Am J Transl Res 2022;14(12):8733-8740
www.ajtr.org /ISSN:1943-8141/AJTR0145106

Original Article

Pedicle screw fixation combined with posterior decompression and bone grafting for thoracolumbar spinal fractures can enhance curative effect and spinal cord function

Dong Chen, Xin Jiang

Department of Orthopedics, China-Japan Friendship Hospital, Beijing 100029, China

Received July 3, 2022; Accepted October 11, 2022; Epub December 15, 2022; Published December 30, 2022

Abstract: Objective: To explore the efficacy of pedicle screw fixation (PSF) combined with posterior decompression and bone grafting for thoracolumbar spinal fractures (TLSFs) and its influence on spinal cord function. Methods: In this retrospective study, 94 patients with TLSFs treated in the China-Japan Friendship Hospital rom June 2015 and September 2020 were selected, including 53 cases in the joint group treated with PSF combined with posterior decompression and bone grafting, and 41 cases in the control group with PSF alone. The two groups were compared in terms of operation time, intra-operational blood loss, length of hospital stay and wound healing as well as the pre- and post-treatment spinal cord function, and patients' clinical outcomes. Pre- and post-operatively, the pain severity was evaluated by the Visual Analogue Scale (VAS), the spinal dysfunction was assessed by Oswestry Disability Index (ODI), and the injured vertebral height and Cobb angles of the thoracolumbar spine (TLS) were compared. The clinical efficacy and postoperative complication rates of the two groups were observed and compared. Results: Less operative time, intraoperative bleeding, hospitalization time and wound healing time were determined in the joint group compared with the control group (all $P<0.05$). The postoperative sensory function and motor function were also better in the joint group (all $P<0.05$). Postoperatively, the joint group showed lower VAS and ODI scores than in the control group, with lower upper and lower TLS Cobb angles, and higher height of the anterior and posterior margins of the fractured vertebra (all $P<0.05$). The total effective rate was higher, and the incidence of postoperative complications was significantly lower in the joint group compared with the control group. Conclusion: PSF combined with posterior decompression and bone grafting is effective in the treatment of TLSFs, which can not only significantly improve the spinal cord function and alleviate spinal dysfunction, but also help to relieve pain and reduce postoperative complications.

Keywords: Pedicle screw fixation, posterior decompression and bone grafting, thoracolumbar spinal fractures, curative effect, spinal cord function

Introduction

Thoracolumbar (TL) spinal fractures (TLSFs) are a kind of spinal damage caused by continuous thoracolumbar spine (TLS) destruction due to external force [1]. Because of the particularity of spine function and location, TLSFs are often combined with neurological loss, as well as organ damage as most are caused by high-energy injuries [2]. Moreover, the resulting spinal canal deviation not only easily oppresses the spinal cord (SC) and nerve roots, but also leads to symptoms such as pain and dyskinesia of the spine, seriously reducing the quality of life of patients [3]. Clinically, TLSFs are mostly treated by surgery, which can accurately reduce and decompress the affected part, thus alleviating SC injury to the greatest extent and improving related functions [4]. In this study, pedicle screw fixation (PSF) combined with posterior decompression and bone grafting was used for the intervention of TLSFs to observe its curative effects.

PSF is a surgical procedure commonly used in clinical practice to treat spinal fractures, which can fix the spine at multiple segments, improve spinal stability, and restore the biomechanical function of the spine, but it cannot improve the SC function of patients [5]. Moreover, after the procedure, most patients experience some adverse reactions, such as loss of corrected height [6]. Research has also shown that although PSF can achieve strong fixation and satisfactory reduction, it can only provide temporary relief and mechanical support and is difficult to effectively promote the bone healing of fractured vertebral bodies [7]. Therefore, it is necessary to combine clinical treatment with other operations to strengthen the stability of the patient's spine, maintain the fracture reduction, and effectively promote the healing of the fracture site, thereby avoiding vertebral height loss and back pain [8]. Posterior decompression and bone grafting is a simple operation with little trauma, with easy removal of internal fixation after healing, and it has a large operating field, which is suitable and safe for the treatment of critical patients with conditions such as spinal fractures [9]. Studies have shown that this procedure has the advantages of less surgical invasion, good kyphosis correction effect and low incidence of complications. Posterior decompression and bone grafting can also be used for debridement and interbody fusion at a limited angle [10].

In this research, PSF combined with posterior decompression and bone grafting was introduced to treat TLSFs, and the effects of the combination of the two methods, as well as PSF alone, for patients' healing and SC function were observed.

Data and methods

General case data

This retrospective research recruited 94 patients with TLSFs who visited the China-Japan Friendship Hospital between June 2015 and September 2020, including 53 cases in the joint group treated with PSF combined with posterior decompression and bone grafting, and 41 cases in the control group intervened by PSF alone. Ethical approval had been obtained from the Hospital Academic Ethics Committee, and the informed consent was signed by patients before sampling. Inclusion criteria: all patients were diagnosed as having TLSFs by X-ray imaging and were treatment naive [11]; patients could correctly understand and answer the relevant content of the questionnaire scale; patients with tolerance for surgical treatment, complete general clinical data, no recent use of drugs that might affect the results of this study, and no serious medical diseases. Exclusion criteria: patients with coagulopathy, hemorrhagic disease, autoimmune disease, systemic infection, severe osteoporosis or other orthopedic diseases; patients who did not cooperate; patients who quit or were lost to follow-ups; or pregnant or lactating patients.

Surgical methods

Both groups were operated under general anesthesia.

After anesthesia, patients in the control group were placed in a prone position, and an incision was made in the middle of the back with the fractured vertebra as the center, followed by incision of the subcutaneous tissues. A periosteum stripper was used for blunt dissection of paravertebral muscles against the spinous process and bilateral laminae, so that the laminae and facet joints of the injured vertebral body and its upper and lower vertebrae are exposed. Then, appropriate pedicle screws were placed along the upper and lower pedicles of the injured vertebra. After X-ray (Shanghai Biodriver Biotechnology Company, China, XCELL160 XRay) fluoroscopy confirmation of good internal fixation, bilateral titanium rods were installed, which were gradually and slowly spread alternately to restore the height of the injured vertebral body. Then, the nuts were tightened, and the vertebral lamina on one side of the injured vertebra was bitten off, with attention paid to the protection of the dural sac and nerve roots. Under direct vision, the fractured fragments protruding into the spinal canal were pressed and reduced, and the SC compression at the injured vertebra was relieved. After X-ray fluoroscopy confirmed that the height of the injured vertebra was restored satisfactorily and the fracture block was well reduced, the transverse connecting rod was installed. After that, the wound was repeatedly rinsed with a large amount of normal saline (Beijing Pufee Biotech, China, PR0279), and the instruments and gauze were counted to ensure no operation errors. A drainage tube (Beijing Anteng Medical, China, anton3) was placed after confirming the absence of active bleeding of the wound, and the incision was closed layer by layer.

On the basis of the operation in the control group, patients in the joint group were supplemented with the protection of the dura sac and nerve roots after pedicle screw placement, the examination of the injured vertebral canal, as well as the gradual excision of the fracture segments protruding into the vertebral canal, so as to decompress the bone marrow and nerve roots. Subtotal vertebral resection was performed for the injured vertebra with large fracture fragments protruding into the spinal canal or difficult reduction of the fracture fragments. Intervertebral distraction and reduction were carried out upon the completion of spinal canal decompression. Then the fracture fragments were cut into pieces and implanted into the injured vertebra, followed by moderate compression.

For all patients, first-generation cephalosporin (Shanghai Fantai Biotech, China, FT-RS8409) was administered within 48 hours after operation to prevent infection. The drainage tube was removed on the 2nd postoperative day or when the drainage flow was lower than 50 ml/d. After the removal of the drainage tube, braces can be worn for gradual activities and rehabilitation exercises. The brace was worn for 6 weeks after surgery. X-ray reexamination was performed at 1, 3 and 6 months postoperatively.

Blood sampling

Blood (5 mL) was drawn intravenously before and 5 weeks after surgery and sent to the laboratory for centrifugation, and the supernatant obtained was placed into anticoagulant tubes (Shanghai Keyuan Biotech, China, 36-7525) for testing within 6 h.

Endpoints

The primary endpoints were SC function, Visual Analogue Scale (VAS) score, upper and lower Cobb angles, heights of the anterior and posterior margins of the injured vertebra, curative effect, and incidence of postoperative complications, while secondary endpoints included operation status and Oswestry Disability Index (ODI) score. The methods of observation and evaluation of specific indicators are as follows:

1. The operative time (OT), intraoperative blood loss (IBL), length of hospital stay (LOS), and wound healing time were evaluated.

2. SC function: it was mainly assessed by measuring the sensory function and motor function of patients after operation.

3. VAS [12] score: pain assessment was conducted before and after surgery. The VAS score ranged from 0 to 10, with 0 indicating no pain and 10 indicating unbearable pain.

4. Patients were assessed for lumbar and leg pain before and after surgery with the ODI [13]. The scale had 10 items with a score range of 0-100. Higher score indicate more severe spinal dysfunction.

5. The upper and lower Cobb angles of the TLS, as well as the heights of the anterior and posterior margins of the injured vertebra were recorded before and after the operation.

6. Response evaluation: Marked response: the patient's postoperative lumbar pain and other symptoms disappeared, with normal lumbar motion and no impact on daily activities; Response: the postoperative symptoms, such as lumbar pain, were alleviated, with some certain lumbar movement limitation that would not affect daily activities; Non-response: the postoperative lumbar pain became severe, with severe lumbar movement limitation that affected daily activities. Overall response rate (ORR) = (marked response + response) cases/total cases × 100%.

7. Incidence of postoperative complications: the number of postoperative complications such as wound infection, screw loosening and spinal instability in the two groups of patients were observed and counted.

Statistics and methods

SPSS 21.0 (SPSS, Inc., USA) was used for data analysis, while GraphPad Prism 6.0 (GraphPad Software Inc., USA) was adopted for figure rendering. A Chi-square test was used for the intra-group comparison of counting data denoted by the number of cases/percentage [n (%)], and a Chi-Square Continuity Correction was further used when the theoretical frequency of the former test was <5. Measurement data represented by mean ± SD and were analyzed by the independent samples t-test between groups, and by the paired t-test within the group before and after surgery. $P<0.05$ suggested the presence of significance.

Table 1. Comparison of general data [n (%)] (mean ± SD)

Classification	Joint group (n=53)	Control group (n=41)	t/χ^2	P
Average age (years old)	49.85±3.43	48.82±4.25	1.300	0.197
Body mass index (kg/m^2)	23.58±2.64	24.05±2.47	0.880	0.381
Smoking history			0.270	0.603
Yes	23 (43.40)	20 (48.78)		
No	30 (56.60)	21 (51.22)		
Drinking history			0.196	0.658
Yes	27 (50.94)	19 (46.34)		
No	26 (49.06)	22 (53.66)		
Cause of injury			0.424	0.809
Falls	18 (33.96)	12 (29.27)		
Car accidents	20 (37.74)	15 (36.59)		
Crushes	15 (28.30)	14 (34.15)		
Fracture site			1.005	0.605
Thoracic fracture	12 (22.64)	13 (31.71)		
Lumbar fracture	17 (32.08)	11 (26.83)		
Thoracolumbar fracture	24 (45.28)	17 (41.46)		

Table 2. Comparison of operation conditions (mean ± SD)

Groups	n	Operative time (min)	Intraoperative blood loss (mL)	Length of hospital stay (d)	Wound healing time (d)
Joint group	53	139.43±15.90	346.42±34.35	8.21±0.77	18.87±1.79
Control group	41	163.37±19.9	534.78±60.6	9.83±1.05	23.88±2.67
T	-	6.485	19.035	8.631	10.870
P	-	<0.001	<0.001	<0.001	<0.001

Table 3. Comparison of spinal cord function before and after surgery (mean ± SD)

Groups	Sensory function		Motor function	
	Before surgery	After surgery	Before surgery	After surgery
Joint group (n=53)	30.43±3.09	69.36±5.91*	14.96±1.29	57.91±5.85*
Control group (n=41)	30.80±2.25	48.93±4.72*	15.32±1.31	34.78±3.80*
T	0.645	18.107	1.333	21.971
P	0.520	<0.001	0.186	<0.001

Note: *P<0.05 compared with preoperative level.

Results

General information

The two groups were non-significantly different in mean age, body mass index (BMI), smoking/drinking history, cause of injury, fracture location and other clinical baseline (all P>0.05). See **Table 1** for details.

Comparison of general surgery conditions

Less OT, IBL, LOS and wound healing time were required in the joint group as compared to the control group (all P<0.05). Please see **Table 2** for details.

Comparison of pre- and post-operative SC function

No statistical differences were found in sensory function and motor function between the joint group and the control group preoperatively (both P>0.05). Improvement of SC function was observed in both groups after surgery, with better sensory function and motor function in the joint group (both P<0.05, **Table 3**).

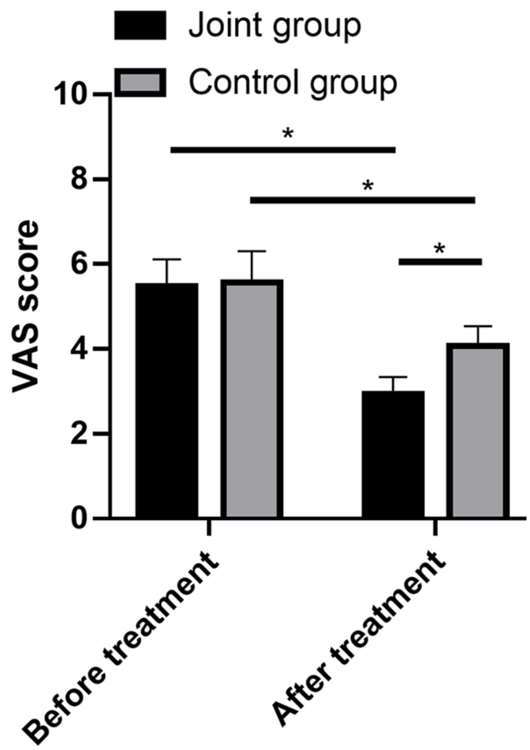

Figure 1. Comparison of pre- and post-operative VAS scores. Note: *P<0.05. VAS, Visual Analogue Scale.

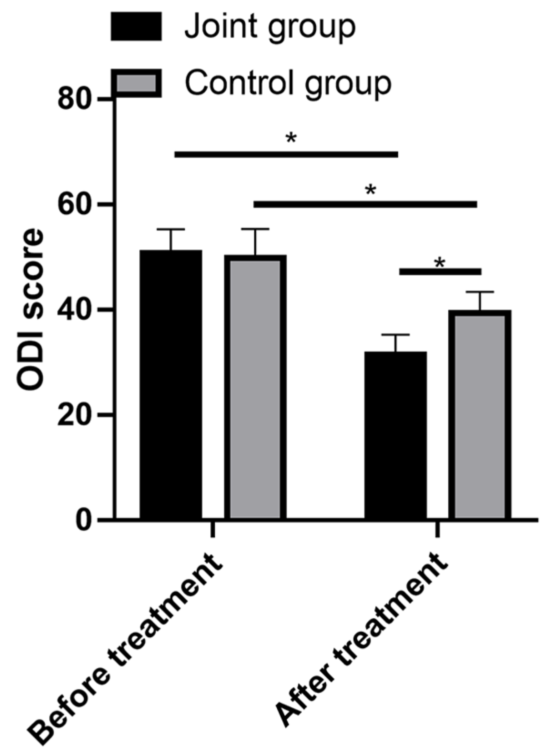

Figure 2. Comparison of pre- and post-operative ODI scores. Note: *P<0.05. ODI, Oswestry Disability Index.

Comparison of pre- and post-operative VAS scores

Similarly, the pain assessed by the VAS differed insignificantly between groups before surgery (P>0.05) but decreased markedly in both cohorts after the treatment, with significantly better pain relief (lower VAS scores) in the joint group (P<0.05, **Figure 1**).

Comparison of pre- and post-operative ODI scores

The preoperative ODI score was not significantly different between groups (P>0.05); while postoperatively, the ODI score improved markedly in both cohorts and was lower in the joint group compared with the control group (P<0.05, **Figure 2**).

Comparison of Cobb angle and injured vertebral height before and after surgery

Preoperatively, the two groups showed no difference in upper and lower TLS Cobb angles and anterior and posterior margin heights of the fractured vertebra (all P>0.05). After surgery, both groups showed significant improvements in the Cobb angle and the height of the injured vertebrae. Moreover, in comparison with the control group, the upper Cobb and lower Cobb angles were lower while the anterior and posterior margin heights of the injured vertebra were higher in the joint group (all P<0.05, **Table 4**).

Comparison of postoperative clinical efficacy

The ORR of the joint group was 92.45%, which was significantly higher compared with the control group (78.05%) (P<0.05, **Table 5**).

Incidence of postoperative complications in the two groups

The postoperative complication rate in the joint group was 1.89%, which was statistically lower compared with the control group (14.63%) (P<0.05, **Table 6**).

Discussion

TLSF is a common axial bone fracture, with approximately two thirds of the cases of it

Table 4. Comparison of Cobb angle and injured vertebral height before and after surgery (mean ± SD)

Indexes		Joint group (n=53)	Control group (n=41)	t	P
Upper Cobb angle (°)	Before surgery	18.54±1.25	18.33±1.34	0.782	0.435
	After surgery	11.72±1.05*	14.31±1.54*	9.682	<0.001
Lower Cobb angle (°)	Before surgery	13.65±1.31	13.32±1.24	1.240	0.218
	After surgery	8.25±0.87*	10.35±1.36*	9.097	<0.001
Anterior margin height of the fractured vertebra (mm)	Before surgery	64.25±6.17	64.18±6.23	0.054	0.957
	After surgery	88.26±8.33*	77.65±7.28*	6.465	<0.001
Posterior margin height of the fractured vertebra (mm)	Before surgery	71.28±6.97	71.22±7.03	0.041	0.967
	After surgery	92.44±9.25*	82.36±8.13*	5.520	<0.001

Note: *P<0.05 compared with preoperative level.

Table 5. Comparison of postoperative clinical efficacy [n (%)]

Groups	Marked response	Response	Non-response	Total response rate (%)
Joint group (n=53)	30 (56.60)	19 (35.85)	4 (7.55)	49 (92.45)
Control group (n=41)	12 (29.27)	20 (48.78)	9 (21.95)	32 (78.05)
χ^2	-	-	-	4.025
P	-	-	-	0.044

Table 6. Incidence of postoperative complications in the two groups [n (%)]

Groups	Joint group (n=53)	Control group (n=41)	χ^2	P
Wound infection	1 (1.89)	2 (4.88)	-	-
Screw loosening	0 (0.00)	3 (7.32)	-	-
Spinal instability	0 (0.00)	1 (1.44)	-	-
Total incidence	1 (1.89)	6 (14.63)	5.450	0.020

occurring between T11 and L2 [14]. This disease not only destroys the structural integrity and stability of the vertebral body, but also easily causes SC and nerve injuries [15, 16], with high morbidity and disability rate. Therefore, for patients with TLSFs, effective measures must be taken in time to promote their recovery as soon as possible, so as to reduce the harm caused by complications [17].

With the continuous improvement of medical level, PSF is increasingly used in clinical practice with recognized surgical effects [18]. Although this surgical method can achieve firm fixation and satisfactory reduction, it is difficult to effectively promote the bone healing of fractured vertebral body [19]. Therefore, in this study, posterior decompression and bone grafting was used for combination therapy, as bone grafting can effectively rebuild spinal stability, and prevents fracture and loosening of internal fixation, effectively promoting healing of the injured vertebral body, and reducing nerve compression [20]. Our results revealed markedly less OT, IBL, LOS and wound healing time in the joint group, indicating that the combination of the two can effectively reduce surgical trauma and postoperative recovery time compared with the control group treated with a single operation. TLSFs can compress the nerves of patients, resulting in trauma to the SC [21]. This study found that after treatment with PSF combined with posterior decompression and bone grafting, the sensory function and motor function of patients in the joint group improved more significantly than in the control group. It suggests that the combination treatment has good clinical effects, which can facilitate patients' recovery, effectively protect SC function, and relieve nerve compression. TLSFs can also induce severe local pain. Wang B reported that [22] PSF could effectively reduce postoperative VAS score and ODI score. Our research determined more markedly reduced VAS and ODI scores in the joint group compared with the control group. The reason may be that the combination of the two can better play the role of muscle tension strap, maintain the stability of fracture reduction, and effectively promote the healing of the fracture site, thus alleviating the pain of patients.

The TL segment is the turning point between the lumbar spine and the thoracic vertebra, which when fractured is associated with SC injury under the action of external force, resulting in nerve compression and loss of the bearing capacity of the spine [23]. Clinical treatment aims to provide spinal reduction and effective decompression and stabilization [24]. However, the research of Li Q showed [25] that traditional PSF for TL fractures would lead to vertebral height loss, kyphosis recurrence, fracture or mechanical loosening. While after applying PSF combined with posterior decompression and bone grafting in the joint group, the upper and lower TLS Cobb angles were found to be statistically lower compared with the control group, while the heights of the anterior and posterior margins of the injured vertebra were significantly higher. This shows that PSF only serves as a temporary and mechanical support, with little effect on promoting bone healing of the fractured vertebral body. Its combination with posterior decompression and bone grafting, on the other hand, can effectively avoid the loosening or fracture of internal fixation; in addition, bone grafting in the vertebral body can fill bone fragments to rebuild the stability of the spine, which not only reduces the compression of spinal nerves, but also effectively achieves the purpose of restoring the height of the anterior edge of the vertebral body. Moreover, the ORR was higher, and the incidence of postoperative complications was lower in the joint group compared with the control group, indicating that PSF combined with posterior decompression and bone grafting can effectively avoid the loosening and fracture of internal fixation, rebuild spinal stability, and reduce the compression of injured vertebrae on nerves, with good therapeutic effects and high safety.

The innovation of this study includes: ① From the aspects of OT, IBL, LOS, wound healing time, curative effect and postoperative complication rate, it is confirmed that PSF combined with posterior decompression and bone grafting has significantly better surgical effect and total effective rate, with high safety; ② It confirmed the positive effect of the combined therapy from the perspectives of SC function, VAS, ODI score, upper and lower cobb angles, and heights of anterior and posterior margins of the injured vertebra, which provides a reliable clinical basis for the optimization of treatment selection and postoperative rehabilitation of such patients.

But this research still has some room for improvement. For example, we can refine the research design by supplementing basic experiments on the therapeutic mechanisms of the two treatments to explore the risk factors that influence patient outcomes at the molecular level. In addition, the quality of life of patients, patient satisfaction, and treatment costs can also be investigated.

Conclusively, PSF combined with posterior decompression and bone grafting is effective in treating TLSFs, which can significantly improve the SC function, alleviate spinal dysfunction, and help to relieve pain.

Disclosure of conflict of interest

None.

Address correspondence to: Xin Jiang, Department of Orthopedics, China-Japan Friendship Hospital, No. 2 Yinghua East Street, Chaoyang District, Beijing 100029, China. Tel: +86-18612561166; E-mail: 18612561166@163.com

References

[1] Verheyden AP, Spiegl UJ, Ekkerlein H, Gercek E, Hauck S, Josten C, Kandziora F, Katscher S, Kobbe P, Knop C, Lehmann W, Meffert RH, Muller CW, Partenheimer A, Schinkel C, Schleicher P, Scholz M, Ulrich C and Hoelzl A. Treatment of fractures of the thoracolumbar spine: recommendations of the spine section of the german society for orthopaedics and trauma (DGOU). Global Spine J 2018; 8: 34S-45S.

[2] Skeers P, Battistuzzo CR, Clark JM, Bernard S, Freeman BJC and Batchelor PE. Acute thoracolumbar spinal cord injury: relationship of cord compression to neurological outcome. J Bone Joint Surg Am 2018; 100: 305-315.

[3] Ruiz Santiago F, Tomas Munoz P, Moya Sanchez E, Revelles Paniza M, Martinez Martinez A and Perez Abela AL. Classifying thoracolumbar fractures: role of quantitative imaging. Quant Imaging Med Surg 2016; 6: 772-784.

[4] Park HJ, Lee SY, Park NH, Shin HG, Chung EC, Rho MH, Kim MS and Kwon HJ. Modified thoracolumbar injury classification and severity score (TLICS) and its clinical usefulness. Acta Radiol 2016; 57: 74-81.

[5] McDonnell M, Shah KN, Paller DJ, Thakur NA, Koruprolu S, Palumbo MA and Daniels AH. Biomechanical analysis of pedicle screw fixation for thoracolumbar burst fractures. Orthopedics 2016; 39: e514-518.

[6] Chan CYW and Kwan MK. Safety of pedicle screws in adolescent idiopathic scoliosis surgery. Asian Spine J 2017; 11: 998-1007.

[7] Su Y, Wang X, Ren D, Liu Y, Liu S and Wang P. A finite element study on posterior short segment fixation combined with unilateral fixation using pedicle screws for stable thoracolumbar fracture. Medicine (Baltimore) 2018; 97: e12046.

[8] Cai M, Xin Z, Kong W, Du Q, Ji W, Wu F, Li J, He J and Liao W. Clinical effect of a novel transpedicular reducer for reduction and bone grafting combined with pedicle screw fixation for thoracolumbar burst fractures. BMC Musculoskelet Disord 2021; 22: 540.

[9] Mehta G, Patel A, Jain S, Merchant ZA and Kundnani V. Clinico-radiological efficacy of posterior instrumentation, decompression, and transpedicular bone grafting in osteoporotic burst fracture associated with neurological deficit. Asian J Neurosurg 2019; 14: 1207-1213.

[10] Yin XH, Yan L, Yang M, Zhang K, He BR, Liu ZK and Hao DJ. Posterolateral decompression, bone graft fusion, posterior instrumentation, and local continuous chemotherapy in the surgical treatment of thoracic spinal tuberculosis. Medicine (Baltimore) 2018; 97: e13822.

[11] Durmaz A, Ilter MH and Tuzlali H. Is magnetic resonance imaging needed for decision making diagnosis and treatment of thoracic and lumbar vertebral fractures? Eur J Orthop Surg Traumatol 2021; [Epub ahead of print].

[12] Li S, Li Z, Hua W, Wang K, Li S, Zhang Y, Ye Z, Shao Z, Wu X and Yang C. Clinical outcome and surgical strategies for late post-traumatic kyphosis after failed thoracolumbar fracture operation: case report and literature review. Medicine (Baltimore) 2017; 96: e8770.

[13] Furnas HJ, Lineaweaver W and Buncke HJ. Blood loss associated with anticoagulation in patients with replanted digits. J Hand Surg Am 1992; 17: 226-229.

[14] Defino HLA, Costa HRT, Nunes AA, Nogueira Barbosa M and Romero V. Open versus minimally invasive percutaneous surgery for surgical treatment of thoracolumbar spine fractures-a multicenter randomized controlled trial: study protocol. BMC Musculoskelet Disord 2019; 20: 397.

[15] van Den Hauwe L, Sundgren PC and Flanders AE. Spinal trauma and spinal cord injury (SCI). In: Hodler J, Kubik-Huch RA, von Schulthess GK, editors. Diseases of the brain, head and neck, spine 2020-2023: diagnostic imaging. Cham (CH): 2020. pp. 231-240.

[16] Srinivasan V and Jea A. Pediatric thoracolumbar spine trauma. Neurosurg Clin N Am 2017; 28: 103-114.

[17] Schwaiger BJ, Schneider C, Kronthaler S, Gassert FT, Bohm C, Pfeiffer D, Baum T, Kirschke JS, Karampinos DC, Makowski MR, Woertler K, Wurm M and Gersing AS. CT-like images based on T1 spoiled gradient-echo and ultra-short echo time MRI sequences for the assessment of vertebral fractures and degenerative bone changes of the spine. Eur Radiol 2021; 31: 4680-4689.

[18] Kim HJ, Jung WI, Chang BS, Lee CK, Kang KT and Yeom JS. A prospective, randomized, controlled trial of robot-assisted vs freehand pedicle screw fixation in spine surgery. Int J Med Robot 2017; 13: 3.

[19] Wang H, Zhou Y, Li C, Liu J and Xiang L. Comparison of open versus percutaneous pedicle screw fixation using the sextant system in the treatment of traumatic thoracolumbar fractures. Clin Spine Surg 2017; 30: E239-E246.

[20] Fan W, Yang G, Zhou T, Chen Y, Gao Z, Zhou W and Gu Y. One-stage freehand minimally invasive pedicle screw fixation combined with mini-access surgery through OLIF approach for the treatment of lumbar tuberculosis. J Orthop Surg Res 2022; 17: 242.

[21] Rahyussalim AJ, Saleh I, Armin MF, Kurniawati T and Safri AY. Pedicle screw position changing policy for nerve injury problems during screw insertion on thoracolumbar compression fractures. Int J Surg Case Rep 2016; 28: 155-160.

[22] Wang B, Fan Y, Dong J, Wang H, Wang F, Liu Z, Liu H, Feng Y, Chen F, Huang Z, Chen R, Lei W and Wu Z. A retrospective study comparing percutaneous and open pedicle screw fixation for thoracolumbar fractures with spinal injuries. Medicine (Baltimore) 2017; 96: e8104.

[23] Cahueque M, Cobar A, Zuniga C and Caldera G. Management of burst fractures in the thoracolumbar spine. J Orthop 2016; 13: 278-281.

[24] Zhao Q, Zhang H, Hao D, Guo H, Wang B and He B. Complications of percutaneous pedicle screw fixation in treating thoracolumbar and lumbar fracture. Medicine (Baltimore) 2018; 97: e11560.

[25] Li Q, Yun C and Li S. Transpedicular bone grafting and pedicle screw fixation in injured vertebrae using a paraspinal approach for thoracolumbar fractures: a retrospective study. J Orthop Surg Res 2016; 11: 115.