

Original Article

Comparison of short- and long-term efficacy between percutaneous and open pedicle screw fixation for thoracolumbar vertebral fracture

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Abstract: Objective: To compare the short-term and long-term efficacy of percutaneous pedicle screw fixation (PPSF) and open pedicle screw fixation (OPSF) in treating thoracolumbar vertebral fracture (TVF). Methods: We performed a retrospective cohort analysis of 158 patients with TVF. Patients were categorized into PPSF (n = 86) and OPSF (n = 72) groups based on the surgical procedure. Perioperative parameters, wound healing, functional outcomes (Visual Analogue Scale [VAS] and Oswestry Disability Index [ODI]), radiological parameters (percentage of anterior vertebral body height [PAVBH] and Cobb angle), and complications were collected at 7 days, 6 months, and 12 months postoperatively. Statistical analysis included independent t-tests, repeated measures ANOVA for longitudinal data, and multivariate linear regression analysis to identify independent predictors of long-term outcomes. Results: The PPSF group demonstrated superior perioperative outcomes, including shorter operative time (P = 0.008), less blood loss, shorter hospital stay, and faster wound healing (all P < 0.001). Repeated-measures ANOVA revealed significant group-by-time interactions for VAS, ODI, PAVBH, and Cobb angle (all P < 0.01). The PPSF group consistently showed better pain control and functional recovery from 6 months onwards, and superior early radiological correction. During the 12-month follow-up, despite radiological outcomes were comparable, the PPSF group maintained significantly lower VAS and ODI scores (both P < 0.001). Multivariate regression analysis confirmed PPSF as an independent factor associated with better 12-month ODI ($\beta = -5.19$, P < 0.001) and VAS scores ($\beta = -0.56$, P < 0.001). The overall complication rate was significantly lower in the PPSF group (P = 0.028). Conclusion: PPSF can reduce surgical trauma, promote faster recovery, and improve functional outcomes in patients with TVF, suggesting it as a promising alternative to OPSF. Further studies are needed to confirm these findings and assess long-term efficacy.

Keywords: Thoracolumbar vertebral fracture, percutaneous pedicle screw fixation, open pedicle screw fixation, efficacy

Introduction

Thoracolumbar vertebral fracture (TVF) refers to a common injury, especially in spinal surgery [1]. This injury usually is caused by high-energy trauma (e.g., traffic accidents, falls, etc.) or osteoporotic fractures. Due to their unique anatomical location, TVFs are often accompanied by spinal cord or nerve root injuries, severely impacting patients' quality of life and potentially leading to permanent disability [2]. With the accelerating aging of the population and the

continued existence of high-risk work activities, the incidence of TVF has been increasing year by year [3, 4]. As a result, how to choose a safe and effective treatment plan has become an important research topic in the field of spinal surgery.

Pedicle screw fixation is a classic surgical procedure for treating TVF, used to reduce and stabilize the fractured segment. The screws are implanted into the pedicle through a constructive rod system, which provides stable fixation

The treatment of thoracolumbar vertebral fracture

and creates favorable conditions for fracture healing [5]. Traditional open pedicle screw fixation (OPSF) has a long history of clinical application due to its visualization advantages, allowing for full exposure of the fracture site and precise fracture reduction [6, 7]. However, OPSF requires extensive dissection of paraspinal muscles and incision of deep tissues, resulting in severe postoperative pain, muscle dysfunction, and prolonged recovery time [8]. Postoperative wound infection and loosening of internal fixation may also affect patient rehabilitation [9]. With the continuous development of minimally invasive spinal surgery techniques, percutaneous pedicle screw fixation (PPSF) has emerged as a new method for TVF in recent years [10]. Guided by imaging technology, PPSF inserts pedicle screws percutaneously through a small incision, avoiding extensive dissection of paraspinal muscles, and has many advantages such as less trauma, bleeding, and postoperative pain [11]. Theoretically, minimally invasive surgery has a protective effect on musculoskeletal structures, enabling patients to achieve better mid- to long-term functional recovery. However, PPSF also has some disadvantages, including high surgical skill requirements, increased intraoperative radiation dose, screw positioning accuracy depending on the surgeon's skill level, and its long-term clinical efficacy still needs to be explored in the clinical settings [12].

Currently, most comparative studies on PPSF and OPSF focus on short-term efficacy, such as operation time, blood loss, and postoperative pain scores. Reports on medium- and long-term efficacy are scarce, as are studies systematically analyzing the dynamic changes in radiological parameters (including percentage of anterior vertebral body height [PAVBH] and Cobb angle) and functional outcomes at multiple follow-up time points (7 days, 6 months, and 12 months). Moreover, existing research rarely elucidates the correlation between the minimally invasive advantages of PPSF and long-term muscle function preservation, a crucial factor for guiding clinical rehabilitation strategies. Therefore, this study aims to comprehensively assess the short- and long-term efficacy of PPSF and OPSF in treating TVF through a survey, providing clinicians with a reference for selecting surgical treatment options for TVF, further optimizing clinical treatment

strategies, and improving patients' treatment outcomes and quality of life.

Materials

Case selection

This study was approved by the Ethics Committee of Shuguang Hospital Affiliated to Shanghai University of Traditional Chinese Medicine. A retrospective cohort study design was used, consecutively including 158 patients with TVF who underwent surgery at Shuguang Hospital Affiliated to Shanghai University of Traditional Chinese Medicine from March 2022 to March 2024. Patients were divided into PPSF and OPSF groups according to different surgical procedures.

Inclusion and exclusion criteria

Inclusion criteria: (1) age ≥ 18 years, gender not limited; (2) new fracture (injury time < 2 weeks); (3) single-segment thoracolumbar fracture (T11-L2) confirmed by clinical imaging examination; (4) patients with type A fractures in the AO classification [13]; (5) spinal canal occupancy rate $< 50\%$ and no obvious neurological function damage; (6) bone mineral density (BMD) T-value > -2.5 (assessed by dual-energy X-ray absorptiometry, i.e., DXA), to exclude obvious osteoporosis; (7) patients with complete clinical data and follow-up records.

Exclusion criteria: (1) multi-segment fractures or combined with injuries to other parts of the spine; (2) pathological fractures; (3) old fractures (injury time > 3 weeks); (4) combined with other spinal deformities (e.g., scoliosis $> 15^\circ$, kyphosis $> 30^\circ$) or a history of previous spinal surgery; (5) severe osteoporosis (bone mineral density T-value ≤ -2.5) or metabolic bone disease; and (6) combined with neurological dysfunction.

Sample size calculation

Sample size was calculated based on the primary outcome measure, the Oswestry Disability Index (ODI) score at 12 months post-surgery. Previous literature indicated that the expected effect size of ODI improvement between groups was 12% [14]. Using G*Power 3.1 software, a significance level (α) of 0.05 (two-tailed) and a statistical power ($1-\beta$) of 0.80 were set, deter-

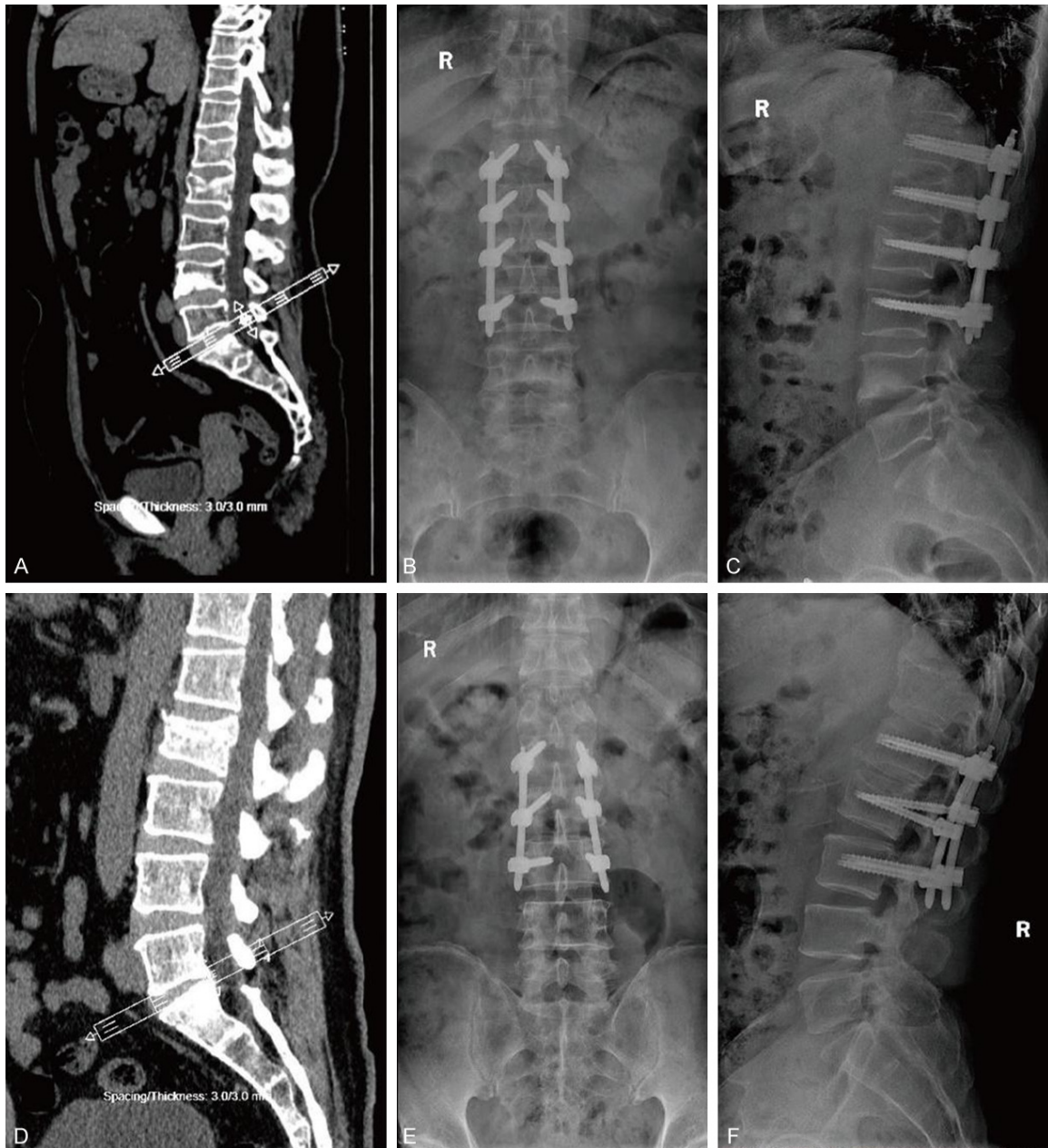


Figure 1. Schematic of PPSF and OPSF surgery. A-C. PPSF surgery; D-F. OPSF surgery. Abbreviations: PPSF, percutaneous pedicle screw fixation; OPSF, open pedicle screw fixation.

mining the minimum required sample size for each group to be 64 patients. Considering a possible 10% loss to follow-up, the final sample size was adjusted to 72 patients in the OPSF group and 86 patients in the PPSF group, totaling 158 patients, meeting the statistical requirements of this study.

Surgical procedures

Surgical diagrams for PPSF and OPSF are shown in **Figure 1**.

OPSF group: Under general anesthesia, the patient was placed in a prone position. A posterior midline incision, approximately 8-12 cm long, was made centered on the fractured vertebra. The skin, subcutaneous tissue, and deep fascia were incised sequentially. The paraspinous muscles were dissected bilaterally along the spinous process to expose the fractured vertebra and the laminae, articular processes, and transverse processes of the adjacent vertebrae. The “V-shaped ridge” positioning method was used to determine the entry point for

The treatment of thoracolumbar vertebral fracture

the pedicle screws. After opening the access channel with a guide wire, the four walls were probed to confirm the correct position, and then the appropriately sized pedicle screws (length and diameter) are inserted. Connecting rods are then installed, and the vertebral height and physiological curvature of the spine were restored through dilation and reduction procedures. The surgical field is thoroughly irrigated, a drainage tube was placed, and the incision was closed layer by layer.

PPSF group: Under general anesthesia, the patient was placed in a prone position. Under fluoroscopic guidance, the pedicles of the fractured vertebral body and the surface projections of adjacent vertebral bodies and pedicles were marked on the skin. A 1.5-2 cm longitudinal incision was made at each marked point. Subcutaneous tissue and muscle were bluntly dissected, and a guidewire was inserted. After confirming the accurate position of the guidewire under fluoroscopy, an expandable cannula was gradually inserted along the guidewire. After tapping the wire, the pedicle screw was implanted. Subsequently, a connecting rod was placed through the percutaneous incision, and percutaneous dilation and reduction were performed to adjust the spinal alignment. Finally, the expandable cannula was removed, the incision was sutured, and no drainage tube was required.

Data collection

Baseline data: Demographic information (age, gender, body mass index [BMI]) and fracture-related characteristics (cause of injury, fracture segment, AO classification) were extracted from the electronic medical record at admission.

Intraoperative and perioperative data: Operation time (from skin incision to suturing completion), intraoperative blood loss (quantified by suction and gauze weighing), drainage volume in the 24 hours postoperatively, bed rest time (from surgery to first ambulation), and total hospital stay (from admission to discharge) were recorded.

Postoperative follow-up data: All patients were followed up at 7 days, 6 months, and 12 months postoperatively. Pain was assessed using the Visual Analogue Scale (VAS, range 0-10, with

higher scores indicating more severe pain) [15]. Functional recovery was evaluated using the validated Chinese version of the ODI questionnaire. The ODI consists of 10 sections (pain intensity, personal care, lifting, walking, sitting, standing, sleep, sexual activity, social life, and travel), with each section scored from 0 to 5. The total score was calculated by summing the scores of all the answer sections, dividing by the possible total score (up to 50 points if all sections were answered), and multiplying by 100 to get the percentage (range 0-100%). The higher the score, the more severe the functional impairment [16]. Radiological parameters were measured by two independent radiologists using standard thoracolumbar standing lateral radiographs. The Cobb angle was measured as the angle between the line drawn along the superior endplate of the vertebra above the fracture and the line drawn along the inferior endplate of the vertebra below the fracture. The percentage of anterior vertebral body height (PAVBH) was calculated as (anterior vertebral body height of the fractured vertebra/average anterior vertebral body height of the adjacent normal vertebrae above and below) × 100%. Adverse events were documented throughout the follow-up period. Screw loosening was assessed by imaging (radioactive band around the screw ≥ 1 mm). Nerve injury was identified by neurological examination or new/worsening nerve root symptoms reported by the patient. Paraspinal muscle injury was identified by clinically persistent localized pain and/or, if necessary, muscle edema/atrophy shown on MRI.

Statistical analysis

All data were analyzed using SPSS 27.0 software (IBM, Armonk, NY, USA). Normally distributed quantitative variables (assessed using the Kolmogorov-Smirnov test) were expressed as mean \pm standard deviation (SD), and independent samples t-tests were used for comparisons between the groups. Categorical variables were expressed as frequencies (percentages), and chi-square tests or Fisher's exact test (when the expected cell frequency < 5) were used for comparisons. Repeated measures ANOVA was used to assess the dynamic changes in VAS score, ODI score, PAVBH, and Cobb angles at multiple time points (preoperative, 7 days postoperative, 6 months postoperative,

The treatment of thoracolumbar vertebral fracture

Table 1. Comparison of general information of the two groups

Variables	Total (n = 158)	PPSF group (n = 86)	OPSF group (n = 72)	Statistic	P
Age, Mean ± SD	48.29 ± 10.40	48.67 ± 10.23	47.83 ± 10.66	t = 0.50	0.614
Gender, n (%)				$\chi^2 = 0.03$	0.862
Female	56 (35.44)	31 (36.05)	25 (34.72)		
Male	102 (64.56)	55 (63.95)	47 (65.28)		
BMI, Mean ± SD	23.37 ± 2.87	23.20 ± 2.83	23.57 ± 2.92	t = -0.83	0.409
Cause of injury, n (%)				$\chi^2 = 1.76$	0.623
Traffic accident	69 (43.67)	38 (44.19)	31 (43.06)		
Crush injury	36 (22.78)	22 (25.58)	14 (19.44)		
Fall	28 (17.72)	15 (17.44)	13 (18.06)		
Others	25 (15.82)	11 (12.79)	14 (19.44)		
fracture segment, n (%)				$\chi^2 = 0.18$	0.981
T11	33 (20.89)	18 (20.93)	15 (20.83)		
T12	42 (26.58)	22 (25.58)	20 (27.78)		
L1	44 (27.85)	25 (29.07)	19 (26.39)		
L2	39 (24.68)	21 (24.42)	18 (25.00)		

Abbreviations: PPSF, percutaneous pedicle screw fixation; OPSF, open pedicle screw fixation; SD, standard deviation; BMI, body mass index.

and 12 months postoperative). The sphericity assumption of repeated measures ANOVA was verified using the Mauchly test of sphericity; if the assumption was not met, Greenhouse-Geisser correction was used. If the interaction effect was statistically significant, pairwise comparisons between groups at each time point were performed using the LSD post-hoc test. Linear regression analysis was performed using VAS and ODI scores at 12 months as dependent variables, surgical procedure as independent variable, and age, gender, and BMI as confounding variables requiring adjustment. Unadjusted and adjusted models were constructed to assess the independent effect of surgical procedure on long-term functional outcomes. All tests were two-tailed, and $P < 0.05$ was considered statistically significant.

Results

General information

No significant differences were found in terms of age, gender BMI, cause of injury, or fracture segment (all $P > 0.05$), ensuring comparability between the two groups (**Table 1**).

Perioperative parameters

The intraoperative and early postoperative outcomes are presented in **Table 2**. Compared

with the OPSF group, the PPSF group exhibited a significantly shorter operation time ($P = 0.008$). Consistent with the minimally invasive nature of this procedure, the PPSF group also demonstrated markedly reduced intraoperative blood loss and postoperative 24-hour drainage volume (both $P < 0.001$). Patients in the PPSF group recovered more quickly, as evidenced by shorter bed rest time ($P = 0.022$) and total hospital stay ($P < 0.001$). Regarding technical accuracy, the screw placement accuracy rates were high and comparable in both groups (PPSF group: 96.12% vs. OPSF group: 94.43%, $P = 0.301$).

Short-term wound and fracture healing

Short-term recovery assessment included wound healing and radiographic fracture healing (**Figure 2**). The incision healing time in the PPSF group was significantly shorter than that in the OPSF group ($P < 0.001$). In contrast, there was no significant difference in radiographic fracture healing time between the two surgical procedures ($P = 0.175$).

Trajectory of postoperative pain and functional recovery

Repeated measures ANOVA was used to analyze the dynamic changes in pain and functional impairment scores at all follow-up time

The treatment of thoracolumbar vertebral fracture

Table 2. Comparison of surgical conditions

Variables	Total (n = 158)	PPSF group (n = 86)	OPSF group (n = 72)	Statistic	P
Operative time, min, Mean ± SD	56.98 ± 12.30	54.63 ± 12.48	59.77 ± 11.54	t = -2.67	0.008
Intraoperative blood loss, mL, Mean ± SD	88.73 ± 34.40	68.94 ± 18.41	112.35 ± 34.21	t = -9.66	< 0.001
Postoperative 24-hour drainage volume, mL, Mean ± SD	20.45 ± 8.10	16.39 ± 6.27	25.32 ± 7.33	t = -8.25	< 0.001
Bed rest duration, Mean ± SD	5.59 ± 1.30	5.37 ± 1.26	5.85 ± 1.32	t = -2.32	0.022
Hospital stay, Mean ± SD	10.32 ± 3.05	9.48 ± 2.59	11.32 ± 3.25	t = -3.88	< 0.001
Accuracy rate of screw insertion, %	95.35	96.12	94.43	$\chi^2 = 1.07$	0.301

Abbreviations: PPSF, percutaneous pedicle screw fixation; OPSF, open pedicle screw fixation; SD, standard deviation.

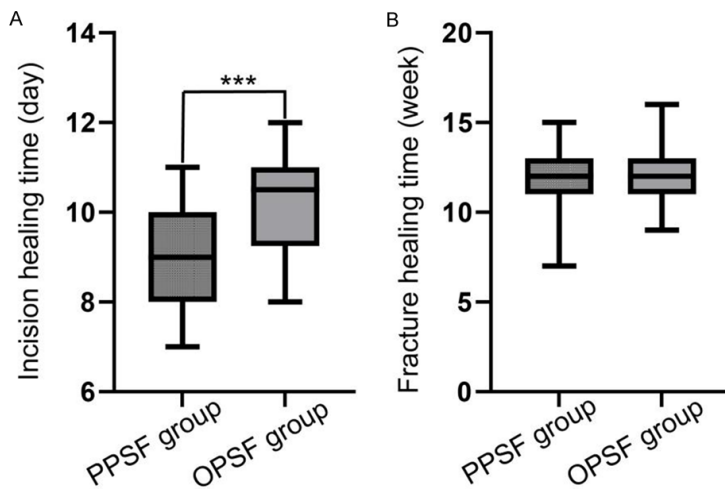


Figure 2. Patient's short-term recovery status. A. Incision healing time; B. Fracture healing time. Abbreviations: PPSF, percutaneous pedicle screw fixation; OPSF, open pedicle screw fixation.

points. Details are shown in **Tables 3** and **4**. For pain intensity measured by the VAS, significant main effects of time ($P < 0.001$), between-group ($P < 0.001$), and a significant interaction effect between time and between-group ($P < 0.001$) were observed. Post-hoc analysis revealed that while VAS scores were comparable between the two groups at 7 days post-operation, the PPSF group exhibited significantly lower scores at 6 months ($P < 0.01$) and 12 months ($P < 0.001$). Similarly, analysis of the ODI scores showed significant main effects of time and between-group, as well as a significant interaction effect ($P < 0.001$). The PPSF group demonstrated superior functional recovery, with significantly lower ODI scores than the OPSF group at 7 days ($P < 0.05$), 6 months ($P < 0.001$), and 12 months ($P < 0.001$).

Radiographic outcomes trajectory

The recovery of spinal alignment and vertebral height was assessed using Cobb angle

and PAVBH. Repeated measures ANOVA results are shown in **Tables 5** and **6**. For PAVBH, there were significant main effects over time and between groups, as well as a significant interaction effect ($P < 0.01$). Post-hoc comparisons indicated that the PPSF group achieved a significantly better vertebral height recovery at 7 days ($P < 0.001$) and 6 months ($P < 0.05$) follow-up. However, at the 12-month assessment, PAVBH was comparable between the two groups ($P > 0.05$). Cobb angle correction also showed significant main and interaction effects ($P < 0.01$). The PPSF group demonstrated a superior early correction at 7

days post-operation ($P < 0.001$), but there were no statistically significant differences between the groups at the 6-month and 12-month assessments (both $P > 0.05$).

Regression analysis of the impact of surgical procedures on key outcomes

Table 7 shows the results of unadjusted and adjusted linear regression analyses with surgical procedure as the independent variable and 12-month VAS and ODI scores as dependent variables. In the unadjusted model, surgical procedure was significantly associated with 12-month ODI scores (regression coefficient = -5.18, 95% CI: -6.23 to -4.13, $P < 0.001$) and 12-month VAS scores (regression coefficient = -0.58, 95% CI: -0.76 to -0.39, $P < 0.001$). After adjusting for confounding factors including age, gender, and BMI, the surgical method remained an independent influencing factor for both the 12-month ODI score (regression coefficient = -5.19, 95% CI: -6.25 to -4.13, $P < 0.001$, $R^2 =$

The treatment of thoracolumbar vertebral fracture

Table 3. Trajectory of VAS scores in patients undergoing different surgical procedures

Group	n	VAS			
		Pre-operation	7 days	6 months	12 months
PPSF group	86	8.17 ± 0.38	5.27 ± 0.82	3.29 ± 0.70**	2.31 ± 0.54***
OPSF group	72	8.12 ± 0.33	5.46 ± 0.87	3.61 ± 0.72	2.89 ± 0.62
F value		F-group = 26.36, F-time = 4263.60, F-interaction = 11.45			
P value		P-group < 0.001, P-time < 0.001, P-interaction < 0.001			

***Compared with the OPSF group, P < 0.001. Mauchly W = 0.749, P < 0.001. **Compared with the OPSF group, P < 0.01. Abbreviations: PPSF, percutaneous pedicle screw fixation; OPSF, open pedicle screw fixation; VAS, visual analog score.

Table 4. Trajectory of ODI scores in patients undergoing different surgical procedures

Group	n	ODI			
		Pre-operation	7 days	6 months	12 months
PPSF group	86	63.24 ± 5.26	55.43 ± 4.88*	27.35 ± 4.13***	16.34 ± 3.13***
OPSF group	72	62.81 ± 5.38	57.26 ± 5.04	31.51 ± 4.25	21.51 ± 3.55
F value		F-group = 54.03, F-time = 4315.58, F-interaction = 13.66			
P value		P-group < 0.001, P-time < 0.001, P-interaction < 0.001			

***Compared with the OPSF group, P < 0.001. Mauchly W = 0.844, P < 0.001. *Compared with the OPSF group, P < 0.05. Abbreviations: PPSF, percutaneous pedicle screw fixation; OPSF, open pedicle screw fixation; VAS, visual analog score; ODI, Oswestry Disability Index.

Table 5. Trajectory of PAVBH in patients undergoing different surgical procedures

Group	n	PAVBH			
		Pre-operation	7 days	6 months	12 months
PPSF group	86	57.39 ± 11.53	72.31 ± 7.37***	81.75 ± 8.16*	90.95 ± 7.14
OPSF group	72	58.16 ± 11.71	65.55 ± 7.25	78.84 ± 8.83	89.33 ± 7.65
F value		F-group = 1082.28, F-time = 364.28, F-interaction = 5.26			
P value		P-group < 0.001, P-time < 0.001, P-interaction = 0.002			

***Compared with the OPSF group, P < 0.001. Mauchly W = 0.811, P < 0.001. *Compared with the OPSF group, P < 0.05. Abbreviations: PPSF, percutaneous pedicle screw fixation; OPSF, open pedicle screw fixation; VAS, visual analog score; PAVBH, percentage of anterior vertebral body height.

0.382) and the 12-month VAS score (regression coefficient = -0.56, 95% CI: -0.74 to -0.38, P < 0.001, R² = 0.221).

Postoperative adverse reactions

The overall incidence of adverse reactions in the PPSF group was 5.81%, significantly lower than 16.67% in the OPSF group ($\chi^2 = 4.81$, P = 0.028) (Table 8). Specifically, in the PPSF group, only 3 cases of infection, 1 case of nerve injury and 1 case of paraspinal muscle injury occurred, with no screw loosening; while in the OPSF group, in addition to 6 cases of infection, 2 cases of nerve injury and 2 cases of paravertebral paraspinal muscle injury, there were also 2 cases of screw loosening. This indicates that the PPSF group has a greater advantage in postoperative safety.

Discussion

As a common type of trauma in spinal surgery, the choice of treatment plan for TVF has always been the focus of clinical research [17]. This study compared the short-term and long-term follow-up data of 158 patients with thoracolumbar fracture and found that the PPSF group was significantly better than the OPSF group in terms of surgical trauma indicators (operation time, intraoperative blood loss, drainage volume in 24 hours after surgery), postoperative recovery efficiency (bed rest time, hospital stay, incision healing time) and functional improvement (VAS, ODI scores), and the PPSF group also had a significantly lower incidence of adverse reactions. In terms of technical indicators, the screw placement accuracy of the PPSF group was comparable to that of the OPSF

The treatment of thoracolumbar vertebral fracture

Table 6. Trajectory of Cobb angle in patients undergoing different surgical procedures

Group	n	Cobb			
		Pre-operation	7 days	6 months	12 months
PPSF group	86	21.43 ± 5.26	14.23 ± 4.15***	10.57 ± 3.72	7.15 ± 3.08
OPSF group	72	20.96 ± 5.55	17.52 ± 4.48	11.62 ± 3.95	7.42 ± 3.17
F value		F-group = 168.73, F-time = 364.85, F-interaction = 4.65			
P value		P-group < 0.001, P-time < 0.001, P-interaction = 0.004			

***Compared with the OPSF group, $P < 0.001$. Mauchly $W = 0.834$, $P < 0.001$. Abbreviations: PPSF, percutaneous pedicle screw fixation; OPSF, open pedicle screw fixation; VAS, visual analog score.

Table 7. Linear regression analysis: The impact of surgical methods on the main outcome indicators

Outcome indicators	Model	Regression coefficient	95% CI	P value	R ²
ODI score 12 months after surgery	Model 1 (Unadjusted)	-5.18	-6.23 - -4.13	0.0000	0.378
	Model 2 (Adjusted ^a)	-5.19	-6.25 - -4.13	0.0000	0.382
VAS score 12 months after surgery	Model 1 (Unadjusted)	-0.58	-0.76 - -0.39	0.0000	0.201
	Model 2 (Adjusted)	-0.56	-0.74 - -0.38	0.0000	0.221

^aAdjusted for age, gender and BMI. Abbreviations: VAS, visual analog score; ODI, Oswestry Disability Index; BMI, body mass index; CI, confidence interval.

Table 8. Comparison of postoperative adverse reactions

Group	Infection	Loose screw	Nerve injury	Paraspinal muscle injury	Total
PPSF group	3	0	1	1	5
OPSF group	6	2	2	2	12
χ^2 value					4.81
P value					0.028

Abbreviations: PPSF, percutaneous pedicle screw fixation; OPSF, open pedicle screw fixation.

group. As for radiological indexes, the PPSF group had an advantage in the early postoperative period (7 days, 6 months) in vertebral anterior height recovery and Cobb angle correction, but there was no significant difference between the two groups in the medium and long terms (12 months). Repeated measures ANOVA further confirmed that surgical approach, follow-up time, and their interaction significantly affected VAS score, ODI score, PAVBH and Cobb angle. Linear regression analysis indicated that after adjusting for confounding factors such as age, gender and BMI, surgical approach remained an independent factor influencing VAS and ODI scores at 12 months. These results indicate that PPSF treatment for TVF combines short-term minimally invasive advantages with medium- to long-term stability, providing important reference for clinical decision-making.

In this study, the operation time in the PPSF group was significantly shorter than that in the OPSF group, which is directly related to the fact that the minimally invasive technique avoids extensive muscle stripping and deep tissue exposure [18]. The PPSF group had less intraoperative blood loss and less drainage within 24 hours postoperatively. The core mechanism may be that PPSF is performed through a percutaneous channel, reducing damage to the paravertebral muscles and surrounding vascular network, thereby lowering the risk of bleeding and postoperative exudate [19]. Our results are consistent with the growing evidence supporting the perioperative efficiency of PPSF. For instance, randomized controlled trials by Choovongkomol et al. and large retrospective studies by Neeley et al. both reported that PPSF had significantly shorter operation time and less bleeding compared to OPSF [20, 21]. Consistent results from different study designs reinforce the validity of the observed advantage of reduced surgical trauma. Meanwhile, the PPSF group had significantly shorter bed rest and hospital stay than the OPSF group, suggesting that minimally invasive techniques can accelerate the recovery of patients' postoperative mobility [22]. On the one hand, PPSF's protection of paraspinal muscles reduc-

es the risk of muscle fibrosis and muscle weakness, enabling patients to regain independent mobility earlier. On the other hand, the reduction of postoperative pain reduces dependence on analgesics, indirectly shortening the recovery period [23]. This accelerated recovery process is consistent with the findings of Tu et al., who also reported that PPSF can shorten hospital stay and accelerate the recovery of patients' mobility [11]. In addition, a recent meta-analysis by Luo et al. synthesized evidence from 35 cohort studies and concluded that the percutaneous approach significantly shortens hospital stay and bed rest compared to the open surgery [22]. However, the study of Tu et al. focused on short-term outcomes, while our study further extended these observations, confirming that the functional advantage (lower ODI score) persisted at 12-month follow-up.

Dynamic changes in VAS and ODI scores revealed differences in pain management and functional recovery between the two procedures. Although there was no significant difference in VAS scores between the two groups at 7 days postoperatively, the advantage of the PPSF gradually became apparent at 6 and 12 months, which is closely related to the protective effect of minimally invasive techniques on paraspinal muscles and soft tissues [24]. It has been hypothesized that PPSF, which relies on a series of expanders, may lead to concentrated muscle compression injury, which may result in more pronounced early pain - a view put forward by some clinicians [25]. However, in our cohort, long-term pain outcomes were more favorable for PPSF. Conventional OPSF is prone to muscle denervation and scar formation due to extensive stripping of muscles such as the erector spinae, thus causing chronic low back pain; while PPSF, by preserving muscle attachment points and blood supply, reduces local inflammation and fibrosis, achieving long-term pain relief [26, 27]. This suggests that the mechanism of postoperative pain is multifactorial. While direct muscle injury is a factor, the extent of soft tissue stripping, disruption of neuromuscular integrity, and subsequent chronic inflammatory changes may play a more dominant role in persistent pain. Our findings align with several recent comparative studies that have shown that minimally invasive techniques can reduce long-term pain scores [28, 29]. The superior ODI scores in the PPSF group

were evident at the first week postoperatively and persisted for up to one year, highlighting its significant functional benefits. This is consistent with the findings of Xu et al., who found that patients undergoing percutaneous fixation had significantly better ODI scores at 6-month follow-up compared to those undergoing open surgery [9]. This result extends beyond pain relief and suggests that PPSF may better maintain the dynamic balance of the spine by protecting muscle groups related to spinal stability, such as the multifidus muscle [30]. Quan et al. emphasized the importance of muscle protection, noting that paraspinal muscle degeneration significantly affects postoperative coronal balance in patients with spinal deformities [31]. Our findings provide clinical support for this biomechanical principle, suggesting that the muscle-preserving properties of PPSF contribute to superior long-term functional outcomes. Therefore, we speculate that the minimally invasive nature of PPSF may promote early patient participation in rehabilitation training by preserving muscle tone, thus forming a virtuous cycle of "minimally invasive - rapid rehabilitation - functional enhancement".

In addition, PPSF also showed certain advantages in anterior vertebral body height restoration and Cobb angle correction. The PPSF group had better recovery of PAVBH at 7 days and 6 months postoperatively, which may be due to the precise reduction under fluoroscopic guidance and the stabilizing effect of muscle tone on the fracture ends during percutaneous operation [32]. However, there was no significant difference between the two groups at 12 months, suggesting that both procedures are equally effective in maintaining long-term height after fracture healing. We hypothesize that this may be related to the biological process of fracture healing, i.e., the initial reduction advantage may be offset by bone remodeling as callus formation and internal fixation load sharing occur [33]. The trend of Cobb angle change was similar, with the PPSF group being significantly better than the OPSF group only at 7 days postoperatively, and no difference in the mid- to long-term. This result suggests that although PPSF is more advantageous in early spinal alignment correction, OPSF can still achieve long-term spinal alignment stability through direct reduction during open surgery [34]. Both surgical approaches

The treatment of thoracolumbar vertebral fracture

ultimately achieved satisfactory radiographic results, which further supports the feasibility of PPSF as an alternative to OPSF in the applicable population.

This study has the following limitations. First, the retrospective cohort design may introduce selection bias; although baseline data were balanced between the two groups, the choice of surgical approach could still be influenced by individual patient factors. Second, the sample size calculation was based on differences in ODI scores, which, while meeting statistical requirements, is insufficient for subgroup analysis (e.g., different fracture segments). Third, intraoperative radiation exposure dose and imaging assessments of screw placement accuracy were not recorded, which are important technical considerations for PPSF. Fourth, the assessment of surgical outcomes relied primarily on two routine patient-reported metrics - VAS and ODI scores. Although these indicators are widely validated, they may not fully reflect the multidimensional aspects of long-term recovery, such as health-related quality of life, return to work, patient satisfaction, or objective physical function indicators (e.g., trunk muscle strength, spinal mobility). Finally, the follow-up period was only one year; complications such as internal fixation loosening and adjacent segment degeneration over longer periods (e.g., 3-5 years) require further observation. Future research can be improved in three aspects: first, by adopting a prospective randomized controlled design to strictly control for confounding factors. Second, by combining three-dimensional CT scans to assess screw placement accuracy and analyzing its association with clinical outcomes; third, by using a wider range of outcome measures, including patient-reported outcomes in addition to pain and functional impairment, functional performance tests, and return-to-activity indicators, to more comprehensively assess long-term efficacy; and fourth, by conducting multicenter studies to expand the sample size to explore subgroup differences and extend follow-up to more than 5 years to assess long-term spinal function and complication risks.

Conclusion

In this study, we compared the short-term and long-term outcomes of PPSF with OPSF for the

treatment of TVF. We found that PPSF has significant advantages in reducing surgical trauma, shortening hospital stays, alleviating postoperative pain, and improving functional impairment. The minimally invasive nature of PPSF contributes to faster postoperative recovery and better pain control, and it also shows certain advantages in early postoperative recovery of PAVBH and Cobb angle correction. In addition, the incidence of postoperative adverse events with PPSF was lower than that with OPSF, indicating better safety. Although the long-term efficacy of PPSF and its applicability in different types of thoracolumbar fractures require further investigation, the results of this study suggest that PPSF is a promising surgical method for treating thoracolumbar fractures and deserves further promotion and application in clinical practice. Future research should validate these findings through prospective randomized controlled trials and assess the long-term efficacy and safety of PPSF in different patient populations.

Disclosure of conflict of interest

None.

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References

- [1] Azizi A, Azizzadeh A, Tavakoli Y, Vahed N and Mousavi T. Thoracolumbar fracture and spinal cord injury in blunt trauma: a systematic review, meta-analysis, and meta-regression. *Neurosurg Rev* 2024; 47: 333.
- [2] Takaoka H, Eguchi Y, Shibahashi K, Ozone E, Teramura S, Takeda T, Kitagawa K, Sai K, Setojima Y, Masaki Y, Mizutani M, Hamabe Y, Sugiyama K, Orita S, Inage K, Shiga Y, Shiko Y, Kawasaki Y and Ohtori S. Characteristics and comparative study of thoracolumbar spine injury and dislocation fracture due to tertiary trauma. *Eur Spine J* 2023; 32: 68-74.

The treatment of thoracolumbar vertebral fracture

- [3] Dong Y, Peng R, Kang H, Song K, Guo Q, Zhao H, Zhu M, Zhang Y, Guan H and Li F. Global incidence, prevalence, and disability of vertebral fractures: a systematic analysis of the global burden of disease study 2019. *Spine J* 2022; 22: 857-868.
- [4] Zheng XQ, Xu L, Huang J, Zhang CG, Yuan WQ, Sun CG, Zhang ZS, Wei C, Wang JX, Cummings SR, Xia WB, Wang SF, Zhan SY and Song CL. Incidence and cost of vertebral fracture in urban China: a 5-year population-based cohort study. *Int J Surg* 2023; 109: 1910-1918.
- [5] Xu W, Liu W, Zhong F, Peng Y, Liu X and Yu L. Efficacy of OLIF combined with pedicle screw internal fixation for lumbar spinal stenosis on spinal canal changes before and after surgery. *J Orthop Surg Res* 2023; 18: 724.
- [6] Harel R, Anekstein Y, Raichel M, Molina CA, Ruiz-Cardozo MA, Orrú E, Khan M, Mirovsky Y and Smorgick Y. The XVS system during open spinal fixation procedures in patients requiring pedicle screw placement in the lumbosacral spine. *World Neurosurg* 2022; 164: e1226-e1232.
- [7] Jiang F, Li XX, Liu L, Xie ZY, Xu YZ, Ren GR, Wu XT and Wang YT. The mini-open wiltse approach with pedicle screw fixation versus percutaneous pedicle screw fixation for treatment of neurologically intact thoracolumbar fractures: a systematic review and meta-analysis. *World Neurosurg* 2022; 164: 310-322.
- [8] Zheng Z, Zhang L, Zhu Y, Chen J, Zhang X, Xia T, Wu T, Quan L, Zhao G, Ji X, Gui Z, Xue S and Yin Z. Percutaneous cortical bone trajectory screw fixation versus traditional open pedicle screw fixation for type A thoracolumbar fractures without neurological deficit. *J Robot Surg* 2023; 17: 233-241.
- [9] Xu Y, Sun Y, Shi R, Li J, Zhang F, Guo L and Zhang W. A clinical comparative study on percutaneous and open approaches for screw internal fixation in treating thoracolumbar fractures. *Orthop Surg* 2023; 15: 2532-2539.
- [10] Trungu S, Ricciardi L, Forcato S, Piazza A, D'Andrea G, Polli FM, Cimatti M, Frati A, Miscusi M and Raco A. Percutaneous pedicle screw fixation without arthrodesis of 368 thoracolumbar fractures: long-term clinical and radiological outcomes in a single institution. *Eur Spine J* 2023; 32: 75-83.
- [11] Tu P, Yan CC, Hao JX, Cao S and Jiang C. Effect of percutaneous minimally invasive pedicle screw internal fixation in the treatment of thoracolumbar vertebral fractures and its impact on quality of life. *Pak J Med Sci* 2022; 38: 100-105.
- [12] Sheng W, Jiang H, Hong C, Hu H, Yuan H, Gu X and Li S. Comparison of outcome between percutaneous pedicle screw fixation and the mini-open wiltse approach with pedicle screw fixation for neurologically intact thoracolumbar fractures: a retrospective study. *J Orthop Sci* 2022; 27: 594-599.
- [13] Vaccaro AR, Lehman RA, Hurlbert RJ, Anderson PA, Harris M, Hedlund R, Harrop J, Dvorak M, Wood K, Fehlings MG, Fisher C, Zeiller SC, Anderson DG, Bono CM, Stock GH, Brown AK, Kuklo T and Oner FC. A new classification of thoracolumbar injuries: the importance of injury morphology, the integrity of the posterior ligamentous complex, and neurologic status. *Spine (Phila Pa 1976)* 2005; 30: 2325-2333.
- [14] Wang B, Fan Y, Dong J, Wang H, Wang F, Liu Z, Liu H, Feng Y, Chen F, Huang Z, Chen R, Lei W and Wu Z. A retrospective study comparing percutaneous and open pedicle screw fixation for thoracolumbar fractures with spinal injuries. *Medicine (Baltimore)* 2017; 96: e8104.
- [15] Åström M, Thet Lwin ZM, Teni FS, Burström K and Berg J. Use of the visual analogue scale for health state valuation: a scoping review. *Qual Life Res* 2023; 32: 2719-2729.
- [16] Fairbank JC and Pynsent PB. The Oswestry disability index. *Spine (Phila Pa 1976)* 2000; 25: 2940-2952.
- [17] Jia X, Xie Y, Yang Y, Deng Y, Zhang K, Shen C, Li Y and Ma L. Comparative analysis of three vertebral screw placement directions in anterior thoracolumbar fracture surgery: a finite element study. *Orthop Surg* 2025; 17: 1464-1477.
- [18] Daher M, Aoun M, Cottrill EJ, Wang Z, Hurley RK, Lavelle WF, Passias PG, Diebo BG, Daniels AH and Sebaaly A. Minimally invasive versus open surgery for thoracolumbar fractures treatment: a meta-analysis of randomized controlled trials and prospective studies. *Spine (Phila Pa 1976)* 2025; 50: 412-419.
- [19] Cabrera JP, Camino-Willhuber G, Muthu S, Guiroy A, Valacco M and Pola E. Percutaneous versus open pedicle screw fixation for pyogenic spondylodiscitis of the thoracic and lumbar spine: systematic review and meta-analysis. *Clin Spine Surg* 2023; 36: 24-33.
- [20] Choovongkomol K, Piyapromdee U, Thepjung S, Tanaviriyachai T, Jongkittanakul S and Sudprasert W. Comparative outcomes of percutaneous and conventional open pedicle screw fixation for single-level thoracolumbar spine injury: randomised controlled trial. *Malays Orthop J* 2024; 18: 106-115.
- [21] Neeley OJ, Kafka B, Tecle NE, Shi C, El Ahmadih TY, Sagoo NS, Davies M, Johnson Z, Caruso JP, Hoeft J, Stutzman SE, Vira S, Hunt Batjer H, Bagley CA, Whitworth L and Aoun SG. Percutaneous screw fixation versus open fusion for the treatment of traumatic thoracolumbar fractures: a retrospective case series

The treatment of thoracolumbar vertebral fracture

- of 185 patients with a single-level spinal column injury. *J Clin Neurosci* 2022; 101: 47-51.
- [22] Luo M, Yang Y, Liu Z, Tan J, Luo J, Long Z, Chen M, Liang C and Xiao Z. Percutaneous versus traditional open approaches for the treatment of thoracolumbar fractures in patients without neurologic deficits: a meta-analysis of 35 cohort studies. *Neurosurg Rev* 2024; 47: 62.
- [23] Ishii K, Funao H, Isogai N, Saito T, Arizono T, Hoshino M and Sato K. The history and development of the percutaneous pedicle screw (PPS) system. *Medicina (Kaunas)* 2022; 58: 1064.
- [24] Giorgi PD, Pallotta ML, Legrenzi S, Nardi M, Andrea M and Schirò GR. Spinal cord compression in thoracolumbar burst fractures: application of high-definition three-dimensional exoscope in minimally invasive lateral surgery. *Eur J Orthop Surg Traumatol* 2023; 33: 2173-2177.
- [25] Park Y and Ha JW. Comparison of one-level posterior lumbar interbody fusion performed with a minimally invasive approach or a traditional open approach. *Spine (Phila Pa 1976)* 2007; 32: 537-43.
- [26] Gaines RW. The use of pedicle-screw internal fixation for the operative treatment of spinal disorders. *J Bone Joint Surg Am* 2000; 82: 1458-1476.
- [27] Liang D, Deng X, Qian J, Han F and Zhou K. Comparison of different pedicle screw fixation schemes in the treatment of neurosurgical spinal fractures: systematic review and meta-analysis. *Ann Palliat Med* 2021; 10: 12678-12689.
- [28] Peng CW, Yue WM, Poh SY, Yeo W and Tan SB. Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. *Spine (Phila Pa 1976)* 2009; 34: 1385-9.
- [29] Khan NR, Clark AJ, Lee SL, Venable GT, Rossi NB and Foley KT. Surgical outcomes for minimally invasive vs open transforaminal lumbar interbody fusion: an updated systematic review and meta-analysis. *Neurosurgery* 2015; 77: 847-74.
- [30] Yun JH and Lee DG. Physical functional ability and quantitative assessment of the multifidus muscle of the lumbar spine in the elderly. *Diagnostics (Basel)* 2023; 13: 2423.
- [31] Quan H, Chengzhen L, Qixin C, Yuanqing S and Fangcai L. Paravertebral muscle degeneration affects coronal balance in patients with degenerative lumbar scoliosis. *World Neurosurg* 2025; 195: 123644.
- [32] Gu X, Li J, Wu S, Yuan L, Qu L, Wang Y, Yang H, Yang S, Sun C and Zou J. The clinical effect of different vertebral body height restoration rates after percutaneous kyphoplasty for osteoporotic vertebral compression fractures. *BMC Musculoskelet Disord* 2024; 25: 711.
- [33] Molitoris KH, Huang M and Baht GS. Osteoimmunology of fracture healing. *Curr Osteoporos Rep* 2024; 22: 330-339.
- [34] Hayoun T, Siboni R, Ohi X and Bredin S. Treatment of thoracolumbar fractures: comparison of the clinical and radiological outcomes of percutaneous versus open surgery. *Eur J Orthop Surg Traumatol* 2023; 33: 2393-2397.