LONG spinal instrumentation constructs often cause excessive stiffness of the spine. Their points of spinal fixation may disrupt facet joints and can, in turn, lead to a painful facet arthropathy. In addition, when long-rod–short-fusion techniques are used, motion in unfused but instrumented spinal segments results in the gradual loosening at the construct–bone interface. These problems often cause chronic pain syndromes that can lead to subsequent operations for removal of the instrumentation.

An ideal spinal construct should immobilize only the unstable spinal segments, and thus only the segments fused. Pedicle fixation techniques have provided operative stabilization with the instrumentation of a minimal number of spinal segments; however, some failures have been observed with pedicle instrumentation. These failures are primarily related to excessive preload forces and limitations caused by the size and orientation of the pedicles.

To circumvent these problems, a new technique, the crossed-screw fixation method, was developed and is described in this report. This technique facilitates short-segment spinal fixation and uses a lateral extracavitary approach, which provides generous exposure for spinal decompression and interbody fusion. The technique employs two large transverse vertebral body screws (6.5 to 8.5 mm in diameter) to bear axial loads, and two unilateral pedicle screws (placed on the side of the exposure) to restrict flexion and extension deformation around the transverse screws and to provide three-dimensional deformity correction. The horizontal vertebral body and the pedicle screws are connected to rods and then to each other via rigid crosslinking. The transverse vertebral body screws are unloaded during insertion by placing the construct in a compression mode after the interbody bone graft is placed, thus optimizing the advantage gained by the significant “toe-in” configuration provided and further decreasing the chance for instrumentation failure.

The initial results of this technique are reported in a series of 10 consecutively treated patients, in whom correction of the deformity was facilitated. Follow-up examination (average 10.1 months after surgery) demonstrated negligible angulation. Chronic pain was minimal. The crossed-screw fixation technique is biomechanically sound and offers a rapid and safe form of short-segment three-dimensional deformity correction and solid fixation when utilized in conjunction with the lateral extracavitary approach to the unstable thoracic and lumbar spine. This approach also facilitates the secure placement of an interbody bone graft.

KEY WORDS • spinal fusion • screw fixation • bone graft • pedicle fixation • spinal instrumentation
to ventrocaudal–dorsorostral. These two factors significantly limit the size of the screw that may be used in this region. Because the loads placed on the spine remain substantial, the chance for instrument failure increases as screw size is diminished.

To circumvent these problems, a new instrumentation technique, the crossed-screw fixation method, has been developed. The initial clinical results of 11 such procedures performed in 10 patients are presented. This technique facilitates short-segment spinal fixation via the lateral extracavitary approach. This same approach also provides generous exposure for spinal decompression and interbody fusion procedures.

**Clinical Material and Methods**

**Patient Population**

Ten patients with posttraumatic instability of the thoracic or upper lumbar spine were surgically managed during an 8-month period, ending April 15, 1993, at the University of New Mexico Affiliated Hospitals in Albuquerque, New Mexico. The patients’ mean age was 33.6 years (range 16 to 56 years) and seven of the 10 were male. The mean follow-up interval to date has been greater than 12 months in the nine surviving patients. The demographic and outcome data regarding these patients are presented in Table 1.

Spinal stabilization was performed using the crossed-screw fixation technique with an accompanying interbody fusion. Eleven procedures were performed in 10 patients, one patient having simultaneously suffered noncontiguous fractures of T-6 and T-12. Spinal angiography was obtained in each case to ascertain that the side and level of the planned decompression would not jeopardize significant radiculomedullary spinal arteries. All patients underwent lateral extracavitary decompression of the involved spinal segment and subsequent interbody fusion with a rib graft through the same approach.

**Operative Technique**

The patient is placed in the prone position on the operating table, and the lateral extracavitary approach to the spine is performed, as initially described by Larson, et al.,7 with minor modification. Instead of a hockey-stick or flap incision, a paramedian linear incision is made approximately 6 cm from the midline. Surgical exposure medial to the paraspinous muscles is not necessary for the spinal decompression, fusion, or placement of the instrumentation construct. The incision extends from 10 cm above to 10 cm below the level of the spinal pathology.

The lateral exposure of the spine provides access for dural sac decompression and for subsequent interbody fusion (Fig. 1A). A high and medial exposure over the transverse processes and facet joints gains access to the ipsilateral pedicle entrance site. This is accomplished by medial retraction of the paraspinous muscles and is facilitated by the longer-than-usual exposure.

The segmental intercostal nerves are next identified and followed medially to clearly define the neuroforamina and pedicles. Removal of the pedicle at the unstable segment prior to dural sac decompression provides excellent visualization of the sac and nerve root origins. It also allows a clear view of the pedicles to be instrumented at the rostral and caudal ends of the instrumentation construct. Palpation of the medial aspect of each of these pedicles provides a good sense of the three-dimensional anatomy, including the orientation and size of the pedicles.

Anterior decompression of the dural sac is then performed in the usual fashion with removal of the posterior half of the fractured vertebral body (Fig. 1B). Total removal of the fractured vertebral bodies is not necessary because bone remaining in the anterior column does not cause neural compression; in fact, the remaining bone will solidify and assist with load bearing and stability. Bleeding from epidural veins along the opposite side of the dural sac can result from overly vigorous efforts at decompression and can be difficult to control. The goal at this stage is simply to decompress the dural sac.
The crossed-screw fixation technique consists of bone-screw fixation of the vertebrae at the rostral and caudal ends of the fusion construct. A screw is placed in the pedicle and another in the vertebral body of each of the segments to be instrumented. The vertebral body screw is then placed in a transverse orientation through the bone. Each of the pedicles to be instrumented is next entered at its posterior aspect with a high-speed air drill and sounded under direct vision. Because the anterolateral aspect of each vertebral body is exposed, the ventral penetration of the sound can be visualized or palpated. The length of the screw required for precise bicortical purchase can then be assessed by measuring the depth of penetration of the sound. Texas Scottish Rite Hospital (TSRH) variable-angle bone screws (5.5 mm or larger) are then placed, following tapping. The screw tip should be just palpable under the ventral vertebral body cortex. The transverse vertebral body screws are placed (in this case, in the middle column) in a similar manner. The screws are affixed to each other via connecting rods which are tightened to a friction-slide tightness and the spine is distracted. A trough in the anterior column is then made with a high-speed burr (inset) and the ventral interbody bone graft(s), usually rib, are inserted into the slots created. The construct is then compressed to provide for the sharing of the load between the construct and the intrinsic spinal structures and for ensuring security of the bone graft placement. A nearly horizontal trajectory is used for the transverse screws. The screw length is determined by one or a combination of the following means: 1) direct measurement of the vertebral body width at the interbody decompression site (taking into account the greater width of the vertebral body at the endplate compared to the midvertebral body region); 2) measurement of the depth of sound penetration; and 3) measurement of the vertebral body width from the computerized tomography scans. Sounding of the vertebral body can also be performed under fluoroscopic guidance with measurements taken from the sound. A TSRH variable-angle screw 6.5 mm or greater in diameter is then inserted into each site, following tapping. Two rods...
of appropriate length are secured to the screws with one or two crosslink eyebolts placed on each rod (Fig. 1C). The screw eyebolts are tightened to a friction-slide tightness and the construct is distracted.

At this point, manipulation of the rods and screws is accomplished to correct a major spinal deformation, if such reduction is necessary. If an angular sagittal plane deformity is present, distraction or compression of either the anterior or the posterior rod can be performed to achieve reduction. For translational deformities in the sagittal plane, the two rods are manipulated simultaneously using either pliers or in situ rod manipulators to provide reduction by means of a parallelogram effect. Correction of coronal plane translational deformation is accomplished after first completely loosening the variable-angle eyebolts on the transverse screws so that rotation can occur on the radially grooved surfaces of the eyebolt and screw. The rod is then positioned with the in situ manipulators until satisfactory alignment is obtained, then the eyebolts are tightened to maintain the alignment. In cases presenting with angular deformity in the coronal plane, simply adjusting the amount of compression on the anterior rod after placement of the bone graft will usually provide satisfactory correction.

A trough for the interbody bone graft is made with a high-speed burr (Fig. 1C inset). The bone graft, usually two equal-length pieces of rib removed during the surgical approach, is inserted into the trough. The implant is then manipulated to compress the construct across the graft site. Final adjustments are made for deformity correction; this provides for significant security of the bone graft placement and for sharing the anticipated load between the bone graft, the vertebral bodies, and the instrumentation construct. Intraoperative radiographs are obtained at this point to confirm satisfactory spinal alignment. Finally, the crosslinks are placed and the entire system is tightened (Fig. 1D).

Results

The crossed-screw fixation technique was utilized during surgical procedures performed on 10 patients to decompress, realign, and stabilize the spine. One patient (Case 6), who suffered fractures at T-6 and T-12, underwent this procedure at two levels during a single operation. For this study, the operation was considered as two procedures and the operative time and blood loss totals for the operation were divided by two, because of the extensive surgical exposure needed for these two widely spaced fractures.

At admission, three of the 10 patients were neurologically intact, five had neurological deficits with some preservation of function, and two had complete myelopathies. Postoperatively, no patient’s condition had worsened. Improvement in neurological function was observed in three of the five patients with neurological deficits. One of the patients has been lost to follow-up study, and one died from a presumed pulmonary embolism 7 weeks postoperatively. The death occurred at an out-of-state rehabilitation hospital, and no autopsy was obtained.

A learning curve for the technique was observed during the period under study. The operative time (incision to dressing) for the first five procedures (mean 395 minutes) was greater than for the following five procedures (mean 271 minutes).

The median blood loss for the 11 procedures was 1750 cc (range 800 to 8000 cc). One patient lost 8 L of blood, which was attributed in part to improperly positioned chest rolls resulting in abdominal venous pressure. Excluding this patient, the average blood loss was 1690 cc per procedure. Subjective results such as patient discomfort and postoperative pain are difficult to measure; nonetheless, the crossed-screw fixation method compares quite favorably with the more traditional treatments for such patients.
Crossed-screw fixation for the unstable spine

Radiographic Results

Postoperative x-ray films showed satisfactory results in all cases. The crossed-screw fixation technique provided excellent reduction of all significant angular and translational deformities. Follow-up x-ray films for the patient with two fractures (Case 6) are depicted in Fig. 2. Preoperative angular deformities of 10° or more (range 10° to 22°) in the sagittal plane were observed in five patients, and all but one of these deformities were reduced to less than 5°. The remaining deformity was 22° in the sagittal plane in a patient with a T-10 fracture, in whom the postreduction angle was 12°. The remaining patients in this series demonstrated insignificant or no spinal deformation.

No deformity was worsened by the surgical procedure. There has been no measurable loss of correction during the follow-up period. No instances of instrumentation failure or radiographic suggestion of pseudoarthrosis have been observed.

Complications

The most frequent complication observed to date has been the need for tube thoracostomy. Pleural space decompression with tube thoracostomy was required in four of the 10 patients. Three patients were known to have had a pleural effusion or hemotorax preoperatively, and one patient had undergone tube thoracostomy placement prior to surgery. None had intraoperative pleural violation. Given the severity and the level of the spinal injuries suffered in these patients, it is not surprising that pleural effusions and hemotorax were frequently encountered. No wound infections were observed in this series. One death, as described, occurred during the rehabilitation phase.

Discussion

Rationale for the Crossed-Screw Fixation Technique

Short-segment fixation of the unstable thoracic and lumbar spine is rapidly becoming the treatment of choice by many surgeons in a variety of clinical circumstances. Pedicle fixation is the most common technique utilized; however, in the upper lumbar spine and above, pedicle morphology causes increasingly greater difficulty regarding the successful and safe performance of pedicle fixation. Compounding the problem are the paraspinal visceral and vascular structures, the presence of the spinal cord (instead of the cauda equina), and the smaller size of the vertebral bodies. Finally, the anterolateral and anterior exposure of the spine necessitates a different approach to the spine than is employed for the decompression if pedicle fixation is the construct type of choice (namely, dorsal midline exposure).

The lateral extracavitary exposure of the spine provides access for decompression, interbody fusion, and dorsal instrumentation placement through the same incision. This approach is unique compared to all other operative approaches for the ventral decompression of the dural sac. Ventral decompression techniques provide adequate access to dural sac decompression and interbody fusion, but not for posterior instrumentation.

Ventral plating techniques for the thoracic and lumbar spine are fraught with complications, including screw fracture, vascular injury, and difficulty of placement in the thoracolumbar and upper-thoracic regions. The limited distance between vertebral body sites of penetration (interscrew distance) by the screws of most ventral plating techniques is biomechanically inferior for ensuring construct security. Conversely, the nearly 90° crossing angle of the screws used with the crossed-screw fixation technique minimizes the chance of screw pullout (Fig. 3). Indeed, the rigid crosslinks bind together all four screws, securing them in the crossed configuration, thus enhancing the triangulated placement of the screws. The lateral extracavitary approach to the spine, combined with the crossed-screw fixation technique, allows excellent positioning of the implant regarding the prevention of vascular and other visceral injury (LP Brown, et al., unpublished data). The direct visualization of the extravertebral implant components intraoperatively (and their relationship to extravertebral structures) further ensures the safety of the crossed-screw fixation technique.

Surgical Indications

Surgical indications in this series included spinal instability resulting from penetrating and nonpenetrating trauma. In each case, the lateral extracavitary approach to dural sac decompression and interbody fusion was complemented by the utilization of the crossed-screw fixation technique. The exposure facilitated both the ease and speed of the operation and the security of the fusion and fixation obtained. The crossed-screw fixation technique, therefore, may be an appropriate alternative to more traditional techniques whenever a lateral extracavitary operative decompression and interbody fusion is planned and short-segment spinal fixation is desired.

Biomechanical Principles

The use of large ventral screws in the crossed-screw fixation technique facilitates the axial load-bearing capabi-
ties of the construct, while the pedicle screws limit movement in the sagittal plane (that is, in flexion or extension they inhibit pivoting about the ventral screws). Because the strength of a rigid round beam of a buttress is proportional to the third power of the radius of the beam, even a slightly larger screw provides a significant increase in strength. Multiple smaller screws are much less effective than fewer larger screws. The construct is only as strong as its weakest link (usually the screw–rod junction). As screws seldom fail simultaneously, other techniques may provide less axial load-resisting ability than constructs with fewer but larger screws; hence, the requirement for only one vertebral body screw at each end of the crossed-screw fixation construct. Placement of the ventral rod in the compression mode also creates load sharing with the bone graft and greatly reduces the load borne by the implant.

The strength (resistance to failure) of a screw is proportional to the third power of its least diameter. A 7.5-mm screw is nearly four times stronger than a 5.5-mm screw; an 8.5-mm screw is nearly eight times stronger than a 5.5-mm screw. The significance of this difference cannot be overemphasized. This principle is effectively used in the crossed-screw fixation technique.

The rigid buttress nature (cantilever beam with a fixed-moment arm) of the ventral screw portion of the construct eliminates the need for bilateral pedicle screw placement. All that is required of the pedicle screws is the prevention of pivoting around the ventral screw. Therefore, unilateral placement, performed safely under direct vision, suffices.

The crosslinking of the two screw systems (those of the pedicles and the vertebral bodies) virtually ensures that pullout will not occur. Triangulation has been shown to afford significant improvement in resistance to pullout. The angular relationship of the two screws is such that, with the known biomechanical advantages of crosslinking, bone failure is unlikely. Crosslinking also adds substantially to the rotational and translational stability of the construct by maintaining the orientation of the screws at approximately a 90° angle to each other.

Load Sharing and Load Bearing

The distraction of the construct (and hence the spine) prior to bone-graft placement and the subsequent compression of the construct (and hence the spine) following bone-graft placement both secure the bone graft in its bed and allow the sharing of the load between the ventral bone structures and the instrumentation construct. If distraction alone is used, the construct will bear the entire anticipated axial load (preloading). This distraction dictates that excessive stresses will be placed on the construct, which in turn relates to the high incidence of construct failure associated with short-segment fixation techniques. These principles have been clinically documented.

Conclusions

The crossed-screw fixation technique is theoretically sound, offers a rapid and safe form of short-segment fixation when used in conjunction with the lateral extracavitary approach to the unstable thoracic and lumbar spine, and facilitates the secure placement of an interbody bone graft. The initial clinical results have borne out the theoretical advantages of this new method.

References


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### TABLE 1

**Clinical summary of 10 patients with posttraumatic instability of the thoracic and lumbar spine***

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Site &amp; Type of Injury</th>
<th>Procedure</th>
<th>Neurological Status</th>
<th>Complication</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31, F T-10, GSW†</td>
<td>T9–11 CSF</td>
<td>intact (7)</td>
<td>intact (7)</td>
<td>pleural effusion, required chest tube</td>
</tr>
<tr>
<td>2</td>
<td>56, F T-12, burst Fx</td>
<td>T11–L1 CSF</td>
<td>intact (7)</td>
<td>intact (7)</td>
<td>pleural effusion, required chest tube</td>
</tr>
<tr>
<td>3</td>
<td>28, M L-1, burst Fx</td>
<td>T12–L2 CSF</td>
<td>complete myelopathy (1)</td>
<td>unchanged (1)</td>
<td>none</td>
</tr>
<tr>
<td>4</td>
<td>42, M L-1, burst Fx</td>
<td>T12–L2 CSF</td>
<td>LE motor 1/5 (3)</td>
<td>unchanged (3)</td>
<td>none</td>
</tr>
<tr>
<td>5</td>
<td>16, M L-1, burst Fx</td>
<td>T12–L2 CSF</td>
<td>intact (7)</td>
<td>intact (7)</td>
<td>introp blood loss 8000 cc</td>
</tr>
<tr>
<td>6</td>
<td>38, F T-6 &amp; T-12, burst Fx</td>
<td>T5–7 &amp; T11–L1</td>
<td>hyperreflexia &amp; bilat LE motor 4/5 (6)</td>
<td>intact (7)</td>
<td>pleural effusion, preop chest tube</td>
</tr>
<tr>
<td>7</td>
<td>29, M T-6, burst Fx</td>
<td>T5–7 CSF</td>
<td>motor 0/5, trace sensory (2)</td>
<td>unchanged (2)</td>
<td>pleural effusion, required chest tube</td>
</tr>
<tr>
<td>8</td>
<td>32, M L-1, burst Fx</td>
<td>T12–L2 CSF</td>
<td>neurogenic bladder, otherwise intact (6)</td>
<td>unchanged (6)</td>
<td>pleural effusion, no Rx required, resolved by hosp discharge</td>
</tr>
<tr>
<td>9</td>
<td>26, M T11–12, dislocation</td>
<td>T11–12 CSF</td>
<td>complete myelopathy (1)</td>
<td>unchanged (1)</td>
<td>none</td>
</tr>
<tr>
<td>10</td>
<td>38, M L-1, burst Fx</td>
<td>T12–L2 CSF</td>
<td>rt LE 0/5, lt LE 1/5 (3)</td>
<td>bilat LE motor 4/5, ambulatory (6)</td>
<td>none</td>
</tr>
</tbody>
</table>

*GSW = gunshot wound; CSF = crossed-screw fixation; Fx = fracture; LE = lower extremity; Rx = treatment.
†Numbers in parentheses denote functional grade as described by Benzol and Larson.²