A Reduction–Fixation System for Unstable Thoracolumbar Burst Fractures

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Thirty-three patients with unstable burst fractures of the lower thoracic and lumbar spine were treated with a reduction–fixation system. The new system is used both as a reduction and a fixation device for disorders of the lower thoracic and lumbar spine. In treatment of spinal fractures, it provides symmetric lordotic distraction to obtain the best possible reduction of intracanal fragments, and rigidly stabilizes the fractured vertebra while involving the minimum number of segments. All patients had a minimum follow-up of 24 months. Most patients in this series had a near-anatomic reduction of all three columns in the involved segment. The "indirect" neurologic decompression was successful in cases treated early after injury. The fixation was rigid enough to allow early mobilization and rehabilitation in a light orthosis within 1 week after surgery, and there was minimal loss of reduction during the follow-up period. The complications were minor. The reduction–fixation system achieved the surgical goals of posterior instrumentation for treatment of unstable thoracolumbar burst fractures. [Key words: unstable burst fracture, reduction–fixation system, intracanal fragments, indirect neurologic decompression]

Successful surgical treatment of thoracolumbar and lumbar spine fractures by a posterior instrumentation system should be directed toward the following goals[3,4,6–8,10–19,21–25,27–38]: 1) attainment and maintenance of anatomic reduction; 2) obtaining a rigid fixation to allow rapid mobilization and rehabilitation; and 3) limiting the number of instrumented vertebral motion segments to as few as possible. This article describes a new internal fixation device for unstable burst fractures of the low thoracic and lumbar spine. In this new system, the above-mentioned goals are met.

Description of the the Reduction–Fixation System

The reduction–fixation system (Figure 1) has four basic components that are used to develop the constructs required to provide reduction and rigid fixation. The components include angled pedicle screws, rods with traction nuts, transverse connectors, and set screws.

Angled Pedicle Screws. The angled pedicle screws for transpedicular fixation in the vertebral bodies are U-shaped head screws 6.25 mm in diameter. The screws are offered in four angles: 0°, 5°, 10°, and 15°. This measurement is the degree of angle between the U-shaped screw head and the shank of the screw. One side of the U-shaped screw head is flat; the other side is concave to accommodate a cone-shaped traction nut. Within each column of the U-shaped screw head there is a small threaded screw hole for a 3-mm set screw to secure the rod to the U-shaped screw head.

Rods with Traction Nuts. The rods are 8 mm in diameter. One side of the rod is flat, and on the other side there is a slot to accommodate the set screw in the U-shaped screw head. There are two types of traction nuts. One type is flat on both sides to abut the flat side of the U-shaped screw head, and the other is cone-shaped to engage the concave side of the U-shaped screw head, to secure the rod further to the U-shaped screw head. A pair of traction nuts (one flat type and one cone-shaped type) is used to fix one angled screw onto the rod. The angled screw can be moved freely along the rod by rotating the paired traction nuts to generate various corrective forces without separation between the rod and the angled pedicle screw, when a set screw within one of the two columns of the U-shaped screw head is screwed into the slot of the rod. The angled screw can be rigidly fixed to the rod by traction nuts with a fixed angle between the shank of the screw and the rod. The angle depends on which angled screw is chosen. In the side walls of the traction nuts there are screw holes for set screws to lock the nuts on the rods to prevent loosening of the construct.

Transverse Connectors. The transverse connector is applied to the rods to add strength to the total construct and to resist torsional forces. The transverse connectors consist of transverse braces and transverse bars. Set screws secure the brace to the rod. The transverse bar is inserted into the medial hole of each brace and secured in place with the set screws.

Set Screws. The set screws are used to prevent the components of the reduction–fixation construct from loosening by tightening them until their heads break.

Surgical Technique

Posterior exposure with localization of the appropriate pedicle and placement of a 3-mm guide wire was done according to the description by Dick.[13] The position of the guide pin should be parallel to the end plate and checked by image intensifier. Once the guide pins were in correct position, the holes were then tapped for the angled pedicle screws with a bone tap. The depth of tapping was monitored by lateral image intensifier, and angled screws of appropriate length were determined. Appro-

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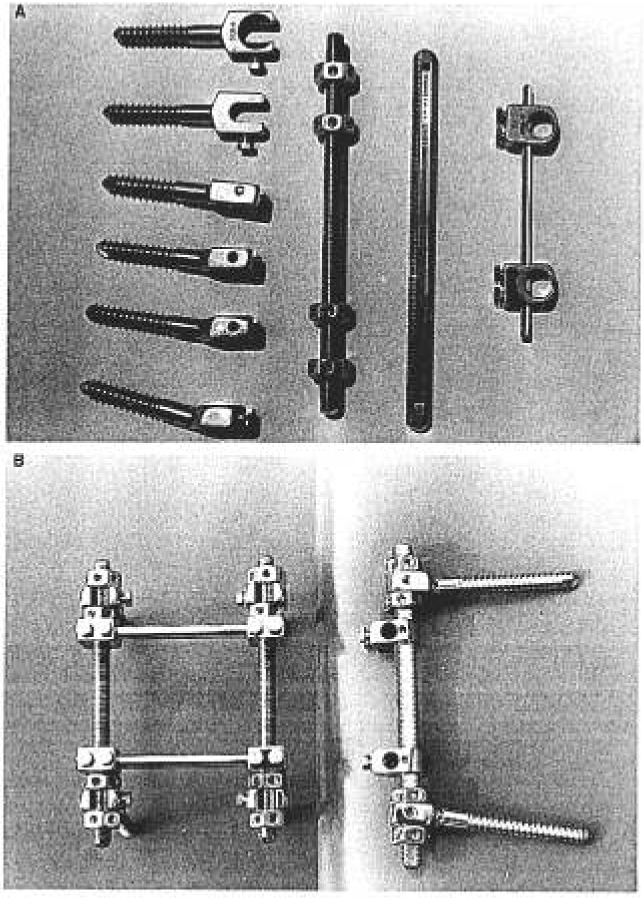

Figure 1. The reduction–fixation instrumentation system. **A**, The dissembled reduction–fixation system: the angled pedicle screws with set screws, the rod with traction nuts, and the transverse connector. The angled pedicle screws are U-shaped head screws and are offered in four angles—0°, 5°, 10°, and 15°. This measurement is the degree of angle between the U-shaped screw head and the shank of the screw. One side of the screw head is flat, the other side is concave to accommodate a cone-shaped traction nut. Within each column of the U-shaped screw head there is a threaded screw hole for a set screw. On one side of the rod there is a slot to accommodate the set screw within the U-shaped screw head to secure the rod to the U-shaped screw head during the generation of various corrective forces from this system. There are two types of hexagonal traction nuts. One type is flattened on both sides; the other type is cone-shaped. In the side walls of the traction nuts screws are set screws to lock the nuts on the rod to prevent loosening of the construct. The transverse connector consists of the transverse brace and the transverse bar, and depends on set screws in the brace to connect the transverse bar with the longitudinal rod. **B**, The assembled reduction–fixation system. The angled pedicle screws can move freely along the rods to provide forces to produce kyphosis, lordosis, distraction, and compression. They can be fixed in the desired lumbar lordotic configuration. Note the lordotic tilt of the angled screws when the paired traction nuts are tightened to the U-shaped screw head. The angle of the lordotic tilt depends on which angled screw is chosen.

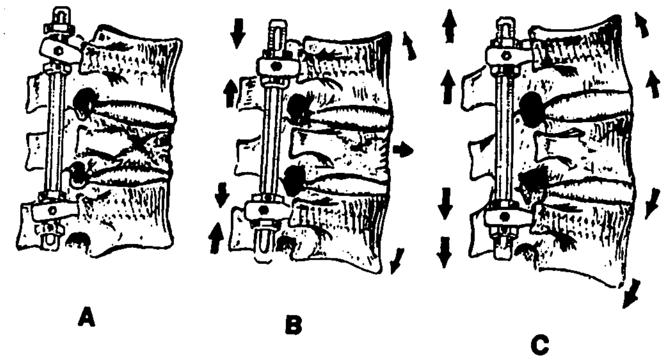

Figure 2. The sequence of reduction of a burst fracture. **A**, The initial position of insertion of the reduction–fixation system is shown before the traction nuts are tightened. **B**, Tightening the nuts to the U-shaped screw head forces the instrumented cephalad and caudad vertebrae to rotate into lordosis, which is determined before surgery. **C**, Moving the angled screws with their paired nuts in opposite directions from each other provides symmetric three-column lordotic distraction for further reduction of vertebral height and intracanal fragments.

priate angled screws were chosen before surgery for creating normal lumbar lordosis. For patients who had preinjury lateral lumbar plain films, the lordosis was gauged based on these films. For patients without preinjury lateral lumbar plain films, the thoracic kyphosis was used as a reference, and the lumbar lordosis was created equal to or slightly larger than this measurement. In general, for T12 and L1 fractures, angled screws of 0° were used to create a straight thoracolumbar junction. For fractures below L1 (L2–L5), screws of 5°, 10°, or 15° were used to create lumbar lordosis, gradually increasing the degree of angulation at each level caudally. Only the fractured vertebra, one above, and one below were included in the fixation. Then, angled screws of determined length and angle were implanted into the vertebrae above and below the fractured vertebra. The rotational malalignment was corrected by manipulation with the long screwdrivers for the angled screws. Next, the rods with pairs of traction nuts were inserted into the U-shaped screw heads and locked onto the screw heads by tightening the set screws in the screw heads.

At this point, reduction of the burst fracture was carried out as follows (Figure 2). The paired traction nuts were tightened to the U-shaped screw head to create the lordosis determined before surgery. Creating lordosis would not only reduce kyphotic deformity, but also force the posterior longitudinal ligament, with its attaching bony fragments, anteriorly away from the neural tissue to enhance the effect of indirect neurologic decompression (Figure 3). The angled screws were moved in opposite directions from each other by rotating the traction nuts to provide symmetric lordotic distraction for further reduction of vertebral height and intracanal fragments. The sequence of the procedure was determined according to our own study.[8] The lordosis should be created first, followed by symmetric lordotic distraction. It was necessary to follow the sequence of the procedure; otherwise, the reduction would not be "near-anatomic." After satisfactory reduction had been achieved, all nuts were rigidly locked to the rods by tightening the set screws in the nuts against the rods until their heads broke, to prevent loosening. Two transverse connectors were added routinely to provide more rotational stability. Facet rhizotomy of all facet joints spanned by the reduction–fixation system was done routinely. After secure reduction and fixation had been achieved, a short fusion of the length of the instrumentation was performed with iliac bone grafts (Figures 4, 5).

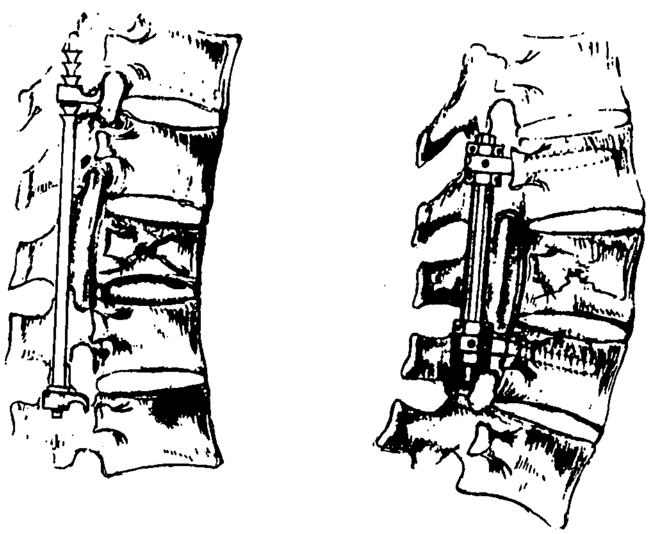

Figure 3. The mechanism of indirect neurologic decompression by lordosis. Lordosis forces the posterior longitudinal ligament with its attaching bony fragments to move anteriorly away from the injured cord or cauda equina. In contrast, the common posterior column-based spinal instrumentation, such as Harrington distraction rods, tends, when distracted, to produce an unwanted kyphotic tilt to the instrumented end vertebrae, forcing the posterior longitudinal ligament with its attaching bony fragments to move posteriorly toward the injured cord or cauda equina and dampening the effect of indirect neurologic decompression.

Materials and Methods

The study included 33 patients with thoracolumbar burst fractures treated by open reduction and internal fixation with the reduction–fixation system, with a minimum postoperative follow-up period of 2 years, at the Orthopedic Division of 803 Army General Hospital, Taiwan, ROC. The mean of follow-up was 32.7 months (range, 24–36 months). The average age of the patients was 33.5 years (range, 19–59 years). The vertebral level of injury was T12 in seven patients, L1 in eight, L2 in five, L3 in seven, both L2 and L3 in one, and L4 in five. Twenty-seven patients had been injured in traffic accidents or in falling from heights, and five in suicide attempts. Denis' classification[9] of burst fractures was used in the evaluation of all patients in this series: type A (9 patients), type B (15 patients), type C (5 patients), and type E (4 patients).

Plain roentgenography was performed before and after surgery, and at follow-up. Computed tomography (CT) was performed before and after surgery for all patients. Spinal alignment, restoration of vertebral body height, and reduction of intracanal fragments were evaluated radiographically.

Preoperative and postoperative anteroposterior and lateral radiographs were measured to quantitate vertebral height, maximum angulation, and maximum displacement. Vertebral height was reported as a percentage of normal anterior vertebral body plus disc space height. Normal height for the injured segment was determined by averaging the vertebral body plus disc height of the first normal segments immediately above and below the injured vertebra. Maximum translation (horizontal displacement) was measured as the perpendicular distance in millimeters between vertical lines projecting from the posterior and lateral edges of the dislocated vertebral bodies. Maximum angulation was determined by Cobb measurement on anteroposterior and lateral radiographs. In this study, I used the cross-level above and the level below to fixed average sectional canal area on CT to assess the degree to which this system alone was able indirectly to decompress the cord or cauda equina. Using computerized planimetry, the area of the canal at the level of maximum impingement was calculated as a percentage of normal. Normal area (the denominator) was based on the average area for the same portion of the adjacent proximal and distal vertebrae.

The neural deficits were categorized according to Frankel grades. In this series, there were 21 patients with neurologic deficits: Frankel B, 5 patients; Frankel C, 9 patients; and Frankel D, 7 patients (Table 1).

The pain scale used in this series was as follows: 1, no pain; 2, mild pain (occasional minimal pain, no pain medication used); 3, moderate pain (occasional pain medication, no significant change in activities of daily living); and 4, severe pain (frequent medication and significant change in activities of daily living).

The average time interval from injury to surgery was 5 days, with a range from within the first 24 hours to 20 days. The delay from injury to surgery was due to late referral. Fortunately, all 10 patients with incomplete neurologic deficits were all operated on within 4 days of injury.

Results

Alignment

Average preoperative vertebral body plus disc space height was 52% of normal (range, 39–77%). Average postoperative restoration of vertebral body plus disc space height for all constructs was 98% (range, 95–100%). The mean correction obtained at surgery was 48%. Maximum preoperative anteroposterior or lateral displacement was 11 mm (range, 3–17 mm). Maximum postoperative anteroposterior or lateral displacement averaged 0.7 mm (range, 0–2 mm). For the majority of patients in this series, kyphosis was completely corrected. Average angulation was −1° of kyphosis or 1° relative lordosis and 0° scoliosis (Table 2).

Neurologic Decompression

For cases treated within 1 week of injury, then reduction–fixation system restored 33% additional canal area (from 24% to 47%). When surgery was done between 7 and 14 days after injury, 24% additional canal area was restored (18–31%). There was little improvement in canal area when treatment was delayed for more than 2 weeks (Table 3).

Every patient presenting with incomplete neurologic deficit showed significant neurologic improvement. Of the five Frankel B patients, two improved to Frankel C, one improved to Frankel D, and two improved to Frankel E. Of the nine patients who were Frankel C, three improved to Frankel D, and six improved to Frankel E. All seven patients who were Frankel D before surgery recovered normal strength and sensation after reduction–fixation instrumentation (Table 1).

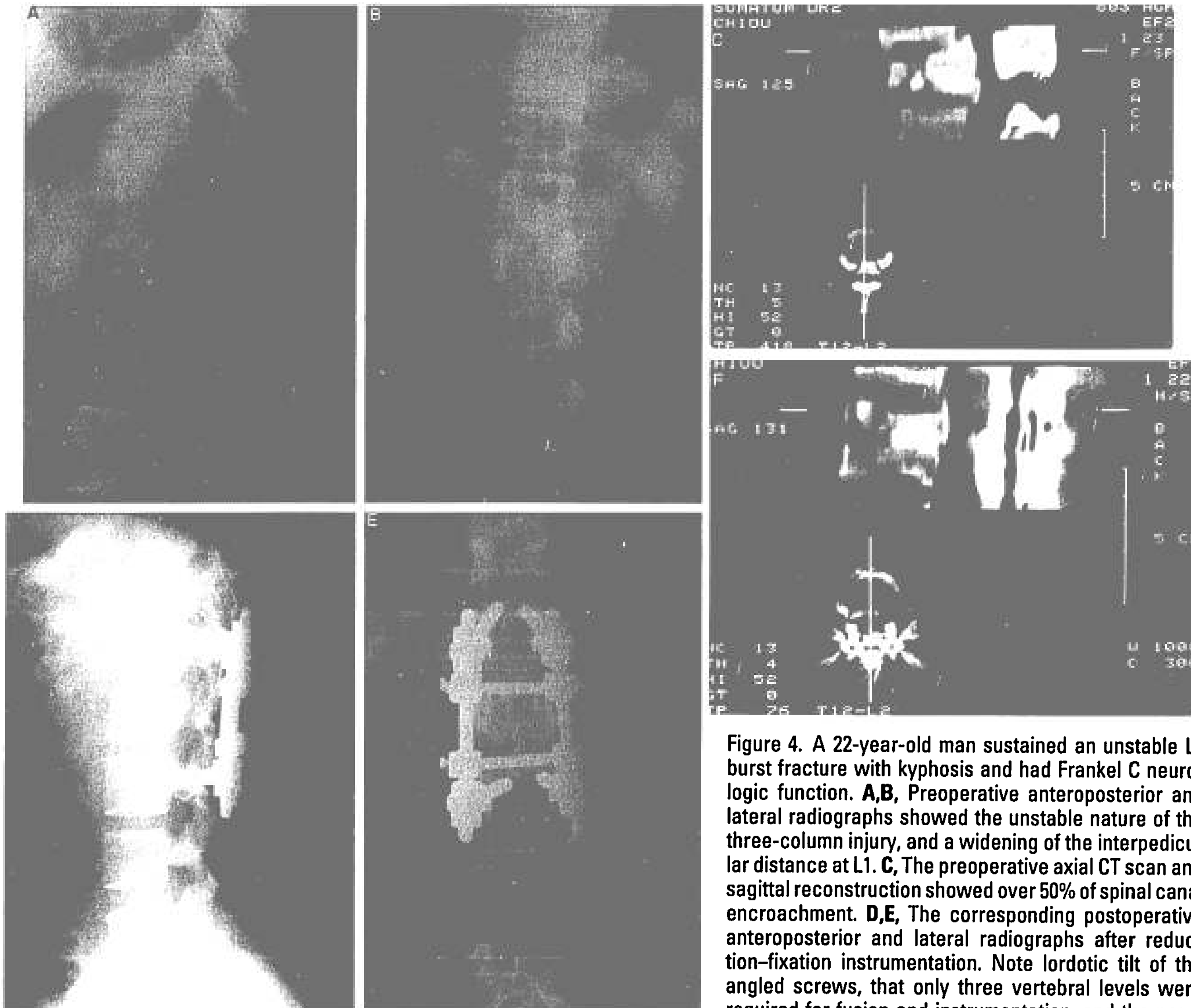

Figure 4. A 22-year-old man sustained an unstable L3 burst fracture with kyphosis and had Frankel C neurologic function. **A,B,** Preoperative anteroposterior and lateral radiographs showed the unstable nature of the three-column injury, and a widening of the interpedicular distance at L1. **C,** The preoperative axial CT scan and sagittal reconstruction showed over 50% of spinal canal encroachment. **D,E,** The corresponding postoperative anteroposterior and lateral radiographs after reduction–fixation instrumentation. Note lordotic tilt of the angled screws, that only three vertebral levels were required for fusion and instrumentation, and the near-anatomic reduction. **F,** The postoperative CT scan and sagittal reconstruction showed marked improvement of the spinal canal area. The patient recovered to Frankel E; hence, an anterior corpectomy was not indicated.

Maintenance of Correction

The effectiveness of any fixation device lies in its ability to provide maintenance of correction. The average loss of height for the disrupted disc space and fractured vertebral body was limited to 1%. The resulting average vertebral height plus disc space height at 24-month follow-up remained approximately 97% of normal. Maximum anteroposterior or lateral angulation (kyphosis or scoliosis) and correction of horizontal displacement (translation) were maintained with no significant loss in position. Overall, at 24-month follow-up the reduction–fixation fixation maintained average correction to within 97% of normal vertebral body plus disc space height, 0° angulation, and 0.7 mm of translation (Table 2).

All patients had a pain level evaluation at their 24-month follow-up. Twenty-three patients were in group 1, reporting themselves to be completely free of pain, and 10 patients were in group 2, having only occasional pain not requiring analgesics. No patients were in groups 3 or 4.

All patients had a minimum number of segments fixated (the fractured vertebrae, one above, and one below). Mean operating time was 2.0 hours (range, 1.7–2.4 hours). The average blood loss was 2 units. The rigidity of this system appeared to minimize postoperative pain and facilitate mobilization; all patients could begin rehabilitation in a light, external orthosis within 1 week. The mean hospitalization time was 15 days (range, 12–21 days).

Complications

There were no wound infections, and no iatrogenic neurologic deficits. Two cases had screw breakage occurring at 9 and 11 months because of nonunion of the

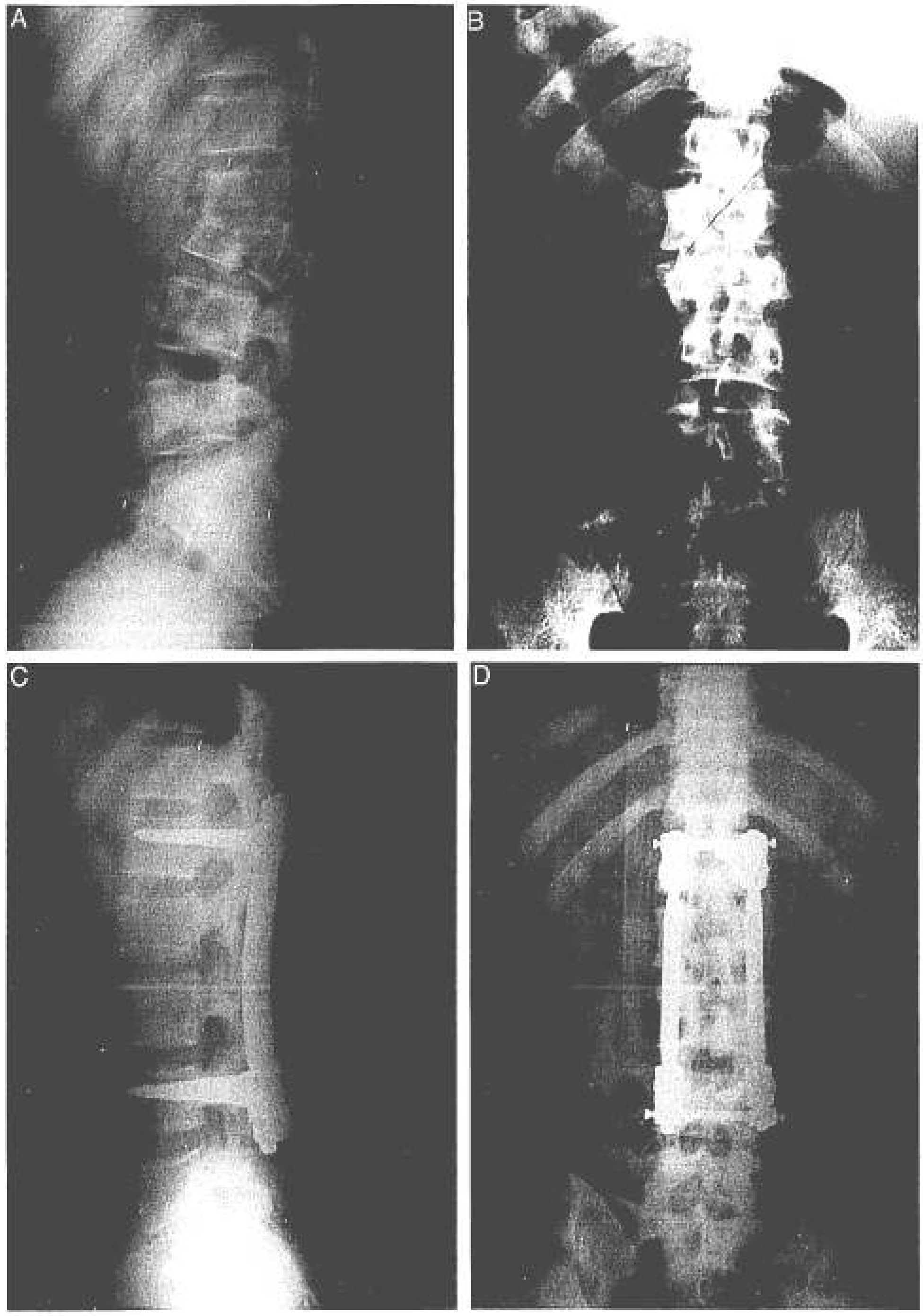

Figure 5. A 24-year-old man sustained both L2 and L3 burst fractures with Frankel C neurologic deficit. **A,B,** Preoperative anteroposterior and lateral radiographs showed a three-column disruption and kyphotic deformity. **C,D,** The corresponding postoperative anteroposterior and lateral radiographs showed near-anatomic reduction after reduction–fixation instrumentation.

fusion. Both cases were treated by repair of the nonunion and replacement of the broken screws, and results in both cases were satisfactory.

Medical complications were also relatively minor, and all were resolved. The most common problem was catheter-related urinary tract infection, in four cases.

■ Discussion

In considering the management of patients with burst injuries to the thoracolumbar spine by posterior instrumentation, both rigid fixation and anatomic reduction should be obtained.

The fixation provided by the reduction–fixation system was rigid enough to allow all patients in this series to begin rehabilitation and mobilization within 1 week after surgery. The fact that there was minimal loss of reduction after an average 2-year follow-up further proved the rigidity of this system.

Full correction of vertebral height, alignment, and displacement with an anatomic reduction maximizes restoration of foraminal and canal areas. This will often indirectly relieve pressure on the cord and roots from intracanal fragments, with the goal of obtaining adequate "indirect" neurologic decompression and reducing

Table 1. Preoperative and Postoperative Functional Neurologic Levels

	Frankel Functional Neurologic Level						
		Postoperative					
Preoperative		A	B	C	D	E	Total
A	0	0	0	0	0	0	0
B	5	0	0	2	1	2	5
C	9	0	0	0	3	6	9
D	7	0	0	0	0	7	7
E	0	0	0	0	0	0	0
Total	21	0	0	2	4	15	21

Note: Twenty-one patients had an incomplete neurologic deficit preoperatively.

the number of cases needing subsequent "direct" decompressive operations through an anterior approach. The mechanism of reduction of spinal fractures by distraction forces is generally thought to be "ligamentotaxis," that is, realigning the bony fragments by applying tensile force to their ligamentous attachments.

According to Denis' classification,[9] the burst fracture results from failure under axial load of both the anterior and middle columns of the vertebra. Hence, an axial distraction force is essential for obtaining anatomic reduction of burst fractures. Any posterior column-based distractive spinal instrumentation system using hooks, such as the Harrington dural distraction rods, works eccentrically from the center of rotation on the posterior column, and tends, when distracted, to produce an unwanted kyphotic tilt to the instrumented end vertebrae. These tilts dampen the effects of reduction and indirect neurologic decompression of a distraction force by forcing the posterior longitudinal ligament with its attaching bony fragments toward the anterior aspect of the dura (Figure 3). Using postoperative magnetic resonance imaging, Batzdorf et al[5] confirmed posterior migration of the spinal cord after enlargement of the cervical spinal canal by laminectomy in patients with relatively normal cervical lordotic curvature, but not in patients with straightened or kyphotic curvature. So, theoretically, lordosis of the levels adjacent to the fractured thoracolumbar vertebra must be created when a posterior distractive instrumentation is used, to allow posterior migration of the injured spinal cord or cauda away from the posteriorly protruded bony fragments or disc material, and to optimize the effect of indirect neurologic decompression. Newer modifications by Moe and Jacob[24] allow the lordosis to be contoured into the rod in combination with distraction force. Contoured rods offer a considerable biomechanical advantage for the treatment of spinal trauma,[3,7,12,26] as they theoretically provide a "third" point of fixation. But in the classic burst fracture the pedicles are discontinuous with the remainder of the vertebral body, which may be pulverized to a greater or lesser degree; hence, applying the correction force directly on the lamina of the fractured level to create lordosis by a sleeve mechanism or by contoured rod, without careful evaluation of the configuration of the burst fractures, is very likely to result in a further narrowing of the spinal canal in some cases. Fredrickson et al[20] confirmed this possibility. They used Harrington distraction rods and a screw-type mechanism (similar to a contoured rod or sleeve mechanism) to reduce intracanal fragments in experimental burst fractures, and confirmed that kyphosis correction by this means can increase canal compromise. Dick,[13] Aebi,[1] and Olerud all emphasize the importance of lordosis for near-anatomic reduction, but they used a three-column level arm mechanism to create lordosis indirectly, rather than pushing directly at the kyphus.

The mechanism of reduction of intracanal fragments of burst fractures was studied in experiments performed at the Orthopaedic Laboratory of SUNY Health Science Center (Syracuse, NY).[8] Experimental burst fractures were created in six young cadaveric spines according to the technique of Fredrickson et al,[20] and reduced by spinal instrumentations to determine what reduction forces are necessary for reduction of intracanal fragments in thoracolumbar burst fractures. Three pedicle screw devices were applied to the specimens following the commonly accepted clinical techniques for each device. The fixateur interne and the reduction–fixation system provided both distraction and lordosis. The Steffee device provided distraction only. Plain films and CT scans of the specimens were taken before and after creation of the fractures, and following application of the three devices. The reduction–fixation system provided symmetric lordotic distraction efficiently, consistently restored prefractured lordosis along with body height, and increased canal area the most. The fixateur interne provided variable lordotic distraction, restored variable lordosis, and moderately increased canal area. The Steffee device provided excellent distraction of vertebral body height, but did not create lordosis, and decreased canal compromise the least. The results confirmed the need for symmetric three-column lordotic distraction of the disc space and vertebral body to obtain the best possible reduction of intracanal fragments (Figure 6). I also emphasize the importance of the sequence of reduction (ie, create lordosis first, then provide symmetric lordotic distraction). The sequence is contrary to the method proposed by Aebi,[2] who recommended that the sequence of reduction using the fixateur interne should be distraction, lordosis, distraction. I believe that once any ligament is tensed by the first distraction, lordosis is hard to create.

■ Summary

The reduction–fixation system provided symmetric three-column lordotic distraction and rigid fixation, achieving near-anatomic reduction and maintenance of fixation in this series of 33 cases. The average vertebral

Table 2. Radiographic Evaluation (in 33 Patients)

	Vertebral Height (%)		Translation (mm)		Angulation Cobb Method (degrees)	
	Range	Mean	Range	Mean	Range	Mean
Preoperative	39–77	52	3–17	11	15–30	21
Postoperative	95–100	98	0–2	0.7	−1–+1	0
Correction	23–59	48	3–15	9.5	15–26	21
Follow-up (24 mo)	94–100	97	0–2	0.7	−1–+1	0
Loss of correction	0–1	1	None	None	None	None

Table 3. Canal Area on CT (%)

	Within 1st Week Following Injury		Between 1 and 2 Weeks Following Injury		More than 2 Weeks Following Injury	
	Range	Mean	Range	Mean	Range	Mean
Preoperative	37–85	67	44–78	69	73–88	76
Postoperative	76–93	89	73–86	79	77–84	79
Correction	24–47	33	18–31	24	0–1	1

body height was restored to 98% of normal, maximal translation was reduced to 0.7 mm, near complete correction of angulation was obtained, and 33% of additional canal cross-sectional area was restored in cases operated on soon after injury. The rigidity of this system allowed rapid mobilization in a light, external orthosis within 1 week. The minimum follow-up in this series was 24 months. Most fracture fusions are healed at this point

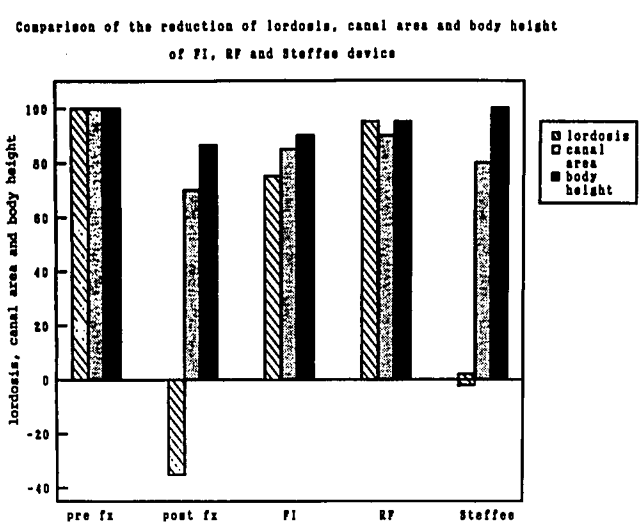

Figure 6. A comparative study of reduction ability of the Fixateur Interne, reduction–fixation, and Steffee systems using a cadaveric burst fracture model. Reduction–fixation could provide symmetric lordotic distraction efficiently, created near-prefracture lordosis constantly, and increased canal area the most. Fixateur Interne provided variable lordotic distraction, created variable lordosis, and increased canal area moderately. The Steffee system provided distraction only, without creating lordosis, and increased canal area the least. The study confirmed that symmetric three-column lordotic distraction resulted in the best possible reduction of intracanal fragments.

and no significant loss of correction has occurred. This device achieved the surgical goals of posterior instrumentation for treatment of thoracolumbar burst fractures, and provides a more effective tool in the spinal surgeon's reduction and fixation armamentarium.

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