#4

ORIGINAL CONTRIBUTION

Efficacy of Surgical Decompression in Regard to Motor Recovery in the Setting of Conus Medullaris Injury

Vafa Rahimi-Movaghar, MD[1]; Alexander R. Vaccaro, MD[2]; Mehdi Mohammadi, MS[3]

[1]Department of Neurosurgery, Zahedan University of Medical Sciences, Zahedan, Iran; [2]Department of Neurosurgery and Orthopaedic Surgery, Thomas Jefferson University and the Rothman Institute, Philadelphia, Pennsylvania; [3]Department of Biostatistics, Zahedan University of Medical Sciences, Zahedan, Iran

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Abstract

Background/Objective: An assessment of neurological improvement after surgical intervention in the setting of traumatic conus medullaris injury (CMI).

Methods: A retrospective evaluation of a cohort of patients with a blunt traumatic CMI from T12 to L1. The neurologic and functional outcomes were recorded from the acute hospital admission to the most recent follow-up. Data collected included age, level of injury, neurologic examination according to the Frankel grading system and motor index score, and the mechanism and timing of CMI decompression.

Results: A total of 24 patients with a mean age of 27 years (men, 87%) were identified. The most common level of bony injury was L1, and the most frequent mechanism of injury was a motor vehicle crash. Before surgical intervention, 16 of 24 patients (66.7%) had a complete neurological deficit below the level of injury. The median interval from injury to surgery was 6 days (range, 7 hours to 390 days). Decompression, fusion, and adjunctive internal fixation were the most common surgical procedures. Median length of follow-up was 32 months after surgery. Improvement in spinal cord and bladder function was seen in 41.6% and 63.6% of patients, respectively. Root recovery was seen in 83.3% of patients.

Conclusions: In the setting of CMI, no correlation between the timing of surgical decompression and motor improvement was identified. Root recovery was more predictable than spinal cord and bladder recovery.

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Key Words: Spinal cord injuries; Conus medullaris injury; Surgical decompression; Spinal surgery; Motor index score

INTRODUCTION

Blunt spinal trauma complicated by injury to the conus medullaris is a devastating event on a personal and family level, as well as a tremendous financial burden to society because of its attendant morbidity, expense, and prolonged treatment requirements (1). Traumatic spinal injury occurs most frequently in the young men with an average age of 35 years. The lack of controlled, prospective, multicenter clinical studies has contributed to confusion regarding optimal treatment methods for patients with injuries to the thoracolumbar spine. The transitional anatomy of the thoracolumbar junction makes it vulnerable to injury resulting from high-energy motor vehicle collisions and falls (2–4). Approximately 40% of patients with traumatic spinal cord injury (SCI) present with a complete SCI, 40% with an incomplete injury, and 20% with either no cord injury or only root lesions (5). Formulation of a treatment plan for patients with injuries to the thoracolumbar spine depends on the presence and extent of neurologic injury and existing spinal stability. Both nonsurgical and surgical treatment options are available to achieve the goals of preservation of neurologic function and restoration of spinal stability (6). To date, the role of decompression in patients with incomplete SCI is only supported by class 3 and limited class 2 medical evidence (2). Because of the absence of scientific literature examining injuries specific to the

Please address correspondence to Vafa Rahimi-Movaghar, MD, Department of Neurosurgery, Khatam-ol-anbia Hospital, Zahedan University of Medical Sciences (ZUMS), Zahedan 98157, Iran; phone: 98.915.342.2682; fax: 98.541.322.0504 (e-mail: v_rahimi@yahoo.com).

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conus medullaris, a retrospective pilot study was undertaken to access the efficacy and potential morbidities related to the surgical management (decompression and stabilization) of these injuries. This study will serve as a foundation for future prospective, multicenter studies evaluating the safety and efficacy of surgical intervention in neurologically and mechanically unstable injuries to the thoracolumbar junction.

METHODS

From October 1994 through March 2005, a total of 108 patients with blunt traumatic SCI were identified at a regional level 1 trauma center in southeastern Iran. Of these patients, a subset was identified in which (a) a neurological deficit was attributable to a traumatic conus medullaris injury (CMI), (b) follow-up was a minimum of 6 months (7), and (c) the CMI was caused by an acute nonpenetrating traumatic event with radiographically documented cord compression caused by cord encroachment by anterior vertebral body elements, disk material, or posterior vertebral elements as a result of fracture subluxation or dislocation.

Patients were excluded if (a) their neurologic deficit was associated with a preexisting spinal cord abnormality or disease process (eg, multiple sclerosis or preexisting myelopathy as a result of severe spondylosis without trauma), (b) they could not actively participate in the follow-up neurologic examination process, or (c) there were inadequate follow-up data available.

Data Collection

Data collected included patient age, sex, associated injuries, mechanism of injury, admitting and follow-up Frankel grade and motor index score (MIS), time interval from injury to surgical decompression and stabilization, imaging studies documenting the spinal injury, and the type of surgical procedure.

Neurologic Evaluation

Motor and sensory examinations (Frankel grade and MIS) were performed at admission, daily during the acute hospitalization, before and after surgery, and at all follow-up outpatient encounters. Patients were assigned an initial MIS that included manual muscle test scores of all key muscles, sensory examination (prick and touch), sacral and deep tendon reflexes, and muscle tone evaluation. Sensory level was recorded as the most caudal dermatomal level of bilateral intact sensation.

Treatment

Standard spinal immobilization and resuscitation were implemented by emergency medical personnel. All patients were prescribed intravenous (IV) methylprednisolone (30 mg/kg IV bolus over 15 minutes followed 45 minutes later by a 5.4-mg/kg/h IV infusion over 23 hours) if they arrived to the emergency room within 8 hours of the accident (8). All patients underwent preoperative myelography, computerized tomography, and/or magnetic resonance imaging. Patients with image-documented spinal cord compression [from vertebral bony elements, spinal malalignment (subluxation or dislocation), or epidural hematoma] underwent surgical decompression and spinal column stabilization. The surgical approach was determined by the location of cord compression and the type and degree of spinal instability. Adequacy of decompression was determined by postoperative computed tomography and magnetic resonance imaging (9). Statistical data analysis was performed using SPSS-11.5 software applications. A P value of less than 0.05 was considered statistically significant.

Outcome Assessment

Outcome assessment was performed using the method of Bohlman and Anderson (10). A patient was considered to have an excellent result if they became a household or community ambulator or had marked improvement in ambulator status. A good outcome was recorded if there was recovery of one or more motor-root levels in the lower extremities or partial recovery of multiple levels. A fair result was recorded if there was partial improvement of 1 or 2 motor-root levels, and a poor result was shown by no cord or root improvement.

RESULTS

Twenty-four patients satisfied the inclusion and exclusion criteria for this study (Table 1). Before treatment, 16 of 24 patients (66.7%) had a functionally complete (Frankel A) neurological deficit below the level of spinal injury (Table 2). Mean patient age was 26.7 ± 8.6 years, and 87.5% of the patients were men (Table 3). The most frequent level of bony injury was L1, followed by T12, and the most frequent mechanism of injury was a motor vehicle crash. The median time interval from injury to surgery was 6 days (range, 7 hours to 390 days). The length of follow-up after surgery ranged from 8 months to 12 years, with a median time period of 32 months (Table 3). The primary indications for surgery were documented spinal cord compression in the setting of a spinal cord neurologic deficit associated with instability. Posterior transpedicular/extracavitary decompression, followed by an intertransverse process fusion without anterior strut graft placement, and instrumentation 2 levels above and below the injury level were the most common surgical procedures performed (Table 2).

Follow-up employment status (listed from most to less frequent job description) was unemployed, member of office staff, housewife, driver, and laborer. Spinal cord functional improvement and nerve root recovery was seen in 10 of 24 (41.6%) and 20 of 24 (83.3%) patients, respectively. Overall, there was an average improvement of 1.5 Frankel grades among the study population. Patients with an initial Frankel grade of A improved an average of 1.6 Frankel grades. No patient had an initial

Table 1. Summary of Patient Data

Patient No.	Age (years)	Sex	Spinal Level	Mechanism	Time to Decompression (days)	Procedure	Compli-cation	Frankel-pre	Frankel-f/u	MIS-pre	MIS-f/u	Root improvement	Outcome
1	22	Female	T12,L1	4	Not documented	1,3	0	A	E	50	100	Yes	Excellent
2	45	Female	L1	4	Not documented	1,2	0	A	A	50	50	No	Poor
3	50	Male	L1,L2	4	0.29	1,2	0	A	C	50	62	Yes	Good
4	18	Male	L1	4	5	1,3	0	A	D	50	89	Yes	Excellent
5	25	Female	T12	4	Not documented	1,2	1	D	E	90	100	Yes	Good
6	25	Male	L1	1	Not documented	1,2	0	A	A	50	50	No	Poor
7	32	Male	T12,L1	1	Not documented	1,2	0	A	A	50	50	No	Poor
8	20	Male	T12,L1,L2	1	0.46	1,2	0	A	C	50	60	Yes	Good
9	19	Male	L1	1	6	1,2	0	A	D	50	88	Yes	Excellent
10	15	Male	T12	3	7	1,3	0	A	C	50	66	Yes	Good
11	24	Male	T12	1	10	1,2	0	A	C	50	58	Yes	Excellent
12	17	Male	L1,L2, L3	1	14	1,2	0	A	C	50	NA	Yes	Good
13	18	Male	T12,L1	1	30	1,2	0	A	C	50	66	Yes	Good
14	29	Male	T12,L1	1	390	1,2	0	A	C	50	66	Yes	Good
15	27	Male	L1	1	0.44	1	1	C	D	75	98	Yes	Excellent
16	31	Male	L1	3	1	1	1	C	D	89	96	Yes	Excellent
17	38	Male	L1	3	3	1,2	1	C	D	70	89	Yes	Excellent
18	25	Male	L1	3	6	1,2	1	A	A	66	70	Yes	Fair
19	27	Male	L1	1	17	1,2	1	C	D	53	68	Yes	Good
20	20	Male	T12	2	3	1	0	A	E	70	100	Yes	Excellent
21	23	Male	L1	2	4	1,2	0	A	A	50	53	Yes	Fair
22	27	Male	L1	2	13	1,2	0	A	A	64	64	No	Poor
23	35	Male	L1	2	Not documented	1,2	1	C	E	NA	100	Yes	Excellent
24	29	Male	L1	2	Not documented	1,2	1	D	E	97	100	Yes	Good

Mechanism: 1, car crash; 2, fall; 3, motorcycle; 4, Not documented.
Procedure: 1, posterior transpedicular/extracavitary decompression and bone grafting; 2, Harrington rod instrumentation; 3, pedicle screw instrumentation.
T, thoracic; L, lumbar; Frankel-pre, preoperative Frankel grade; Frankel-f/u, latest follow-up Frankel grade; MIS-pre, preoperative motor index score; MIS-f/u, latest follow-up MIS; NA, not available.

Table 2. Patient Data By Frequency

Variable	No. (%)
Sex	
Female	3 (12.5)
Male	21 (87.5)
Level of injury	
T12	19 (31.3)
L1	9 (67.8)
Mechanism	
Car crash	10 (41.7)
Motorcycle	4 (16.7)
Fall	5 (20.8)
Not documented	5 (20.8)
Surgeon	
Primary author	19 (79.2)
Other	5 (20.8)
Procedure	
No instrumentation	3 (12.5)
Harrington rod	18 (75.0)
Pedicle screw fixation	3 (12,5)
SCI	
Complete	16 (66.7)
Incomplete	8 (33.3)
Result	
Excellent	9 (37.5)
Good	9 (37.5)
Fair	2 (8.3)
Poor	4 (16.7)

T, thoracic; L, lumbar.

Frankel grade of B. Patients with an initial Frankel grade of C improved an average of 1.2 grades. All patients with an initial Frankel grade of D improved to a Frankel grade of E (Table 4). Overall, there was an average MIS improvement of 14.5 points in the study population. Patients with an initial Frankel grade of A improved an average of 15.1 motor points. Patients with an initial Frankel grade of C improved an average of 16 motor points, and patients with an initial Frankel grade of D improved an average of 6.5 points (Table 4).

Bladder function improvement was seen in 7 of 11 (63.6%) patients (Table 5). Partial or complete bladder function was documented at follow-up in 5 of 8 (62.5%) patients with an initial Frankel grade of A, one-half (50%) of patients with an initial Frankel grade of C, and 1 of 1 (100%) patients with an initial grade of D. Bladder function outcome was not adequately documented in the remaining 13 patients.

Table 4. Average Improvement of Neurologic Function According to the Frankel Scale and MIS

Preoperative Frankel	Frankel Grade Improvement	MIS Improvement
A	1.6	15.1
B	—	—
C	1.2	16
D	1	6.5
Total	1.5	14.5

Additionally, there was no significant correlation between time to spinal cord decompression and spinal cord or nerve root improvement according to the Frankel grading system and the MIS (Table 6).

Complications were recorded in 10 patients, including 6 cases of delayed instrumentation failure, 2 extended urinary tract infections, 2 cases of symptomatic pressure ulcers, and 1 case of severe neuropathic pain syndrome. The cases with instrumentation failure were not associated with recurrent or progressive spinal deformity and did not result in symptomatic neural compression.

DISCUSSION

Our study showed that, in cases of blunt traumatic CMI, some degree of spinal cord recovery was seen in 41.6% of the patients who underwent surgical intervention. Root recovery was seen in 83% of the patients. A precise understanding of spinal cord vs peripheral nerve root recovery was difficult because of the close proximity of the conus medullaris to the cauda equina and the common occurrence of nerve root escape. This made assessment of bowel and bowel function extremely valuable in understanding improvement in spinal cord function. Of the 11 patients assessed, 7 (63.6%) were noted to have improvement in bowel and bladder function.

The efficacy or futility of surgical intervention could not be determined in the absence of a control (non-

Table 3. Patient Data: Mean, Median, and Range

Variable	Mean ± SD or Median	Range	No. of patients
Age	26.7 ± 8.6	18–50	24
Frankel grade improvement	1.5	0–4	24
Follow-up (months)	32	8–144	24
Time to decompression (days)	8.5	0.29–390	17

Table 5. Bladder Function Improvement According to the Frankel Scale

Preoperative Frankel Grade	No. of Patients	No. of Patients With Partial Bladder Function Improvement (%)	No. of Patients With Complete Bladder Function Improvement (%)	No. of Patients With Partial or Complete Bladder Function Improvement (%)
A	8	1 (12.5)	4 (50)	5 (62.5)
B	0	—	—	—
C	2	1 (50)	0 (0)	1 (50)
D	1	1 (100)	—	1 (100)

surgical) group because of the retrospective nature of this study. A retrospective review of our blunt trauma patient population did not produce any patient treated nonsurgically with a CMI injury and evidence of spinal instability. Our data, however, did show a defined neurologic outcome that can be expected if a surgeon decides to surgically decompress a compromised spinal cord in a posttraumatic patient with a CMI.

The efficacy of decompression after SCI in enhancing neurological recovery in animal models has been widely shown (7, 11–20). There are 8 prospective nonrandomized case series (class 2 evidence) (21–28) and several retrospective case series with historical controls (class 3 evidence) that have addressed the role of spinal cord decompression in the setting of a contused and compressed spinal cord. None have shown an advantage to surgery in the setting of a complete SCI.

An extensive review of the literature did not discuss any clinical reviews of patients with SCIs specific to the conus medullaris. The majority of studies were retrospective reviews of a mixture of thoracic and lumbar injuries with various degrees of spinal cord and peripheral nerve root injuries. In general, patients with an incomplete neurologic deficit often showed improved lower extremity motor and/or bladder function with either nonoperative or operative intervention (29–41).

Boerger et al (42) performed a meta-analysis of the world's literature in 2000 to evaluate the effectiveness of surgical decompression in the context of a neurological deficit associated with a thoracolumbar burst fracture. The design of 9 studies was sufficiently similar to allow pooling of their results, all of which failed to establish a significant advantage of surgical over nonsurgical treatment in regard to neurological improvement. They found that patients with an incomplete neurological deficit who had undergone surgical decompression and stabilization experienced a better neurological recovery compared with patients who had undergone nonsurgical treatment (43). Comparison of surgical intervention using Harrington instrumentation and recumbence therapy showed that neurological improvement was much more predictable with surgical intervention in the complete paraplegia group from T9 to L2, but there was no difference in neurological recovery between the 2 groups in patients with incomplete paraplegia (44). However, Waters et al (27) showed motor recovery did not significantly differ between patients categorized in various surgical subgroups or between those having surgery and those treated nonoperatively. Geisler et al (45) concluded that the sparseness of prospective data on the treatment of traumatic spinal cord injury at 28 centers in North America suggests that treatment guidelines have limited empirical support and should be made cautiously.

To date, no definitive data exist that correlate the timing of surgery with neurologic outcome (32, 46–49). Clohisy et al (50) observed that early anterior thoracolumbar decompression for traumatic injuries at the

Table 6. Correlation of Time to Decompression and Neurologic Outcome According to the Frankel Grading System and MIS

	Time-Related SCI Decompression							
	Frankel Grading System Change				Motor Index Score (MIS) Change			
	N	R	95% CI	*P*	N	R	95% CI	*P*
T12 to L1	17	0.017	−0.47, 0.49	0.949	16	−0.140	−0.59, 0.38	0.604

N = number of patients. CI = confidence interval. R = Spearman's correlation test, a measure of linear association between 2 variables. Values of R range between −1 (a perfect negative relationship in which all points fall on a line with a negative slope) and +1 (a perfect positive relationship in which all points fall on a line with apositive slope). A value of 0 indicates no linear relationship.

thoracolumbar junction was associated with improved rates of neurologic recovery compared with late decompression in the presence of an incomplete neurologic deficit.

Transfeldt et al (34) showed that late decompression of more than 3 months resulted in neurologic improvement in 46.5% of patients with an incomplete posttraumatic spinal injury. If the surgery was performed less than 2 years after injury, neurologic improvement occurred in 68%, with an improvement in Frankel grades of 32%. Bladder function improved overall in 27% of patients, and if decompression occurred less than 2 years after injury, improvement occurred in 43% of patients. Conus medullaris decompression resulted in a 50% improvement in bladder function. There was an 83% improvement in the pattern of pain after spinal decompression. Because of the retrospective nature of our study, a correlation between the timing of neurologic compression and neurologic improvement could not be determined.

An intrinsic problem with our study is the small number of cases, which decreases the power of our study and prevents us from employing any meaningful statistical analysis. A true understanding of the role of surgical intervention in the setting of traumatic thoracic spinal cord can only be determined through a randomized, multicenter controlled clinical trial.

CONCLUSIONS

Partial spinal cord and bowel and bladder recovery was identified in this patient cohort. In the setting of CMI, no correlation between the timing of surgical decompression and motor improvement according to the Frankel grading system and the MIS was identified. Root recovery was more predictable than spinal cord recovery. Clearly, to better define the role of surgery in the management of acute SCI, randomized, controlled prospective trials are required.

REFERENCES

1. Kiwerski J, Weiss M. Neurological improvement in traumatic injuries of cervical spinal cord. *Paraplegia.* 1981;19: 31–37.
2. Fehlings MG, Sekhon LHS, Tator C. The role and timing of decompression in acute spinal cord injury: what do we know? What should we do? *Spine.* 2001;26:S101–S110.
3. Fehlings MG, Tator CH. An evidence-based review of surgical decompression for acute spinal cord injury: rationale, indications, and timing based on experimental and clinical studies. *J Neurosurg (Spine).* 1999;91:1–11.
4. Kraus JF, Franti CE, Riggins RS, Richards D, Borhani NO. Incidence of traumatic spinal cord lesions. *J Chronic Dis.* 1975;28:471–492.
5. Rizzolo SJ, Vaccaro AR, Cotler JM. Cervical spine trauma. *Spine.* 1994;19:2288–2298.
6. Vaccaro AR, Kim DH, Brodke DS, et al. Diagnosis and management of thoracolumbar spine fractures. *Instr Course Lect.* 2004;53:359–373.
7. Rosa GLa, Conti A, Cardali S, Cacciola F, Tomasello F. Does early decompression improve neurological outcome of spinal cord injured patients? Appraisal of the literature using a meta-analytical approach. *Spinal Cord.* 2004;42: 503–512.
8. Bracken MB, Shepard MJ, Collins WF, et al. A randomized controlled trial of methylprednisolone or naloxone in the treatment of acute spinal cord injury. Results of the Second National Acute Spinal Cord Injury Study. *N Engl J Med.* 1990;322:1405–1411.
9. Quencer RM, Sheldon JJ, Post MJD, et al. Magnetic resonance imaging of the chronically injured cervical spinal cord. *Am J Neuroradiol.* 1986;7:457–464.
10. Bohlman HH, Anderson PA. Anterior decompression and arthrodesis of the cervical spine: long-term motor improvement. Part 1—Improvement in incomplete traumatic quadriparesis. *J Bone Joint Surg Am.* 1992;74:671–682.
11. Brodkey JS, Richards DE, Blasingame JP, Nulsen FE. Reversible spinal cord trauma in cats. Additive effects of direct pressure and ischemia. *J Neurosurg.* 1972;37:591–593.
12. Carlson GD, Minato Y, Okada A, et al. Early time-dependent decompression for spinal cord injury, vascular mechanisms of recovery. *J Neurotrauma.* 1997;14:951–962.
13. Croft TJ, Brodkey JS, Nulsen FE. Reversible spinal cord trauma: a model for electrical monitoring of spinal cord function. *J Neurosurg.* 1972;36:402–406.
14. Delamarter RB, Sherman J, Carr JB. Pathophysiology of spinal cord injury: recovery after immediate and delayed decompression. *J Bone Joint Surg Am.* 1995;77:1042–1049.
15. Dolan EJ, Tator CH, Endrenyi L. The value of decompression for acute experimental spinal cord compression injury. *J Neurosurg.* 1980;53:749–755.
16. Guha A, Tator CH, Endrenyi L, Piper I. Decompression of the spinal cord improves recovery after acute experimental spinal cord compression injury. *Paraplegia.* 1987;25:324–339.
17. Kobrine AI, Evans DE, Rizzoli HV. Correlation of spinal cord blood flow and function in experimental compression. *Surg Neurol.* 1978;10:54–59.
18. Kobrine AI, Evans DE, Rizzoli HV. Experimental balloon compression of the spinal cord: factors affecting disappearance and return of spinal evoked potential. *J Neurosurg.* 1979;51:841–845.
19. Nystrom B, Berglund JE. Spinal cord restitution following compression injuries in rats. *Acta Neurol Scand.* 1988;78: 467–472.
20. Sekhon LHS, Fehlings MG. Epidemiology, demographics, and pathophysiology of acute spinal cord injury. *Spine.* 2001;26:2–12.
21. Chen TY, Dickman CA, Eleraky M, Sonntag VKH. The role of decompression for acute incomplete cervical spinal cord injury in cervical spondylosis. *Spine.* 1998;22:2398–2403.
22. Duh MS, Shepard MJ, Wilberger JE, Bracken MB. The effectiveness of surgery on the treatment of acute spinal cord injury and its relation to pharmacological treatment. *Neurosurgery.* 1994;35:240–249.
23. Ng WP, Fehlings MG, Cuddy B, et al. Surgical treatment for acute spinal cord injury study pilot #2: evaluation of protocol for decompressive surgery within 8 hours of injury. *Neurosurg Focus.* 1999;6:3.

24. Pointillart V, Petitjean ME, Wiart L, et al. Pharmacological therapy of spinal cord injury during the acute phase. *Spinal Cord.* 2000;38:71–76.
25. Tator CH, Duncan EG, Edmonds VE, Lapzack LI, Andrews DF. Comparison of surgical and conservative management in 208 patients with acute spinal cord injury. *Can J Neurol Sci.* 1987;14:60–69.
26. Vaccaro AR, Daugherty RJ, Sheehan TP, et al. Neurologic outcome of early versus late surgery for cervical spinal cord injury. *Spine.* 1997;22:239–246.
27. Waters RL, Adkins RH, Yakura JS, Sie I. Effect of surgery on motor recovery following traumatic spinal cord injury. *Spinal Cord.* 1996;34:188–192.
28. Waters RL, Meyer PR, Adkins RH, Felton D. Emergency, acute, and surgical management of spine trauma. *Arch Phys Med Rehabil.* 1999;80:1383–1890.
29. Young B, Brooks WH, Tibbs PA. Anterior decompression and fusion for thoracolumbar fractures with neurological deficits. *Acta Neurochir (Wien).* 1981;57:287–298.
30. Lobosky JM, Hitchon PW, McDonnell DE. Transthoracic anterolateral decompression for thoracic spinal lesions. *Neurosurgery.* 1984;14:26–30.
31. Benzel EC, Larson SJ. Functional recovery after decompressive operation for thoracic and lumbar spine fractures. *Neurosurgery.* 1986;19:772–778.
32. Bostman OM, Myllynen PJ, Riska EB. Unstable fractures of the thoracic and lumbar spine: the audit of an 8-year series with early reduction using Harrington instrumentation. *Injury.* 1987;18:190–195.
33. Riska EB, Myllynen P, Bostman O. Anterolateral decompression for neural involvement in thoracolumbar fractures. A review of 78 cases. *J Bone Joint Surg Br.* 1987;69:704–708.
34. Transfeldt EE, White D, Bradford DS, Roche B. Delayed anterior decompression in patients with spinal cord and cauda equina injuries of the thoracolumbar spine. *Spine.* 1990;15:953–957.
35. Mayer H, Schaaf D, Kudernatsch M. Use of internal fixator in injuries of the thoracic and lumbar spine. *Chirurg.* 1992; 63:944–949.
36. Huang TJ, Chao EK, Chen YJ, Du YK, Chen JY, Hsu RW. Complete fracture-dislocation of the thoracic spine with spontaneous neurologic decompression: a case report. *Changgeng Yi Xue Za Zhi.* 1995;18:387–391.
37. Beisse R, Muckley T, Schmidt MH, Hauschild M, Buhren V. Surgical technique and results of endoscopic anterior spinal canal decompression. *J Neurosurg Spine.* 2005;2:128–136.
38. Krengel WF III, Anderson PA, Henley MB. Early stabilization and decompression for incomplete paraplegia due to a thoracic-level spinal cord injury. *Spine.* 1993;18:2080–2087.
39. Sridhar K, Vasudevan MC, Ramamurthi B. Posttraumatic total dislocation of the upper thoracic spine. *Surg Neurol.* 2004;61:343–346.
40. Frankel H, Hancock D, Hyslop G, et al. The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. Part. 1. *Paraplegia.* 1969;7:179–192.
41. Bohlman HH, Freehafer A. Late anterior decompression of spinal cord injuries. *J Bone Joint Surg Am.* 1975;57:1025.
42. Boerger TO, Limb D, Dickson RA. Does 'canal clearance' affect neurological outcome after thoracolumbar burst fractures? *J Bone Joint Surg Br.* 2000;82:629–635.
43. Harrop JS, Gabriel EH Jr, Vaccaro AR. Conus medullaris and cauda equina syndrome as a result of traumatic injuries: management principles. *Neurosurg Focus.* 2004;16:e4.
44. Lifeso RM, Arabie KM, Kadhi SK. Fractures of the thoracolumbar spine. *Paraplegia.* 1985;23:207–224.
45. Geisler FH, Coleman WP, Grieco G, Poonian D. Sygen Study Group. Recruitment and early treatment in a multicenter study of acute spinal cord injury. *Spine.* 2001;26(24 Suppl):58–67.
46. Alho A. Operative treatment as a part of the comprehensive care for patients with injuries of the thoracolumbar spine. A review. *Paraplegia.* 1994;32:509–516.
47. Carlsson CA, Pellettieri L. Treatment of spinal cord injuries in the thoracolumbar region. *Scand J Rehabil Med.* 1987; 19:71–75.
48. Chapman JR, Anderson PA. Thoracolumbar spine fractures with neurologic deficit. *Orthop Clin North Am.* 1994;25: 595–612.
49. Korovessis P, Piperos G, Sidiropoulos P, Karagiannis A, Dimas T. Spinal canal restoration by posterior distraction or anterior decompression in thoracolumbar spinal fractures and its influence on neurological outcome. *Eur Spine J.* 1994;3:318–324.
50. 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.* 1992;17(8 Suppl):325–330.