Biomechanical efficacy of monoaxial or polyaxial pedicle screw and additional screw insertion at the level of fracture, in lumbar burst fracture: An experimental study

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Abstract

Background: Use of a pedicle screw at the level of fracture, also known as an intermediate screw, has been shown to improve clinical results in managing lumbar fracture, but there is a paucity of biomechanical studies to support the claim. The aim of this study was to evaluate the effect of adding intermediate pedicle screws at the level of a fracture on the stiffness of a short-segment pedicle fixation using monoaxial or polyaxial screws and to compare the strength of monoaxial and polyaxial screws in the calf spine fracture model.

Materials and Methods: Flexibility of 12 fresh-frozen calf lumbar spine specimens was evaluated in all planes. An unstable burst fracture model was created at the level of L3 by the pre-injury and dropped-mass technique. The specimens were randomly divided into monoaxial pedicle screw (MPS) and polyaxial pedicle screw (PPS) groups. Flexibility was retested without and with intermediate screws (MPSi and PPSi) placed at the level of fracture in addition to standard screws placed at L2 and L4.

Results: The addition of intermediate screws significantly increased the stability of the constructs, as measured by a decreased range of motion (ROM) in flexion, extension, and lateral bending in both MPS and PPS groups ($P < 0.05$). There was neither any significant difference in the ROM in the spines of the two groups before injury, nor a difference in the ROM between the MPSi and PPSi groups ($P > 0.05$), but there was a significant difference between MPS and PPS in flexion and extension in the short-segment fixation group ($P < 0.05$).

Conclusions: The addition of intermediate screws at the level of a burst fracture significantly increased the stability of short-segment pedicle screw fixation in both the MPS and PPS groups. However, in short-segment fixation group, monoaxial pedicle screw exhibited more stability in flexion and extension than the polyaxial pedicle screw.

Key words: Monoaxial or polyaxial, pedicular screw, lumbar spine, burst fracture, intermediate screw at fracture level

Introduction

Posterior transpedicular pedicle screw fixation is widely used for obtaining internal fixation for management of the unstable spine mainly caused by trauma, and burst fractures comprise 10–20% of such injuries.[1] The aims of surgery in these fracture cases include decompression of the neural components, fracture reduction, and providing a stable fixation until arthrodesis is achieved. Transpedicular short-segment fixation became popular after the introduction of transpedicular screws by Roy-Camille[2,3] and the internal fixator by Dick.[4] This approach includes pedicle screw fixation one vertebra above and one vertebra below the fracture. Short-segment spinal instrumentation has been beneficial in the management of thoracolumbar spinal fractures for better correction of kyphotic deformity, greater initial stability, early painless mobilization, and indirect decompression of the spinal canal.[5-7] Despite the advantages of this approach, it is also associated with loss of reduction and instrumentation failure in some cases.[4-9] In an attempt to achieve stiffer short-segment constructs, some surgeons add pedicle screws at the fractured vertebra. These screws can be termed "intermediate screws."

According to several biomechanical and clinical studies,

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monoaxial or polyaxial pedicle screws inserted at the level of fractured vertebrae, along with the segmental fixation of burst fractures, improved biomechanical stability of the construct.[10-12] In the past 20 years, the design and implantation techniques of the pedicle screw systems have been modified to reduce the rate of pedicle screw breakage and to facilitate easy application of the connecting rod without undue stress on the construct.[13-16] The polyaxial head coupling of the pedicle screw was found to reduce the compression bending strength at the screw–rod mount, in comparison with a monoaxial screw design.[15,16]

Based on research findings, use of the intermediate screw in conjunction with short-segment fixation for fracture reduction and kyphosis correction carries the additional advantages of construct stabilization, lordosis restoration, and preventing screw breakage.[10] However, there have been few reports regarding short-segment fixation, which have compared the biomechanical performance of polyaxial versus monoaxial pedicle screws with or without an intermediate screw at the fractured vertebra. This study utilized a calf experimental model of an unstable burst fracture to compare the stiffness of a short-segment pedicle fixation using either monoaxial or polyaxial pedicle screws placed at the level of fracture.

Materials and Methods

Specimen preparation

Twelve fresh-frozen calf lumbar specimens (L1–L5) were obtained from a regional slaughterhouse. All specimens were wrapped in doubled plastic bags and stored frozen at −20°C. Before biomechanical testing, the specimens were thawed at room temperature in a humidity-controlled environment for 8 h. The soft tissues were removed by dissection, leaving the ligaments, facet joint capsules, and intervertebral discs intact. The end vertebrae were trimmed, fixed with plain screws, and embedded in liquid self-curing denture base material and denture base resin (Type II). Each pot included a 10-mm screw secured to a metal plate that was incorporated in the resin cast. This screw was located at the level of the middle column of the vertebrae and was used as an anchor for the testing machine. The resin was left to cure for 30 min. To avoid the influence of air exposure on biomechanical behavior, all specimens were kept moist during the tests by spraying them with saline solution. Handling experimental material routinely used in *in vitro* biomechanical investigation in this manner, does not alter the material characteristics of the bone and soft tissues.

Creation of an experimental fracture

After the intact spine was tested for flexibility, an unstable burst fracture was created in the L3 vertebra using the pre-injury and the dropped-mass technique. A 2-mm drill bit was used to create holes in the L3 vertebral body with V-shaped corpectomy [Figure 1]. After the pre-injury model had been created, the specimen was mounted through its pots on a ferric base. The specimen was flexed to approximately 10° and a 10-kg weight was dropped from a height of 0.5 m on a vertical rail, and then from 0.6, 0.7, 0.8 m, and so on, until the V-shaped cut closed. After the creation of the L3 vertebral fracture, it was ensured that the pedicle remained intact for further experimentation.

Grouping and testing protocol

The specimens were randomly divided into monoaxial pedicle screw (MPS) group and polyaxial pedicle screw (PPS) group by random digits table, and six calves were allocated in each group. Two kinds of spinal fixations (i.e., with or without intermediate screw placement) were studied in each group [Figure 1]. After a fracture was created, a short-segment posterior pedicle screw construct was used to realign and stabilize the spine. The specimens in the MPS group were fixated with monoaxial pedicle screws, and polyaxial pedicle screws were used for those in the PPS group. Short-segment pedicle screw devices were used in this study. The specimens in which an intermediate screw was not applied received a 4-screw (monoaxial or polyaxial) construct incorporating one vertebra above and one vertebra below the fracture. The remaining specimens (MPSi and PPSi) underwent a 6-screw construct in which two intermediate screws were added to the fractured vertebrae in addition to the 4-screw construct described above [Figure 2]. The intermediate screws were of the same length and were inserted to the same depth as the other four screws. We reused the same specimens in MPS group and MPSi group, PPS group and PPSi group in order to standardize the procedure and avoid any difference amongst the specimens in the same group. A flowchart depicting testing sequence is provided in Figure 3.

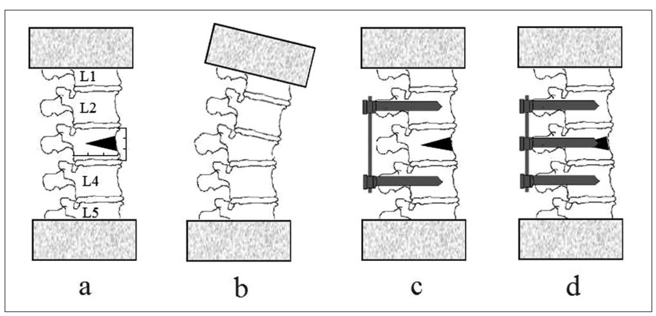

Figure 1: A line diagram of the specimens in the MPS and PPS groups showing. (a) The V-shaped corpectomy of the L3 vertebra; (b) the dropped-mass technique used after osteotomy to simulate an unstable burst fracture of the L3 vertebra; (c) short-segment pedicle screw construct involving transpedicular fixation of vertebrae one above and one below the fracture site; (d) use of an intermediate screw at the level of the fractured vertebra to test improvement in stability of the construct

Biomechanical test

Each specimen was tested for flexion, extension, lateral bending, and axial rotation as an intact spine, as a fractured spine, and as a fractured spine fixed by either a 4-screw or 6-screw construct. All specimens were subjected to 0–500 N flexion and axial compression in a displacement-controlled mode at a rate of 5 mm/min on an MTS858 (Material Testing System, MTS) testing machine. The MTS858 testing machine is used to make the specimen move in the mode of flexion, extension, lateral bending, and axial rotation. The ranges of motion (ROMs) of the relative intervertebral motions were automatically recorded by the Eagle-4 and Motion Analysis position capture and measurement system (Micron Company, California, USA). The camera system recorded the movements of infrared LED markers attached to each of the levels, L2–L4. A digitizing probe was used to locate landmarks on each vertebra from which local coordinate systems were established. The local coordinate systems were aligned to the primary anatomic planes (sagittal, coronal, and axial). The relations of the superior vertebral local coordinate system with respect to the inferior vertebral coordinate system were quantified with Euler angle transformations. These transformations were calculated to determine the ROM. ROM was defined as the change in angular position relative to the origin. Subsequent transformations were then used to determine the ROM of L2–L4.

Statistical analysis

The ROMs calculated for the 4- and 6-screw constructs were then compared with the values obtained for the intact and fractured specimens. Because the 4- and 6-screw construct results in the MPS or PPS group were compared for the same specimen, paired Student's *t*-test was used for statistical analyses, using SPSS 15.0 statistical software (SPSS/PC, Chicago, IL, USA). Biomechanical data were evaluated using a general linear model procedure for analysis of variance (ANOVA) and the Student Newman–Keuls *post hoc* test in each group (MPS or PPS). The differences in ROM between the two groups were evaluated with independent *t*-tests. The differences in ROM within the same group were evaluated with paired *t*-tests. A *P*-value <0.05 was considered significant.

Results

The ROM results for L2–L4 in all directions for the MPS and PPS groups are summarized in Table 1. The addition of an intermediate screw decreased the ROM of the L2–L4 segments in both the MPS and PPS groups. A smaller ROM due to the use of an intermediate screw represents

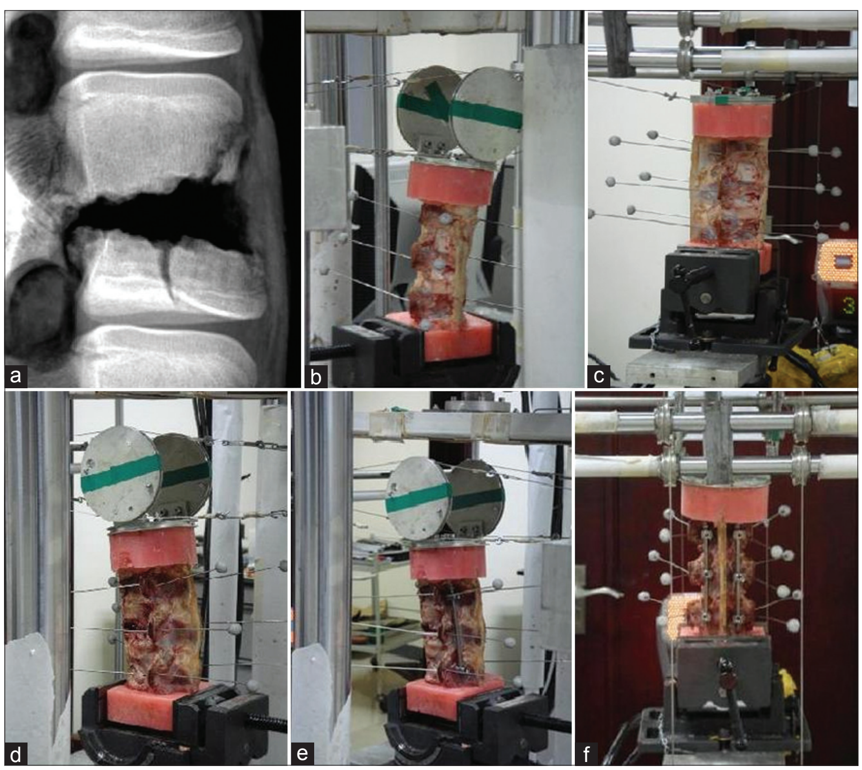

Figure 2: X-ray film and photographs. (a) The film showing the burst fracture of vertebral body and the preservation of the anterior longitudinal ligament; (b) mechanical testing for lateral bending (intact specimen); (c) mechanical testing for axial rotation (intact specimen); (d) mechanical testing for flexion and extension (fracture specimen); (e) mechanical testing for flexion and extension (short-segment fixation specimen); (f) mechanical testing for flexion and extension (intermediate screw fixation specimen)

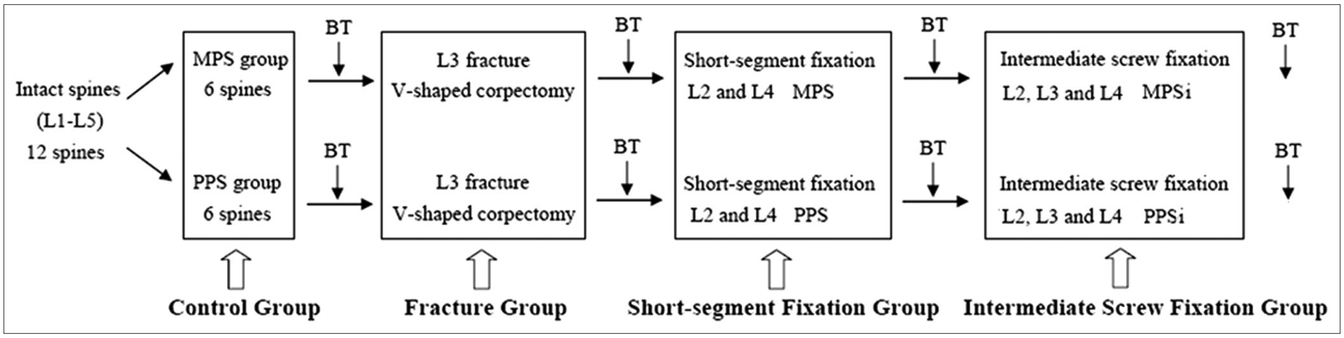

Figure 3: Flow chart showing the sequence of events for each specimen. BT = Biomechanical testing; MPS = Monoaxial pedicle screw; PPS = Polyaxial pedicle screw; MPSi = Monoaxial pedicle screws with intermediate pedicle screws fixation; PPSi = Polyaxial pedicle screws with intermediate pedicle screws fixation

Table 1: ROM in various planes of the intact, fracture model, and postinternal fixation spine within the same group (n = 6; °; mean ± standard deviation)

Groups (*n*)	Flexion	Extension	Lateral bending	Axial rotation
Control (intact)				
MPS (6)	3.71 ± 0.60	3.01 ± 0.72	7.27 ± 0.85	1.33 ± 0.54
PPS (6)	3.29 ± 0.52	3.00 ± 0.65	7.35 ± 1.16	1.27 ± 0.64
t	1.279	0.026	−0.145	0.182
P	0.230	0.980	0.887	0.859
Fracture				
MPS (6)	9.34 ± 0.73	8.74 ± 1.08	14.96 ± 1.23	9.27 ± 0.53
PPS (6)	9.67 ± 0.92	8.93 ± 0.72	15.45 ± 0.61	9.20 ± 0.63
t	−0.680	−0.348	−0.875	0.217
P	0.612	0.142	0.160	0.470
SSF				
MPS (6)	2.20 ± 0.55	1.93 ± 0.37	1.76 ± 0.55	5.27 ± 0.81
PPS (6)	4.19 ± 0.81	3.99 ± 0.74	2.47 ± 0.64	5.83 ± 0.86
t	−4.992	−6.134	−2.081	−1.169
P	0.001	0.000	0.064	0.270
ISF				
MPSi (6)	1.34 ± 0.45	1.24 ± 0.31	1.21 ± 0.24	3.13 ± 0.69
PPSi (6)	1.87 ± 0.56	1.43 ± 0.49	1.55 ± 0.30	2.65 ± 0.52
t	−1.786	−0.813	−2.147	1.352
P	0.104	0.435	0.057	0.206

SSF = Short-segment fixation, ISF = Intermediate screw fixation

enhanced stability of the construct, in contrast to a larger ROM that was observed in the standard short-segment construct. Compared to the short-segment transpedicular fixation group, the addition of intermediate screws provided a smaller ROM in flexion, extension, lateral bending, and torsion in the MPS group ($P = 0.001$, 0.006, 0.077, and 0.000, respectively), and in flexion, extension, lateral bending, and torsion in the PPS group ($P = 0.000$, 0.000, 0.017, 0.000, respectively). There was neither a difference in the ROM in the spines of the two groups before injury, nor a difference in ROM between the MPSi and PPSi groups ($P > 0.05$). However, when using the intermediate screw in injured spines, the stiffness in the MPSi and PPSi groups increased significantly as compared with the intact spine ($P < 0.05$). There was a significant difference between MPS and PPS in flexion ($P < 0.01$) and extension ($P < 0.05$) [Figure 4].

Discussion

Management options for unstable burst fractures include anterior, posterior, or combined (circumferential) fixation. Many surgeons believe that anterior column reconstruction is critical in correcting kyphotic deformity and reestablishing the anterior load bearing capacity of the vertebral component. Short-segment posterior spinal instrumentation using pedicle screws remains the standard method for the fixation of thoracic and lumbar fractures, with acceptable results. The advantages of this technique include less surgical dissection, blood loss, and time in surgery, and as a result, decreased perioperative morbidity. However, loss of reduction and instrumentation failure associated with this technique is well described in the literature.[1,5-9] These failures have been attributed to poor bone quality, inadequate anterior column support, and insufficient points of fixation.

The biomechanical properties of monoaxial pedicle screws have been widely reported.[17-20] Segmental fixation with additional monoaxial pedicle screws at the level of the fracture increases construct stiffness and shields the fractured vertebral body from anterior loads. Furthermore, this additional point of fixation allows for a 3-point reduction maneuver, analogous to that used for reduction of long bone fractures. In a recent prospective randomized study, the efficacy of the fracture-level screw combination in achieving and maintaining correction for the treatment of unstable thoracolumbar burst fractures was evaluated.[21] The authors of that study concluded that reinforcement with a fracture-level screw could help provide and maintain improved kyphosis correction. It also offered immediate spinal stability in patients with thoracolumbar burst fracture. Another mid-term clinical study demonstrated superior results with the fracture-level screw combination, supporting the evidence of other reports.[22] Interestingly, in most of these studies, the pedicle screws used were monoaxial, despite the current trend toward using polyaxial screws in short-segment fracture fixation.[10-12,21] On review of the literature, we found that there was a paucity of data, both

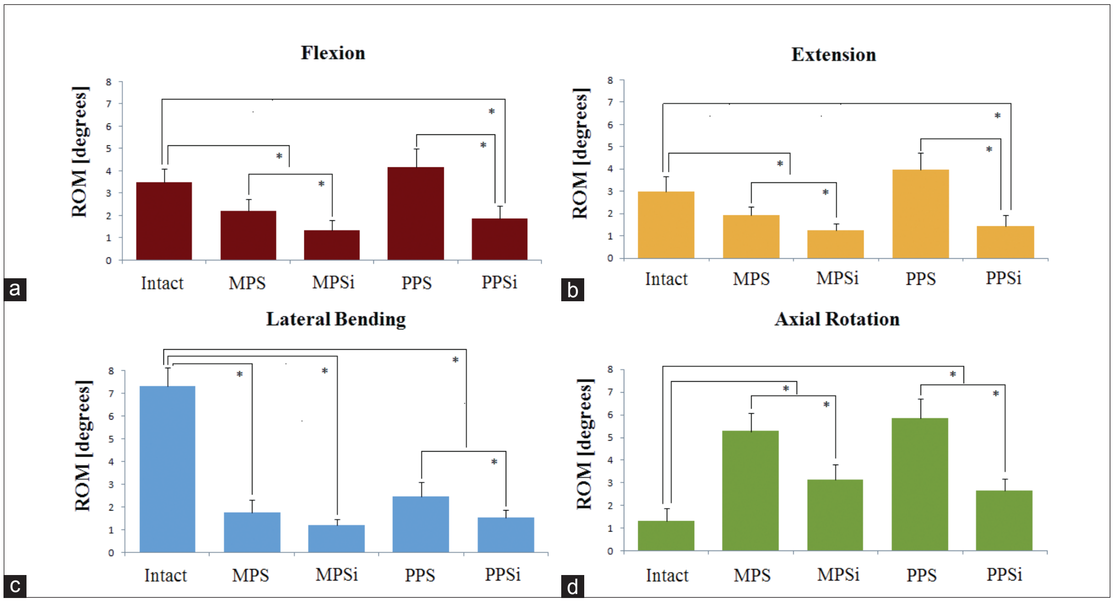

Figure 4: Bar graphs showing the ROM compared with intact spine for (a) flexion, (b) extension, (c) lateral bending, and (d) axial rotation loading. MPS = Monoaxial pedicle screw; PPS = Polyaxial pedicle screw; MPSi = Monoaxial pedicle screws with intermediate pedicle screws fixation; PPSi = Polyaxial pedicle screws with intermediate pedicle screws fixation. **P*, 0.05 for significant difference between groups

clinical and biomechanical, on the use of polyaxial screw as an intermediate in unstable burst fractures, and thus this biomechanical study was instituted.

The current study showed that when short-segment constructs contained intermediate screws, flexion, extension, and torsion decreased in both the MPSi and PPSi groups, compared to the respective constructs (MPS and PPS) without this reinforcement. Lateral bending also decreased in the PPSi group. Without intermediate screws, the short-segment construct in the PPS group had significantly greater ROM in flexion and extension when compared with the MPS group. However, there were no significant differences between the MPSi and PPSi groups. The addition of intermediate screws at the level of a burst fracture significantly increased the stiffness of the short-segment pedicle fixation, irrespective of whether monoaxial or polyaxial pedicle screws were used. However, this increase was more significant for the MPSi construct, as the PPSi already had significantly increased stiffness as compared to the MPSi. These results may be because there is a better coupling between the polyaxial screw heads and the connecting rod. Thus, there is less torsion at the coupling site and consequently less stress on the entire construct. The intermediate screw provides a 3-point fixation of the fractured segment. When using monoaxial screws, the addition of an intermediate forces the surgeon to bend the connecting rod to accommodate the additional screw. Polyaxial screws, on the other hand, facilitate the installation of the connecting rod, and their biomechanical properties have been reported in several studies.[14-16,23] Stanford *et al.*[15] suggested that the rod–screw link design of the polyaxial screw reduces its static compressive bending yield strength as compared with the fixed screw designs. Liu *et al.*[24] pointed out that there were significant differences between the monoaxial screws and polyaxial screws in the bending stiffness, yield load, yield torque, and torsional stiffness in static tests ($P < 0.05$). Shepard *et al.*[16] suggested that polyaxial screws do not significantly decrease the stiffness of the construct. On the contrary, the polyaxial constructs create more security by permitting better contact and holding strength between the screw head and the rod. When there is the combined effect of bending loads and shear force on the rods, there would be higher resistance to rotational slippage between the rod and the screw head.

The limitations of study are that the data were pertinent to results immediately after surgery, but do not take into account early bone resorption or the cyclical loading effect which have long-term impacts on outcome. The flexibility of the construct was tested on a burst fracture model that was created in a controlled and reproducible manner by the pre-injury and dropped-mass technique. Nevertheless, the pattern and nature of a spinal burst fracture in clinic is more variable and unpredictable. Anekstein *et al.*[12] hypothesized that the true mechanical effect of the intermediate screws is less predictable in *in vivo* settings. Only a prospective clinical study can show the true practical significance of the addition of intermediate screws.

We used, a model of fresh-frozen calf spines. Although not human, calf spine has been used before as a valid biomechanical model.[25-27] Calf is a tetrapod; its anatomical characteristics and common fracture site are different from those of the human, and because the calf lumbar spines (L1–L5) can be easily dissected from the other vertebrae of calf, we chose the L1–L5 calf lumbar spines and made the L3 vertebral fracture instead of the T12 or L1 which are the most common fracture sites in humans. Calf spine segments are presumed to have higher bone mineral density than human spines, and therefore have different biomechanical behavior. This difference may influence the results of any biomechanical study. Nevertheless, the use of an animal model allows for smaller inter-specimen differences, as the human spine has been shown to have significant variability in bone mineral density that might potentially affect the test results.[28,29] As this study is comparative, the authors favored the animal model to that of the human cadaver spine. It can be argued that the number of cases in each group was less in the present study to reach a meaningful conclusion. However, in the previous biomechanical studies,[18,30,31] the number of the cases used in the experiment was usually six or seven. In the present study, we used 12 cases and 6 cases in each group and we believe that these numbers have brought forward meaningful results. Another disadvantage of this study is that there was no comparison with long-segment fixations and application of the cross link, which have been shown to have better biomechanical stability than the short segment in managing unstable burst fractures.

In conclusion, the addition of intermediate screws at the level of a burst fracture significantly increases the stability of a short-segment pedicle fixation, using either monoaxial or polyaxial pedicle screws. However, the short-segment MPS fixation group was significantly more stable in flexion and extension than the short-segment PPS fixation group. We believe that this study provides a biomechanical rationale for using an intermediate screw at the level of fractured vertebrae with posterior short-segment fixation, especially when using monoaxial screws for fixing the unstable burst fractures of the lumbar region.

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