Clinical Article

Radiological and Clinical Results of Laminectomy and Posterior Stabilization for Severe Thoracolumbar Burst Fracture : Surgical Technique for One-Stage Operation

Myeong-Soo Kim, M.D., Jong-Pil Eun, M.D., Ph.D., Jeong-Soo Park, M.D.

Department of Neurosurgery, Research Institute of Clinical Medicine, Institute for Medical Science, Chonbuk National University Medical School/ Hospital, Jeonju, Korea

Objective : This study aimed to show the possibility of neural canal enlargement and restoration of bony fragments through laminectomy and minimal facetectomy without pediculectomy or an anterior approach, and also to prove the adequacy of posterior stabilization of vertebral deformities after thoracolumbar bursting fracture.

Methods : From January 2003 to June 2009, we experienced 45 patients with thoracolumbar burst fractures. All patients enrolled were presented with either a neural canal compromise of more than 40% with a Benzel-Larson Grade of VI, or more than 30% compromise with less than a Benzel-Larson Grade of V. Most important characteristic of our surgical procedure was repositioning retropulsed bone fragments using custom-designed instruments via laminectomy and minimal facetectomy without removing the fractured bone fragments. Beneath the dural sac, these custom-designed instruments could push the retropulsed bone fragments within the neural canal after the decompression and bone fragment repositioning.

Results : The mean kyphotic deformities measured preoperatively and at follow-up within 12 months were 17.7 degrees (±6.4 degrees) and 9.6 degrees (±5.2 degrees), respectively. The mean midsagittal diameter improved from 8.8 mm (±2.8 mm) before surgery to 14.2 mm (±1.6 mm) at follow-up. The mean traumatic vertebral body height before surgery was 41.3% (±12.6%). At follow-up assessment within 12 months, this score showed a statistically significant increase to 68.3% (±12.8%). Neurological improvement occurred in all patients.

Conclusion : Though controversy exists in the treatment of severe thoracolumbar burst fracture, we achieved effective radiological and clinical results in the cases of burst fractures causing severe canal compromise and spinal deformity by using this novel custom-designed instruments, via posterior approach alone.

Key Words : Spinal fracture · Thoracolumbar spine · Surgical fixation devices · Spinal fusion · Surgical instrument.

INTRODUCTION

Half of all spinal fractures and a respectable percentage of acute spinal cord injuries usually results from trauma[40]. Considering this incidence and the significant impacts of this kind of injury, surgical managements of thoracolumbar trauma has advanced significantly. In spite of continued evolution of spinal instrumentations and surgical techniques, surgical decision-making in spine injuries remains controversial[34]. Management of fracture can vary widely, from bracing to invasive 360° fusion, based on geographical, institutional, or individual prefer-

ences with little scientific basis[36]. Most thoracolumbar burst fractures are stable injuries that can be treated nonsurgically[34,39]. Regardless of neurologic deficits, unstable burst fracture that have retropulsed bone fragments compromising the canal requires surgical interventions such as decompression of neural structures, correction of spinal deformities and stabilization[1,4,5,7,10]. Usual surgical procedures may include very invasive procedures such as lateral extracavitary approaches, laminectomy, pediculectomy, and anterior vertebrectomy or corpectomy[7,10,23,28,38].

However, conventional operation for unstable thoracolumbar fracture have been associated with major complication rates as high as 28-86%[43]. Minimally-invasive surgical approaches provide the possibility to reduce some of the complications associated with conventional invasive surgeries such as lateral extracavitary approaches and anterior vertebrectomy or corpectomy[9,15,22,41].

The burst vertebrae will heal and begin to bear axial loads, after undergoing stabilization and loading protection for a certain period. On the other hand, retropulsed bone fragments should be re-

moved from the canal space, because the recovery of normal canal dimensions is possibly associated with improvements in neurological function for patients with partial deficits[2,3,7,10,11,14,23,29,32]. From this perspective, removing only the retropulsed bone fragments from the spinal canal and then protecting the injured level against load-bearing conditions for a time via a construct seems an effective, alternative surgical method for treatment of patients with burst fractures.

We tried to demonstrate the possibilities of neural canal enlargement and restoration of vertebral height through laminectomy and minimal facetectomy, repositioning retropulsed bone fragments with custom-designed instruments without pediculectomy or an anterior approach.

MATERIALS AND METHODS

Inclusion criteria and clinical and radiological studies

From January 2003 to June 2009, we enrolled 45 patients with thoracolumbar burst fractures in this study retrospectively. We also used our surgical procedure on those patients with a Benzel-Larson Grade of VI and neural canal encroachment greater than 40% on axial computed tomography (CT). In addition, we included patients with a Benzel-Larson Grade less than V and more than 30% neural canal encroachment in this study.

The percentage of the canal compromise was determined using the formula $\alpha=(1-x/y)\times100$, where α is the percentage of canal compromise, x is the narrowest mid-sagittal diameter of the spinal canal at the level of injury, and y is the average mid-sagittal diameter of the spinal canal at one level above and below the injured segment[18,22]. The fractured vertebral body angle of kyphotic deformity was measured as the angle between the upper margin of the vertebral body and the lower margin of the vertebral body (Fig. 1A)[12,18]. The vertebral body height was determined using the formula=$2F/(A+B)\times100$, where F is the height of the fractured vertebral body, A is the height of the upper vertebral body, and B is the height of the lower vertebral body (Fig. 1B)[18].

To evaluate the patients' myelopathic dysfunction, we employed the Benzel-Larson Grading system (Table 1)[3]. We analyzed each patient's operation records, progression notes, reports of preoperative and postoperative radiological studies, and follow-up evaluation notes from outpatients clinic. Analysis included the following factors : kyphosis angle and correction, the mean midsagittal diameter, the vertebral body height. We evaluated neurologic outcome according to the Benzel-Larson Grading system. Simple plain films, CT, and magnetic resonance imaging were used to determine the level of injury and to estimate the extent of neural compression and the spinal deformity. We routinely undertook

patients' CT scans just after their operations to check repositioning of the retropulsed bone fragments', kyphotic deformities, and to measure the vertebral body heights. Acute spinal cord injury (SCI) patients underwent high-dose intravenous steroid therapy. Methylprednisolone (MP) should be given as a bolus dose of 30 mg/kg over 15 minutes, and followed by a continuous infusion of 5.4 mg/kg/hour. If treatment is initiated within 3 hours after sustaining SCI, the infusion would be for 23 hours (total treatment time of 24 hours). However, if treatment is initiated within 3-8 hours then the infusion should be continued for 47 hours (total treatment time of 48 hours). No MP should be given if the patient arrives 8 hours or more after SCI[37]. All surgical procedures were performed on an emergency basis.

Operation technique

According to the Denis three-column theory, the undamaged part of a spinal structure in burst fracture is the posterior column[8]. Our surgical procedure was attempted to reach the retropulsed bone fragments through performing both laminectomy and minimal facetectomy. In prone position, we made a midline skin incision to expose the laminae 1 or 2 levels above
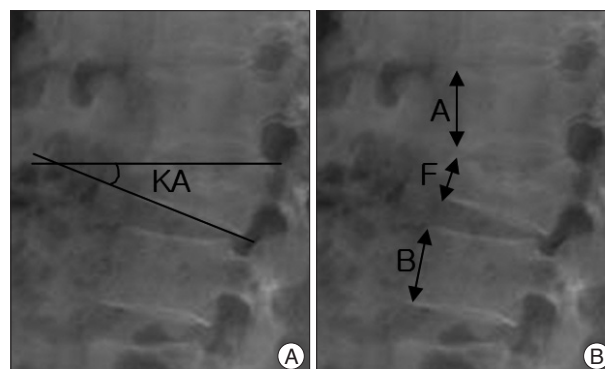
Fig. 1. A : The fractured vertebral body angle of kyphotic deformity is measured as the angle between the upper margin of the vertebral body and the lower margin of the vertebral body. B : The vertebral body height was determined using the formula=$2F/(A+B)\times100$, where F is the height of the fractured vertebral body, A is the height of the upper vertebral body, and B is the height of the lower vertebral body.

Table 1. Benzel-Larson neurological grading system of thoracic and lumbar spine injuries with regard to myelopathic function

Grade	Description
I	Complete functional neural transection : no motor or sensory function
II	Motor complete : no voluntary motor function w/preservation of some sensation
III	Motor incomplete–nonfunctional : minimal nonfunctional voluntary motor function
IV	Motor incomplete–functional (nonambulatory) : some functional motor control that is useful but not sufficient for independent walking
V	Motor incomplete–functional (limited ambulation) : walking w/assistance or unassisted but w/significant difficulty that limits patient mobility
VI	Motor incomplete–functional (unlimited ambulation) : difficulty w/micturition : significant motor radiculopathy; discoordinated gait
VII	Normal : neurologically intact or minimal deficits that cause no functional difficulties

and below the injured levels. We performed blunt dissection until the facet joints on both sides were seen. After routine laminectomy, we removed facet joints minimally to expose nerve root of both sides.

Once posterior decompression was completed, surgical channel for custom-designed instruments was made from lateral side of dura to reach the retropulsed bone fragments, employing surgical microscopic guidance (Fig. 2). Then, beneath the dural sac, we could push the retropulsed bone fragments down into the fractures vertebral body by using these custom-designed instruments (Fig. 3A, B) to their rightful position in the bursted vertebral body. The manipulation was ought to be performed with great care to avoid damage to the neural structures. This was a crucial procedure to decompress the neural canal without the removal of the retropulsed bone fragments. After the posterior decompression and bone fragment repositioning, the transverse processes, laminae of above and below level, and other posterior bony surfaces were decorticated by means of a high-speed drill for posterolateral fusion. Then, we carried out the classical pedicle screw instrumentation (transpedicular screw and rod instruments). Finally, we embedded sufficient amount of harvested bone fragments and artificial bone chips (Bonegros®, carbon-apatite) in the posterolateral sides of the column (Fig. 4).

Follow-up evaluation

Most patients underwent rehabilitation. The ones with good motor function became mobile as soon as possible after their surgery. Long-term follow-up evaluations ranging from 12 to

Fig. 2. After laminectomy and minimal facetectomy, the retropulsed bone fragments within the neural canal can be pushed by custom and company designed instruments under the dural sac. The surgeon pushes the bone fragments anteriorly into the bursted vertebral body (upper : posterior view, lower : lateral view).
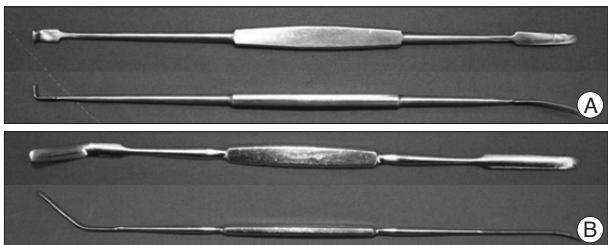
Fig. 3. Photographs of the instruments (A and B : custom-designed). The instrument is made of one piece of stainless steel, and is 20 cm long with double foot plates, blunt blades and angled from the shaft. The shaft has a flat portion at its center for the surgeon's finger. Two instruments are available for use, with a 5 mm or a 3 mm wide foot plate (A : Angled 90° and 140° from the shaft, 5 mm and 15 mm long foot plates. B : Angled 140° from the shaft, 20 mm and 6 mm long foot plates). The foot plate of the instrument is gently located into the spinal canal and, taking a firm grip on the instrument with both hands, the surgeon pushes the retropulsed fragments anteriorly into the vertebral body.

Fig. 4. Patient 11 (upper left). Preoperative simple film of a 26-year-old female patient who sustained L1 burst fracture (upper right). Preoperative CT scan image demonstrating a significant spinal canal encroachment by retropulsion of the fragments of the fracture vertebra (preoperative evaluation : KA=15°, Height=31%, MSD=10.1 mm, SCC=47%, B-L grade=IV) (lower left, right). Postoperative simple film and CT scan image (postoperative evaluation : KA=3°, Height=68%, MSD=16.5 mm, SCC=14%, B-L grade=VI). *KA : kyphotic angle, height : vertebral body height, MSD : mid-sagittal diameter, SCC : spinal canal compromise, B-L : Benzel-Larson.

Table 2. Clinical characteristics and demographics for 45 patients

No.	Age (yr)	Sex	Vector	Level	KA (degree)		Ht (%)		NG		CC (%)	MSD (mm)	
					Pre	Post	Pre	Post	Pre	Post		Pre	Post
1	35	F	FD	T12	9	6	43	78	V	VII	38	8.2	12.1
2	44	F	FD	T12	11	5	52	75	IV	VI	43	7.3	12.1
3	54	F	MVA	L1	8	5	30	70	IV	VI	55	7.0	14.6
4	40	M	MVA	L3	8	5	45	73	VI	VII	50	9.0	12.9
5	51	M	FD	T11	11	5	55	81	II	III	45	6.8	12.9
6	43	M	MVA	T12	6	4	62	78	IV	VII	35	7.3	14.1
7	24	M	MVA	L1	16	10	40	75	VI	VII	50	7.9	13.7
8	31	M	Sliding	L1	20	10	34	69	V	VII	58	7.3	12.5
9	58	M	Sliding	L1	12	7	30	77	VI	VII	56	12.1	14.1
10	49	F	Others	L2	29	20	28	79	III	VI	73	7.0	12.9
11	26	F	FD	L1	15	3	31	68	IV	VI	47	10.1	16.5
12	42	F	MVA	T12	24	14	42	68	IV	VI	55	7.5	13.1
13	28	F	FD	L1	17	10	49	81	IV	VII	47	10.0	15.3
14	35	M	FD	L1	19	10	34	63	III	V	60	7.3	15.9
15	37	F	Sliding	L2	20	8	54	75	VI	VII	38	13.0	16.7
16	71	F	FD	L1	17	14	40	71	IV	VI	58	8.2	16.9
17	37	M	FD	T12	8	5	60	72	V	VII	30	8.5	14.6
18	43	M	MVA	L2	28	22	53	73	VI	VII	40	15.8	17.1
19	75	M	Others	L4	30	20	64	79	VI	VII	36	16.2	18.0
20	23	F	MVA	L2	21	10	50	71	IV	VI	50	11.3	16.0
21	51	F	FD	L1	18	5	55	90	V	VI	38	10.8	16.8
22	52	M	MVA	L4	15	9	60	75	V	VII	35	13.1	14.8
23	54	M	MVA	L1	17	7	53	71	V	VI	51	9.1	14.9
24	37	M	FD	T12	10	5	47	68	IV	VII	38	8.5	13.8
25	62	M	FD	L1	24	19	30	68	III	V	78	2.8	12.9
26	62	F	FD	T12	14	6	55	80	IV	VI	46	6.8	12.9
27	19	M	FD	L2	28	20	40	73	IV	VII	37	14.0	14.5
28	24	F	MVA	T11	15	5	52	81	IV	VII	40	7.8	13.2
29	43	F	FD	L1	28	19	37	70	V	VII	56	7.1	13.1
30	43	M	FD	L1	22	13	42	89	III	VI	74	3.5	13.2
31	22	F	FD	T12	13	4	50	87	V	VII	43	6.5	12.9
32	30	M	MVA	L1	13	8.7	46	50	VI	VII	37	12.5	14.1
33	40	M	FD	L2	22	12	45	60	VI	VII	40	9.0	16.9
34	34	M	MVA	L1	15	8	30	54	III	V	50	8.0	12.7
35	49	M	MVA	L3	18	10	40	62	VI	VII	52	12.4	15.6
36	50	M	MVA	L1	21	11	45	63	V	VII	45	10.3	14.8
37	34	M	FD	L3	22	12	45	70	VI	VII	60	8.5	12.6
38	25	M	Sliding	L2	24	3	5	37	VI	VII	60	6.7	15.4
39	18	M	MVA	L3	14	4	24	55	IV	VI	71	5.1	13.7
40	48	F	FD	L2	19	13	18	41	VI	VII	76	3.9	12.8
41	17	F	MVA	L2	14	10	26	35	VI	VII	55	8.1	14.4
42	16	F	Sliding	L2	19	15	34	55	VI	VII	44	8.6	11.2
43	53	M	FD	L1	11	5	31	44	V	VI	49	9.3	12.4
44	28	F	FD	T12	31	6	25	59	VI	VII	40	9.9	15.8
45	23	F	MVA	L2	22	9	29	63	VI	VII	43	9.0	14.0

KA : kyphotic angle, Ht : vertebral body height, NG : Benzel-Larson neurological grade, CC : canal compromise, MSD : mid-sagittal diameter, FD : fall down, MVA : motor vehicle accidents

72 months after the operation were consisted of re-grading the patients' neurological statuses according to the Benzel-Larson Grading system and radiographic analyses. Radiological follow-ups were completed for all patients. We evaluated patients' radiographs pre- and post-operatively as well as in the long-term follow-ups. We also employed plain and dynamic radiographic studies, including flexion-extension and oblique views and CT scans to assess fusion status.

Statistical analysis

The data were analyzed by the paired samples t-test from the SPSS software package, version 13.0 (SPSS Inc., Chicago, IL, USA). A p value less than 0.01 was considered significant.

RESULTS

This study included 25 male and 20 female patients whose mean age at the time of injury was 39.5±14.4 (SD) years (range; 16-75 years). Major cause of these fractures was a fall (21 patients, 47%). Other causes were motor vehicle accidents (17 patients, 38%) and direct blunt traumas such as sliding and violence (7 patients, 15%). Most frequently fractured levels were L1 (17 patients, 38%) and L2 (11 patients, 24%). Fractures of T11 and T12 was 24%.

Table 2 lists the demographic data and individual preoperative characteristics of 45 patients, summarizing the preoperative and postoperative neurologic statuses. No severe complications that needed revision were observed at each patient's last follow-up. In this study, we achieved posterolateral intersegmental fusion between each T11, T12, L1, and L2 levels, without interbody fusion. Stabilization and bony fusion were completed in

Fig. 5. Classification of the neurological conditions of patients according to Benzel-Larson grading system (n=45).
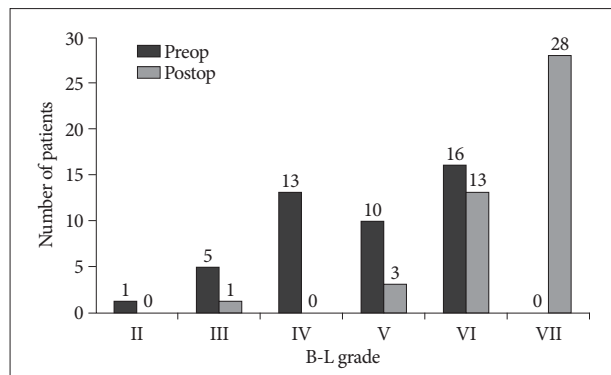
all patients and ascertained by long-term radiological studies and clinical follow-up within 12 months.

Most of patients experienced loss of more than 40% of the vertebra body's height and compromise of more than 40% in canal. Its overall mean values was 41.3% (±12.6%) and 49.4% (±11.7%), respectively. No statistically significant correlation appeared between the canal compromise and loss of vertebral body height (p>0.05). However, the mean kyphotic deformities, measured preoperatively and at within 12 months follow-up, were 17.7 degrees (±6.4 degrees) and 9.6 degrees (±5.2 degrees). The mean mid-sagittal diameter improved from 8.8 mm (±2.8 mm) before surgery to 14.2 mm (±1.6 mm) at within 12 months follow-up, with a significant difference between preoperative and postoperative values (p<0.01). The mean vertebral body height before surgery was 41.3% (±12.6%). At follow-up assessment, this score showed a statistically significant increase, to 68.3% (12.8%; p<0.01). All patients experienced neurological improvement (Fig. 5). There was also a statistically significant improvement between the preoperative and postoperative Benzel-Larson Grades (p<0.01). Patients with Benzel-Larson Grades VI and VII comprising 35.6% of total enrolled patients preoperatively, had increased to 91.1% postoperatively (Table 3).

DISCUSSION

The goals of surgery in thoracolumbar burst fractures include decompression of the neural elements to expedite neurological recovery, correction of spinal deformity, fusion with rigid stabilization to prevent delayed neural injuries and maintenance of anatomic alignment[6,10,11,17,20,21,29]. However, the specific approaches to be used in surgical management of such fractures are controversial[1,4,5,7,17,19].

In this study, we demonstrated to some extent the feasibility and relative safety of this technique for directly reducing the retropulsed bone fragments after posterior, indirect reduction and stabilization. In the modified transpedicular approach by Kaya and Aydin[24], they described drilling a hole in the pedicles in a burst fracture and removing the retropulsed bone fragments that was inserted for minimal structure damage. They concluded the modified transpedicular approach, drilling a hole in the pedicles, might reduce the loss of posterior column continuity and increase structural stability. Numerous papers have been described the results of a variety of treatment options, but no previous study has been considered the posterior approach alone, with a procedure to push the retropulsed bone fragments into the burst vertebral body for canal enlargement and restoration of vertebral height. However, other posterior surgical techniques, such as the classical transpedicular approach and similar approaches, involves removing part of the laminae and facet joints, which, according to the three-column

Table 3. Correlations between the preoperative and postoperative Benzel-Larson grades (p<0.01)

		Postoperative Benzel-Larson grade			
		II, III	IV, V	VI, VII	Total
Preoperative Benzel-Larson grade	II, III	1 (2%)	4 (9%)	1 (2%)	6 (13%)
	IV, V	-	-	22 (49%)	22 (49%)
	VI, VII	-	-	17 (38%)	17 (38%)
Total		1 (2%)	4 (9%)	38 (89%)	45 (100%)

theory, diminishes biomechanical stability[8]).

In the literature, the popular idea for the management of burst fractures causing severe neural canal compromise (more than 20%) and severe vertebral deformity (loss of vertebral height more than 50%) is an anterior approach combined with posterior fixation[11,17,19,20,23,25,26,38]). The combined anterior and posterior approach is important because of its ease of neural canal enlargement and potential for restoring the spine's anterior column. However, the anterior approach is associated with increased approach-related complications compared with the posterior approach such as painful intercostal neuralgia, abdominal wall outpouching, pneumothorax[7,35]). In addition, recent studies showed uncertain advantages when comparing the anterior and posterior surgical procedures[11,17,19,23,25,26,30,35,38]). Actually, anterior fusion will ultimately occur spontaneously after a posterior fusion and stabilization, because the pedicle screw fixation causes disc space immobility[13]). Some prior research works showed that the anterior surgical procdure was considered to be more comfortable for patients than the posterior ones. Our surgical procedure of repositioning fractured bony fragments needs laminectomy and minimal facetectomy which is needed in the surgery for the central lumbar disc herniation[13,17,25,26,38]). We believe that our surgical procedure is safe and easy to decompress the neural canal and restore the vertebral height.

Transpedicular screw and rod instruments provide rigid segmental fixation along all three columns of the spine and allow physicians to selectively apply a combination of forces (distraction, compression, or rotation) to spinal segments[1,16,27,28,31,33]). Thus, transpedicular screw fixation improves the physician's ability to correct a spinal deformity. However, surgeons control only two columns (anterior and middle) during the anterior approach, which compromises their correction ability, especially in rotational deformities. Nevertheless, long-segment transpedicular screw fixation causes immobilization of a greater number of mobile segments than the anterior approaches do, which can cause mechanical back pain in the long term[16,28]). Based on the present study's results, we conclude that our surgical method - the posterior approach alone, laminectomy with minimal facetectomy, repositioning of bone fragments, and, finally, pedicle screw fixation - could provide reliable neurologic improvements in patients with incomplete neurologic deficits[1,18,27,28,31,33]). Our surgical procedure does not require removal of the bone fragments, thereby preserving thoracolumbar spine elements. Therefore, our procedure's advantages include the reduction of unnecessary extra work in enlarging the neural canal, as opposed to, for instance, the anterior approach with surgical removal of part of the vertebral body. Repositioning the bone fragments seems to provide a more compact vertebral body, making screw insertions in the vertebral body and bone fusion easier. In addition, this technique should make it easier for surgeons to reduce deformities of the spine. Just by laminectomy and minimal facet removal, we were able to approach to the bone fragments and this is the same method with operation of lumbar disc hernia-

tion. The narrowed spinal canal was widened by only putting the bone fragments back into the original place and neurologic deficit of the patients progressed favorably as well. In the range of our experience, this procedure was enough to obtain satisfied results. Moreover, our operation procedure enabled less tissue damage and saving operation time was possible by not removing bone fragments[43]).

Though our one stage operation is suitable for thoracolumbar burst fracture, it is a procedure with its own limitation, as our procedure is not applicatable to upper or mid-thoracic burst fractures because of upper and mid thoracic spine have narrow interpedicular space. Besides, it would be premature for us to advocate for this procedure based on the small number of patients in this study. An additional study, with a larger group of patients and a comparison group treated with a different technique, should be performed.

CONCLUSION

Even though controversy exists regarding specific surgical treatments for severe thoracolumbar burst fractures, we were able to obtain good radiological and clinical results in severe thoracolumar burst fractures through posterior approach alone, laminectomy and minimal facetectomy, repositioning the retropulsed bone fragments without pediculectomy or anterior approach.

References

1. Aebi M, Etter C, Kehl T, Thalgott J : Stabilization of the lower thoracic and lumbar spine with the internal skeletal fixation system. Indications, techniques, and first results of treatment. **Spine (Phila Pa 1976) 12** : 544-551, 1987
2. Patel AA, Dailey A, Brodke DS, Daubs M, Harrop J, Whang PG, et al. : Thoracolumbar spine trauma classification : the Thoracolumbar Injury Classification and Severity Score system and case examples. J Neurosurg **Spine (Phila Pa 1976) 10** : 201-206, 2009
3. Benson DR : Unstable thoracolumbar fractures, with emphasis on the burst fracture. **Clin Orthop Relat Res** : 14-29, 1988
4. Benzel EC, Larson SJ : Functional recovery after decompressive operation for thoracic and lumbar spine fractures. **Neurosurgery 19** : 772-778, 1986
5. Bradford DS, McBride GG : Surgical management of thoracolumbar spine fractures with incomplete neurologic deficits. **Clin Orthop Relat Res** : 201-216, 1987
6. Chapman JR, Anderson PA : Thoracolumbar spine fractures with neurologic deficit. **Orthop Clin North Am 25** : 595-612, 1994
7. Clohisy JC, Akbarnia BA, Bucholz RD, Burkus JK, Backer RJ : Neurologic recovery associated with anterior decompression of spine fractures at the thoracolumbar junction (T12-L1). **Spine (Phila Pa 1976) 17** : S325-S330, 1992
8. Danisa OA, Shaffrey CI, Jane JA, Whitehill R, Wang GJ, Szabo TA, et al. : Surgical approaches for the correction of unstable thoracolumbar burst fractures: a retrospective analysis of treatment outcomes. **J Neurosurg 83** : 977-983, 1995
9. Denis F : The three-column spine and its significance in the classification of acute thoracolumbar spinal injuries. **Spine (Phila Pa 1976) 8** : 817-831, 1983
10. Dhall SS, Wang MY, Mummaneni PV : Clinical and radiographic com-

parison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. **J Neurosurg Spine 9** : 560-565, 2008

11. Durward QJ, Schweigel JF, Harrison P : Management of fractures of the thoracolumbar and lumbar spite. **Neurosurgery 8** : 555-561, 1981

12. Esses SI, Botsford DJ, Kostuik JP : Evaluation of surgical treatment for burst fractures. **Spine (Phila Pa 1976) 15** : 667-673, 1990

13. Farcy JP, Weidenbaum M, Glassman SD : Sagittal index in management of thoracolumbar burst fractures. **Spine (Phila Pa 1976) 15** : 958-965, 1990

14. Fraser RD, Bleasel JF, Moskowitz RW : Spinal degeneration: pathogenesis and medical management in Frymoyer JW(ed) : **The adult spine, principles and practice**. New York : Lippincott-Raven, 1997, pp735-759

15. Gertzbein SD : Scoliosis Research Society. Multicenter spine fracture study. **Spine (Phila Pa 1976) 17** : 528-540, 1992

16. Guiot BH, Khoo LT, Fessler RG : A minimally invasive technique for decompression of the lumbar spine. **Spine (Phila Pa 1976) 27** : 432-438, 2002

17. Gurr KR, McAfee PC : Cotrel-Dubousset instrumentation in adults. A preliminary report. **Spine (Phila Pa 1976) 13** : 510-520, 1988

18. Haas N, Blauth M, Tscherne H : Anterior plating in thoracolumbar spine injuries. Indication, technique, and results. **Spine (Phila Pa 1976) 16** : S100-S111, 1991

19. Hamilton A, Webb JK : The role of anterior surgery for vertebral fractures with and without cord compression. **Clin Orthop Relat Res** : 79-89, 1994

20. Hollowell JP, Maiman DJ : Management of thoracic and thoracolumbar spine trauma in : Rea GL, Miller CA(eds) : **Spinal trauma: current evaluation and management**. Park Ridge, IL : American Association of Neurological Surgeons, 1993, pp127-156

21. Hoshimoto T, Kaneda K, Abumi K : Relationship between traumatic spinal canal stenosis and neurologic deficits in thoracolumbar burst fractures. **Spine (Phila Pa 1976) 13** : 1268-1272, 1988

22. Jaikumar S, Kim DH, Kam AC : History of minimally invasive spine surgery. **Neurosurgery 51** : S1-S14, 2002

23. Kaneda K, Abumi K, Fujiya M : Burst fractures with neurologic deficits of the thoracolumbar-lumbar spine. Results of anterior decompression and stabilization with anterior instrumentation. **Spine (Phila Pa 1976) 9** : 788-795, 1984

24. Kaya RA, Aydin Y : Modified transpedicular approach for the surgical treatment of severe thoracolumbar or lumbar burst fractures. **Spine J 4** : 208-217, 2004

25. Kostuik JP : Anterior fixation for fractures of the thoracic and lumbar spine with or without neurologic involvement. **Clin Orthop Relat Res 189** : 103-115, 1984

26. Kostuik JP : Anterior fixation for burst fractures of the thoracic and lumbar spine with or without neurological involvement. **Spine (Phila Pa 1976) 13** : 286-293, 1988

27. Krag MH, Beynnon BD, Pope MH, Frymoyer JW, Haugh LD, Weaver DL : An internal fixator for posterior application to short segments of the thoracic, lumbar, or lumbosacral spine. Design and testing. **Clin Orthop Relat Res** : 75-98, 1986

28. Krag MH, Fredrickson BE, Yuan HA : Biomechanics of transpedicle spinal fusion in : Weinstein JN,Wiesel SW(eds). **The Lumbar Spine**. Philadelphia : WB Saunders, 1990, pp916-940

29. Larson SJ, Holst RA, Hemmy DC, Sances A Jr : Lateral extracavitary approach to traumatic lesions of the thoracic and lumbar spine. **J Neurosurg 45** : 628-637, 1976

30. Lu DC, Lau D, Lee JG, Chou D : The transpedicular approach compared with the anterior approach : an analysis of 80 thoracolumbar corpectomies. **J Neurosurg Spine 12** : 583-591, 2010

31. Luque ER : The anatomic basis and development of segmental spinal instrumentation. **Spine (Phila Pa 1976) 7** : 256-259, 1982

32. Maiman DJ, Larson SJ, Benzel EC : Neurological improvement associated with late decompression of the thoracolumbar spinal cord. **Neurosurgery 14** : 302-307, 1984

33. McAfee PC, Farey ID, Sutterlin CE, Gurr KR, Warden KE, Cunningham BW : 1989 Volvo Award in basic science. Device-related osteoporosis with spinal instrumentation. **Spine (Phila Pa 1976) 14** : 919-926, 1989

34. Wang MY, Mummaneni PV : Minimally invasive surgery for thoracolumbar spinal deformity : initial clinical experience with clinical and radiographic outcomes. **Neurosurg Focus 28** : E9, 2010

35. The National SCI Statistical Center : **Spinal Cord Injury, Facts and Figures at a Glance, January 2008**. Birmingham : University of Alabama, 2008

36. Oner FC, Wood KB, Smith JS, Shaffrey CI : Therapeutic decision making in thoracolumbar spine trauma. **Spine (Phila Pa 1976) 35** : S235-S244, 2010

37. Oskouian RJ Jr, Shaffrey CI, Whitehill R, Sansur CA, Pouratian N, Kanter AS, et al. : Anterior stabilization of three-column thoracolumbar spinal trauma. **J Neurosurg Spine 5** : 18-25, 2006

38. Sayer FT, Kronvall E, Nilsson OG : Methylprednisolone treatment in acute spinal cord injury : the myth challenged through a structured analysis of published literature. **Spine J 6** : 335-343, 2006

39. Schnee CL, Ansell LV : Selection criteria and outcome of operative approaches for thoracolumbar burst fractures with and without neurological deficit. **J Neurosurg 86** : 44-55, 1997

40. Shen WJ, Liu TJ, Shen YS : Nonoperative treatment versus posterior fixation for thoracolumbar junction burst fractures without neurologic deficit. **Spine (Phila Pa 1976) 26** : 1038-1045, 2001

41. Wei FX, Liu SY, Liang CX, Li HM, Long HQ, Yu BS, et al. : Transpedicular fixation in management of thoracolumbar burst fractures: monosegmental fixation versus short-segment instrumentation. **Spine (Phila Pa 1976) 35** : E714-E720, 2010

42. Haiyun Y, Rui G, Shucai D, Zhanhua J, Xiaolin Z, Xin L, et al. : Three-column reconstruction through single posterior approach for the treatment of unstable thoracolumbar fracture. **Spine (Phila Pa 1976) 35** : E295-E302, 2010

43. Zheng F, Cammisa FP Jr, Sandhu HS, Girardi FP, Khan SN : Factors predicting hospital stay, operative time, blood loss, and transfusion in patients undergoing revision posterior lumbar spine decompression, fusion, and segmental instrumentation. **Spine (Phila Pa 1976) 27** : 818-824, 2002