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Comprehensive Approach to Percutaneous Minimally Invasive Spine Stabilization for Lumbar and Thoracolumbar Disorders

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ABSTRACT

Background : Minimally invasive spine surgery has revolutionized the management of thoracolumbar disorders by reducing operative trauma and promoting faster recovery.

Objective : This study aimed to evaluate the clinical and radiological outcomes of percutaneous pedicle screw (PPS) fixation, with or without vertebroplasty or kyphoplasty, in patients with lumbar and thoracolumbar vertebral pathology.

Patients and Methods : This prospective study included 20 patients treated under fluoroscopy guidance in the last 2 years (2023-2024) at Neurosurgery department, Zagazig university Hospitals and Orthopaedic surgery department, Alahrar teaching hospital, Zagazig, Egypt. Initial care involved a multidisciplinary trauma team that stabilized vital functions and performed diagnostic imaging. Preoperative preparation included thorough patient selection based on specific inclusion and exclusion criteria. The Sextant system was utilized for screw fixation. Patients received general anesthesia and were positioned prone. A minimally invasive approach involved a small incision to access the pedicle, with careful fluoroscopic guidance for screw placement.

Results : The cohort had a mean age of 28.65 ± 8.29 years, with traumatic fractures being the most common pathology. VAS scores improved significantly from 7.45 ± 1.05 preoperatively to 1.65 ± 0.88 after one year ($p < 0.001$). Radiological assessments showed significant differences in vertebral body angle, local kyphosis angle, and wedge index, indicating improved alignment and stability.

Conclusion : The PPS technique, combined with anterior column reconstruction, demonstrated promising outcomes in pain relief and spinal stability, suggesting it as a safe and effective substitute to traditional surgical methods for thoracolumbar vertebral diseases. Further studies with larger cohorts are warranted to confirm these findings.

Keywords : Minimally invasive spine surgery, Percutaneous pedicle screw, Thoracolumbar fracture, Vertebroplasty, Kyphoplasty.

INTRODUCTION

Minimally invasive techniques are increasingly gaining traction in spinal surgery. The emergence of these less invasive methods has prompted numerous investigations comparing percutaneous and open procedures for thoracolumbar spine stabilization. In a randomized controlled trial, Jiang and co-authors [1] noticed improved pain relief and functional outcomes in patients undergoing the percutaneous technique. The minimally invasive surgical approach to pedicle screw fixation in the thoracolumbar spine has been shown to limit soft tissue disruption, decrease intraoperative blood loss, and yield superior postoperative pain outcomes compared to traditional open methods [2]. The concept of percutaneous pedicle screw (PPS) instrumentation was first introduced by Magerl in 1977, with further emphasis provided in his work 1984, where he initially employed external fixation systems for temporary spinal stabilization [3].

Despite the growing adoption of navigation-assisted techniques driven by technological advancements, fluoroscopic guidance continues to offer key benefits. Navigation systems such as fluoronavigation are often limited by prolonged setup durations, while CT-based navigation relies on preoperative imaging that may not accurately represent anatomical shifts following decompression or intraoperative repositioning. Additionally, CT-guided navigation is highly operator-dependent, requiring precise registration of anatomical landmarks between the preoperative scans and the intraoperative field. Nonetheless, one of the primary advantages of navigation techniques remains their potential to reduce the incidence of pedicle screw malposition [4].

This research assessed the clinical and radiological results of PPS technique used in stabilization of lumbar and thoracolumbar vertebral diseases in addition to vertebroplasty or kyphoplasty for anterior column reconstruction if needed.

PATIENTS AND METHODS

This prospective study involved 20 patients with thoracolumbar vertebral diseases treated using a minimally invasive PPS technique under fluoroscopy guidance during the last 2 years (2023-2024) at Neurosurgery department, Zagazig university Hospitals and Orthopaedic surgery department, Alahrar teaching hospital, Zagazig,

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Egypt. Additional procedures, such as vertebroplasty or kyphoplasty, were performed as needed.

Inclusion Criteria : Burst fractures without significant canal compression, pathological fractures, spondylodiscitis, grade 1 spondylolisthesis without complications, and fractures of pars interarticularis with low back pain.
Exclusion Criteria : Patients with significant spinal canal compression, stenosis, severe spondylolisthesis, radicular pain, osteoporosis, and morbid obesity.
Patient counseling covered the surgical plan, potential complications, and rehabilitation expectations.

Initial patient care : Upon admission, all patients were evaluated and managed by a multidisciplinary trauma team comprising specialists in general surgery, orthopedic surgery, neurosurgery, and cardiothoracic surgery. Critical physiological functions (Airway, breathing, and circulation) were systematically assessed and appropriately stabilized. After stabilizing the patient hemodynamically, diagnostic imaging (X-rays and CT scans) was performed to identify the injury level and fracture type.

Preoperative components
Patient selection and counseling: The preoperative phase included several essential components:

1. **Patient selection:** Inclusion criteria focused on specific conditions, such as burst fractures without significant spinal canal compression, pathological fractures, spondylodiscitis, and grade 1 spondylolisthesis without complications. Exclusion criteria included marked bony compression, spinal canal stenosis, severe spondylolisthesis, radicular pain, osteoporosis, and morbid obesity.
2. **Patient Counseling:** Counseling was crucial, encompassing discussions about preoperative investigations, operative details, potential complications, postoperative rehabilitation, and expected recovery timelines.

Patient Evaluation
A detailed evaluation was conducted for each patient, involving:
1. **Clinical evaluation:**
   - **History**: Collection of personal data, trauma details, neurological assessments, and past-medical history.
   - **Examination**: Included general and spine-specific assessments, neurological evaluations (sensory, motor, and reflex examinations), and palpation of the spine to check for deformities.
2. **Radiological evaluation:**
   - **X-Ray analysis**: Parameters such as the vertebral body angle, local kyphosis, and wedge index were measured to compare preoperative, immediate postoperative, and long-term follow-up results.
   - **CT scan analysis**: Evaluated the number of affected columns, the degree of comminution, and apposition of vertebral body fragments.
3. **Preoperative preparation:** Routine investigations such as CBC, liver and renal function tests, and ECG were conducted. Patients were instructed to fast for eight hours prior to surgery and were required to sign informed consent.

Operative procedure
Surgical tools preparation: The Sextant system was employed for the surgical procedure, which included various components :
- **Cannulated screws** : Titanium screws were used for secure fixation.
- **Rods** : Pre-contoured titanium rods were prepared for spinal stabilization.
- **Instruments** : Included screw extenders, rod inserters, tap, and dilators for creating appropriate pathways.

Anesthesia and positioning : All patients received general anesthesia with endotracheal intubation. They were positioned prone on a radiolucent operating table to allow optimal access to the surgical site, with careful attention to avoid abdominal compression.

Surgical technique : The surgical approach involved several steps:
- A longitudinal incision was made to access the pedicle, followed by blunt dissection to reach the facet joint.
- A Jamshidi needle or cannulated awl was introduced through the pedicle, guided by fluoroscopic imaging to ensure proper placement.
- Guide wires were inserted, and serial dilators were used to prepare the pedicle for screw insertion.
- Cannulated screws were carefully placed, ensuring that they crossed the posterior border of the vertebral body without damaging surrounding structures. The rods were then applied to stabilize the spine. If vertebral body height was not restored, distractors were used to assist in height restoration.

Postoperative management

Immediate care: Postoperatively, all patients received intravenous antibiotics and analgesics. Ambulation was encouraged on the first day, and

patients wore dorsolumbar support during movement. Regular checks for wound healing were conducted, and most patients were discharged within 48-72 hours.

Follow-up evaluations: Follow-up assessments were scheduled at two weeks, six weeks, three months, six months, and one year postoperatively. These evaluations included:

1. **Clinical evaluation**: Monitoring of vital signs and neurological status.
2. **Radiographic evaluation**: Postoperative imaging to assess screw placement, vertebral height, bone fusion and any complications.

Functional evaluation

Patients were assessed using visual analog scale (VAS) for pain and the Oswestry Disability Index (ODI) to evaluate functional status.

Ethical considerations : The study was conducted following approval by the Institutional Review Board, Zagazig University. Written informed consent was obtained from each patient prior to enrollment. The consent form clearly explained their voluntary participation and agreement to the use and publication of their anonymized data, ensuring confidentiality and privacy. This research was carried out in accordance with the ethical principles outlined in The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving human subjects.

Statistical Analysis

Data were analyzed using SPSS software, with categorical data expressed as means and standard deviations. Appropriate statistical tests were applied, with a significance level set at ≤ 0.05.

RESULTS

This investigation was prospective study conducted on 20 patients with lumbar or thoracolumar vertebral diseases managed by minimaly invasive percutaneous pedicle screw technique under fluoroscopy guidance with or without reconstruction of the anterior column via vertebroplasty or kyphoplasty if needed according to each case. All cases were operated upon in Neurosurgery Department, Zagazig University Hospitals and Orthopaedic surgery department, Alahrar teaching hospital, Zagazig, Egypt during the period from January, 2023 to June, 2024. Follow up period of the cases ranged from 10 to 14 months with a mean of 12 month. The mean age of patients was 28.65 ± 8.29 years with range (18-47 years old). Most of the study group were male 14 (70%) and 6 (30%) were females (Table 1).

Table (1): Demographic data among study group

		No	%
Sex	Male	14	70.0
	Female	6	30.0
Age	mean±SD	28.65±8.29	
	Median	27.5	
	Range	18-47	

According to clinical data among study group, table (2) showed that the most type of pathology found was traumatic fracture with road traffic accidents (RTA) (55%) then traumatic fracture with falling from hight (FFH) (25%), fracture pars in 2 (10%) patients and spondylolysthesis grade1 in 2 (10%) patients.

L1 was the most affected level of injury and was detected in 7 (35%) patients, L4 in 4 (20%) patients, L3 in 3 (15%) patients, L5 in 2 (10%) patients, D12 in 2 (10%) patients, L1-2 in one (5%) patient and L2-3 in another one (5%) patient. Number of level fixed was 1 in 18 (90%) of patients, while in the other 2 (20%) patient was 2 levels of fixation.

Table (2): Clinical data among study group

Type of pathology	Fracture pars	2	10.0
	Spondylolysthesis Grade1	2	10.0
	Traumatic fracture (FFH)	5	25.0
	Traumatic fracture (RTA)	11	55.0
Level of injury	D12	2	10.0
	L1	7	35.0
	L1-2	1	5.0
	L2-3	1	5.0
	L3	3	15.0
	L4	4	20.0
	L5	2	10.0
No. of level fixed	1	18	90.0
	2	2	10.0

According to VAS comparison between pre-, immediate, after 6 months, and after 1 year, It was 7.45 ± 1.05 preoperative and became 5.8 ± 0.95 after sugery (just before leaving hospital). After 6 months of surgery VAS was 3.85 ± 0.93 and decreased to 1.65 ± 0.88 after 1 year. Figure (1) showed that there was highly significant difference between VAS pre, immediate, after 6 months, and after 1 year (P<0.001).

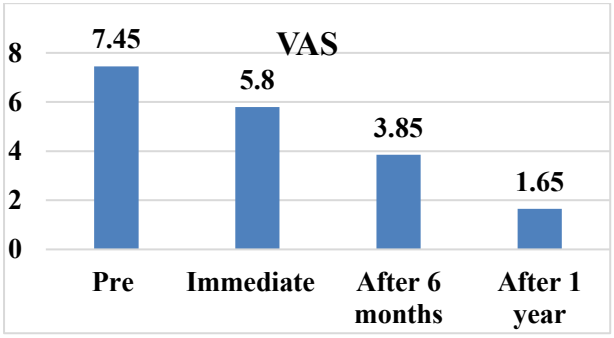

Figure (1) : VAS pre, immediate, after 6 months, and after 1 year.

The vertebral body angle (VBA) was 16.75 ± 11.34 degree preoperative and decreased to 7.75 ± 5.27 after 1 year of operation. Figure (2) showed that there was highly significant difference between VBA pre- & post-syrgery (P < 0.001).

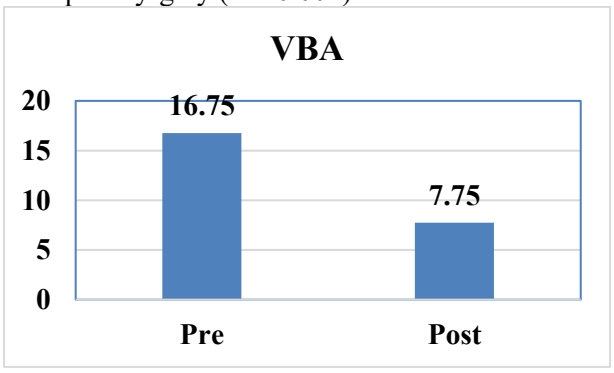

Figure (2): VBA pre- and post-surgery.

Local kyphotic angle (LKA) was 15.25 ± 8.88 degree pre-operative and decreased to 6.3 ± 4.3after 1 year of operation. Figure (3) showed that there was highly significant difference between LKA pre- & post-operative (P<0.001).

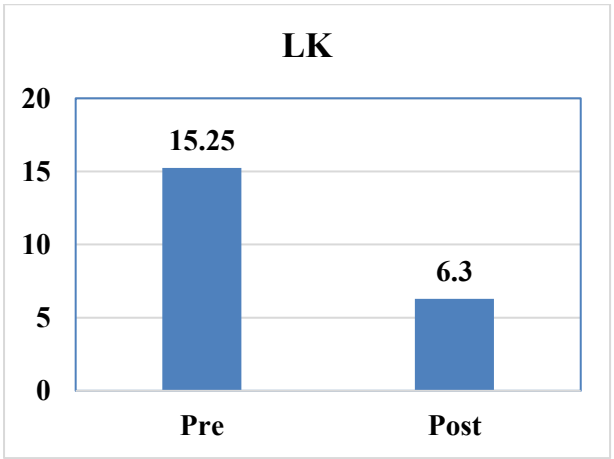

Figure (3) : LKA pre- and post-wedge index.

Wedge index (WI) was 0.636 ± 0.177 preoperative and improved to 0.869 ± 0.073 after 1 year of operation. Figure (4) showed that there was highly significant difference between WI pre post (P<0.001).

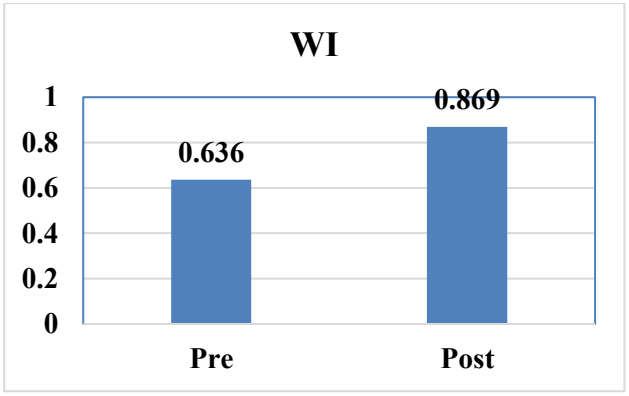

Figure (4) : WI pre and post.

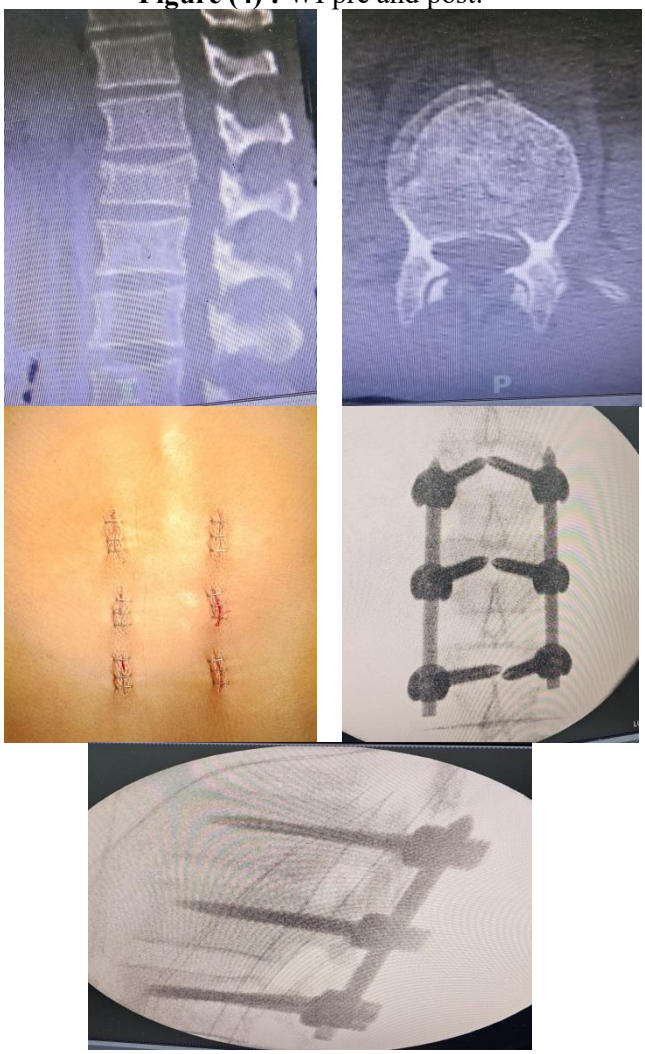

Figure (5) : Case (1), male patient aged 21 years old came to emergency after road traffic accident and CT detected L2-3 fracture. Patient was operated by percutaneous minimally invasive spine stabilization. VAS was 7 before surgery and decreased to 5 after surgery and before leaving hospital and became 0 after 1 year of surgey. The vertebral body angle (VBA) was 15 (L2) -18 (L3) degree preoperative and decreased to 10 (L2) -12 (L3) after 1 year of operation. Local kyphotic angle (LKA) was 16 degree preoperative and decreased to 4 after 1 year of operation. Wedge index (WI) was 0.62 preoperative and improved to 0.80 after 1 year of operation.

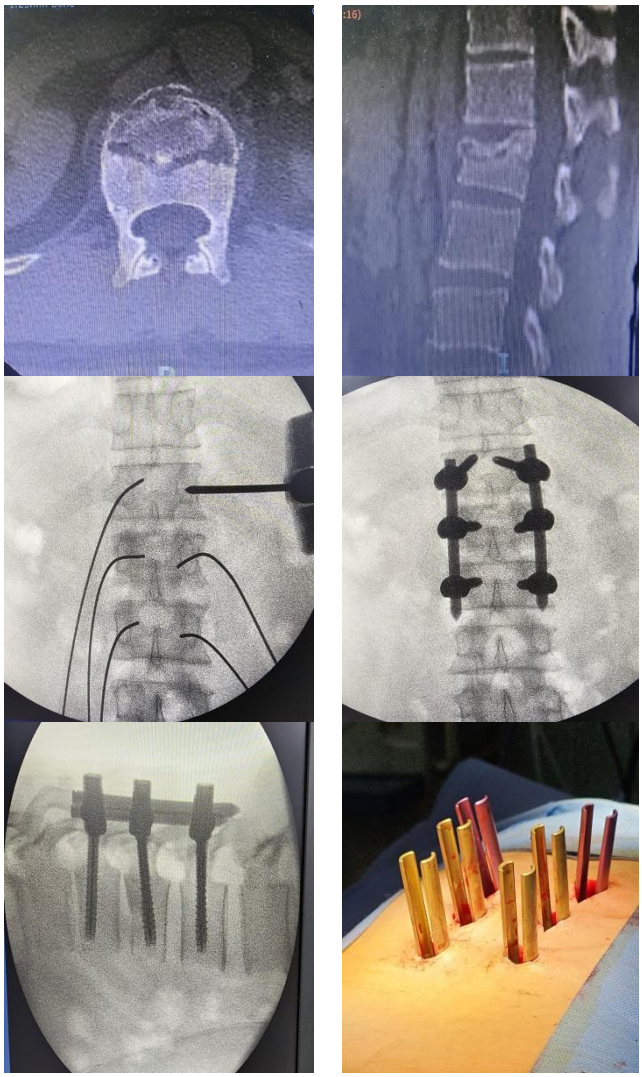

Figure (6) : Case (2), male patient aged 39 years old came to emergency after Road traffic accident and CT revealed D12 unstable fracture. Patient was operated by percutaneous minimally invasive spine stabilization. VAS was 7 before surgery and decreased to 6 after surgery and before leaving hospital and became 2 after 1 year of surgey. The vertebral body angle (VBA) was 19 degree preoperative and decreased to 13 after 1 year from operation. Local kyphotic angle (LKA) was 33 degree preoperative and decreased to 21 after 1 year of operation. Wedge index (WI) was 0.40 preoperative and improved to 0.97 after 1 year of operation.

DISCUSSION

The thoracolumbar region is the most frequently involved site in traumatic spinal column fractures. Biomechanically, it serves a critical function as a transitional zone between the relatively rigid thoracic spine, stabilized by its articulation with the ribs and sternum, and the more mobile lumbar spine, which allows for greater flexibility and range of motion [5]. The aim of this study was to assess the clinical and radiological results of percutaneous pedicle screw (PPS) technique used in stabilization of lumbar and thoracolumbar vertebral diseases in addition to vertebroplasty or kyphoplasty for anterior column reconstruction if needed.

This study was prospective study conducted on 20 patients with thoracolumar vertebral diseases managed by minimaly invasive percutaneous pedicle screw technique under fluoroscopy guidance with or without reconstruction of the anterior column via vertebroplasty or kyphoplasty if needed according to each case.

All cases were operated upon in Neurosurgey Departement, Zagazig University Hospitals and Orthopaedic surgery department, Alahrar Teaching Hospital, Zagazig, Egypt from January 2023 to June, 2024. Follow up period of the cases ranged from 10 to 14 months with a mean of 12 month.

Percutaneous dorsal stabilization has become the cornerstone technique in contemporary thoracolumbar spine surgery. Compared to traditional open reduction methods, it offers several documented advantages, including shorter operative duration, preservation of soft tissues, decreased intraoperative blood loss, and lower rates of postoperative complications [6, 7].

Two studies that examined the duration of patients' surgery that was operated percutaneously for unstable thoracolumbar fractures reported a range of 60–122 min [8, 9].

The mean age of patients was 28.65 ± 8.29 years with range (18-47 years old). Most of the study group were male 14 (70%) and 6 (30%) were females. In the same line with **Salem and co-authors** [10] who reported a cohort comprising 12 males and 18 females, the traumatic group in that study included patients aged 20 to 70 years. The mean age for males was 44.3 ± 15.9 years, while for females it was 41.8 ± 15.4 years. These age distributions closely align with those reported by **Bartolome´ and co-authors** [11] who analyzed 123 patients with traumatic, non-pathological thoracic spine fractures and observed an age range between 19 and 72 years.

According to clinical data among study group, the most type of pathology found was traumatic fracture with road traffic accidents (RTA) (55%) then traumatic fracture with falling from hight (FFH) (25%), fracture pars in 2 (10%) patients and spondylolysthesis grade1 in 2 (10%) patients. L1 was the most level of injury and was detected in 7 (35%) patient, L4 in 4 (20%) patients, L3 in 3 (15%) patients, L5 in 2 (10%) patients , D12 in 2 (10%) patients, L1-2 in one (5%) patient and L2-3 in another one (5%) patient. Number of level fixed was 1 in 18 (90%) of patients while the other 2 (20%) patients showed 2 levels of fixation. These findings are comparable to that of **Bartolome´ and co-authors** [11] who identified motor vehicle accidents as the most common mechanism of injury

(48%), followed by falls from height (43.1%). The variation in injury patterns between the studies may be attributed to differences in gender distribution, where their patients were predominantly male population, with 44 males (86.3%) and only 7 females (13.7%). Given that motor vehicle accidents are more prevalent among males, the higher male representation in their study may explain the increased incidence of this injury mechanism.

According to VAS comparison between pre-, immediate, after 6 months, and after 1 year, there were highly significant differences between VAS pre-, immediate, after 6 months, and after 1 year ($P<0.001$).

Regarding the vertebral body angle (VBA), there were highly significant differences between VBA pre- and post-operative ($P<0.001$).

Concerning local kyphotic angle (LKA), there were highly significant differences between LKA pre- and post-operative being decreased significantly after 1 year ($P<0.001$).

Wedge index (WI) was 0.636 ± 0.177 preoperative and improved to 0.869 ± 0.073 after 1 year of operation. There were highly significant differences between WI pre- and post-surgery ($P<0.001$).

In the study conducted by **Byvaltsev and co-authors** [12], a significant reduction in pain severity was observed, with mean VAS scores decreasing from 90 mm preoperatively to 5.5 mm at late follow-up ($P < 0.001$). Additionally, marked improvements were noted in both physical and psychological components of health based on the SF-36 questionnaire, increasing from 28.78 to 39.26 ($P < 0.001$) and from 36.93 to 41.43 ($P = 0.006$) respectively. Long-term outcomes assessed via the MacNab scale showed excellent results in 52.9% of patients, good in 38.3%, and satisfactory in 8.8%, with no cases of unsatisfactory outcomes. Four perioperative complications (11.8%) were reported but managed successfully with conservative treatment. Furthermore, a notable restoration of sagittal alignment was achieved, accompanied by only minor changes in blood pressure. Follow-up evaluation over an average of 30 months using the American Spinal Injury Association (ASIA) scale indicated that 85.4% of patients achieved grades E and D.

Similarly, **Younus and his colleage** [9] investigated the efficacy of minimally invasive percutaneous stabilization in comparison with the conventional open approach in a cohort of 51 patients over a five-year period. Their findings demonstrated significant advantages in the percutaneous group, including reduced surgical duration ($P = 0.007$), lower intraoperative blood loss ($P < 0.001$), decreased early postoperative pain ($P < 0.001$), shorter hospital stays ($P = 0.0017$), and higher one-year patient satisfaction rates ($P < 0.001$). Based on these outcomes, the authors advocate for the percutaneous approach as the preferred method for managing thoracolumbar fractures. Moreover, **Shin and co-authors** [13] analyzed outcomes in 22 patients with unstable thoracolumbar fractures managed using minimally invasive corpectomy combined with percutaneous transpedicular fixation. They reported average operative time was 293.9 minutes, with intraoperative blood loss averaging 1566.6 ml, and a mean hospital stay of 40.8 days. Sagittal alignment changes were noted, with the Cobb angle improving from 18.3 ± 5.60 degrees preoperatively to 21.8 ± 11.30 degrees at follow-up, though a loss of correction averaging 9.8 ± 10.60 degrees was also recorded. Postoperative complications included two cases of surgical site infection (9%) and one case of screw fixation instability.

In the study conducted by **Tabaraee *et al.*** [14], a comparative evaluation was conducted involving three surgical strategies for traumatic thoracolumbar injuries: Minimally invasive thoracolumbar corpectomy with percutaneous transpedicular stabilization ($n = 6$), open circumferential stabilization ($n = 2$), and conventional dorsal decompression with stabilization ($n = 1$). The findings indicated that the minimally invasive approach was associated with several advantages, including shorter operative time, reduced perioperative blood loss, a lower incidence of postoperative infections, and decreased reliance on narcotic analgesics for pain management.

The ongoing debate surrounding the choice between open and minimally invasive decompression and stabilization techniques for thoracolumbar spine trauma stems from differences in the ability to achieve adequate neural decompression and visualization of the epidural space—factors inherently tied to the surgical approach used [15]. However, it has been suggested that the reduced anatomical exposure associated with minimally invasive procedures does not compromise neurological outcomes. Postoperative neuroimaging has confirmed adequate decompression of the spinal canal, indicating that the minimally invasive approach does not inherently increase the risk of residual neurological deficits [13]. Nonetheless, despite the well-documented advantages of minimally invasive spine surgery (MISS) in managing thoracolumbar trauma, certain limitations persist. These include the technical challenges of operating within a confined field, the requirement for in-depth knowledge of both surgical and radiographic anatomy, a steep learning curve, and elevated exposure to intraoperative radiation [16].

CONCLUSION

Percutaneous minimally invasive spine stabilization is a safe alternative to open surgical methods for lumbar and thoracolumbar vertebral diseases with less muscle and bone damage and faster recovery.

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Conflict of Interest: Nil.

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