Article

Clinical Effectiveness of Minimally Invasive Surgery on Spinal Trauma

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AIM: Minimally invasive spinal trauma surgery includes percutaneous pedicle screw fixation and miniature open anterolateral retractor-based approaches, which can improve surgical outcomes by reducing blood loss, operative time, and postoperative pain. Therefore, this study aimed to evaluate the effect of minimally invasive surgery on pain scores, functional recovery, and postoperative complications in patients with spinal trauma.

METHODS: This retrospective study included 100 spinal trauma patients treated in Suzhou Hospital of Integrated Traditional Chinese and Western Medicine between May 2019 and May 2022. Patients who underwent traditional open surgery were included in the traditional group, and those who received percutaneous pedicle screw internal fixation combined with posterior minimally invasive small incision decompression were included in the research group, each comprising 50 patients. The effectiveness of these two surgical approaches was determined by assessing their outcome measures, including surgery-related indices, postoperative pain, spinal morphology, functional recovery, and postoperative complications.

RESULTS: Minimally invasive surgery was associated with significantly shorter surgical wounds, length of hospital stay, operative time, and postoperative time-lapse before off-bed activity, and less intraoperative hemorrhage volume and postoperative drainage volume compared to open surgery ($p < 0.001$). Compared to open surgery, patients with minimally invasive surgery showed significantly lower visual analogue scale (VAS) scores at 3 days, 3 months, and 6 months after surgery and lower Oswestry dysfunction index (ODI) at 7 days and 3 months after surgery ($p < 0.05$). Furthermore, the difference in the spine morphology between the two arms did not achieve statistical significance ($p > 0.05$). Additionally, minimally invasive surgery resulted in a significantly lower incidence of postoperative complications than open surgery ($p < 0.05$).

CONCLUSIONS: Minimally invasive surgery causes less surgical damage for patients with spinal trauma, improves surgery-related indexes, alleviates postoperative pain, and provides better morphological and functional recovery of the spine.

Keywords: minimally invasive surgery; spinal trauma; pain; functional recovery; complications

Introduction

Spinal trauma is an external injury affecting the spine, resulting in pain, swelling, and limited spinal movement. It accounts for 5–6% of all traumatic injuries and poses a higher risk of disability [1, 2]. Traumatic spine fractures predominantly (60–70%) occur in the thoracolumbar region, typically at the T11 or L2 level due to biomechanical vulnerabilities. X-rays are essential after spinal trauma to evaluate the extent of injury. In the event of a spinal fracture with a spinal compression fracture greater than 1/2 the height of the vertebral body spinal instability and symptoms such as nerve injury, surgical treatment is mostly indicated. Delayed treatment often leads to spinal deformity, spinal stenosis, and myelitis, substantially impacting mobility and compromising the daily life of the patient [3].

Surgical intervention is clinically effective in achieving neurological tissue decompression, spinal reconstruction and stabilization, and restoration of intersegmental volume [3]. However, open surgery is associated with substantial surgical trauma, extensive intraoperative bleeding, increased risk of various complications, and reduced postoperative recovery [4]. Additionally, patients may experience poor postoperative spinal stability, and simple screw fixation often fails to provide long-term support for the injured spine, which can delay fracture healing.

With advancements in medical technology, minimally invasive techniques have received significant clinical attention because of their ability to reduce paravertebral tissue injury during surgery [4]. Posterior percutaneous minimally invasive pedicle screw internal fixation has become increasingly popular for the treatment of spinal fractures. Research reveals that percutaneous pedicle screw fixation significantly

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improves biomechanical strength and offers greater internal fixation stability, thereby facilitating early ambulation for the patient [5]. The approach restores the height of the anterior column of the injured vertebra, effectively improves kyphosis, and prevents the straining and over-extension of the upper and lower intervertebral discs during internal fixation. Minimally invasive percutaneous pedicle screw fixation, combined with injured spine nailing, improves surgical indices, pain relief, and the ratio of injured spine Cobb angle to anterior margin height [5, 6]. Wänman *et al.* [7] reported that minimally invasive surgery provides sufficient surgical stability for fracture healing and results in an acceptable number of complications, making it an appropriate option for treating spinal fractures associated with ankylosing spondylitis. However, there is limited research on the impact of minimally invasive surgery on patients with spinal trauma.

Therefore, the present study aimed to assess the effect of minimally invasive surgery on pain scores, functional recovery, and postoperative complications in patients with spinal trauma.

Materials and Methods

Study Participants

In this retrospective study, data from 105 spinal trauma patients treated in Suzhou Hospital of Integrated Traditional Chinese and Western Medicine between May 2019 and May 2022 were collected. After initial screening, 100 patients were included in the final analysis. Patients who underwent traditional open surgery were included in the traditional group, and those who received percutaneous pedicle screw internal fixation combined with posterior minimally invasive small incision decompression were placed in the research group, with 50 individuals in each group.

Ethical approval was granted by the Ethics Committee of Suzhou Hospital of Integrated Traditional Chinese and Western Medicine (ethical approval number: TC890234), and the study design followed the Declaration of Helsinki. Informed consent was waived, and all patient information was anonymized and de-identified to ensure patient privacy and confidentiality. Additionally, strict measures were followed to protect patient confidentiality throughout the study.

Inclusion and Exclusion Criteria

The inclusion criteria for this study were as follows: (1) Patients diagnosed with spinal trauma based on clinical symptoms, signs, and imaging indexes. (2) Patients whose diagnosis aligns with the criteria for thoracolumbar vertebral body fracture as outlined in the Diagnosis and Treatment of Lumbar Spine Injuries, regardless of sex, including radiographic evidence of vertebral body fracture in the thoracolumbar region, localized pain and tenderness in the thoracolumbar spine, restricted range of motion and difficulty in performing spinal movements, and neurological symptoms such as numbness, tingling, or weakness in the lower extremities [8]. (3) Patients without contraindications to the relevant treatment and with normal coagulation function. (4) Patients with a clear history of spinal trauma without evident spinal cord compression. (5) Patients whose limb fracture block is not substantially subluxated. (6) Those with detailed medical records.

Furthermore, exclusion criteria were set as follows: (1) Spinal dislocation, incomplete articular prominence, or rupture of the vertebral arch. (2) Patients with malignant tumor or severe systemic organ disease. (3) Those with osteoporosis, systemic infection, or lumbar spinal stenosis. (4) Patients with a history of previous spinal trauma. (5) Those with pathological fractures observed on imaging. (6) Time from fracture to surgery $\geq$2 weeks. (7) Those with severe organ dysfunction. (8) Patients with incomplete data.

The patients were clinically diagnosed following previously reported diagnostic criteria [9], which indicated that patients had an modified American Spinal Injury Association Impairment Scale (mcSCI) at or above the T10 neurological level, as confirmed by the International Standards for Neurological Classification of SCI examination. A flow chart of the data collection procedure is illustrated in Fig. 1.

Treatment Procedure

Patients in the traditional group received conventional open surgery. The procedure was conducted under general anesthesia with tracheal intubation, with the patient in a prone position, and a soft pillow was placed under the chest and iliac bones to suspend the abdomen. Subsequently, routine preoperative disinfection and draping were performed. A longitudinal incision of approximately 10–12 cm was made in the center of the spine. The paraspinal tissue was separated, and pedicle screws and screw systems were placed for incisional repositioning and fixation. The spinous process and posterior ligamentous complex were preserved, and the lamina and spinal canal were decompressed unilaterally or bilaterally. After this, bone grafting was done, and transverse connections were placed in the incision, followed by hemostasis, irrigation, and retention of drains. Finally, the incision was then closed layer by layer.

In the research group, patients underwent percutaneous internal fixation with pedicle screws and posterior minimally invasive small incision decompression. The preoperative preparations were identical for both groups. A 4–5 cm incision was made in the posterior midline of the decompressed segment to separate the soft tissue immediately adjacent to the spinous process and preserve the spinous process and ligaments. A small amount of the lamina and the inner edge of the pedicle were resected to expose the decompression area. After this, percutaneous pedicle screws were placed under x-ray fluoroscopic guidance. With neurological monitoring, the fixation rod was placed into the spinal canal. Once decompression was confirmed, a bone graft was placed on the connecting rod for internal fixation, and

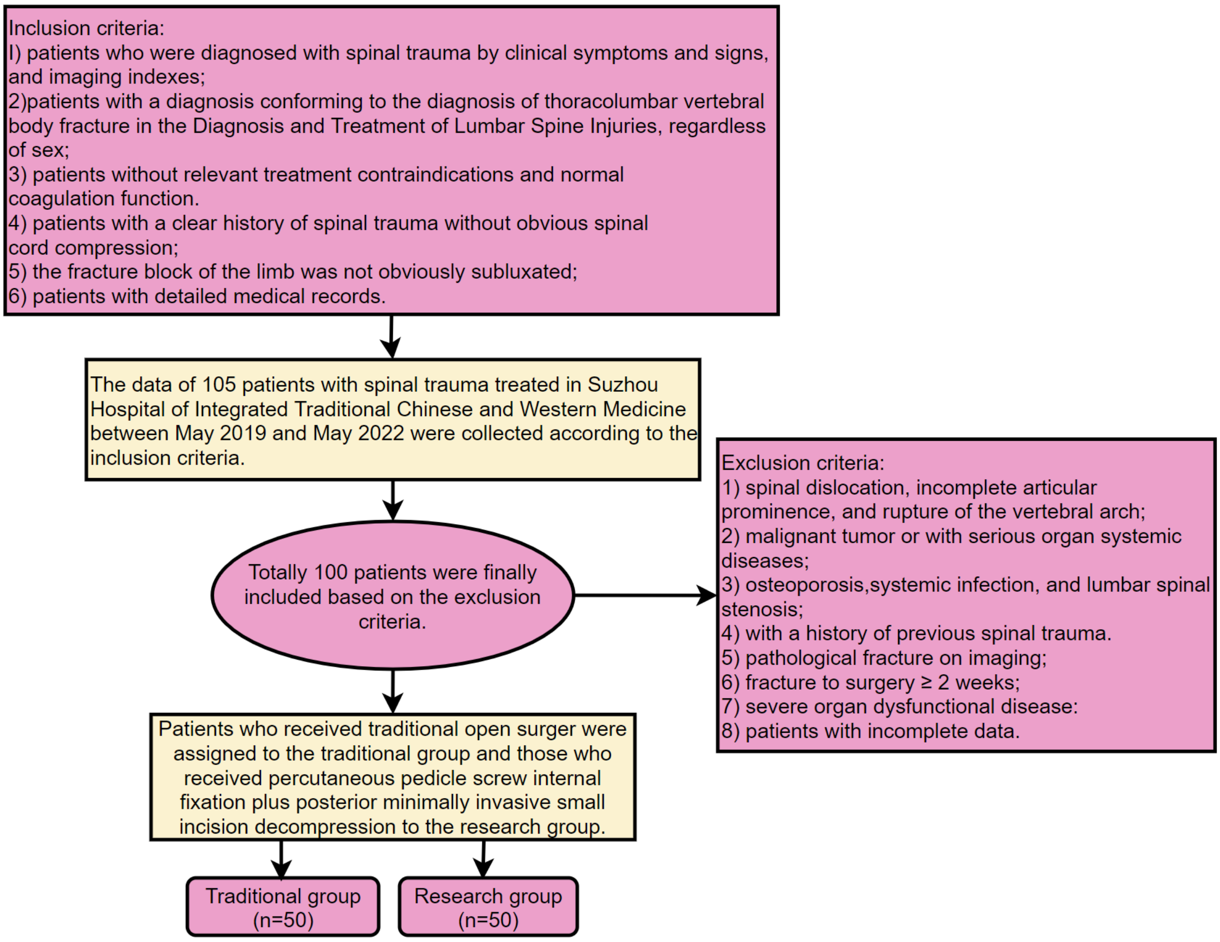

Fig. 1. A flow chart of the data collection procedure.

the fixation rod was positioned on the other side. After fluoroscopic confirmation of a good screw position, the screw was reset and fixed, then placed through an incision in the horizontal joint, followed by hemostasis, saline irrigation, and placement of a drainage tube. Finally, the procedure was completed with suturing [10].

Outcome Measures

The outcome measures were assessed as follows:
(1) The baseline patient profiles were collected.
(2) Surgery-related indices for all patients were recorded, including incision length, operative time, intraoperative bleeding, postoperative drainage, the time before postoperative bed activities, and hospitalization duration.
(3) The pain visual analogue scale (VAS) scale [11] was used to evaluate the pain of patients before treatment, 3 days after treatment, 3 months after treatment, and 6 months after treatment. The scale scores ranged from 0–10, with a score of $\leq$3 indicating mild pain, 4–6 indicating moderate pain (significant pain but tolerable), and $\geq$7 indicating severe and intolerable pain. Higher scores indicated more severe pain.
(4) Patients' anterior vertebral body height (the ratio of the height of the anterior edge of the injured vertebral body to that of the normal vertebra) and the posterior convexity Cobb's angle were recorded before and after treatment. Cobb's angle is a perpendicular line drawn from the lower endplate line of the injured vertebra to the upper endplate of the superior vertebra.
(5) The Oswestry dysfunction index (ODI) [12] was determined for all patients before treatment, 7 days after treatment, and 3 months after treatment, including the severity of pain, daily living ability, lifting, and walking, with a total of 10 questions scored out of 50. The higher the score, the more severe the functional impairment.
(6) The occurrence of complications, including nerve injury, motor impairment, incisional infection, and traumatic paraplegia, was recorded.

Statistical Analysis

GraphPad Prism 8 (GraphPad Software, Inc., San Diego, CA, USA) was used for image processing, while SPSS 26.0 software (IBM Corp, Armonk, NY, USA) was used to organize and statistically analyze the data. The data were assessed for normality using the Shapiro–Wilk test and all

Table 1. Baseline characteristics of the study participants ($\bar{x} \pm$ s, %).

Variables		Research group	Traditional group	t/χ^2	p-value
n		50	50	-	-
Sex	Male	23 (46.00)	21 (42.00)	0.162	0.687
	Female	27 (24.00)	29 (58.00)		
Age (years)	Mean	40.26 ± 9.61	40.57 ± 9.23	0.165	0.869
AO classification	A1	30 (60.00)	31 (62.00)	0.387	0.824
	A2	13 (26.00)	14 (28.00)		
	A3	7 (14.00)	5 (10.00)		
Fracture site	Lumbar spine	24 (48.00)	25 (50.00)	0.040	0.841
	Thoracic spine	26 (52.00)	25 (50.00)		
Cause of injury	Violence	3 (6.00)	2 (4.00)	0.522	0.914
	Falls	19 (38.00)	18 (36.00)		
	Traffic accidents	23 (46.00)	26 (52.00)		
	Other	5 (10.00)	4 (8.00)		

AO, Arbeitsgemeinschaft für Osteosynthesefragen.

log-transformed variables were found to be normally distributed. Measurement data were expressed as mean ± standard deviation and analyzed using the *t*-test. Statistical data were expressed as percentages (%) and analyzed using the chi-square test. The Friedman's test was used to detect differences across multiple time points within each group. Statistical significance was achieved at a p-value < 0.05.

Results

Baseline Characteristics of the Study Participants

In the research group, there were 23 males and 27 females, aged 20–70 (40.26 ± 9.61) years. Based on Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification, there were 30 cases of A1, 13 cases of A2, and 7 cases of A3. There were 24 cases of fractures at the lumbar spine and 26 cases of fractures at the thoracic spine, 3 cases of violence-induced facture, 19 cases of fall-induced fracture, 23 cases of traffic accident-induced fracture, and 5 cases of other-induced fracture. In the traditional group, there were 21 males and 29 females, aged 20–70 (40.57 ± 9.23) years. Based on AO classification, there were 31 cases of A1, 14 cases of A2, and 5 cases of A3. There were 25 cases of fractures at the lumbar spine and 25 cases of fractures at the thoracic spine, 2 cases of violence-induced facture, 18 cases of fall-induced facture, 26 cases of traffic accident-induced fracture, and 4 cases of other-induced facture. The patient characteristics were balanced between the two groups ($p > 0.05$). The baseline characteristics of the study participants are shown in Table 1.

Surgical Indices

In the research group, patients had an incision length of 6.94 ± 1.15 cm, operative time of 90.12 ± 12.65 minutes, intraoperative bleeding of 80.15 ± 15.56 mL, postoperative drainage of 15.89 ± 2.86 mL, postoperative time-lapse before off-bed activities of 7.88 ± 0.85 weeks, and hospital stay duration of 8.18 ± 1.83 days. In the traditional group, the incision length was 14.25 ± 1.68 cm, operative time was 123.12 ± 15.65 minutes, intraoperative bleeding was 254.14 ± 20.18 mL, postoperative drainage was 149.15 ± 18.14 mL, postoperative time-lapse before off-bed activities was 12.58 ± 1.04 weeks, and hospital stay was 14.52 ± 3.48 days. Compared to open surgery, minimally invasive surgery resulted in significantly shorter surgical wounds, hospital stay, operative time, and postoperative time-lapse before off-bed activity, as well as less intraoperative hemorrhage and postoperative drainage ($p < 0.001$). The surgical indices of the study groups are shown in Table 2.

VAS Scores

In the research group, the VAS score was 7.21 ± 2.18 before treatment, 3.15 ± 1.15 at 3 days after treatment, 1.18 ± 0.94 at 3 months after treatment, and 0.77 ± 0.35 at 6 months after treatment. In the traditional group, the VAS score was 7.24 ± 2.14 before treatment, 5.88 ± 1.45 at 3 days after treatment, 3.74 ± 1.25 at 3 months after treatment, and 1.88 ± 0.94 at 6 months after treatment. Patients who underwent minimally invasive surgery showed significantly lower VAS scores at 3 days, 3 months, and 6 months postoperatively than those who underwent open surgery ($p < 0.05$). The VAS scores for the two groups are depicted in Fig. 2.

Spine Morphology

In the research group, the pre-treatment anterior vertebral body height was 64.52 ± 6.14 and the posterior convex Cobb's angle was 30.16 ± 7.14°. However, after treatment, the anterior vertebral body height was 90.15 ± 3.14, and the posterior convex Cobb's angle was 13.82 ± 3.95°. In the traditional group, the height of the anterior border of the vertebral body was 64.32 ± 6.21 and the posterior convex

Table 2. A comparison of surgical indices between the two groups ($\bar{x} \pm s$).

Variables	Research group (n = 50)	Traditional group (n = 50)	*t*-value	*p*-value
Incision length (cm)	6.94 ± 1.15	14.25 ± 1.68	25.389	<0.001
Operative time (min)	90.12 ± 12.65	123.12 ± 15.65	11.596	<0.001
intraoperative bleeding (mL)	80.15 ± 15.56	254.14 ± 20.18	48.280	<0.001
Postoperative drainage (mL)	15.89 ± 2.86	149.15 ± 18.14	51.312	<0.001
Postoperative time-lapse before off-bed activity (w)	7.88 ± 0.85	12.58 ± 1.04	24.743	<0.001
Hospital stays (d)	8.18 ± 1.83	14.52 ± 3.48	11.402	<0.001

Table 3. Spine morphology of study participants before and after treatment ($\bar{x} \pm s$).

		Research group (n = 50)	Traditional group (n = 50)	*t*-value	*p*-value
Before treatment	Anterior vertebral body height (%)	64.52 ± 6.14	64.32 ± 6.21	0.162	0.872
	Posterior convexity Cobb's angle (°)	30.16 ± 7.14	30.35 ± 6.94	0.135	0.893
After treatment	Anterior vertebral body height (%)	90.15 ± 3.14	89.99 ± 3.22	0.252	0.802
	Posterior convexity Cobb's angle (°)	13.82 ± 3.95	13.59 ± 4.02	0.289	0.773

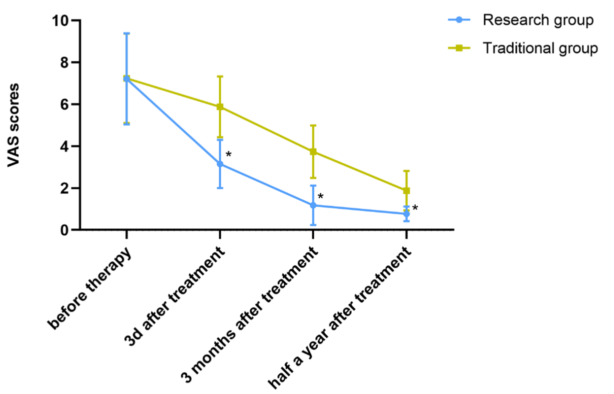

Fig. 2. The VAS scores of the study participants. Patients who underwent minimally invasive surgery had considerably lower VAS scores at 3 days, 3 months, and 6 months after surgery than those who underwent open surgery. Note: * indicates $p < 0.05$. VAS, visual analogue scale.

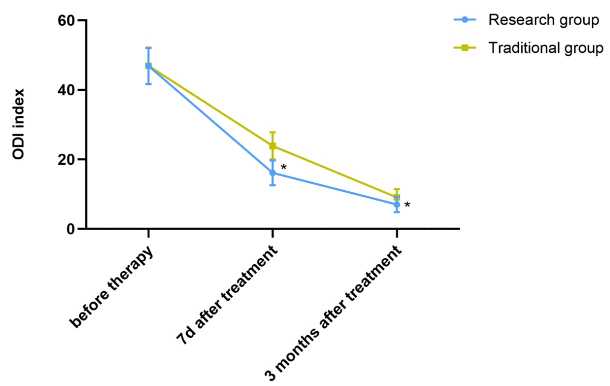

Fig. 3. Functional recovery of the patients. Before treatment, there was no significant difference in functional recovery between the two groups, and the ODI scores after 7 days and 3 months following treatment were significantly lower in the research group compared to the conventional group. Note: * indicates $p < 0.05$; ODI, Oswestry dysfunction index.

Cobb's angle was 30.35 ± 6.94° before treatment. After treatment, the height of the anterior border of the vertebral body was 89.99 ± 3.22 and the posterior convex Cobb's angle was 13.59 ± 4.02°. However, the difference in the spine morphology between the two groups did not achieve statistical significance ($p > 0.05$, Table 3).

Functional Recovery

The ODI for patients in the research group was 46.86 ± 5.16 before treatment, 16.15 ± 3.58 seven days after treatment, and 7.02 ± 2.21 three months after treatment. However, the ODI for patients in the traditional group was 46.91 ± 5.25 before treatment, 23.85 ± 3.94 seven days after treatment, and 9.05 ± 2.37 three months after treatment. The ODI scores at 7 days and 3 months after treatment were substantially lower in the research group than in the traditional group ($p < 0.05$, Fig. 3).

Postoperative Complications

In the research group, there was no case of nerve injury or motor disorders, one case of incisional infection, and no case of traumatic paraplegia. However, the traditional group has one case of nerve injury, two cases of motor disorders, five cases of incisional infection, and one case of traumatic paraplegia. Minimally invasive surgery resulted in a significantly lower incidence of postoperative complications compared to open surgery ($p < 0.05$, Table 4).

Discussion

Spinal injuries are frequently occurring issues in clinical orthopedics, with their incidence increasing in recent years. The most common cause is severe injuries to the spine due to excessive external forces such as falls from heights and traffic accidents [13, 14]. Spinal damage can result in significant adverse effects on normal physiological and physi-

Table 4. Postoperative complications in study participants.

Variables	Research group (n = 50)	Traditional group (n = 50)	χ^2	*p*-value
Nerve injuries	0 (0.00)	1 (2.00)	-	-
Motor impairment	0 (0.00)	2 (4.00)	-	-
Incisional infection	1 (2.00)	5 (10.00)	-	-
Traumatic paraplegia	0 (0.00)	1 (2.00)	-	-
Total incidence	1 (2.00)	9 (18.00)	7.111	0.008

cal functions [15]. The surgical approach to thoracolumbar fractures generally follows the principles of degenerative diseases described by Ozgur *et al*. [16]. The posterior pleural approach is preferred, with intraoperative fluoroscopy being essential to accurately identify the level of pathology and determine the optimal location for incision and exposure.

The primary surgical approaches include the open posterior approach for decompression and internal fixation, percutaneous pedicle screw surgery, minimally invasive small incision decompression, and other minimally invasive procedures. Traditional open surgery mainly involves a midline incision followed by spinal fixation to restore normal spinal function [17, 18]. Despite its efficacy, open surgery causes significant trauma to the patient, resulting in postoperative complications and poor prognosis. With advancement in medical technology, minimally invasive surgery has become a widely used approach in the clinical management of spinal trauma. This approach avoids postoperative vertebral cavity issues, rebuilds the bearing capacity of the anterior and middle columns of the spine, and significantly improves the shortcomings of posterolateral implant fusion.

The findings of our study indicated no statistically significant difference in spinal morphology between the two experimental groups of patients before and after treatment. Traditional open surgery restores spinal alignment and spinal stability, providing clear anatomical visibility, adequate operative field exposure, ease of procedure, and convenient decompressive interbody fusion. The treatment outcomes for thoracolumbar fractures in patients with mild neurological injury using minimally invasive surgery are comparable to those of traditional open surgery, with the clinical efficacy of minimally invasive surgery being equally significant in treating spinal trauma [19]. These observations are consistent with previous studies. Previous studies suggest that despite the minor difference in spinal morphology between the two procedures, traditional open surgery can cause damage to the vertebral body, muscle stripping, and traction, potentially leading to nerve damage and muscle necrosis, as well as postoperative complications. In contrast, minimally invasive surgery obviates the need to excise spinal muscles and offers advantages such as rapid postoperative recovery, low intraoperative blood loss, and short operative time. This allows for early rehabilitation after surgery, significantly alleviating hospital stay and aiding in rapid recovery [20, 21]. Moreover, this indicates that open surgery has higher safety risks, while minimally invasive fixation obviates the need for muscle stripping and minimizes soft tissue damage. The smaller intraoperative incision reduces external contact, thereby reducing the risk of complications such as incisional infection and lower limb dysfunction. This was also evidenced by the results of our study, indicating that minimally invasive surgery resulted in significantly better surgical indices, lower VAS and ODI scores, and decreased incidence of postoperative complications.

This procedure has been shown to reduce postoperative pain and facilitate postoperative functional recovery. Minimally invasive percutaneous pedicle screw internal fixation can be performed using a fluoroscopic surgical bed, which ensures precise screw positioning and avoids irreversible spinal cord and nerve damage from improper puncture. Additionally, this approach eliminates removing the paravertebral muscles, thereby preserving the muscles around the spinous process. Furthermore, this prevents the impact of prolonged muscle stretching on the blood supply to the cortical nerves and paravertebral muscles, decreasing the risk of widespread numbness or atrophy of the paravertebral muscles [22].

Minimally invasive spine techniques provide spinal stability after thoracolumbar trauma and decompress the spine when needed. Percutaneous pedicle screw fixation offers internal support during fracture healing while preserving innervation, blood supply, and muscle insertion. When properly implemented, it ensures ligamentous convergence through traction, biomechanical stabilization, and spinal realignment, maximizing restoration of neurologic function and maintaining long-term spinal alignment [23]. Due to the small incision and exposure of the percutaneous minimally invasive pedicle screw internal fixation procedure, it effectively reduces intraoperative blood loss and postoperative drainage in patients and shortens the length of hospital stay [22]. Notably, our study showed a relatively small amount of graft material inserted into the intervertebral disc space compared to studies by Yoo *et al*. [24] and Kleiner *et al*. [25]. This difference may be due to the mechanical design of the cannula. During graft insertion, the space between the bone graft particles might be reduced or collapsed, resulting in a deviation in the final volume. In the MIS fusion procedure, the biological environment may differ from that of a conventional open fusion procedure, and may be more favorable to the fusion itself due to a larger surface area and a larger cage to accommodate more graft material. Overall, the evidence from previous literature is consistent with the results of our study, suggesting that minimally invasive surgery minimizes patient pain, optimizes surgical metrics, and reduces complications while ensuring surgical efficacy compared to open surgery.

Additionally, this procedure indicates good efficacy through articular or intertransverse fusion, effectively preventing secondary kyphotic deformity and delayed spinal cord damage [26]. Since the healing of vertebral fractures relies on bone repair, minimally invasive percutaneous pedicle screw fixation mainly follows the principles of repositioning, decompression, and fixation to enhance the repositioning effect. This technology increases the height and SI of the anterior edge of the injured vertebra and reduces the posterior convex Cobb angle [27, 28]. However, minimally invasive percutaneous pedicle screw fixation has some limitations. Compared to traditional open surgery, the smaller incision can make it challenging to quickly locate the injured pedicle, requiring a high level of surgical experience from the surgeon.

Our study explored minimally invasive treatment approaches and provided insights into future therapeutic alternatives for clinicians. Despite the lack of identified effective biomarkers and precise treatment, spinal injuries have been less studied, making the evidence-based findings of this study significant. Our study suggests that percutaneous pedicle screw fixation and miniature open anterolateral retractor-based approaches for endovascular opening are safe and feasible in clinical practice. Nonetheless, these results should be interpreted with caution as they are based on clinical observations from a single center.

Despite some promising outcomes, this study has several limitations. Firstly, the small sample size in this study may limit the generalizability of the findings. A larger sample size would provide more robust statistical power and enhance the reliability of the results. Secondly, the inclusion of patients with thoracolumbar vertebral body fractures may introduce potential confounding factors. Different underlying conditions or injury mechanisms in these patients could influence treatment outcomes and prognosis. Future studies should focus on patients with a specific condition or limit the study population to those with a precise diagnosis. Furthermore, the exclusion of studies involving multiple diseases and surgical procedures may limit a comprehensive understanding of the topic. The inclusion of a diverse range of diseases and surgical interventions would provide a broader perspective on factors influencing prognosis.

Additionally, the lack of long-term follow-up beyond one year postoperatively is another limitation of this study. Prognostic outcomes can change over time, making it crucial to evaluate the long-term effects of the treatment to assess its success. The retrospective study design also has limitations, such as lack of control over data consistency and reliability, potential retrospective bias, and inability to establish causality. To address these limitations, future research can be a prospective study focusing on larger sample sizes, specific patient populations, and diverse diseases and surgical procedures with a long-term follow-up.

Minimally invasive techniques in spine surgery have grown exponentially over the past two decades. Implementing minimally invasive techniques requires extensive surgical experience, a thorough understanding of surgical indications, familiarity with invasive surgical operating systems, strict adherence to aseptic principles, and a high degree of responsibility. The concept of “minimally invasive” prioritizes patient-centered care, aiming to get the highest benefit with the least invasive intervention, thereby maximizing physical and psychological recovery for the patient. Minimally invasive has promising prospects and represents a key direction of future surgery development.

Conclusions

Minimally invasive surgery leads to less surgical damage for patients with spinal trauma, improves surgical outcomes, alleviates postoperative pain, and enhances morphological and functional recovery of the spine.

Abbreviations

VAS, visual analogue scale; ODI, Oswestry dysfunction index; mcSCI, modified American Spinal Injury Association Impairment Scale.

Availability of Data and Materials

All data generated or analysed during this study are included in this published article.

Author Contributions

GCW and JPC formed the research. LLW and FJM designed this study. LLW, FJM, GCW and JPC performed the research. GCW and JPC collected and analyzed the data. LLW and FJM have been involved in drafting the manuscript. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Ethical approval was granted by the Ethics Committee of Suzhou Hospital of Integrated Traditional Chinese and Western Medicine (ethical approval number: TC890234). The study design followed the Declaration of Helsinki. Informed consent was waived, and all patient information was anonymized and deidentified to ensure patient privacy and confidentiality. Additionally, strict measures were followed to protect patient confidentiality throughout the study.

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Conflict of Interest

The authors declare no conflict of interest.

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