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A retrospective study comparing percutaneous and open pedicle screw fixation for thoracolumbar fractures with spinal injuries

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Abstract

Background: The purpose of this study was to evaluate the effectiveness between percutaneous and open pedicle screw fixation for treating thoracolumbar fractures with spinal injuries.

Methods: A total of 105 patients with thoracolumbar fractures and spinal injuries were divided into a percutaneous pedicle screw fixation (PPSF) group with 56 patients, who underwent percutaneous pedicle screw fixation, and an open pedicle screw fixation (OPSF) group with 49 patients, who underwent open pedicle screw fixation in accordance with the treatment project. Relative operation indexes, radiologic, and effectiveness parameters were assessed and compared between the 2 groups.

Results: Demographic and clinical features including age, body mass index, gender, fracture level, fracture classification, and Frankel grade in both groups were not significantly different (all $P > .05$). The PPSF group exhibits significantly lower operation time, intraoperative blood loss, postoperative drainage volume, and hospital stay on average compared with the OPSF group (all $P < .05$). Besides, the average postoperative radiologic parameters, including Cobb angle (CA), vertebral wedge angle (VWA), vertebral front height percentage (VFHP), and sagittal index (SI), in both the groups were not significantly different (all $P > .05$). Nevertheless, both visual analogue scale (VAS) and Oswestry disability index (ODI) after surgery decreased more substantially in the PPSF group than in the OPSF group (all $P < .05$) while no significant difference in VAS scores or ODI during the last follow-up period was demonstrated in both the groups (both $P > .05$). Frankel classifications were stimulated in both the groups during the last follow-up period.

Conclusion: PPSF has a smaller incision, less intraoperative blood loss, shorter recovery time, higher safety measures on average compared with OPSF with respect to managing thoracolumbar fractures with spinal injuries.

Abbreviations: CA = Cobb angle, ODI = Oswestry disability index, OPSF = open pedicle screw fixation, PPSF = percutaneous pedicle screw fixation, SI = sagittal index, VAS = Visual analogue scale, VFHP = vertebral front height percentage, VWA = vertebral wedge angle.

Keywords: open pedicle screw fixation, percutaneous pedicle screw fixation, retrospective study, thoracolumbar fractures

1. Introduction

Thoracolumbar fracture was one of the most common fractures in spines and more than 160,000 injury cases happened every year.[1,2] Notably, a large portion of thoracolumbar fractures occurs at the T11 to L2 level which is biomechanically weak against external stress.[3] Thoracolumbar fractures are usually high-energy injuries caused by motor vehicle and falling accidents.[4] And the selection of treatments including conservative management and surgical treatment depends on specific circumstances of fractures. Surgical treatment methods on patients with thoracolumbar fractures can often obtain relatively better therapeutic outcomes in comparison with conservative management such as bed rest and immobilization.[5] However, surgery often leads to excessive blood loss or serious infectious problems.

Pedicle screw fixation has been developed and widely applied in clinical practice to provide stable spinal fixation, which exerts few negative influence on the nervous system, blood vessels, and internal organs of the patients.[6–8] Despite that the use of a traditional open pedicle screw fixation (OPSF) and reduction of thoracolumbar fractures has demonstrated good radiologic and clinical outcomes,[9] several potential disadvantages can result from OPSF, including trauma, blood loss, long duration of hospital stay, high risk of postoperative complications, which may increase the suffering and economic burden of the patients

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especially in low-income families.[10] All of these disadvantages should be carefully considered before clinical practices of OPSF.

With the rapid development of modern navigation equipment and computer technology over the past several decades, a wide range of minimally invasive therapeutic methods have been extensively performed in clinical practices, including kyphoplasty and percutaneous screw fixation.[11] Intraoperative computer-assisted navigation system provides the feasibility of real-time, 3-dimensional images of the navigation tool, which may simplify the surgeon's selection of the pedicle screw entry point and trajectory.[12] And percutaneous pedicle screw fixation (PPSF), a novel minimally-invasive surgical procedure, has been used for thoracolumbar fracture with spinal cord injury. It applies navigation systems for percutaneous placement in spinal internal fixator, which avoids serious soft tissue and muscle stripping, reduces intraoperative blood loss and promotes postoperative recovery compared with OPSF.[13–15] This approach only requires a 1cm incision at each screw insertion point, which is extremely convenient for the placement of the spinal-access needle, K-wire, and series of dilator tubes. Besides, Lee et al[16] also revealed that PPSF provided relatively earlier pain relief and functional improvement in comparison with OPSF. These advantages of PPSF have been widely recognized by many orthopedic surgeons and patients with thoracolumbar fractures.[17]

In the domain of spine surgery, it is still controversial whether a patient is appropriate for OPSF or PPSF and the current article aimed primarily to compare the clinical outcomes of PPSF and OPSF in treating thoracolumbar fractures with spinal cord injury. Therefore, we believed that our results would provide solid theoretical and clinical foundations for improving the therapeutic methods of thoracolumbar fractures in the future.

2. Results

2.1. Baseline characteristics of patients

The demographic and clinical characteristics of a total of 105 patients, including 61 males and 44 females, were summarized in Table 1. There were 56 patients (32 males and 24 females) in the PPSF group, and 49 patients (29 males and 20 females) in the OPSF group. The average age of patients in the PPSF group and the OPSF group was 40.3 ± 11.1 years (ranging from 22 to 71 years old) and 38.8 ± 10.2 years (ranging from 21 to 66 years old), respectively. The variables including mean age, body mass index , gender, fracture level, facture classification, and Frankel grade between PPSF group and OPSF group were not considered significantly different (all $P > .05$). All of the patients were followed up with a mean time of 23 months (ranging from 16 to 33 months).

2.2. Operation indexes

As shown in Table 2, the mean operation indexes in the PPSF group and OPSF group were as follows: operation time was 122 ± 30 minutes and 180 ± 51 minutes; intraoperative bleeding volume was 99.3 ± 44.3 mL and 591.5 ± 340.1 mL; postoperative drainage volume was 42.3 ± 16.3 mL and 343.1 ± 161.6 mL; hospital stay was 9.4 ± 3.2 days and 20.7 ± 5.2 days. In the PPSF group, the operation time, intraoperative bleeding volume, postoperative drainage volume, and hospital stay duration were significantly lower than those in the OPSF group (all $P < .05$). However, there was no statistical difference among 2 groups in terms of postoperative complications as was shown in Table 3 (all $P > .05$).

Table 1

Demographic and clinical characteristics of patients in PPSF group and OPSF group.

Clinical characteristics	PPSF group	OPSF group	P
Cases	56	49	
Age, y	40.3 ± 11.1	38.8 ± 10.2	.476*
BMI	20.8 ± 2.1	21.1 ± 2.2	.477*
Gender			
Male	32	29	.833†
Female	24	20	
Fracture level			
T12	17	15	.915†
L1	18	18	
L2	12	8	
L3	9	8	
Fracture classification			
A1	15	13	.993†
A2	12	12	
A3	15	11	
B1	2	2	
B2	2	3	
C1	8	6	
C2	2	2	
Frankel grade			
A	3	3	.899†
B	8	9	
C	29	22	
D	16	15	

OPSF = open pedicle screw fixation, PPSF = percutaneous pedicle screw fixation.
* Unpaired *t* test.
† χ^2 test.

2.3. Radiologic parameters

As was described in Table 4, the average preoperative Cobb angle (CA) of PPSF group and OPSF group were 15.8 ± 6.3° and 16.4 ± 6.6°, respectively. The average preoperative and postoperative CA between the PPSF group and OPSF group were not considered significantly different (all $P > .05$). The average preoperative vertebral wedge angles (VWA) of the PPSF group and OPSF group were 19.3 ± 5.2° and 20.4 ± 4.9°, respectively. This included a significant decrease after surgery in both the groups and was well maintained until the last follow-up. The average preoperative and postoperative VWA between the PPSF group and OPSF group were not considered significantly different (all $P > .05$).

The average preoperative vertebral front height percentage (VFHP) of the PPSF group and OPSF group were 61.0 ± 15.3% and 58.6 ± 16.1%, respectively. This included a remarkable

Table 2

Comparison of operation indexes between PPSF group and OPSF group.

Operation indexes	PPSF group	OPSF group	P*
Operative time, min	122 ± 30	180 ± 51	<.001
Intraoperative bleeding loss, mL	99.3 ± 44.3	591.5 ± 340.1	<.001
Postoperative drainage volume, mL	42.3 ± 16.3	343.1 ± 161.6	<.001
Hospital stay, d	9.4 ± 3.2	20.7 ± 5.2	<.001

OPSF = open pedicle screw fixation, PPSF = percutaneous pedicle screw fixation.
* Unpaired *t* test.

Table 3

Comparison of postoperative complications between PPSF group and OPSF group.

Postoperative complications	PPSF group	OPSF group	P*
Incorrect screw positioning	3	2	.759
Wound infection	2	4	.312
Adjacent segment degeneration	2	2	.892
Dural sac laceration	1	1	.924
Neurological symptom	1	2	.481

OPSF = open pedicle screw fixation, PPSF = percutaneous pedicle screw fixation.
* Unpaired *t* test.

increase after surgery in both groups, and had been well maintained at the last follow-up. The average preoperative and postoperative VFHP between PPSF group and OPSF group were not considered significantly different (all $P > .05$).

The average preoperative sagittal index (SI) of PPSF group and OPSF group were $13.8 \pm 3.9°$ and $14.9 \pm 4.3°$, respectively. This included a drop after surgery in both groups and well maintained at the last follow-up. The average preoperative and postoperative SI between PPSF group and OPSF group were not considered significantly different (all $P > .05$).

2.4. Effectiveness parameters

Table 5 addresses the results of effectiveness parameters in this study, including visual analogue scale (VAS) and Oswestry disability index (ODI). Before operation, VAS scores for back pain were 8.3 ± 1.8 and 8.5 ± 1.7 points in the PPSF group and OPSF group, respectively, and these were remarkably decreased in both groups after surgery. VAS scores at 3 days and 6 months after surgery decreased more dramatically in the PPSF group than the VAS scores in the OPSF group (both $P < .05$). However, there was no significant difference of VAS scores at the last follow-up between the PPSF group and OPSF group ($P > .05$).

Table 4

Comparison of radiologic parameters between PPSF group and OPSF group.

Radiologic parameters	PPSF group	OPSF group	P*
CA (°)			
Preoperative	15.8 ± 6.3	16.4 ± 6.6	.614
3-d post	4.9 ± 2.6	5.4 ± 2.6	.376
6-mo post	6.5 ± 2.9	7.0 ± 2.9	.434
Last	9.5 ± 4.1	10.2 ± 3.8	.394
VWA (°)			
Preoperative	19.3 ± 5.2	20.4 ± 4.9	.268
3-d post	8.6 ± 3.1	9.6 ± 3.1	.100
6-mo post	9.3 ± 3.2	10.5 ± 3.5	.072
Last	11.2 ± 3.6	11.9 ± 3.3	.304
VFHP (%)			
Preoperative	61.0 ± 15.3	58.6 ± 16.1	.435
3-d post	91.5 ± 9.1	92.2 ± 8.3	.686
6-mo post	87.8 ± 8.9	88.4 ± 8.5	.723
Last	81.8 ± 9.5	82.9 ± 9.8	.560
SI (°)			
Preoperative	13.8 ± 3.9	14.9 ± 4.3	.177
3-d post	7.4 ± 1.9	8.0 ± 2.2	.138
6-mo post	8.6 ± 1.5	8.9 ± 2.0	.392
Last	9.9 ± 2.0	10.5 ± 2.3	.154

CA = Cobb angle, OPSF = open pedicle screw fixation, PPSF = percutaneous pedicle screw fixation, SI = sagittal index, VFHP = vertebral front height percentage, VWA = vertebral wedge angle.
* Unpaired *t* test.

Table 5

Comparison of clinical parameters between PPSF group and OPSF group.

Clinical parameters	PPSF group	OPSF group	P*
VAS			
Preoperative	8.3 ± 1.8	8.5 ± 1.7	.553
3-d post	2.5 ± 1.2	3.8 ± 1.5	<.001
6-mo post	1.9 ± 0.6	3.2 ± 1.2	<.001
Last	1.4 ± 0.5	1.6 ± 0.6	.117
ODI			
Preoperative	65.7 ± 7.8	68.8 ± 9.0	.062
3-d post	–	–	
6-mo post	7.2 ± 2.1	16.0 ± 6.1	<.001
Last	6.0 ± 1.6	6.7 ± 2.3	.073

ODI = Oswestry disability index, OPSF = open pedicle screw fixation, PPSF = percutaneous pedicle screw fixation, VAS = visual analogue scale.
* Unpaired *t* test.

Before the operation, ODI were 65.7 ± 7.8 and 68.8 ± 9.0 points in the PPSF group and OPSF group, respectively, and these were dramatically dropped in both the groups after surgery. ODI at 6 months after surgery decreased more dramatically in the PPSF group than in the OPSF group ($P < .05$). However, there was no significant difference of ODI at the last follow-up between PPSF group and OPSF group ($P > .05$).

In addition, as was shown in Table 1, there was no statistical significance in preoperative Frankel grade between PPSF group and OPSF ($P = .899$). And at the last follow-up, Frankel classifications were all promoted in both groups after surgery, which was demonstrated in Table 6.

2.5. Postoperative complications

One case in PPSF group as well as 2 cases in OPSF group was detected with wound infection, and no patient in both the groups was detected with pseudarthrosis, recurrence, or obvious kyphosis. There was no significant difference in postoperative complications between PPSF group and OPSF group ($P > .05$). Patients with wound infection were treated with surgical debridement combined with antibiotic treatment.

3. Discussion

Thoracolumbar fractures are a common orthopedic injury caused by an external force which leads to the migration or curvature of thoracolumbar spinal.[18,19] The main treatments of it are to

Table 6

Preoperative and postoperative Frankel classification of PPSF group and OPSF group.

	Preoperative (PPSF group)				Preoperative (OPSF group)			
Frankel classification	A	B	C	D	A	B	C	D
Postoperative								
A								
B	1							
C		2			1	2		
D	2	5	6		2	5	7	
E		1	23	16		2	15	15

OPSF = open pedicle screw fixation, PPSF = percutaneous pedicle screw fixation. .

relieve spinal pressure and to reset and fix the spinal cord accurately and timely. OPSF, more commonly used in clinical practices, though has a clearer operative field and exposure to the vertebrae, it is associated with a large amount of blood loss and slow postoperative recovery. On the other hand, PPSF could reduce the damage of paraspinal soft tissue and promote the recovery of scaffold structure of vertebral trabecular bone.[18] In this study, we evaluated the effectiveness between OPSF and PPSF for treating thoracolumbar fractures with spinal injuries.

A total of 105 patients with thoracolumbar fractures and spinal injuries were divided into a PPSF group with 56 patients and an OPSF group with 49 patients. The demographic and clinical variables including age, body mass index, gender, fracture level, facture classification, and Frankel grade in both the groups were not significantly different. In the PPSF group, operation time, intraoperative blood loss, postoperative drainage volume, and hospital stay were significantly lower than those in the OPSF group, which was consistent with previous research.[20] A new meta-analysis also confirmed our study results.[19] Low incidence of postoperative complications was an indicator reflected of the effect of surgery,[21] and there was no significant difference between PPSF and OPSF postoperative complications. This indicated that PPSF would not bring more adverse reactions in the treatment of thoracolumbar fractures compared with OPSF. For further comparison of postoperative recovery of the 2 groups, preoperative and postoperative imaging findings were analyzed. CA, VWA, SI, and VFHP were the radiographic parameters of the normal anatomical position.[22] In both the groups, CA, VWA, and SI were significantly decreased, whereas VFHP increased after surgery. Despite that, they were not considered significantly different. This suggested that there was no significant difference in the recovery of thoracolumbar fracture and no greater change in the thoracolumbar anatomical structure, which was beneficial to its function restoration. VAS and ODI were also indicators of the effect of surgery. After surgery, VAS and ODI decreased more dramatically in the PPSF group than in the OPSF group, but there was no significant difference of VAS scores and ODI at the last follow-up between 2 groups, which were consistent with previous findings.[20] Thus, PPSF could promote the early recovery of patients as compared with OPSF.

Studies had shown that the incidence rate of fracture and dislocation of thoracolumbar fractures reached up to 65% to 75%, and effective internal fixation was pivotal for preventing it.[18,23] OPSF had many disadvantages such as more blood loss, while PPSF has been widely used for the treatment of thoracolumbar fractures and its effectiveness has been significant.[21] Using technique of 3 vertebral body 6 nail fixation, PPSF connected the upper and lower injured vertebrae and used distraction fixed rod to maintain the vertebral height. This method could effectively fix the vertebras, help reduce kyphosis, and realize the reduction and fixation of displacement of the spine. In addition, it reduced the concentration of stress internal fixation device and the stress load of rod greatly. Biomechanical stability was improved and normal vertebral height can be restored in time, which then reduced the occurrence of intervertebral space collapse.[24,25] Besides, PPSF promoted wound healing and improved curative effects.

In summary, our results suggested that compared with OPSF treatment, PPSF had a relatively small incision, less intraoperative blood loss, shorter recovery time, higher safety measures, and relatively better therapeutic outcomes. Thus, PPSF is more desirable than OPSF for patients with thoracolumbar fractures accompanied by spinal injuries.

4. Materials and methods

4.1. Patient samples

This retrospective study included 105 patients with thoracolumbar fractures and spinal injuries who were treated in the neurosurgery department of Xijing Hospital, the Fourth Military Medical University (Xi'an, China) from May 2012 to July 2015. Injuries were caused by motor vehicle accidents (33 cases), falling from heights (63 cases), and direct blows (9 cases). The exclusion criteria were as follows: younger than 18 years old, prior systemic diseases including cardiopathy, pathologic fractures with spinal tumors or bone tuberculosis, F Frankel grade or previous spine surgery. According to patients' conditions and permissions, these patients were subsequently divided into 2 groups of surgical approach in this research: a PPSF group with 56 patients, who underwent percutaneous pedicle screw fixation and an OPSF group with 49 patients, who underwent open pedicle screw fixation.

Procedures were in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Human Experimentation of Xijing Hospital, the Fourth Military Medical University. All 105 patients and their relatives have been informed prior to the commencement of this study and corresponding informed consent has been signed as well.

4.2. Surgical procedure

General endotracheal anesthesia was performed for patients lying on a radiolucent operational table in prone position while gel pads were used to support the chest, abdomen, and pelvis of patients. After posterior spinal elements were cleaned and exposed, initial skin incision was carried out for the purpose of screw fixation which was specifically guided by the intraoperative three-dimensional computer navigation system.

In PPSF group, an approximately 1.0 to 2.0 cm incision was performed laterally from the pedicle for the purpose of crew fixation and the underlying fascia was split and the paraspinal muscle was directly in contact with the surgeon's finger. A PAK needle (Medtronic, Minneapolis, MN) was positioned on the medial edge of the transverse process and slowly advanced into the pedicle and posterior half of the vertebral body. Following that, a guided wire was inserted into the vertebral body through the needle, and the needle was carefully removed. The dilation tube was placed through the guide wire, and tapping was done for screw insertion. After tapping to the junction of the pedicle and vertebral body, a cannulated percutaneous pedicle screw was placed through the guided wire into the pedicle and vertebral body through a pedicle screw spinal rod connector, and the guided wire was then removed after proper positioning of the screw. The situation of vertebral canal decompression was detected during the surgery, and then decided whether the additional corporectomy or posterior fusion surgery was necessary. Using the same approach, pedicle screws were inserted into above and below the fractured vertebra including the fractured level. Under fluoroscopic guidance, a longitude rod was placed in the percutaneous pedicle screw heads through a small incision made on the thoracic region. If compression was required for spinal alignment, it was performed prior to placement of locking nuts. Incisions for screws and rods placement were irrigated and closed.

Patients in OPSF group were treated with traditional open pedicle screw fixation surgery according to the previous literature.[10]

4.3. Outcome assessment

In this study, plain radiographs were obtained before surgery, 3 days and 6 days after surgery and during the final following-up period. CA, VWA, VFHP, and SI were measured on neutral lateral radiographs.

Operation indexes mainly included the operation time, intraoperative bleeding volume, postoperative drainage volume, and hospital stay duration. The effectiveness assessment in this research included VAS, ODI, and Frankel grade. VAS scores were measured 3 days and 6 months after surgery and at end of the follow-up period, ODIs 6 months after surgery and at the end of the follow-up period as well as Frankel grades at the end of the follow-up period.

4.4. Statistical analysis

All statistical analyses in this study were performed using SPSS 17.0 statistical software (IL, USA). Continuous variables addressed as mean ± standard deviation were compared using the unpaired t test, and categorical variables demonstrated as counted data were compared using the χ^2 test. For all analyses, $P < .05$ was regarded as statistical significance.

References

[1] Xie Q, Chen X, Lu F, et al. Aberrant expression of microRNA 155 may accelerate cell proliferation by targeting sex-determining region Y box 6 in hepatocellular carcinoma. Cancer 2012;118:2431–42.

[2] Alpantaki K, Bano A, Pasku D, et al. Thoracolumbar burst fractures: a systematic review of management. Orthopedics 2010;33:422–9.

[3] Gertzbein SD. Scoliosis Research SocietyMulticenter spine fracture study. Spine (Phila Pa 1976) 1992;17:528–40.

[4] Katsuura Y, Osborn JM, Cason GW. The epidemiology of thoracolumbar trauma: a meta-analysis. J Orthop 2016;13:383–8.

[5] Abudou M, Chen X, Kong X, et al. Surgical versus non-surgical treatment for thoracolumbar burst fractures without neurological deficit. Cochrane Database Syst Rev 2013;CD005079.

[6] Fennell VS, Palejwala S, Skoch J, et al. Freehand thoracic pedicle screw technique using a uniform entry point and sagittal trajectory for all levels: preliminary clinical experience. J Neurosurg Spine 2014;21:778–84.

[7] Rivkin MA, Okun JF, Yocom SS. Novel free-hand T1 pedicle screw method: review of 44 consecutive cases. J Neurosci Rural Pract 2014; 5:349–54.

[8] Kim YJ, Lenke LG. Thoracic pedicle screw placement: free-hand technique. Neurol India 2005;53:512–9.

[9] Alvine GF, Swain JM, Asher MA, et al. Treatment of thoracolumbar burst fractures with variable screw placement or Isola instrumentation and arthrodesis: case series and literature review. J Spinal Disord Tech 2004;17:251–64.

[10] Kim DY, Lee SH, Chung SK, et al. Comparison of multifidus muscle atrophy and trunk extension muscle strength: percutaneous versus open pedicle screw fixation. Spine (Phila Pa 1976) 2005;30:123–9.

[11] Court C, Vincent C. Percutaneous fixation of thoracolumbar fractures: current concepts. Orthop Traumatol Surg Res 2012;98: 900–9.

[12] Tian W, Xu Y, Liu B, et al. Lumbar spine superior-level facet joint violations: percutaneous versus open pedicle screw insertion using intraoperative 3-dimensional computer-assisted navigation. Chin Med J (Engl) 2014;127:3852–6.

[13] Datta G, Gnanalingham KK, Peterson D, et al. Back pain and disability after lumbar laminectomy: is there a relationship to muscle retraction? Neurosurgery 2004;54:1413–20.

[14] Gejo R, Matsui H, Kawaguchi Y, et al. Serial changes in trunk muscle performance after posterior lumbar surgery. Spine (Phila Pa 1976) 1999;24:1023–8.

[15] Park Y, Ha JW. Comparison of one-level posterior lumbar interbody fusion performed with a minimally invasive approach or a traditional open approach. Spine (Phila Pa 1976) 2007;32:537–43.

[16] Lee JK, Jang JW, Kim TW, et al. Percutaneous short-segment pedicle screw placement without fusion in the treatment of thoracolumbar burst fractures: is it effective?: comparative study with open short-segment pedicle screw fixation with posterolateral fusion. Acta Neurochir (Wien) 2013;155:2305–12.

[17] Mobbs RJ, Sivabalan P, Li J. Minimally invasive surgery compared to open spinal fusion for the treatment of degenerative lumbar spine pathologies. J Clin Neurosci 2012;19:829–35.

[18] Wood KB, Li W, Lebl DR, et al. Management of thoracolumbar spine fractures. Spine J 2014;14:145–64.

[19] Phan K, Rao PJ, Mobbs RJ. Percutaneous versus open pedicle screw fixation for treatment of thoracolumbar fractures: systematic review and meta-analysis of comparative studies. Clin Neurol Neurosurg 2015; 135:85–92.

[20] Li K, Li Z, Ren X, et al. Effect of the percutaneous pedicle screw fixation at the fractured vertebra on the treatment of thoracolumbar fractures. Int Orthop 2016;40:1103–10.

[21] Luo P, Xu LF, Ni WF, et al. [Therapeutic effects and complications of percutaneous pedicle screw fixation for thoracolumbar fractures]. Zhonghua Wai Ke Za Zhi 2011;49:130–4.

[22] Wang J, Zhou Y, Zhang ZF, et al. Radiological study on disc degeneration of thoracolumbar burst fractures treated by percutaneous pedicle screw fixation. Eur Spine J 2013;22:489–94.

[23] Charles YP, Steib JP. Management of thoracolumbar spine fractures with neurologic disorder. Orthop Traumatol Surg Res 2015;101: S31–40.

[24] Dahdaleh NS, Smith ZA, Hitchon PW. Percutaneous pedicle screw fixation for thoracolumbar fractures. Neurosurg Clin N Am 2014; 25:337–46.

[25] Yang WE, Ng ZX, Koh KM, et al. Percutaneous pedicle screw fixation for thoracolumbar burst fracture: a Singapore experience. Singapore Med J 2012;53:577–81.