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Association Between a Modified Percutaneous Pedicle Screw Placement Technique and Immediate Severe Pain After Thoracolumbar Fracture Fixation: A Retrospective Before-and-After Cohort Study

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Abstract

Background

Immediate severe postoperative pain may occur after percutaneous pedicle screw fixation (PPSF) for thoracolumbar fractures, but the role of screw trajectory, facet joint violation (FJV), and implant-related mechanical irritation remains unclear. This study evaluated the association between a modified percutaneous pedicle screw placement technique and immediate severe postoperative pain after PPSF.

Methods

This single-center retrospective before-and-after cohort study included 103 patients with single-segment AO Spine type A thoracolumbar fractures treated with PPSF between January 2021 and December 2024. Patients treated before technical modification were assigned to the conventional group, whereas those treated after implementation of the modified technique were assigned to the modified group. Immediate severe postoperative pain was defined as a maximum visual analogue scale (VAS) score ≥ 7 within 0–6 h after surgery. Postoperative pain, early recovery outcomes, FJV, and pedicle screw misplacement were compared between groups. Multivariable logistic regression was used to explore factors associated with immediate severe postoperative pain.

Results

The conventional group included 57 patients and the modified group included 46 patients, with comparable baseline characteristics. The modified group had a lower incidence of immediate severe postoperative pain [6.5% (3/46) vs. 31.6% (18/57), P = 0.002], lower maximum VAS score within 0–6 h after surgery, and lower postoperative day 3 VAS score than the conventional group (both P < 0.001). The incidence of FJV was also lower in the modified group [2.2% (1/46) vs. 24.6% (14/57), P = 0.001]. In the fully adjusted model, the modified technique remained associated with a lower risk of immediate severe postoperative pain (OR = 0.214, 95% CI: 0.053–0.864, P = 0.030). Higher preoperative VAS score and FJV were associated with increased risk, whereas pedicle screw misplacement showed a positive but statistically non-significant association after adjustment.

Conclusions

The modified percutaneous pedicle screw placement technique was associated with a lower early postoperative pain burden and a lower incidence of facet joint violation after PPSF for thoracolumbar fractures. Given the retrospective before-and-after design and the limited number of pain events, these findings should be interpreted as exploratory and require prospective validation.

1. Introduction

Thoracolumbar fractures are common traumatic injuries in spine surgery and frequently occur at the thoracolumbar junction, a biomechanical transition zone of the spine [1]. For patients with AO Spine type A thoracolumbar fractures without obvious neurological deficits, the main treatment goals are to restore spinal stability, relieve pain, and facilitate early mobilization [2]. Surgical fixation may also help correct vertebral height loss and kyphotic deformity. Percutaneous pedicle screw fixation (PPSF) has become an important minimally invasive option for these injuries because it can reduce paraspinal muscle dissection and intraoperative blood loss compared with conventional open posterior fixation [3]. Previous meta-analyses have also shown that PPSF is associated with shorter hospital stay and favorable early clinical outcomes in selected patients [4].

However, the minimally invasive nature of PPSF does not completely eliminate early postoperative pain. Some patients experience marked low back pain shortly after recovery from anesthesia, which may interfere with turning over, early ambulation, rescue analgesic requirements, and patients' perceived surgical recovery. Acute postoperative pain is influenced by multiple factors, including preoperative pain intensity, surgical stimulation, analgesic strategy, and individual pain sensitivity [5]. Pain within the first 0–6 h after surgery differs from pain assessed on postoperative day 1, postoperative day 3, or during long-term follow-up. This immediate postoperative period may more directly reflect the combined effects of surgical stimulation, implant-related mechanical irritation, anesthetic recovery, perioperative analgesia, and preexisting pain sensitization [6]. However, immediate severe postoperative pain within this early time window has not been sufficiently investigated in patients undergoing PPSF for thoracolumbar fractures.

In addition to patient-related and fracture-related factors, technical factors during percutaneous screw placement may be associated with early postoperative pain. PPSF requires the establishment of a screw trajectory through a limited skin incision and paraspinal soft-tissue corridor under fluoroscopic guidance. Inappropriate control of the skin incision, puncture entry point, screw trajectory, insertion depth, or screw-tail position may increase the risk of facet joint violation (FJV), pedicle cortical breach, or local soft-tissue irritation [7]. Because the facet joint is richly innervated by capsular and dorsal ramus-related structures, mechanical irritation of this region may represent a potential source of postoperative low back pain [8]. Previous studies have shown that FJV is not uncommon during percutaneous pedicle screw placement and may be influenced by the surgical approach and screw insertion trajectory [9]. Pedicle screw-associated violation of the adjacent facet joint has also been linked to insufficient postoperative pain relief and adjacent-segment problems after posterior instrumentation [10].

Pedicle screw misplacement is another technical factor that may affect postoperative pain and clinical safety. The Gertzbein–Robbins classification is widely used to evaluate pedicle screw position according to the degree of pedicle cortical breach [11]. Previous systematic evidence has shown that screw placement accuracy varies among freehand, fluoroscopy-guided, and navigation-assisted techniques [12]. Although navigation- and robot-assisted techniques may improve pedicle screw accuracy, these

technologies are not universally available in many clinical settings [13]. Therefore, technical refinement under conventional C-arm fluoroscopy remains clinically relevant, especially in centers where advanced navigation systems are not routinely used.

To address these potential technical sources of early postoperative pain, we implemented a modified percutaneous pedicle screw placement technique to optimize incision location, puncture entry point, screw trajectory, screw length, screw-tail space, rod position, and deep soft-tissue handling. This technique was designed to reduce potential mechanical irritation of the facet joint and deep paraspinal soft tissues while maintaining safe screw placement and effective fracture fixation. However, whether this modified technique is associated with a lower burden of immediate postoperative pain remains unclear.

Therefore, this single-center retrospective before-and-after cohort study compared a modified percutaneous pedicle screw placement technique with the conventional technique in patients with single-segment AO Spine type A thoracolumbar fractures treated with PPSF. The primary aim was to evaluate the association between the modified technique and immediate severe postoperative pain within 0–6 h after surgery. The secondary aim was to compare screw-related radiographic outcomes and early recovery outcomes between groups and to explore factors associated with immediate severe postoperative pain.

2 Materials and methods

2.1 Study design and patients

This single-center retrospective before-and-after cohort study included patients with single-segment thoracolumbar fractures who underwent percutaneous pedicle screw fixation (PPSF) between January 2021 and December 2024. Clinical, perioperative, pain-related, and radiographic data were retrospectively collected from inpatient medical records, anesthesia records, operative records, nursing records, pain assessment records, and radiographic systems. All data were anonymized before analysis. This study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

A total of 110 patients were initially screened. Patients treated before implementation of the technical modification between January 2021 and December 2022 were assigned to the conventional group, whereas those treated after implementation of the modified technique between January 2023 and December 2024 were assigned to the modified group. Because this was a retrospective before-and-after study, group allocation was based on treatment period rather than randomization. After excluding 7 patients because of loss to follow-up or incomplete key clinical or radiographic data, 103 patients were included in the final analysis, including 57 patients in the conventional group and 46 patients in the modified group.

Surgical indications and perioperative pathways were kept consistent throughout the study period to minimize potential time-period-related bias. All procedures were performed by the same spine surgery team under the supervision of the same senior spine surgeon. However, because of the before-and-after design, potential time-period effects and learning-curve effects could not be completely eliminated.

The study was approved by the institutional ethics committee, which waived the requirement for written informed consent because of the retrospective design and the use of anonymized clinical data.

2.2 Inclusion and exclusion criteria

Patients were included if they met the following criteria:

(1) age 30–60 years;

1. diagnosis of a single-segment thoracolumbar fracture confirmed by radiography, computed tomography (CT), or magnetic resonance imaging;
2. fracture level between T8 and L5;
3. AO Spine thoracolumbar injury classification type A injury;
4. no definite spinal cord, conus medullaris, or cauda equina neurological deficit;
5. Thoracolumbar Injury Classification and Severity Score (TLICS) ≥ 4, with surgical indication determined according to fracture morphology, pain severity, instability, and the need for early mobilization;
6. treatment with PPSF and complete clinical, perioperative, pain assessment, and radiographic data.

Patients were excluded if they had:

(1) multisegment thoracolumbar fractures;

1. AO Spine type B or C injuries;
2. spinal canal compromise, dural sac compression, or neurological deficit requiring open decompression;
3. osteoporotic vertebral compression fracture, pathological fracture, or tumor-related fracture;
4. previous surgery at the same spinal level;
5. severe concomitant injuries affecting postoperative pain assessment;
6. long-term opioid use, severe psychiatric disorder, or cognitive impairment;
7. chronic low back pain requiring regular medication or degenerative lumbar disease causing preoperative pain unrelated to the fracture;
8. incomplete postoperative imaging, pain score, perioperative, or follow-up data.

- The age range was restricted to 30–60 years to reduce the potential confounding effect of osteoporotic vertebral compression fractures and age-related degenerative pain.

2.3 Grouping and perioperative consistency control

Patients were divided into the conventional and modified groups according to whether the modified percutaneous pedicle screw placement technique was used. The conventional group included patients treated before technical modification, whereas the modified group included patients treated after implementation of the modified technique.

Baseline characteristics, including age, sex, body mass index, education level, preoperative visual analogue scale (VAS) score, TLICS score, AO Spine classification, and time from injury to surgery, were compared between groups. The same perioperative clinical pathway was used throughout the study period, including anesthetic management, patient-controlled intravenous analgesia, rescue analgesic criteria, postoperative pain assessment, rehabilitation guidance, ambulation criteria, and postoperative CT evaluation. Because the two groups were defined according to different treatment periods, the results were interpreted as associations rather than causal effects.

2.4 Surgical procedures

All operations were performed under general anesthesia in the prone position by the same spine surgery team under the supervision of the same senior spine surgeon. Preoperative imaging was used to determine the responsible level, fracture morphology, pedicle anatomy, and planned fixation levels. Intraoperatively, C-arm fluoroscopy was used for level confirmation, pedicle localization, and incision marking.

2.4.1 Conventional group: conventional percutaneous pedicle screw placement technique

Patients in the conventional group underwent the conventional percutaneous pedicle screw placement technique.

Step 1: Conventional incision design and entry point selection.

Under anteroposterior and lateral fluoroscopic guidance, a 1.0–1.5 cm longitudinal skin incision was made near the tangent line of the lateral border of the pedicle. For thoracic screws, the entry point was selected at the region between the lateral border of the facet joint and the upper one-third of the transverse process; for lumbar screws, the entry point was selected at the apex of the conventional “herringbone crest” (Fig. 3B).

Step 2: Establishment of the puncture trajectory.

The puncture needle was advanced under alternating anteroposterior and lateral fluoroscopy. The trajectory was considered satisfactory when lateral fluoroscopy showed the needle tip within the anterior one-third of the vertebral body and anteroposterior fluoroscopy confirmed that the needle had not crossed the medial pedicle border or vertebral midline.

Step 3: Guidewire insertion, screw placement, and reduction fixation.

After satisfactory needle positioning, a guidewire was inserted, followed by sequential dilation, tapping, and pedicle screw insertion. Screw direction and depth were monitored under fluoroscopy, and trajectory deviation was corrected when necessary. After bilateral screw placement, connecting rods were installed and distraction reduction was performed to restore vertebral height and sagittal alignment. Final fluoroscopy confirmed screw position and reduction quality, followed by wound irrigation and closure.

2.4.2 Modified group: modified percutaneous pedicle screw placement technique

Patients in the modified group underwent the modified percutaneous pedicle screw placement technique. This technique was based on three principles: lateralization of the screw corridor, preservation of the screw-tail–facet joint space, and reduction of deep soft-tissue entrapment. The technique included optimization of incision location, puncture entry point, screw trajectory, screw length, screw-tail space, rod position, and deep soft-tissue handling.

Step 1: Lateralized incision design.

A 1.0–1.5 cm longitudinal skin incision was made along a line approximately 2 cm lateral to the tangent line of the lateral border of the pedicle. Compared with the conventional incision, this lateralized incision was intended to provide a more appropriate lateral puncture angle and to facilitate establishment of a screw trajectory away from the adjacent facet joint (Fig. 2).

Step 2: Lateralized puncture entry point.

The intersection between the midline of the transverse process and the lateral border of the superior articular process was defined as the main puncture entry point, which was more lateral than the conventional entry point (Fig. 3A). This entry point was intended to direct the puncture trajectory away from the superior facet joint and reduce interference of the puncture needle or screw trajectory with the facet joint.

Step 3: Fluoroscopy-guided screw-tract establishment.

Screw-tract establishment, guidewire insertion, dilation, tapping, and screw insertion were performed using the same fluoroscopic safety principles as in the conventional group. Screw direction and insertion depth were repeatedly checked to reduce pedicle cortical breach and screw misplacement.

Step 4: Screw length selection and screw-tail space control.

Screw length was determined according to the effective pedicle–vertebral bony corridor length measured on preoperative CT. The effective bony corridor length was defined as the distance along the planned screw trajectory from the posterior bony entry point of the pedicle to the safe endpoint within the anterior vertebral cortex on sagittal or multiplanar reconstructed CT images. The selected screw length was approximately 80% of the effective bony corridor length, aiming to ensure sufficient bony

purchase while preserving screw-tail space and reducing excessive contact between the screw tail or connecting structure and the adjacent facet joint (Fig. 4). This 80% value was used as an approximate preoperative planning reference rather than a rigid criterion, with the aim of balancing adequate bony purchase and preservation of screw-tail space.

Step 5: Rod placement close to the screw tail.

After bilateral screw placement, the connecting rods were positioned as close as possible to the pedicle screw tails to avoid superficial rod placement that could cause entrapment or compression of muscle, fascia, or subcutaneous soft tissue. After distraction reduction, vertebral height and sagittal alignment were restored. Fluoroscopy was repeated to confirm screw position, rod position, and reduction quality.

Step 6: Deep soft-tissue inspection and release.

Before wound closure, the incision was thoroughly irrigated. A medium-sized vascular clamp was inserted into the incision to gently open the fascia and release the muscle, allowing the paraspinal muscles to naturally cover the screws and rods. This step was intended to reduce continuous compression of the muscle and fascia by the internal fixation construct and to minimize deep soft-tissue entrapment around the screw tail or connecting rod.

Step 7: Wound closure.

After hemostasis and wound irrigation, the incision was closed according to the intraoperative wound condition. Deep fascial closure was performed selectively according to the size of the fascial opening, local tissue tension, and the presence of dead space or hematoma. The skin was closed in a standard full-thickness manner.

2.5 Postoperative management and analgesic protocol

Both groups received the same perioperative management and analgesic protocol. Patient-controlled intravenous analgesia was routinely administered after surgery using sufentanil citrate 150 μg and dexmedetomidine hydrochloride 0.2 mg diluted with normal saline to 100 mL and infused at 2 mL/h. The analgesic protocol remained unchanged throughout the study period.

Rescue analgesia was administered according to the same clinical criteria in both groups. Ketorolac tromethamine 30 mg was administered intramuscularly when patients reported pain aggravation or requested additional analgesia after clinical assessment. If immediate severe postoperative pain occurred, tramadol 100 mg was administered intravenously after evaluation by the attending physician. Detailed rescue analgesic consumption was not completely available for all patients and was therefore not quantitatively compared between groups.

Vital signs, wound condition, and sensory and motor function of both lower limbs were routinely monitored. When vital signs were stable, pain was tolerable, and postoperative imaging showed no obvious abnormalities, patients were instructed to ambulate gradually with brace protection.

2.6 Pain assessment and outcome definitions

Pain intensity was assessed using the VAS, ranging from 0 to 10. The primary outcome was immediate severe postoperative pain, defined as a maximum VAS score ≥ 7 within 0–6 h after surgery, based on previous pain intensity stratification studies [14, 15].

VAS scores were extracted from standardized nursing and postoperative pain assessment records. VAS scores were routinely recorded after recovery from anesthesia and at routine nursing assessment intervals within the first 6 h after surgery. Additional VAS assessments were performed when patients reported pain aggravation or required rescue analgesia. The maximum VAS score within 0–6 h after surgery was used for analysis.

Secondary outcomes included maximum VAS score within 0–6 h after surgery, VAS score on postoperative day 3, time to first ambulation, length of hospital stay, facet joint violation, and pedicle screw misplacement.

2.7 Data collection and variables

Data were collected from inpatient medical records, anesthesia records, operative records, nursing records, pain assessment records, radiographic systems, and follow-up data. Collected variables included demographic characteristics, injury-related variables, treatment group, preoperative pain score, surgical variables, screw-related radiographic variables, and recovery-related variables.

For statistical analysis, treatment group was coded as 0 for the conventional group and 1 for the modified group. Immediate severe postoperative pain was coded as 0 for absence and 1 for presence. Facet joint violation and pedicle screw misplacement were coded as patient-level binary variables. Patients with missing key variables, missing postoperative imaging data, or incomplete pain score records were excluded.

2.8 Radiographic assessment

All patients underwent postoperative thoracolumbar CT to assess screw position and facet joint violation. Postoperative CT was routinely performed before discharge, usually within 3 days after surgery. Radiographic evaluations were independently performed by two physicians experienced in spinal imaging assessment, both of whom were blinded to group allocation and postoperative pain scores. The assessors were not involved in the surgical procedures. Disagreements were resolved by a third senior spine surgeon.

Interobserver agreement was assessed for the main radiographic and classification variables. Continuous or score-based variables were evaluated using the intraclass correlation coefficient, and categorical or ordinal variables were evaluated using Cohen’s kappa or weighted kappa, as appropriate [16, 17].

2.8.1 Assessment of facet joint violation

Facet joint violation was assessed using axial, sagittal, and coronal reconstructed postoperative CT images and was recorded at the patient level as present or absent. FJV was defined as any screw trajectory, screw tail, or related internal fixation structure violating the adjacent facet articular surface, directly contacting the facet joint surface, or involving the facet joint space. If one or more inserted screws caused FJV in a patient, the patient was classified as having patient-level FJV [18, 19]. Because postoperative pain was evaluated at the patient level, FJV was primarily analyzed as a patient-level binary variable.

2.8.2 Assessment of pedicle screw misplacement

Pedicle screw position was evaluated on postoperative CT according to the Gertzbein–Robbins classification [11]. Grade A indicated no cortical breach; grade B, cortical breach < 2 mm; grade C, cortical breach of 2–4 mm; grade D, cortical breach of 4–6 mm; and grade E, cortical breach > 6 mm. Grades A and B were defined as clinically acceptable screw placement, whereas grades C–E were defined as pedicle screw misplacement.

If a patient had at least one grade C–E screw, the patient was classified as having patient-level pedicle screw misplacement. Screw-level information was used for radiographic classification, but the main statistical analysis was performed at the patient level to match the patient-level pain outcome [12].

2.9 Statistical analysis

Statistical analyses were performed using SPSS version 26.0. The normality of continuous variables was assessed using the Shapiro–Wilk test. Continuous variables are presented as means ± standard deviations or medians with interquartile ranges, as appropriate, and were compared using the independent-samples t test or Mann–Whitney U test. Categorical variables are presented as numbers and percentages and were compared using the chi-square test or Fisher’s exact test. Interobserver agreement was assessed using the intraclass correlation coefficient, weighted kappa, or Cohen’s kappa, as appropriate.

Immediate severe postoperative pain was used as the dependent variable. To evaluate the association between the modified technique and immediate severe postoperative pain, multivariable logistic regression models were constructed. Model 1 included treatment group and preoperative VAS score. Model 2 additionally included facet joint violation and pedicle screw misplacement. Odds ratios and 95% confidence intervals were calculated. In the regression models, the conventional group, absence of FJV, and absence of pedicle screw misplacement were used as reference categories.

Because only 21 immediate severe postoperative pain events occurred, a parsimonious multivariable modeling strategy was used to reduce the risk of overfitting. The models were restricted to clinically prespecified variables most directly related to the study hypothesis, including treatment group, preoperative VAS score, facet joint violation, and pedicle screw misplacement. Calendar year was not

included as an additional covariate because it was highly collinear with treatment group and because of the limited number of pain events. All statistical tests were two-sided, and $P < 0.05$ was considered statistically significant.

3 Results

3.1 General demographic characteristics

A total of 103 patients with single-segment AO Spine type A thoracolumbar fractures treated with PPSF were included in this study, including 57 patients in the conventional group and 46 patients in the modified group. No significant differences were observed between the two groups in age, sex, BMI, or education level (Table 1).

Table 1
Baseline demographic characteristics of the conventional and modified groups

Variable	Conventional group (n = 57)	Modified group (n = 46)	t/χ^2 value	P value
Age (years, mean ± SD)	50.82 ± 10.48	54.46 ± 8.91	-1.868	0.065
Sex (male/female)	35/22	27/19	0.078	0.780
BMI (kg/m², mean ± SD)	24.52 ± 3.12	24.09 ± 2.22	0.793	0.429
Education level (years, mean ± SD)	10.93 ± 3.43	10.96 ± 2.65	-0.043	0.965
Note: BMI, body mass index; SD, standard deviation.				

The mean age was 50.82 ± 10.48 years in the conventional group and 54.46 ± 8.91 years in the modified group ($P = 0.065$). There were 35 men and 22 women in the conventional group and 27 men and 19 women in the modified group, with no significant difference in sex distribution ($P = 0.780$). BMI was 24.52 ± 3.12 kg/m² in the conventional group and 24.09 ± 2.22 kg/m² in the modified group ($P = 0.429$). Education level was also comparable between the two groups (10.93 ± 3.43 vs. 10.96 ± 2.65 years, $P = 0.965$).

3.2 Preoperative fracture characteristics and baseline pain

Preoperative fracture characteristics and baseline pain variables were comparable between the two groups, with no significant differences in preoperative VAS score, TLICS score, AO Spine classification, or time from injury to surgery (Table 2).

Table 2
Preoperative fracture characteristics and baseline pain in the conventional and modified groups

Variable	Conventional group (n = 57)	Modified group (n = 46)	t/χ^2 value	P value
Preoperative VAS score (points, mean ± SD)	6.81 ± 1.50	6.80 ± 1.65	0.059	0.953
TLICS score (points, mean ± SD)	4.91 ± 1.01	4.70 ± 1.36	0.927	0.356
AO classification (A1/A2/A3)	31/15/11	23/14/9	0.248	0.883
Time from injury to surgery (days, mean ± SD)	2.92 ± 1.32	2.69 ± 1.00	0.944	0.348

Note: VAS, visual analogue scale; TLICS, Thoracolumbar Injury Classification and Severity Score; AO, AO Spine thoracolumbar injury classification; SD, standard deviation.

The preoperative VAS score was 6.81 ± 1.50 in the conventional group and 6.80 ± 1.65 in the modified group (P = 0.953). The TLICS score was 4.91 ± 1.01 in the conventional group and 4.70 ± 1.36 in the modified group (P = 0.356). Regarding AO Spine classification, 31, 15, and 11 patients in the conventional group had A1, A2, and A3 injuries, respectively, compared with 23, 14, and 9 patients in the modified group, with no significant difference in distribution (P = 0.883). Time from injury to surgery was 2.92 ± 1.32 days in the conventional group and 2.69 ± 1.00 days in the modified group (P = 0.348).

3.3 Intraoperative parameters and screw-related radiographic outcomes

Comparison of intraoperative parameters and screw-related radiographic outcomes showed that operative time was shorter and the incidence of facet joint violation was lower in the modified group than in the conventional group. No significant differences were observed in intraoperative blood loss or pedicle screw misplacement between the two groups (Table 3).

Table 3
Intraoperative parameters and screw-related radiographic outcomes

Variable	Conventional group (n = 57)	Modified group (n = 46)	t/χ^2 value	P value
Operative time (min, mean ± SD)	80.91 ± 16.72	74.30 ± 14.80	2.097	0.039
Intraoperative blood loss (mL, mean ± SD)	89.25 ± 28.04	81.42 ± 18.33	1.633	0.106
Facet joint violation (FJV) [n (%)]	14 (24.6)	1 (2.2)	10.254	0.001
Pedicle screw misplacement (grade C–E) [n (%)]	6 (10.5)	1 (2.2)	2.804	0.094

Note: FJV, facet joint violation; SD, standard deviation. Pedicle screw misplacement was defined as the presence of at least one Gertzbein–Robbins grade C–E screw on postoperative CT at the patient level. In this cohort, no grade E screw was observed.

Operative time was significantly shorter in the modified group than in the conventional group (74.30 ± 14.80 min vs. 80.91 ± 16.72 min, P = 0.039). Intraoperative blood loss was 81.42 ± 18.33 mL in the modified group and 89.25 ± 28.04 mL in the conventional group, with no significant difference between groups (P = 0.106).

For screw-related radiographic outcomes, the incidence of FJV was significantly lower in the modified group than in the conventional group [2.2% (1/46) vs. 24.6% (14/57), P = 0.001]. The incidence of pedicle screw misplacement was 2.2% (1/46) in the modified group and 10.5% (6/57) in the conventional group, but the difference did not reach statistical significance (P = 0.094).

3.4 Postoperative pain and recovery outcomes

Postoperative pain and early recovery outcomes showed that the modified group had a lower incidence of immediate severe postoperative pain, lower maximum VAS score within 0–6 h, lower VAS score on postoperative day 3, shorter time to first ambulation, and shorter hospital stay than the conventional group (Table 4).

Table 4
Postoperative pain and early recovery outcomes

Variable	Conventional group (n = 57)	Modified group (n = 46)	t/χ^2 value	P value
Immediate severe postoperative pain [n (%)]	18 (31.6)	3 (6.5)	9.847	0.002
Maximum VAS score within 0–6 h after surgery (points, mean ± SD)	6.36 ± 1.65	3.43 ± 1.18	10.116	< 0.001
VAS score at postoperative day 3 (points, mean ± SD)	4.41 ± 1.44	2.48 ± 0.92	7.882	< 0.001
Time to first ambulation after surgery (days, mean ± SD)	2.64 ± 0.97	1.58 ± 0.51	6.695	< 0.001
Length of hospital stay (days, mean ± SD)	7.62 ± 1.82	5.20 ± 1.04	8.029	< 0.001

Note: Immediate severe postoperative pain was defined as a maximum VAS score ≥ 7 within 0–6 h after surgery. VAS, visual analogue scale; SD, standard deviation.

The incidence of immediate severe postoperative pain was significantly lower in the modified group than in the conventional group [6.5% (3/46) vs. 31.6% (18/57), P = 0.002]. The maximum VAS score within 0–6 h after surgery was also significantly lower in the modified group than in the conventional group (3.43 ± 1.18 vs. 6.36 ± 1.65, P < 0.001). Similarly, the VAS score on postoperative day 3 was lower in the modified group than in the conventional group (2.48 ± 0.92 vs. 4.41 ± 1.44, P < 0.001).

Regarding early recovery outcomes, time to first ambulation was shorter in the modified group than in the conventional group (1.58 ± 0.51 days vs. 2.64 ± 0.97 days, P < 0.001). Length of hospital stay was also shorter in the modified group than in the conventional group (5.20 ± 1.04 days vs. 7.62 ± 1.82 days, P < 0.001).

3.5 Logistic regression analysis of factors associated with immediate severe postoperative pain

To evaluate the association between the modified technique and immediate severe postoperative pain, two logistic regression models were constructed (Table 5, Fig. 5). In Model 1, after adjustment for preoperative VAS score, the modified technique was associated with a lower risk of immediate severe postoperative pain compared with the conventional technique (OR = 0.141, 95% CI: 0.038–0.529, P = 0.004). Preoperative VAS score showed a positive but statistically non-significant association with immediate severe postoperative pain in Model 1 (OR = 1.376, 95% CI: 0.964–1.965, P = 0.079).

Table 5
Logistic regression models for immediate severe postoperative pain

Variable	Model 1 OR	95% CI	P value	Model 2 OR	95% CI	P value
Modified group vs conventional group	0.141	0.038–0.529	0.004	0.214	0.053–0.864	0.030
Preoperative VAS score	1.376	0.964–1.965	0.079	1.509	1.020–2.233	0.040
FJV, yes vs no	—	—	—	4.391	1.166–16.538	0.029
Pedicle screw misplacement, yes vs no	—	—	—	3.706	0.569–24.143	0.171

Note: Model 1 included treatment group and preoperative VAS score. Model 2 additionally included facet joint violation and pedicle screw misplacement. FJV, facet joint violation; VAS, visual analogue scale; OR, odds ratio; CI, confidence interval.

In Model 2, after further adjustment for FJV and pedicle screw misplacement, the modified technique remained associated with a lower risk of immediate severe postoperative pain (OR = 0.214, 95% CI: 0.053–0.864, P = 0.030). Higher preoperative VAS score was associated with an increased risk of immediate severe postoperative pain (OR = 1.509, 95% CI: 1.020–2.233, P = 0.040). FJV was also associated with immediate severe postoperative pain (OR = 4.391, 95% CI: 1.166–16.538, P = 0.029). Pedicle screw misplacement showed a positive but statistically non-significant association after adjustment (OR = 3.706, 95% CI: 0.569–24.143, P = 0.171).

3.6 Interobserver agreement

Interobserver agreement was assessed for the TLICS score, AO Spine classification, FJV, and pedicle screw misplacement. The results showed good to almost perfect agreement for all evaluated variables (Table 6).

Table 6
Interobserver agreement for radiographic and clinical classification variables

Imaging/Clinical Indicator	Statistical Method	Consistency Coefficient	95% CI	P value	Interpretation
TLICS score	ICC	0.892	0.845–0.931	< 0.001	Good
AO classification	Weighted kappa	0.824	0.756–0.892	< 0.001	Almost perfect
Facet joint violation	Cohen's kappa	0.856	0.782–0.930	< 0.001	Almost perfect
Pedicle screw misplacement	Cohen's kappa	0.812	0.710–0.914	< 0.001	Almost perfect

Note: TLICS, Thoracolumbar Injury Classification and Severity Score; AO, AO Spine thoracolumbar injury classification; ICC, intraclass correlation coefficient; CI, confidence interval. Interobserver agreement for TLICS score was assessed using ICC, AO classification was assessed using weighted kappa, and binary variables were assessed using Cohen's kappa.

The ICC for the TLICS score was 0.892 (95% CI: 0.845–0.931, P < 0.001). The weighted kappa value for AO Spine classification was 0.824 (95% CI: 0.756–0.892, P < 0.001). The Cohen's kappa values for FJV and pedicle screw misplacement were 0.856 (95% CI: 0.782–0.930, P < 0.001) and 0.812 (95% CI: 0.710–0.914, P < 0.001), respectively.

4 Discussion

In this retrospective before-and-after cohort study of 103 patients with single-segment AO Spine type A thoracolumbar fractures treated with PPSF, the modified percutaneous pedicle screw placement technique was associated with a lower incidence of immediate severe postoperative pain, lower maximum VAS score within 0–6 h after surgery, lower VAS score on postoperative day 3, and shorter time to first ambulation and hospital stay. The modified technique was also associated with a lower incidence of FJV. In the fully adjusted logistic regression model, the modified technique remained associated with a lower risk of immediate severe postoperative pain, whereas higher preoperative VAS score and FJV were associated with increased risk. Pedicle screw misplacement showed a positive but statistically non-significant association after adjustment. These findings suggest that immediate postoperative pain after PPSF may be related not only to preoperative pain status but also to screw trajectory, facet joint involvement, and implant-related mechanical irritation.

4.1 Immediate postoperative pain and the modified technique

Although PPSF is widely used for thoracolumbar fractures because of its minimally invasive advantages, early postoperative pain is not completely avoided. Previous comparative evidence has shown that

percutaneous fixation can reduce intraoperative blood loss, postoperative pain, and hospital stay compared with conventional open posterior fixation in selected patients with type A thoracolumbar fractures [20]. However, most previous studies have focused on perioperative outcomes, screw accuracy, radiographic reduction, and mid-term functional recovery [3, 21]. The present study specifically focused on immediate severe pain within the first 0–6 h after surgery.

Pain within this early window is close to anesthetic recovery and may reflect the combined effects of surgical stimulation, implant-related mechanical irritation, early analgesic efficacy, and preexisting pain sensitization. Severe low back pain during this period may interfere with turning over, early bedside activity, brace-assisted ambulation, and patients' perceived surgical recovery. Therefore, the maximum VAS score within 0–6 h may help capture the earliest postoperative pain burden and identify potentially modifiable technical factors.

The modified technique in this study consisted of several coordinated refinements, including lateralized skin incision, lateralized puncture entry point, screw length optimization, screw-tail space preservation, rod-position adjustment, and deep soft-tissue release. These steps were designed to reduce potential mechanical irritation of the facet joint, screw tail, connecting rod, paraspinal muscles, and fascia. Notably, the modified technique remained associated with a lower risk of immediate severe postoperative pain even after adjustment for preoperative VAS score, FJV, and pedicle screw misplacement. This suggests that the lower early pain burden observed in the modified group may not be explained solely by baseline pain differences or screw-related radiographic variables. Other factors, such as screw-tail space preservation, rod-position optimization, and reduction of deep soft-tissue entrapment, may also be involved.

The shorter time to first ambulation and hospital stay observed in the modified group should be interpreted as supportive secondary findings rather than direct effects of the modified technique. These outcomes may be partly related to lower early pain intensity but may also be affected by rehabilitation workflow, nursing practice, discharge policy, patient preference, and time-period-related management factors. Because the modified technique consisted of multiple components, this study could not determine the independent contribution of each component.

4.2 FJV and screw-related factors

FJV appeared to be an important technical factor associated with immediate severe postoperative pain. In this study, the incidence of FJV was significantly lower in the modified group than in the conventional group, and FJV remained associated with immediate severe postoperative pain in the fully adjusted model. This supports the hypothesis that facet joint involvement may represent an important technical correlate of early pain after PPSF.

FJV is a recognized technique-related issue during posterior pedicle screw placement. Archavlis et al. reported that the rate of superior facet joint violation differed according to screw insertion technique and surgical approach [22]. Herren et al. also showed that FJV may occur during both open and minimally

invasive pedicle screw placement in trauma patients [23]. Because the facet joint is richly innervated by capsular, synovial, and dorsal ramus-related neural structures, violation or mechanical irritation of this region may induce capsular traction, articular surface irritation, local inflammatory responses, or dorsal ramus stimulation, thereby contributing to early postoperative low back pain.

The modified technique used a more lateralized skin incision and puncture entry point to establish a screw trajectory away from the superior facet joint. In conventional percutaneous screw placement, a relatively medial incision or bony entry point may increase the likelihood that the puncture needle, screw shaft, screw tail, or connecting structure approaches the facet joint. By contrast, defining the intersection between the midline of the transverse process and the lateral border of the superior articular process as the main entry point may help lateralize the screw corridor and reduce facet joint involvement. Although previous studies have linked pedicle screw-associated FJV to adjacent-segment problems [24], the present study focused only on immediate postoperative pain and could not evaluate long-term degenerative consequences.

Pedicle screw misplacement showed a positive but statistically non-significant association with immediate severe postoperative pain after adjustment. Although the point estimate suggested a potentially increased risk, the confidence interval was wide and crossed 1, indicating substantial uncertainty. Although pedicle screw misplacement was not statistically significant in the fully adjusted model, pedicle cortical breach or trajectory deviation may anatomically irritate the periosteum, paraspinal soft tissues, nerve roots, or dural sac. Previous evidence has shown that screw accuracy varies among placement techniques [25], and robot-assisted systems may improve pedicle screw accuracy in selected settings [13]. Medial pedicle breach has also been associated with neurological deficit risk, particularly when the breach is large [26]. However, because the number of misplacement events was small in this cohort, the present data do not support pedicle screw misplacement as an independent risk factor. Larger studies with screw-level and trajectory-specific analyses are needed.

4.3 Preoperative pain status

Preoperative pain status also appeared to be relevant to immediate severe postoperative pain. In the fully adjusted model, higher preoperative VAS score was associated with increased risk. In patients with thoracolumbar fractures, higher preoperative VAS score may reflect more severe fracture-related nociceptive input, paraspinal muscle spasm, local soft-tissue injury, and pain sensitization. These factors may increase susceptibility to surgical stimulation, implant-related traction, and local soft-tissue compression after recovery from anesthesia.

Previous studies have identified preoperative pain intensity as an important predictor of poor postoperative pain control [6, 27]. Pain-related psychological factors, including anxiety, depression, pain catastrophizing, sleep disturbance, and individual pain sensitivity, may also influence acute and persistent postsurgical pain outcomes [28]. However, psychological factors, sleep quality, and pain sensitivity were not systematically assessed in the present study. Therefore, preoperative VAS score

should be considered a clinically relevant pain-related marker rather than a comprehensive measure of pain vulnerability.

4.4 Clinical implications

The findings of this study suggest that prevention of immediate severe postoperative pain after PPSF should not rely solely on postoperative analgesic medications. Technical refinement aimed at minimizing FJV, optimizing screw trajectory, preserving screw-tail–facet joint space, avoiding excessive screw-tail irritation, and reducing deep soft-tissue entrapment may also be clinically relevant. Previous comparative evidence in type A thoracolumbar fractures has supported PPSF as a safe and effective minimally invasive option [20]. The present study further suggests that technical details within PPSF itself may also be relevant to early postoperative pain.

Compared with navigation- or robot-assisted techniques, the modified technique described in this study mainly relies on conventional CT-based planning, C-arm fluoroscopy, and anatomical landmarks. Therefore, it may be feasible in clinical settings where advanced navigation systems are not routinely available. This does not reduce the value of navigation or robotic systems, but suggests that technical refinement under conventional fluoroscopy remains clinically meaningful.

4.5 Limitations

This study has several limitations. First, this was a single-center retrospective before-and-after cohort study. The conventional and modified groups were treated during different time periods rather than concurrently or randomly assigned. Therefore, unmeasured time-period effects, changes in perioperative workflow, and learning-curve effects could not be fully excluded. Although surgical indications, perioperative pathways, analgesic protocols, rehabilitation criteria, and radiographic assessment procedures were kept consistent throughout the study period, these measures cannot replace randomization.

Second, the sample size was relatively limited, and the number of immediate severe postoperative pain events was small, especially in the modified group. The number of pedicle screw misplacement events was also small, resulting in a wide confidence interval and limited statistical power to determine its independent association with immediate severe postoperative pain. Given the limited number of events, we used a parsimonious multivariable modeling strategy to reduce the risk of overfitting, but the identified associations should still be considered exploratory.

Third, the modified technique consisted of multiple components, including lateralized incision placement, lateralized puncture entry point, screw length optimization, screw-tail space preservation, rod-position adjustment, and deep soft-tissue release. This study could not determine the independent contribution of each component to postoperative pain improvement. Detailed rescue analgesic consumption was not completely available for all patients and therefore could not be quantitatively compared between groups. In addition, psychological factors, pain catastrophizing, sleep quality, and individual pain sensitivity were not systematically evaluated.

Finally, long-term follow-up data were not available. Therefore, the effects of the modified technique on long-term low back pain, adjacent-segment degeneration, implant failure, and functional recovery remain unknown. FJV and pedicle screw misplacement were analyzed at the patient level, which did not allow evaluation of screw-level, segment-level, trajectory-specific, or breach-direction-specific factors. Future prospective multicenter studies with larger sample sizes, detailed analgesic data, quantitative trajectory measurements, and longer follow-up are needed to validate these findings.

5. Conclusion

In this retrospective before-and-after cohort study, the modified percutaneous pedicle screw placement technique was associated with a lower early postoperative pain burden and a lower incidence of FJV in patients with single-segment AO Spine type A thoracolumbar fractures treated with PPSF. In the fully adjusted model, the modified technique remained associated with a lower risk of immediate severe postoperative pain, whereas higher preoperative VAS score and FJV were associated with increased risk. Pedicle screw misplacement showed a positive but statistically non-significant association after adjustment. These exploratory findings require validation in larger prospective multicenter studies.

Abbreviations

PPSF
Percutaneous pedicle screw fixation
VAS
Visual analogue scale
FJV
Facet joint violation
CT
Computed tomography
MRI
Magnetic resonance imaging
TLICS
Thoracolumbar Injury Classification and Severity Score
BMI
Body mass index
ICC
Intraclass correlation coefficient
OR
Odds ratio
CI
Confidence interval
SD
Standard deviation

IQR
Interquartile range
SPSS
Statistical Package for the Social Sciences
AO Spine
AO Spine thoracolumbar injury classification

Declarations

Clinical trial number
Not applicable.

Ethics approval and consent to participate
This retrospective study was conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments. The study protocol was reviewed and approved by the Ethics Committee of the Affiliated 960th Hospital of the PLA (Approval No. 2025084). Given the retrospective design and the use of anonymized clinical data, the requirement for written informed consent was waived by the Ethics Committee of the Affiliated 960th Hospital of the PLA in accordance with relevant national regulations.

Consent for publication
Not applicable. This study was a retrospective analysis using anonymized clinical data, and no individual patient-identifiable information is included in this publication.

Availability of data and materials
The datasets generated and/or analyzed during the current study are not publicly available due to institutional regulations regarding patient data confidentiality, but are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

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Authors' contributions

Zheng Zhang and Xin Xu contributed equally to this study as co-first authors. Zheng Zhang, Xin Xu, and Fuxin Wang participated in study design, data collection, and statistical analysis, and were major contributors to manuscript drafting. Ang Li, Kun Wang, and Junlin Han were responsible for clinical data management, imaging measurements, and figure preparation. Ruoxian Song supervised the entire

research process, critically revised the manuscript for important intellectual content, and approved the final version for submission. All authors read and approved the final manuscript.

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Figures

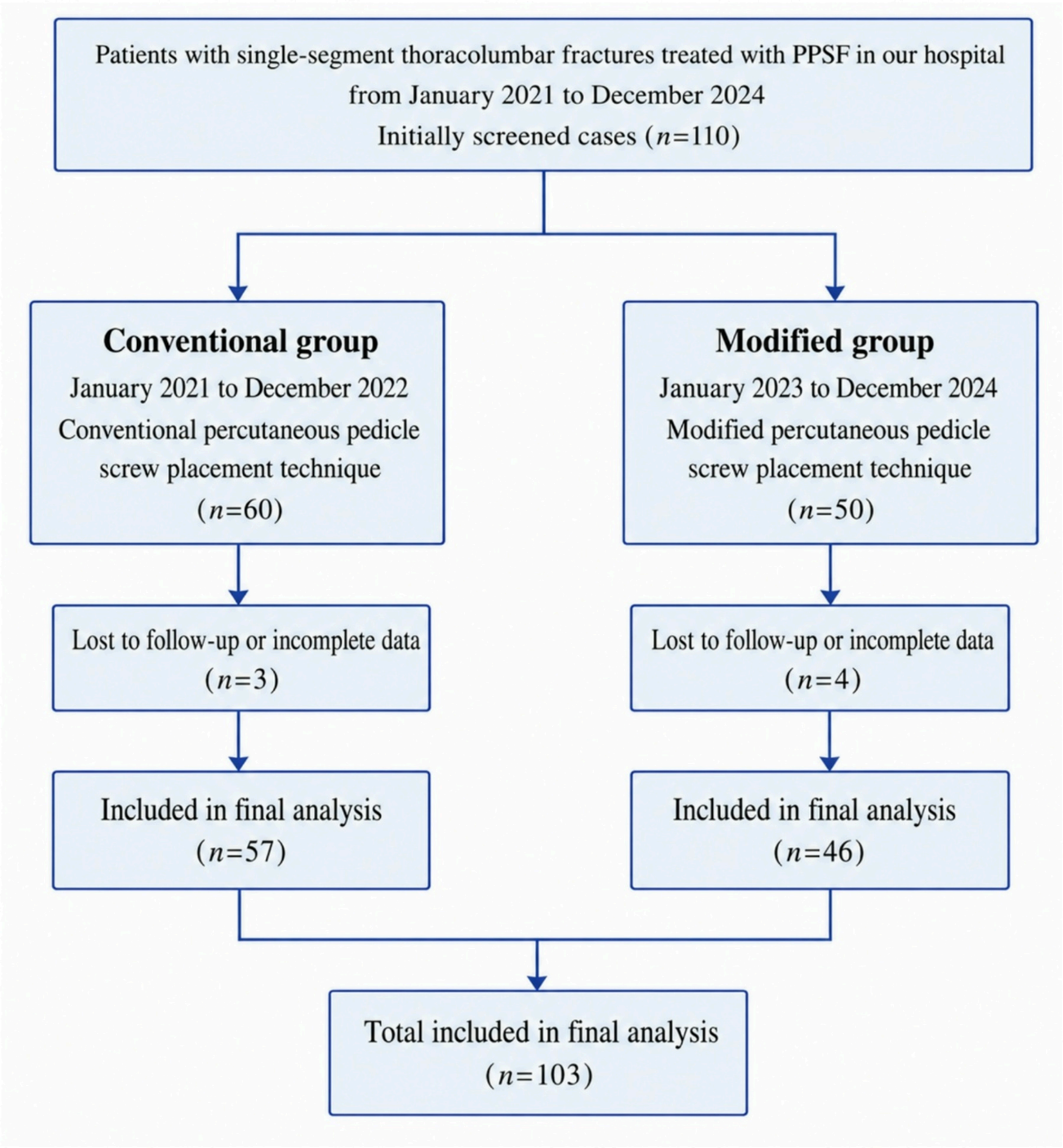


Figure 1

Flowchart of patient selection and group allocation.

A total of 110 patients with single-segment thoracolumbar fractures treated with percutaneous pedicle screw fixation were initially screened. After excluding 7 patients because of loss to follow-up or incomplete key clinical or radiographic data, 103 patients were included in the final analysis, including 57 patients in the conventional group and 46 patients in the modified group. PPSF, percutaneous pedicle screw fixation.

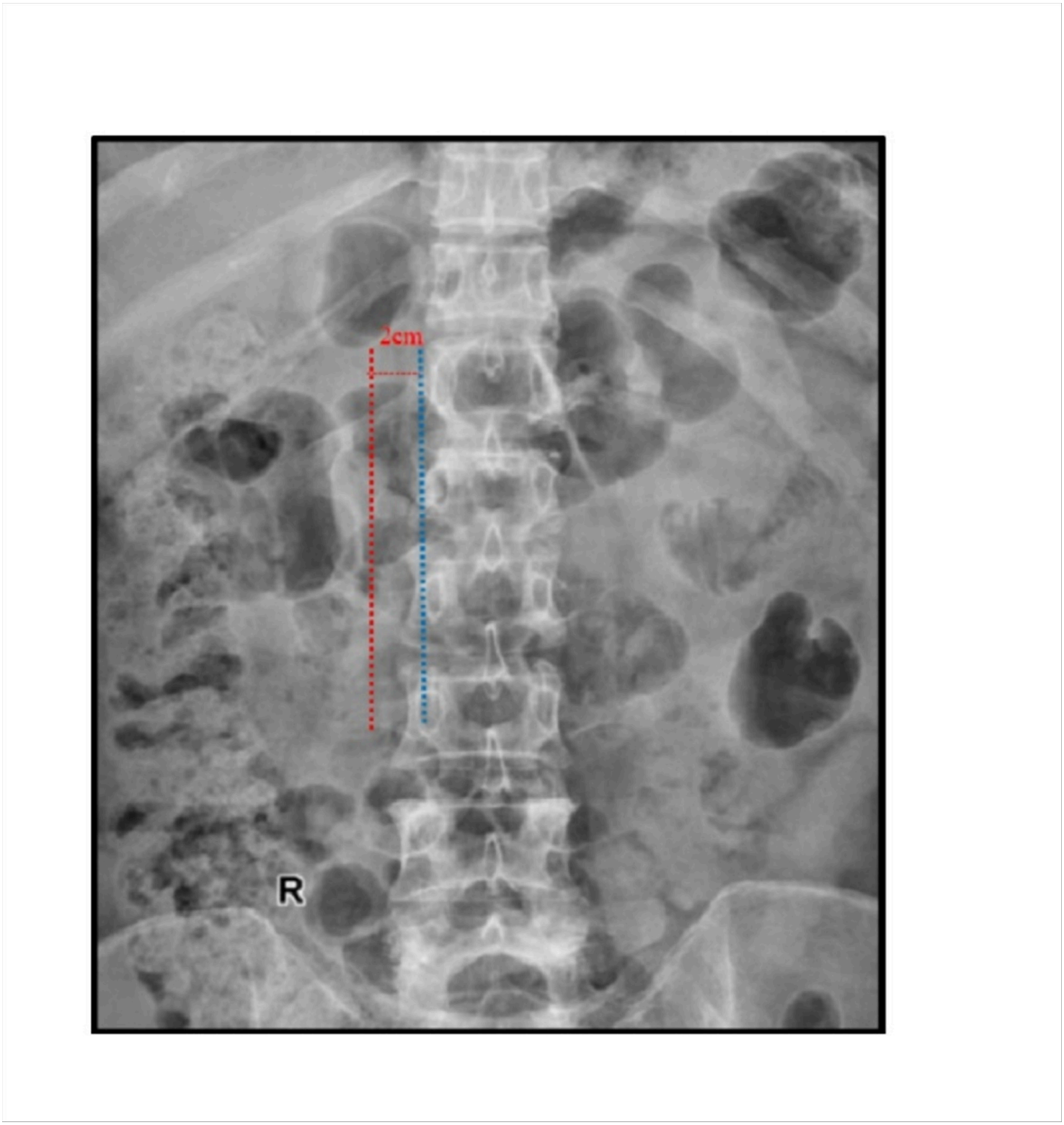


Figure 2

Modified skin incision design.

The blue dashed line represents the conventional incision reference line along the lateral border of the pedicle projection, whereas the red dashed line represents the modified incision reference line, which was approximately 2 cm lateral to the conventional line. The modified incision was positioned to obtain a more lateralized puncture trajectory during percutaneous pedicle screw placement.

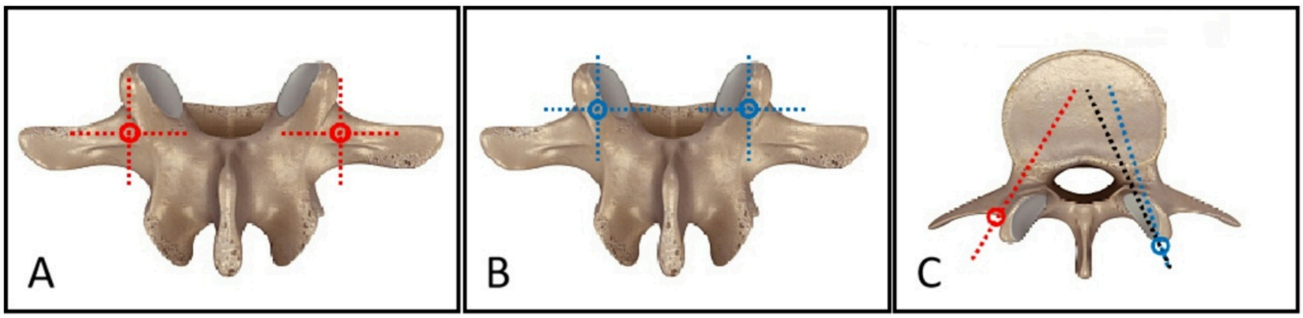


Figure 3

Comparison of puncture entry points between the modified and conventional percutaneous pedicle screw placement techniques.

A: In the modified technique, the puncture entry point was defined as the intersection between the midline of the transverse process and the lateral border of the superior articular process.

B: In the conventional technique, the entry point was selected at the apex of the “herringbone crest.”

C: In panel C, the red line indicates the lateralized trajectory of the modified technique, the blue line indicates the relatively medial trajectory of the conventional technique, and the black line indicates a trajectory with potential risk of medial pedicle wall breach. FJV, facet joint violation.

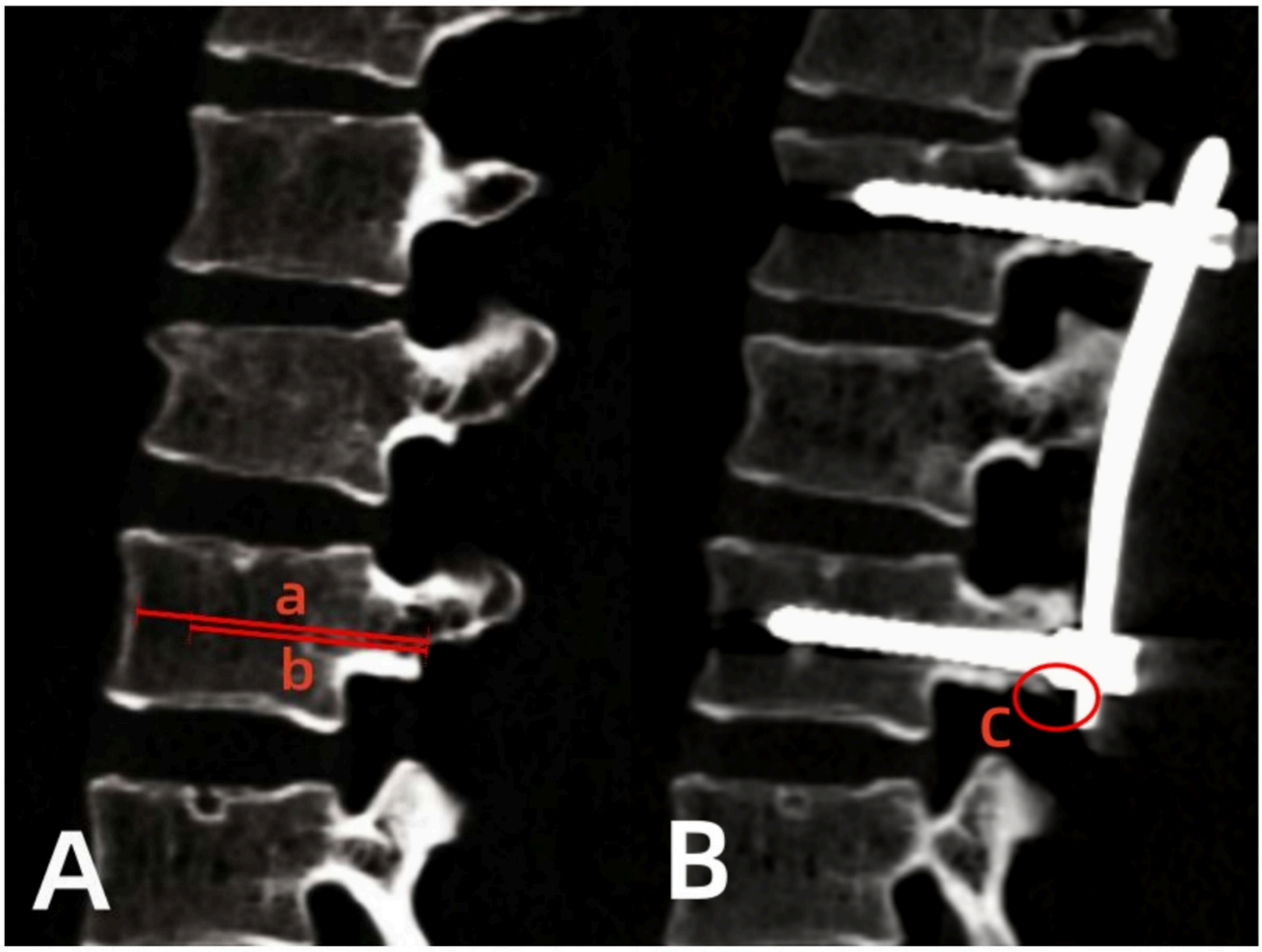


Figure 4

Screw length selection and screw-tail space control in the modified percutaneous pedicle screw placement technique.

A: Preoperative sagittal CT measurement of the effective pedicle–vertebral bony corridor length. “a” indicates the effective bony corridor length along the planned screw trajectory, and “b” indicates the planned screw length, which was approximately 80% of the effective bony corridor length.

B: Postoperative sagittal CT image showing screw placement. “c” indicates the reserved screw-tail space between the screw tail and the adjacent facet joint.

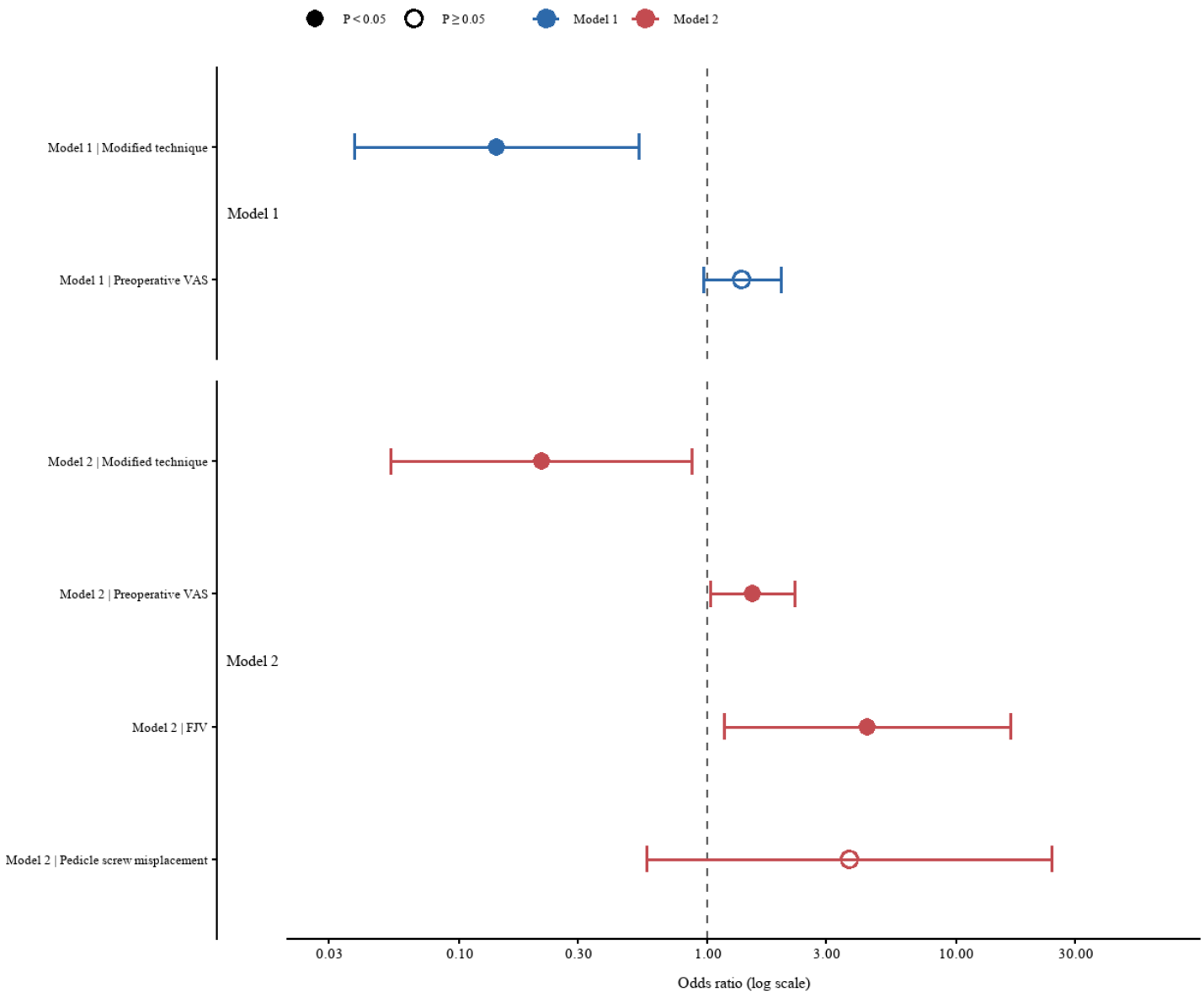


Figure 5

Forest plot of logistic regression models for immediate severe postoperative pain.

Model 1 included treatment group and preoperative VAS score. Model 2 additionally included facet joint violation and pedicle screw misplacement. Dots indicate odds ratios, horizontal lines indicate 95% confidence intervals, and the dashed vertical line indicates an odds ratio of 1. FJV, facet joint violation; VAS, visual analogue scale; OR, odds ratio; CI, confidence interval.