N, Oliveira L, Amaral R, Coutinho E, Pimenta L. Radiographic and clinical evaluation of cage subsidence after stand-alone lateral interbody fusion. J Neurosurg Spine. 2013;19(1):110–8.
12. Slucky AV, Brodie DS, Bachus KN, Droge JA, Braun JT. Less invasive posterior fixation method following transfornaminal lumbar interbody fusion: a biomechanical analysis. Spine J. 2009;9(1):78–85.
13. Cappuccino A, Cornwall GB, Turner AW, et al. Biomechanical analysis and review of lateral lumbar fusion constructs. Spine. 2010;35(26 Suppl):S361–7.
14. Hou Y, Yuan W. Influences of disc degeneration and bone mineral density on the structural properties of lumbar end plates. Spine J. 2012;12(3):249–56.
15. Berjano P, Langella F, Damilano M, et al. Fusion rate following extreme lateral lumbar interbody fusion. Eur Spine J. 2013;22(3):S369–71.
16. Malham GM, Ellis NJ, Parker RM, Seex KA. Clinical outcome and fusion rates after the first 30 extreme lateral interbody fusions. TheScientificWorldJOURNAL. 2012;2012:246989.
17. Gao Y, Li J, Cui H, et al. Comparison of intervertebral fusion rates of different bone graft materials in extreme lateral interbody fusion. Medicine. 2019;98(44):e17685.
18. Pimenta L, Marchi L, Oliveira L, Coutinho E, Amaral R. A prospective, randomized, controlled trial comparing radiographic and clinical outcomes between stand-alone lateral interbody fusion with either silicate calcium phosphate or rh-BMP2. J Neurolog Surg A, Centr Eur Neurosurg. 2013;74(6):343–50.
19. Wang L, Cui W, Kalaia JP, Hoof TV, Liu BG. To investigate the effect of osteoporosis and intervertebral disc degeneration on the endplate cartilage injury in rats. Asian Pac J Trop Med. 2014;7(10):796–800.
20. Gilbert SG, Johns PC, Chow DC, Black RC. Relation of vertebral bone screw axial pullout strength to quantitative computed tomographic trabecular bone mineral content. J Spinal Disord. 1993;6(6):513–21.
21. Pisano AJ, Fredericks DR, Steelman T, Riccio C, Helgeson MD, Wagner SC. Lumbar disc height and vertebral Hounsfield units: association with interbody cage subsidence. Neurosurg Focus. 2020;49(2):E9.
22. Sohn MJ, Kayanja MM, Kilinčer C, Ferrara LA, Benzyl EC. Biomechanical evaluation of the ventral and lateral surface shear strain distributions in central compared with dorsolateral placement of cages for lumbar interbody fusion. J Neurosurg Spine. 2006;4(3):219–24.
23. Tokuhashi Y, Ajiro Y, Umezawa N. Subsidence of metal interbody cage after posterior lumbar interbody fusion with pedicle screw fixation. Orthopedics. 2009;32(4):261–7.
24. Wong E, Altay F, Oh LJ, Gray RJ. Adult degenerative lumbar scoliosis. Orthopedics. 2017;40(6):e930–e9.
25. Sharma AK, Kepler CK, Girardi FP, Cammisa FP, Huang RC, Sama AA. Lateral lumbar interbody fusion: clinical and radiographic outcomes at 1 year: a preliminary report. J Spinal Disord Tech. 2011;24(4):242–50.
26. Pojskic M, Saij B, Völger B, Nimsky C, Carl B. Extreme lateral interbody fusion (XLIF) in a consecutive series of 72 patients. Bosn J Basic Med Sci. 2021;21(5):587–97.
27. Chen E, Xu J, Yang S, Zhang Q, Yi H, Liang D, et al. Cage subsidence and fusion rate in extreme lateral Interbody fusion with and without fixation. World Neurosurg. 2019;122:e969–e77.
28. Lamartina C, Berjano P. Prone single-position extreme lateral interbody fusion (pro-XLIF): preliminary results. Eur Spine J. 2020;29(Suppl 1):6–13.
29. Mu X, Yu C, Wang C, Ou Y, Wei J, He Z. Comparison of extreme lateral approach with posterior approach in the treatment of lumbar degenerative diseases: a meta-analysis of clinical and imaging findings. Surgeon. 2021;19(5):268–78.
30. Lee DG, Park CK, Lee DC. Clinical and radiological comparison of 2 level anterior lumbar interbody fusion with posterolateral fusion and percutaneous pedicle screw in elderly patients with osteoporosis. Medicine. 2020;99(10):e19205.
31. Epstein NE. Extreme lateral lumbar interbody fusion: do the cons outweigh the pros? Surg Neurol Int. 2016;7(Suppl 25):S692–S700.
32. Epstein NE. High neurological complication rates for extreme lateral lumbar interbody fusion and related techniques: a review of safety concerns. Surg Neurol Int. 2016;7(Suppl 25):S652–s5.
33. Khajavi K, Shen A, Lagina M, Hutchison A. Comparison of clinical outcomes following minimally invasive lateral interbody fusion stratified by preoperative diagnosis. Eur Spine J. 2015;24(Suppl 3):322–30.