Biomechanical Analysis of Pedicle Screw Fixation for Thoracolumbar Burst Fractures

Matthew McDonnell, MD; Kalpit N. Shah, MD; David J. Paller, MS; Nikhil A. Thakur, MD; Sarath Koruprolu, MS; Mark A. Palumbo, MD; Alan H. Daniels, MD

Abstract

Treatment of unstable thoracolumbar burst fractures remains controversial. Long-segment pedicle screw constructs may be stiffer and impart greater forces on adjacent segments compared with short-segment constructs, which may affect clinical performance and long-term outcome. The purpose of this study was to biomechanically evaluate long-segment posterior pedicle screw fixation (LSPF) vs short-segment posterior pedicle screw fixation (SSPF) for unstable burst fractures. Six unembalmed human thoracolumbar spine specimens (T10-L4) were used. Following intact testing, a simulated L1 burst fracture was created and sequentially stabilized using 5.5-mm titanium polyaxial pedicle screws and rods for 4 different constructs: SSPF (1 level above and below), SSPF+L1 (pedicle screw at fractured level), LSPF (2 levels above and below), and LSPF+L1 (pedicle screw at fractured level). Each fixation construct was tested in flexion-extension, lateral bending, and axial rotation; range of motion was also recorded. Two-way repeated-measures analysis of variance was performed to identify differences between treatment groups and functional noninstrumented spine. Short-segment posterior pedicle screw fixation did not achieve stability seen in an intact spine (P<.01), whereas LSPF constructs were significantly stiffer than SSPF constructs and demonstrated more stiffness than an intact spine (P<.01). Pedicle screws at the fracture level did not improve either SSPF or LSPF construct stability (P>.1). Long-segment posterior pedicle screw fixation constructs were not associated with increased adjacent segment motion. Although the sample size of 6 specimens was small, this study may help guide clinical decisions regarding burst fracture stabilization. [Orthopedics. 2016; 39(3):e514-e518.]

The authors are from the Department of Orthopaedic Surgery (MM), Rutgers University Robert Wood Johnson Medical School, Somerset, New Jersey; the Department of Orthopaedic Surgery (KNS, DJP, SK, MAP, AHD), Warren Alpert Medical School of Brown University and Rhode Island Hospital, Providence, Rhode Island; and the Department of Orthopaedic Surgery (NAT), Upstate Orthopedics, State University of New York, East Syracuse, New York.

Dr McDonnell has received nonfinancial support from DePuy Spine. Dr Shah has received nonfinancial support from DePuy Spine. Mr Paller has received nonfinancial support from DePuy Spine. Dr Thakur is a paid consultant for Stryker and has received nonfinancial support from DePuy Spine. Mr Koruprolu has received nonfinancial support from DePuy Spine. Mr Palumbo is a paid consultant for Stryker Spine, has received fellowship support from Globus Medical, and has received nonfinancial support from DePuy Spine. Dr Daniels has received personal fees from Stryker Spine and Osseus and nonfinancial support from DePuy Spine.

Correspondence should be addressed to: Alan H. Daniels, MD, Department of Orthopaedic Surgery, Warren Alpert Medical School of Brown University and Rhode Island Hospital, 2 Dudley St, Providence, RI 02905 (alandanielsmd@gmail.com).

Received: April 8, 2015; Accepted: November 18, 2015.

doi: 10.3928/01477447-20160427-09

Treatment methods for unstable thoracolumbar burst fractures remain controversial. Surgical stabilization options include anterior, posterior, and combined anteroposterior instrumentation. Posterior-only pedicle screw instrumentation has become increasingly popular.1 Pedicle screw constructs provide stable 3-column support and allow for fracture reduction and reversal of deformity.2 Short-segment posterior pedicle screw fixation (SSPF) has been used in an effort to preserve motion segments and involves placement of pedicle screws 1 level above and 1 level below the fracture site.3,4 Several studies have compared the use of long-segment posterior pedicle screw fixation (LSPF) and posterior-only pedicle screw fixation (SSPF) in the treatment of thoracolumbar burst fractures.5-8 While LSPF constructs have been shown to be stiffer than SSPF constructs,9 these studies did not evaluate the impact on adjacent segments, which may affect clinical performance and long-term outcome. The purpose of this study was to biomechanically evaluate LSPF vs SSPF for unstable burst fractures.
eral studies have reported high failure rates and subsequent progressive kyphosis associated with loss of fixation after SSPF due to instrumentation failure, osteoporosis, and inadequate points of fixation.5-7

Long-segment posterior pedicle screw fixation (LSPF) constructs may impart greater fracture stability and have proven reliable and effective for treating these injuries, but at the cost of sacrificing motion segments. In addition, it is unclear how these constructs of variable length affect adjacent or nearby segments. Longer constructs have been shown to be associated with increased adjacent segment range of motion (ROM) and intradiskal pressure in both the cervical and thoracolumbar spine. These biomechanical effects are believed to hasten degeneration of the adjacent motion segment.8,9

To compensate for the less stable fixation of short-segment constructs, several authors have advocated the use of SSPF with the addition of pedicle screw fixation at the fractured vertebral level.10-12 Insertion of pedicle screws at the level of the fracture provides additional fixation points through the posterior column. Although studies have demonstrated modest improvements in construct stability, long-term maintenance of deformity correction has demonstrated mixed results.10-12 No previous study has compared the biomechanical stability or adjacent segment pressure of LSPF constructs to SSPF constructs using pedicle screws at the level of the fracture. The hypotheses for the current study were: (1) SSPF constructs would be less stiff and have decreased adjacent level ROM compared with LSPF constructs, and (2) introduction of pedicle screws into the fractured vertebral level would increase the stiffness of either construct.

**MATERIALS AND METHODS**

Six unembalmed human thoracolumbar spine specimens from a commercial tissue bank (T10-L4; mean age, 64.8 years [range, 57-71 years]) were used for this investigation. Institutional review board approval was not required for this study. All muscle tissue was removed and care was taken to preserve all ligamentous structures and intervertebral disks. Specimens were screened fluoroscopically for gross anatomical defects and scanned using dual-energy x-ray absorptiometry (DEXA) prior to testing (mean bone mineral density, 1.045 g/cm²). The cephalad and caudal ends of the spine segments (T10 and L4) were rigidly embedded using a urethane potting compound (Smooth-On Inc, Easton, Pennsylvania).

A custom apparatus applied pure moments about 3 principal anatomic axes with a biaxial servohydraulic load frame (Instron Corp, Norwood, Massachusetts). Light-emitting diode (LED) flags were rigidly installed on each vertebral body, and the motion of each vertebra was tracked with an optoelectronic camera (Optotrak 3020; NDI, Waterloo, Ontario, Canada). Intact spines were tested in flexion-extension, lateral bending, and axial rotation, and ROM of each vertebral segment was measured.

Following intact testing, a burst fracture was simulated by resecting the inferior half of the L1 vertebral body and L1-L2 disk10 (Figure 1). The fractured spine was stabilized sequentially using 5.5-mm titanium polyaxial pedicle screws and rods (DePuy Spine, Raynham, Massachusetts) for 4 different constructs: SSPF (1 level above and 1 level below), SSPF+L1 (pedicle screw at fractured level), LSPF (2 levels above and 2 levels below), and LSPF+L1 (pedicle screw at fractured level) (Figure 2).

Each experimental group was tested in flexion-extension, lateral bending, and axial rotation, and ROM was recorded. A 2-way repeated measures analysis of variance (ANOVA) was performed using SigmaStat (Systat Software Inc, San Jose, California) to identify differences between treatment groups and functional spinal level. Significance was set at P<.05 a priori.

**RESULTS**

Total ROM (T10-L4) in flexion-extension was 34.2°±8.2° for intact specimens, 38.7°±10.2° for SSPF,
22.8°±6.1° for LSPF, 37.2°±6.6° for SSPF+L1, and 21.6°±3.4° for LSPF+L1 (P<.01) (Figure 3). Lateral bending ROM was 37.3°±10.2° for intact specimens, 34.9°±5.4° for SSPF, 20.5°±3.1° for LSPF, 32.9°±8.6° for SSPF+L1, and 18.9°±4.0° for LSPF+L1 (P<.01). Axial rotation ROM was 21°±4.8° for intact specimens, 29.9°±6.3° for SSPF, 22.0°±4.0° for LSPF, 25.3°±5.0° for SSPF+L1, and 18.4°±3.7° for LSPF+L1 (P<.01). Intact specimens had greater ROM in all modes compared with the treatment constructs. SSPF and SSPF+L1 constructs had significantly more total spine ROM compared with LSPF and LSPF+L1 for all test modes (P<.01) (Figure 3).

The LSPF and LSPF+L1 constructs were significantly stiffer than intact specimens in both flexion-extension and lateral bending (P<.002) (Figures 4A-B). The SSPF construct was significantly less stiff compared with intact specimens in axial rotation (P<.001) (Figure 4C).

At the T11-T12 and L2-L3 levels, SSPF treatments were significantly less stiff compared with LSPF groups in lateral bending, flexion-extension, and axial rotation (P<.05) (Figure 5). At the T11-T12 and T12-L1 level, both LSPF treatments were significantly stiffer than intact specimens for lateral bending (P<.03). At the fractured L1-L2 level, LSPF constructs were stiffer (P<.02) than the SSPF constructs in flexion-extension. There were no statistically significant differences between SSPF and SSPF+L1 (P>.105), and between LSPF and LSPF+L1 (P>.290) in total spine stiffness for axial rotation, lateral bending, and flexion-extension (Figure 3).

No significant differences were reported for ROM at the cephalad and caudal adjacent levels between treatment groups (Figure 5).

**Discussion**

The results of this biomechanical investigation provide insight into the immediate postoperative stability of short-segment and long-segment posterior pedicle screw fixation constructs for fixation of thoracolumbar burst fractures. Stabilization of simulated thoracolumbar burst fractures with SSPF resulted in a construct that was less stiff than an intact spine, whereas LSPF resulted in a construct that was stiffer than the intact spine. The addition of fracture segment pedicle screws did not change the ROM or the stiffness of the constructs.
Increasing the biomechanical stability of a short-segment posterior pedicle screw fixation construct may improve outcomes of SSPF and reduce failure rates. The addition of crosslinks is one potential method of increasing stiffness of pedicle screw constructs. Wahba et al. demonstrated increased stiffness in axial rotation of short-segment pedicle screw constructs with the addition of crosslinks. However, none of the short-segment constructs restored stability to the preinjury intact spine level.

Other authors have advocated the use of SSPF with the addition of pedicle screws at the level of the fracture to improve the construct stability. Mahar et al. performed a cadaveric biomechanical study comparing SSPF constructs with and without pedicle screw fixation at the fractured level. The authors concluded that the addition of screws into the fractured level improved construct stiffness in axial rotation but not flexion-extension or lateral bending. The same authors also performed a retrospective radiographic review of patients treated by this method. The 12 patients treated by this method demonstrated the ability to achieve 15° of kyphotic deformity correction and vertebral height restoration. However, no comparison was made to patients treated by SSPF alone. Of the 9 patients for whom follow-up data were available, only 1 patient had failure of fixation.

A prospective randomized study by Guven et al. evaluated 72 patients treated by LSPF and SSPF both with and without the addition of pedicle screws at the fractured level with an average follow-up of 50 months. The authors concluded that intraoperative kyphotic deformity correction was lowest for patients treated with SSPF. At follow-up, the SSPF group was less likely to maintain correction compared with LSPF constructs or SSPF constructs with screws at the fractured level. In addition, the authors found that anterior vertebral height restoration was significantly lower for patients treated with SSPF alone compared with SSPF with screws at the fractured level or LSPF constructs with and without additional fracture level screws. The current study provides a potential explanation for these clinical results given the demonstration of decreased stiffness of short-construct fixation compared with long-construct fixation.

Another retrospective review of 25 patients treated with SSPF and placement of pedicle screws at the burst fracture level reported a high rate of failure of kyphosis correction and an 8% reoperation rate due to either hardware failure or pseudarthrosis. Despite the loss of deformity correction, the study population showed an overall improvement in clinical pain and disability at long-term follow-up.

In contrast to previous studies that have shown the placement of pedicle screws into fractured vertebra may improve biomechanical stability, the current study did not demonstrate a significant increase in stiffness. In fact, there was no difference noted in total spine ROM between SSPF and SSPF+L1 constructs. Although a pedicle screw at the level of the fractured vertebra may help with reduction of the fracture and possibly with maintaining sagittal alignment, no biomechanical advantage to the screw was found in the current model. In addition, neither of the SSPF constructs restored the stability of an intact spine. The impaired stiffness of short constructs is consistent with higher failure rates seen clinically with SSPF constructs and the inability to maintain long-term kyphotic deformity correction. Surgeons should be cautious using SSPF constructs, particularly in patients with osteoporosis who may already be at increased risk of construct failure.

In this study, LSPF resulted in a construct that was stiffer compared with SSPF. LSPF also resulted in decreased total ROM compared with intact specimens. Adjacent-segment degeneration after long-segment fixation or fusion may be influenced by the increased moment arm created by fixation of several contiguous spinal segments due to increased stress on the cranial and caudal-adjacent intervertebral disks and facet joints. Markers used to experimentally measure for adjacent-level stress include range of motion and intradiscal pressure. The current authors hypothesized that LSPF would be associated with increased adjacent segment ROM as has been demonstrated in prior studies.

No significant differences were found in adjacent segment motion between LSPF and SSPF constructs. This finding challenges the theory that longer segment constructs lead to increased adjacent segment motion and hasten degenerative disk disease. Although motion segments are lost by extending the construct, it may not necessarily lead to hastened degeneration of adjacent levels. Further studies to evaluate adjacent segment disk pressure following fixation with long and short constructs.
would help to indirectly estimate differences in load fluctuations delivered to the anterior column and further characterize the risk for hastened adjacent segment degeneration with longer segment constructs. Future clinical study will help determine the rate of adjacent segment degeneration following burst fracture fixation.

The current study was limited by the inability to maintain soft tissues and prevent biologic decomposition of specimens long enough to perform prolonged cyclical loading or test to failure. Desiccation of the intervertebral disk after freezing and thawing may have had an additional effect on intradiskal pressure data, although biomechanical cadaver studies commonly use frozen samples.

Another potential limitation of this study was the corpectomy model used to simulate a burst fracture. The model has been described previously by Mahar et al. to recreate a similar injury pattern and represents complete loss and destabilization of the anterior and middle columns. Although the model does not perfectly mimic the in vivo fracture, this method does create a reliably reproducible injury compared with other previously described techniques. It represents a worst-case clinical scenario resulting in complete lack of anterior or middle column support. Furthermore, the contribution of muscles and soft tissue as well as the effects of fracture healing to spinal stability could not be assessed by the current study. Finally, the small sample size was another limitation of this study; a larger sample size than 6 specimens may allow for further statistical confidence in the findings. Despite these limitations, the current investigation provides important data regarding the biomechanical behavior of pedicle screw construct fixation for burst fracture treatment.

Future research considerations include prospective, randomized studies to elicit clinical differences seen in patients who receive instrumentation at the level of the fractured vertebra compared with those who do not. Given that LSPF is a longer moment arm, it would be worthwhile to evaluate the risk of developing adjacent segment disease in this population.

**CONCLUSION**

This study evaluated the biomechanical characteristics of short- and long-segment pedicle screw constructs both with and without introduction of screws at the fractured vertebral level in a human cadaveric unstable thoracolumbar burst fracture model. SSPF did not achieve baseline stability compared with the intact spine. LSPF constructs were significantly stiffer than SSPF constructs and demonstrated more stiffness than an intact spine. Introduction of pedicle screws at the level of the fracture did not improve either SSPF or LSPF construct stability. LSPF constructs were not associated with increased adjacent segment motion but may fall prey to cyclic loading and potentially place patients at risk for adjacent segment degeneration. Although the sample size of 6 specimens was small, this study may help guide clinical decisions regarding burst fracture stabilization.

**REFERENCES**


