Thoracolumbar Spine Trauma: II. Principles of Management

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Abstract

The care of patients with thoracolumbar spine trauma with or without neurologic deficits has evolved dramatically over the past 20 years with the emergence of tertiary-care spinal injury centers and the development of more effective spinal instrumentation and anesthesia techniques. Despite these advances, the majority of patients with thoracolumbar injuries are still treated nonoperatively with cast or brace immobilization and early ambulation. More aggressive treatment is guided by the use of classification systems that detail the mechanism of injury, the degree of compromise of spinal structures, and the potential for late mechanical instability or neural injury. The goal of treatment remains attainment of spinal stability with protection or improvement of the patient's neurologic status, allowing rapid and maximal functional recovery.

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There are a variety of issues to be considered in the management of patients with thoracolumbar spine trauma. Initial management issues include immobilization, medical stabilization, and achievement of spinal alignment. Definitive management decisions are based on spinal stability at the injury site and the need for decompression of neural elements, followed by appropriate rehabilitation to maximize the patient's functional outcome.

Immobilization

Immobilization has been shown experimentally to help limit further damage to the injured spinal cord and is often beneficial in controlling the pain associated with a spinal column injury. Simple bed rest with log-rolling can be used, but problems may occur with improper log-rolling of the patient or miscommunication concerning the patient's spinal stability and activity level. An oscillating bed is useful for shifting the patient's body weight without moving the patient. If traction is deemed desirable, this is an effective means of providing spinal immobilization.

Medical Stabilization

Medical stabilization of the trauma patient with a thoracolumbar injury is of paramount importance. Hypotension secondary to neurogenic shock or hemorrhagic shock must be reversed through fluid and/or blood replacement, with or without the use of vasopressors. Critical organ systems must be evaluated and treated as needed.

Medical treatment of the injured spinal cord is directed at minimizing or preventing the secondary cord injury caused by edema and ischemia. Intravenous methylprednisolone is routinely administered in all cases of blunt spinal cord injury, in accordance with the protocol established by Bracken et al[1] (bolus of 30 mg/kg of body weight, followed by 5.4 mg/kg/hr by continuous infusion for a total of 23 hours). Its efficacy has been established only in situations in which treatment is started within 8 hours of injury and in cases of blunt spinal cord injury. The efficacy of corticosteroid use has not been shown for pure root injuries. The complications of steroid use, including a higher rate of postoperative infection and gastric ulcers,

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must be considered. Although the study by Bracken et al has been criticized for methodologic flaws, their protocol is currently considered by many to be the standard of care in acute spinal cord injury and should be followed. Newer pharmacologic agents, such as b-glycosides and growth factors, are currently being evaluated prospectively in major spinal cord injury centers.

Thromboembolic disease remains a considerable problem in acutely traumatized patients, and patients with spinal injuries are no exception.[2] We aggressively employ mechanical prophylaxis (intermittent external pneumatic compression devices) for lower-extremity deep-vein thrombosis and the more serious pulmonary embolism in all cases of significant spinal trauma. Routine prophylaxis also includes subcutaneous heparin in a dosage of 5,000 units every 12 hours. The use of intravenous low-molecular-weight heparin is currently being investigated. Deep-vein thrombosis is diagnosed with the use of real-time B-mode ultrasonography. Venography is used if the ultrasound results are unclear. The presence of pulmonary embolism is assessed with ventilation-perfusion scanning and, if needed, pulmonary angiography. Treatment includes heparin or warfarin if the patient clearly does not have an operative problem. If surgery is required, the thromboembolic problem is treated by percutaneous placement of an inferior vena cava filter.

Alignment

Various means have been employed to improve spinal alignment in the peri-injury period. Postural reduction with simple bed rest and placement of a small padded bolster at the apex of a spinal deformity may be effective in certain injury patterns. If the desire is to improve anterior vertebral column height and reduce the degree of kyphosis, Gardner-Wells tong–bifemoral skeletal traction may be a useful adjunct. This form of immobilization certainly ensures patient compliance in terms of bed rest. The skin beneath any padded bolster must be examined daily for evidence of skin breakdown, which could significantly compromise a posterior surgical site.

Evaluation of Spinal Stability

In determining the optimal treatment in cases of spine trauma, the stability of the particular spinal injury must be carefully assessed following a complete clinical and radiographic evaluation. In the most general sense, the spinal column is considered stable if it is able to withstand normally applied physiologic loads without the development of neural irritation or damage, unacceptable deformity, or chronic pain due to abnormal motion.

Early reports assessing the degree of spinal stability focused on the integrity of the posterior elements. More recent analysis considers the degree of osseous and ligamentous destruction in conjunction with the degree of canal compromise, deformity, and neurologic deficit.

In 1983, Denis used computed tomographic analysis of thoracolumbar fractures and dislocations in the development of the three-column theory of spinal stability,[3,4] as described in the accompanying article. The spine is considered to be unstable if two or more columns are injured. Denis described three categories of instability. Mechanical instability includes severe compression fractures, in which posterior elements are injured in distraction and late kyphotic collapse is possible. Cases of neurologic instability include burst fractures without neurologic deficit, in which the late onset of neurologic deficits is sometimes seen. The most unstable injuries, those characterized by mechanical and neurologic instability, include burst fractures with neurologic deficit and fracture dislocations.

White and Panjabi[5] have devised a clinical checklist for thoracic and lumbar instability. In their system, they consider radiographic criteria (subluxation, segmental angulation) and the degree of neural injury, as well as anticipated dangerous loading, to determine the degree of spinal instability.

At our institutions, we use Denis' definition as a broad guideline for the assessment of stability of a thoracolumbar injury. Spinal injuries with any associated neurologic deficit are considered to be unstable. These injuries usually require operative stabilization to adequately immobilize the injured segments and protect the injured and at-risk neurologic structures.

Nonoperative Treatment

Nonoperative treatment in thoracolumbar trauma is reserved for those injuries that are considered to be stable without the potential for progressive deformity or neural compression with ambulatory treatment and external immobilization. In 1992, Gertzbein[6] reported the findings from the Scoliosis Research Society multicenter prospective study of 1,109 patients with spinal fractures. At the 2-year follow-up, patients with a kyphotic deformity of more than 30 degrees had an increased incidence of significant back pain.

One-column injuries are stable by definition; these include wedge compression fractures and fractures of the posterior elements. These injuries will heal well when treated in an ambulatory fashion with external immobilization by means of a plaster cast or orthosis. The form of immobilization chosen should provide a force vector opposite to the initial major injury force, such as an extension cast or an orthosis for a compressive flexion injury. For injuries above T7, an occipitocervicothoracic orthosis is used until healing, which is expected in 8 to 12 weeks. For lesions at T7 or below, a thoracolumbosacral orthosis is prescribed, and healing is expected in 12 to 16 weeks. In low lumbar injuries, the cast or orthosis should include one thigh for the first 6 to 12 weeks in order to stabilize the pelvis.

Nonoperative treatment is also an option for certain isolated injuries with bone instability and no neurologic deficits. For example, flexion-distraction injuries through bone (Chance fractures) will heal when immobilized in an extension cast or a custom-molded orthosis. Certain vertical compression fractures (stable burst fractures) with minimal or no middle-column comminution or shortening and minimal kyphosis can also be treated in an extension cast or a custom-molded brace.

Operative Treatment

Surgical Indications

Operative management of thoracolumbar injuries is indicated for lesions that are considered to be unstable and to have the potential for further compromise to the neurologic elements. Even in patients with complete neurologic lesions, surgical stabilization can allow more rapid mobilization and earlier commencement of physical rehabilitation. Controversy exists as to the treatment of unstable spinal column injuries in patients without neurologic injury. Proponents of initial nonoperative treatment believe that good results can be obtained in most cases and that late neurologic deficits, bone deformity, and instability can be corrected if they occur. We agree with others who believe that surgical stabilization facilitates the most rapid functional return and reintegration into society for patients with unstable fractures. This approach also prevents the late complications of neurologic injury, deformity, and painful instability. The surgical methods needed to correct the sequelae of late instability and fixed deformity are quite complex and fraught with significant morbidity.

In cases of middle-column disruption, decompression of persistent spinal canal compromise is often indicated, even in the presence of complete neurologic lesions, in the hope of additional root recovery. This is most important in the case of trauma at the thoracolumbar junction and in the upper lumbar spine, where recovery of an additional root level may have tremendous functional significance.

Decompression

Spinal canal intrusion by bone or soft-tissue fragments may require surgical decompression. Most often, compression occurs anteriorly in the spinal canal due to retropulsion of bone or disk fragments from the middle column. Posterior compression by lamina fragments can also occur. In cases of significant spinal canal compromise with an incomplete neurologic deficit, persistent neural compression should be assumed to necessitate spinal decompression. In the case of complete lesions of the thoracolumbar junction and lumbar spine, additional root recovery may provide important functional benefits; decompression may be indicated if significant canal compromise exists. In cases without neurologic deficit, canal decompression may not be indicated as long as spinal stability can be ensured due to eventual remodeling of retropulsed bone fragments.

Decompression of the spinal column can be done via an anterior, a posterolateral, or a posterior approach. Anterior decompression by means of a vertebrectomy is useful for spinal canal compromise due to retropulsion of bone and disk fragments from the middle column in the thoracic spine and thoracolumbar junction. The vertebral body is commonly reconstructed with the use of an autogenous anterior iliac-crest strut graft. Anterior decompression and vertebral reconstruction require additional stabilization, which can be accomplished by means of external immobilization, anterior instrumentation, or posterior instrumentation and fusion.

Posterolateral decompression in the thoracolumbar spine can be performed with the use of a modified costotransversectomy approach by removal of the transverse process and pedicle. Although posterior spinal stabilization can be performed through the same incision, structural grafting of the anterior column is difficult via this approach because of the limited exposure.

Another method of posterolateral decompression that can be employed at the level of the conus medullaris involves removing the medial half of the pedicle at the level of injury, undercutting anterior to the retropulsed fragment, and impacting the fragment back into the vertebra without retraction of the dura. We have no experience with this technique and prefer anterior decompression in these situations for more complete visualization of the compressed dural sac.

Posterior decompression of the retropulsed middle column can be done either directly or indirectly. We use direct posterior decompression only below the conus medullaris in the region of the cauda equina. Retraction of the dural sac may be necessary for direct posterior decompression; this can cause damage to the spinal cord and conus medullaris. The safe region is typically at the level of L2 and more caudally. This can be easily confirmed with a preoperative magnetic resonance imaging study.

Indirect posterior decompression through the use of distraction and lordosis forces can be useful in the thoracic spine and at the thoracolumbar junction. Distraction instrumentation has been shown to be effective in reducing retropulsed middle-column fragments in the spinal canal, especially when done within 2 days of injury. Transpedicular screw constructs that allow distraction and lordosing force applications can also be used for indirect canal decompression. It has been shown experimentally that indirect reduction results from the insertion of the posterior annulus fibrosus into the superior vertebral endplate, not the posterior longitudinal ligament.[7] Distraction, not lordosis, was shown to be the major reduction force, and a combination of distraction and lordosis was found to provide the optimal indirect reduction forces necessary for spinal realignment.

Laminectomy alone as a decompressive procedure has been shown to be ineffective in alleviating anterior spinal canal compression. Laminectomy is indicated in patients with neurologic deficits and laminar fractures, to allow inspection for trapped neural elements and dural tears. In all cases in which a laminectomy is performed, the spinal column is further destabilized, and fusion with instrumentation is mandatory.

Timing of Surgery

We believe that surgical decompression, if needed, and stabilization of thoracolumbar injuries should be done on an urgent, not emergent, basis. Patients are medically stabilized as active fracture bleeding abates, and hematoma is allowed to form, minimizing surgical blood loss, especially with anterior decompressive procedures. The only emergent indications for surgery in cases of thoracolumbar trauma are a progressive neurologic deficit and an incomplete neurologic deficit associated with an irreducible dislocation, both of which are uncommon. No studies have documented improved neurologic outcomes with emergent stabilization of unstable thoracolumbar injuries with or without neural decompression. Studies have shown, however, that even late decompression of persistent thoracolumbar spinal cord compression can be beneficial in terms of improved neurologic status.[8]

Posterior Instrumentation

The choice of posterior instrumentation and the selection of the method of application are based on a number of factors. The mechanism of injury and the resultant fracture pattern determine the force application that must be supplied by the instrumentation system. In general, distraction instrumentation is used for compression injuries with intact posterior elements. Distraction and lordosing constructs are also useful for indirect decompression of spinal canal compromise due to middle-column compression. Distraction can be achieved with either hook, pedicle-screw, or hybrid constructs connecting longitudinal rods. Compression constructs are used for flexion-distraction injuries if the middle column is not comminuted and the facets are intact. Segmental stabilization with hooks, sublaminar wires, and transpedicular screws is used in the highly unstable flexion-rotation and translational injuries and can be used in conjunction with compression or distraction forces if needed. In cases of posterior stabilization after anterior decompression and strut-graft stabilization of the anterior and middle columns, compression instrumentation creates the most stable overall construct.

Treatment of Specific Injuries

Middle-Column Disruption With Canal Compromise

We agree with others that anterior decompression is the most reliable method of achieving a complete decompression and is preferred for cases of anterior canal compromise with incomplete neurologic deficits. Direct posterior decompression is used for injuries below the conus medullaris. In cases without neurologic deficit in which stabilization is required, indirect posterior decompression is performed. In cases of complete injury, if one is attempting decompression for added functional root recovery, we prefer either anterior decompression at or above the conus level or direct posterior decompression below the conus level; if not, stabilization is accomplished posteriorly, with indirect reduction of the spinal canal.

After anterior decompression, we utilize an autologous tricortical anterior iliac-crest strut graft, placed between the superior endplate of the vertebral body above and the inferior endplate of the vertebral body below, with the anterior column under distraction. This is followed by posterior fusion with compression instrumentation with use of a rod-hook system or a rigid pedicle screw-rod construct.

Anterior instrumentation systems can obviate the need for posterior surgery. While certain older anterior systems were associated with late injury to the great vessels, newer systems present a lower profile and are placed along the lateral aspect of the vertebral body. These have been used safely to stabilize vertebral reconstructions for trauma and tumor surgery. If anterior instrumentation is used, the bone graft is sized to fit between the inferior endplate of the cranial vertebra and the superior endplate of the caudal vertebra, to allow fixation into undisturbed vertebral bone. We remain reluctant to use hardware anteriorly at L5 and the sacrum, because of the potential for late injury to the great vessels.

Middle-Column Disruption and Posterior-Element Fractures

Posterior surgery is an integral part of the operative treatment of vertical compression or burst fractures with associated laminar fractures and neurologic deficits. A number of reports have documented dural tears and entrapment of neural elements with laminar fractures. It is hypothesized that the initial splaying of the pedicles and the posterior-element displacement are followed by the recoiling to the stable position that is seen on radiographic evaluation.[9] The dura and neural elements become trapped within the fractured posterior elements and injured during the recoil. Recognition of trapped neural elements and their decompression can be accomplished only through posterior exploration.

Special care must be taken during the approach. Because the dura and neural elements can be encountered before reaching the lamina, exposure of the lamina above and below the injury level is done first. The injury level is then exposed by careful blunt dissection. Visualization of the dura or nerve roots is an indication for hemilaminectomy to explore the surrounding dura for tears, which are repaired if possible.

Hemilaminectomy and exploration may also benefit patients with laminar fractures without posteriorly visible neural elements, as neural entrapment along the anterior aspect of the lamina is possible. This might be particularly useful in patients with neural deficits and only a small amount of anterior compression, in whom occult neural injury secondary to laminar entrapment is more likely.

Thoracic Spine (T1-T10)

In the thoracic spine, we treat Ferguson-Allen type I compressive flexion injuries[10] with an extension cast and early ambulation. Type II and type III compressive flexion injuries with or without neurologic deficit are generally stabilized with segmental instrumentation with the use of a hook-and-rod construct. In the presence of a complete spinal cord injury, sublaminar wires can be utilized in addition to a hook-rod construct. Alternatively, one may use an inexpensive rectangular Luque rod with sublaminar wires (Fig. 1). The Luque rectangle is prebent in mild hypokyphosis to reduce the segmental kyphosis at the level of injury. The instrumentation generally incorporates three levels above and two to three levels below the injury. Other acceptable instrumentation constructs include standard Luque rods with spinous-process wiring and distraction rods with supplemental segmental fixation.

Ferguson-Allen type III compressive flexion injuries with significant canal compromise and an incomplete neural deficit are treated by one-stage anterior decompressive vertebrectomy and autologous iliac-crest strut grafting followed by posterior compression instrumentation and fusion. The posterior instrumentation incorporates only the motion segments involving the strut graft, provided the hooks are placed out of the zone of spinal cord injury. Anterior instrumentation is an acceptable fixation alternative.

Translational and rotational injuries are highly unstable and require posterior segmental instrumentation. In most cases, patients have complete neurologic injuries but will benefit from early stabilization and mobilization. Following postural reduction, fixation is achieved with hook and / or sublaminar wire constructs, as described for the severe compressive flexion injuries.

Thoracolumbar Junction (T11-L2)

Ferguson-Allen type II compressive flexion injuries of the thora-

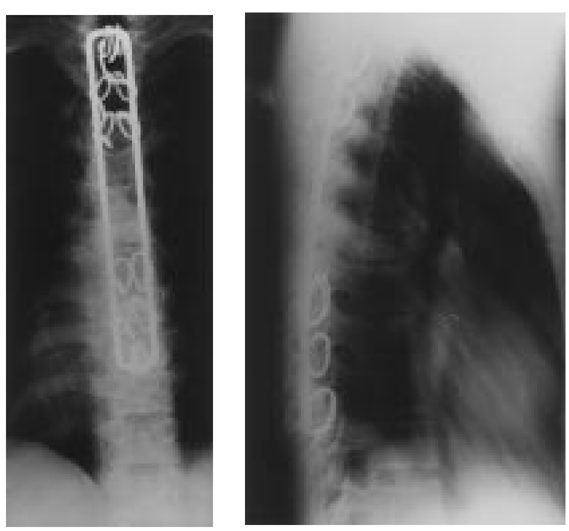

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Fig. 1 Anteroposterior **(A)** and lateral **(B)** radiographs show successful fusion following operative treatment of an unstable T6 fracture in a patient with a complete spinal cord injury. A Luque rectangle was used, with sublaminar wire fixation of three intact levels above and three intact levels below the injury site. Additional noninstrumented levels within the construct had posterior element fractures.

columbar junction are treated by posterior compression instrumentation, with the intact middle column being used as a hinge to restore lordosis. Type III injuries without significant canal compromise are treated with the use of distraction-lordosis instrumentation to maintain the middle-column height and restore the anterior-column height. Care must be taken to avoid overdistraction in patients with concomitant posterior-column tension injuries. Caution must be exercised if one chooses to use short-segment pedicle-screw stabilization in cases of anterior- and middle-column compromise. High fixation failure rates have been reported in these clinical situations.[11] We have utilized this form of treatment with postoperative immobilization in a hyperextension plaster body cast for a minimum of 3 months and have found fewer instrumentation failures than reported. A custom-molded thoracolumbosacral orthosis may also be acceptable for postoperative immobilization, but we have no experience with it in this clinical setting.

In cases of significant canal compromise and incomplete or complete neurologic injury, we prefer anterior decompression by means of vertebral corpectomy and autologous iliac-crest strut grafting, followed by posterior compression instrumentation with the use of hooks or transpedicular screws. Acceptable alternative treatment options include (1) anterior decompression with reconstruction and anterior internal fixation and (2) posterior fixation and indirect reduction followed by postoperative examination of the spinal canal with myelography or computed tomography and second-stage anterior decompression and vertebral reconstruction if significant canal compromise and neurologic deficit persist. One objection we have to the latter approach is that an anterior structural bone graft is supported by posterior distraction instrumentation, which is a less stable construct than posterior compression instrumentation.

In vertical compression injuries with compromise of the anterior and middle columns, the decision for surgical stabilization rests on the integrity of the posterior ligament-bone complex. If the posterior elements are intact without significant kyphosis (less than 20 degrees) or anterior loss of vertebral body height (less than 50%), ambulatory nonoperative treatment with an extension body cast or custom-molded extension thoracolumbosacral orthosis can be used (usually including a single thigh cuff). We generally stabilize vertical compression injuries with three-column involvement posteriorly. Patients with anterior thecal sac compression and an incomplete neurologic deficit, regardless of the integrity of the posterior elements, are treated operatively by one-stage anterior vertebrectomy and strut grafting followed by posterior compression instrumentation (Fig. 2). Anterior decompression followed by anterior instrumentation is certainly an acceptable option.

Distractive flexion injuries are treated by reduction and compression instrumentation, as described previously. Lateral flexion injuries can be treated with combined ipsilateral distraction and contralateral compression, applied with the use of hooks or transpedicular screws above and below the level of injury. The compression force is applied first, to improve the lordosis and prevent kyphosis from the distraction force.

Translational and torsional flexion injuries are treated by segmental instrumentation, preferably with pedicle screws. Hook constructs and screw-hook combination constructs can also be used.

Low Lumbar Injuries (L3-L5)

Compressive flexion and vertical compression injuries of the low lumbar spine are managed by transpedicular screw instrumentation, fusing one level above and one level below the injury (Fig. 3). Caution must be exercised with the use of short-segment instrumentation when there is loss of anterior- or middle-column support, because of the

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Fig. 2 Anteroposterior **(A)** and lateral **(B)** radiographs obtained after surgical treatment of a patient with an incomplete neurologic deficit and significant bony canal compromise after a Ferguson-Allen type III compressive flexion injury. The procedure involved a one-stage anterior L1 corpectomy with autogenous iliac-crest strut grafting and posterior T12-L2 fusion with compression-rod instrumentation.

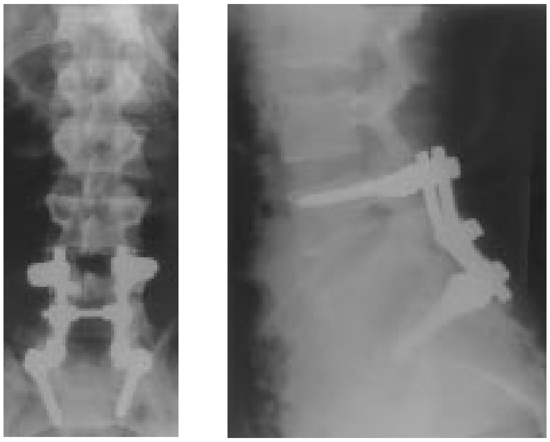

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Fig. 3 Anteroposterior **(A)** and lateral **(B)** radiographs obtained after operative treatment of an L5 vertical compression injury in a 21-year-old man with a partial neurologic deficit. The operative procedure included L5 laminectomy and direct posterior decompression and stabilization with pedicle-screw fixation, with which mild distraction and lordosis forces were applied. Postoperatively, the patient was allowed to ambulate in a body cast, molded in extension and incorporating a thigh segment.

potential for screw failure. Transpedicular bone grafting of the injured level may be of benefit, but we have no experience with this technique. If decompression is needed, we prefer the posterior direct technique via laminotomy, although anterior decompression can be done as well. Decompression should be considered even for complete neurologic lesions, to allow for possible additional lumbosacral root return. Distraction-rod instrumentation is less desirable in this region because of the associated loss of lordosis and the need to instrument additional levels above and below the injury site.

Translational and flexion-rotation injuries in the low lumbar spine also require segmental instrumentation. This is easily accomplished by transpedicular screw fixation one level above and one level below the injury (Fig. 4).

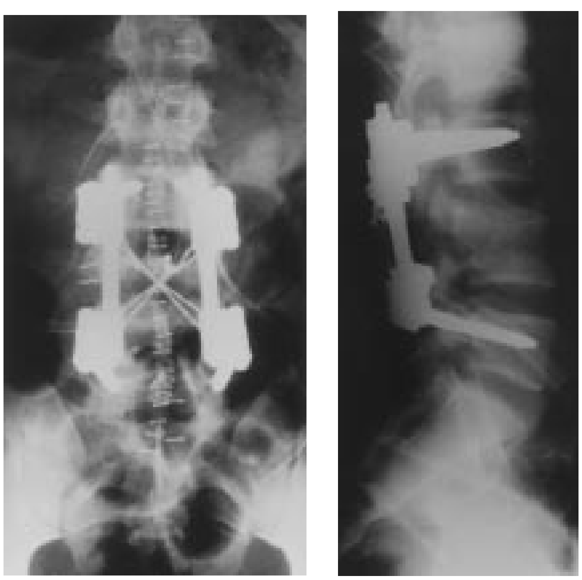

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Fig. 4 Anteroposterior **(A)** and lateral **(B)** radiographs show segmental transpedicular instrumentation of a highly unstable translational injury after postural reduction. (This is the same injury seen in Figure 6, C, in the accompanying article.)

Rehabilitation

In patients with a residual neurologic deficit, passive motion exercises and splinting are useful in the early postinjury period to maintain joint flexibility and maximize functional potential. Upper-body strength training is essential for functional paraplegic patients to facilitate self-transfers and a return to independence in society. The application and use of orthotic devices with appropriate training can allow independent ambulation by patients with functional motor strength at low lumbar levels. Assistive devices and vocational retraining help the patient to regain maximal functional and financial independence.

Summary

Successful management of thoracolumbar spine injuries protects the patient from further spinal deformity and neurologic deficit. The majority of patients with thoracolumbar injuries are still treated nonoperatively with cast or brace immobilization and early ambulation. There is no clear consensus as to the absolute indications for surgical intervention in patients with many types of thoracolumbar fractures. Opinions vary most in cases of complete spinal cord injury or no neurologic deficit at all. Operative treatment, including both decompression and stabilization, is more universally accepted in cases of incomplete spinal cord injury with radiographic evidence of persistent mechanical compression of the neural structures. Controlled prospective studies evaluating contemporary classification systems and recommended treatment protocols (both nonoperative and operative) are necessary to better define the role of surgical intervention in these potentially devastating injuries.

References

1. 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.
2. Weinmann EE, Salzman EW: Deep-vein thrombosis. *N Engl J Med* 1994;331:1630-1641.
3. Denis F: The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. *Spine* 1983;8:817-831.
4. Denis F: Spinal instability as defined by the three-column spine concept in acute spinal trauma. *Clin Orthop* 1984;189: 65-76.
5. White AA III, Panjabi MM: *Clinical Biomechanics of the Spine*, 2nd ed. Philadelphia: JB Lippincott, 1990, pp 277-378.
6. Gertzbein SD: Scoliosis Research Society multicenter spine fracture study. *Spine* 1992;17:528-540.
7. Fredrickson BE, Edwards WT, Rausch-ning W, et al:. Vertebral burst fractures: An experimental, morphologic, and radiographic study. *Spine* 1992;17:1012-1021.
8. Bradford DS, McBride GG: Surgical management of thoracolumbar spine fractures with incomplete neurologic deficits. Clin Orthop 1987;218:210-216.
9. Cammisa FP Jr, Eismont FJ, Green BA: Dural laceration occurring with burst fractures and associated laminar fractures. *J Bone Joint Surg Am* 1989;71:1044-1052.
10. Ferguson RL, Allen BL Jr: A mechanistic classification of thoracolumbar spine fractures. *Clin Orthop* 1984;189: 77-88.
11. McLain RF, Sparling E, Benson DR: Early failure of short-segment pedicle instrumentation for thoracolumbar fractures: A preliminary report. *J Bone Joint Surg Am* 1993;75:162-167.