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Spinal Reconstruction Techniques for Traumatic Spinal Injuries: A Systematic Review of Biomechanical Studies

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Abstract

Study Design: Systematic literature review.

Objectives: Many studies have provided evidence that short-segment posterior fixation (SSPF—1 level above and 1 below) with screws at the fracture level (SFL) are enough to achieve stability in some injury patterns, such as burst fractures, avoiding the need for circumferential reconstruction and long-segment instrumented fusion (LSIF—at least 2 levels above and 2 below). Given the potential benefits of avoiding unnecessary fusion in mobile healthy spinal segments, we performed a systematic review of biomechanical studies comparing different spinal reconstruction techniques for fractures of the thoracolumbar spine.

Methods: A systematic literature review was performed in the PubMed and OVID databases of biomechanical studies comparing biomechanical differences between techniques of spine reconstructions.

Results: Eight studies were included and evaluated. Five of 6 studies reported stiffness improvement with SSPF and SFL, even comparable to circumferential fusion for a burst fracture. Two studies reported that LSPF has higher stiffness and restricts range of motion better than SSPF, but inclusion of screws in the fracture level is similar to LSPF (1 study). Finally, although SSPF is less stiff than anterior reconstruction, adding a SFL in SSPF results in similar stiffness than circumferential fusion for unstable burst fractures.

Conclusions: Biomechanical studies analyzed generally suggested that SFL in SSPF may improve construction stiffness, and can even be compared with long-segment fixation or circumferential reconstruction in some scenarios. This construct option may be used to enhance stiffness in selected injury patterns, avoiding the needs of an additional anterior approach.

Keywords
biomechanics, burst fracture, posterior fusion, short segment, long segment, circumferential

Introduction

Traumatic spinal injuries are common and range from nondisplaced low-energy fractures to dangerously unstable distraction injuries with neurologic compromise. Thoracolumbar spine (T10-L2) injuries are the most common and result from the transition from the rigid and fixed thoracic spine to the mobile and dynamic lumbar spine.[1] Panjabi and White[2] described spinal stability as the ability to withstand a physiologic load without progressive deformity or neurologic compromise. While stable injuries have been shown to have improved long-term outcomes with nonoperative treatment, surgical stabilization is necessary in the setting of spinal instability to prevent such deformity and neurologic risk.[3] Currently, pedicle screws are the most common form of spinal fixation to reestablish stability given the ability to instrument all 3 columns with minimal posterior approach–related risk.[4] Short-segment fixation (1 level above and below) offers the advantage of

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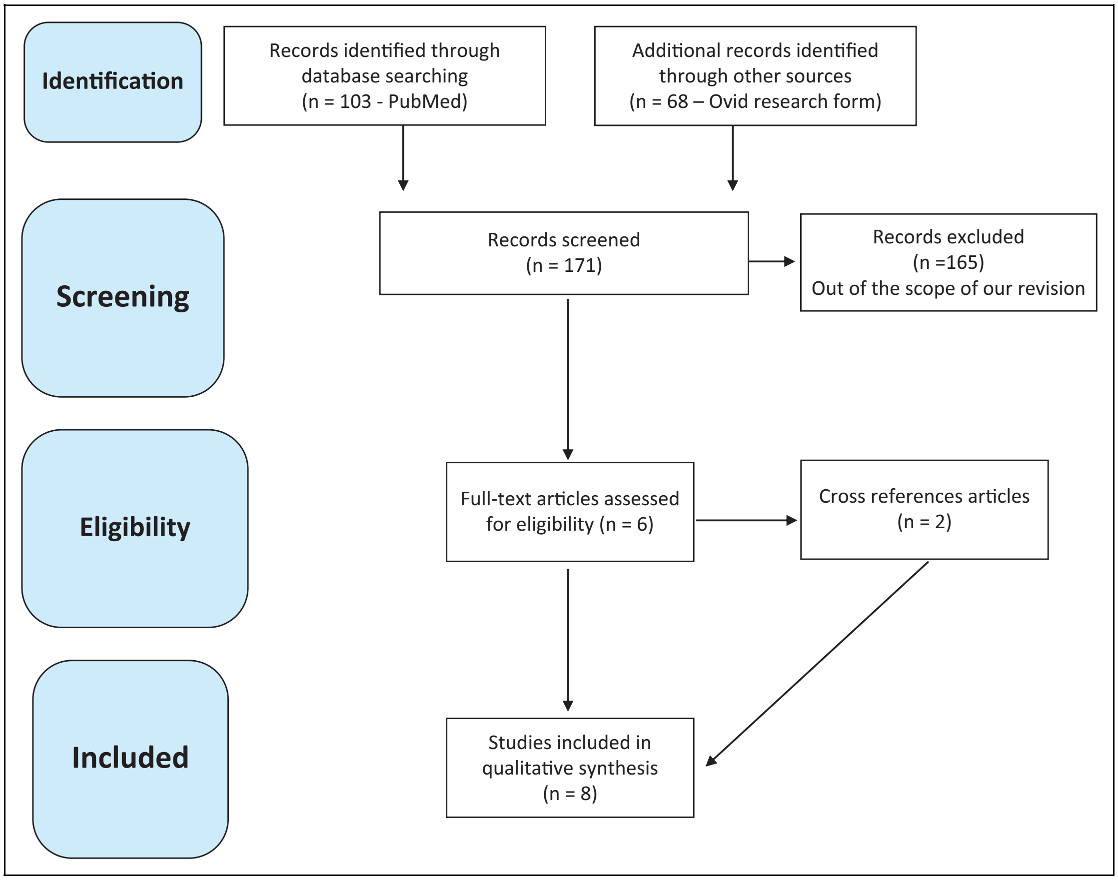

Figure 1. Flowchart of our search mechanism.

sparing motion segments and minimizing impact forces at adjacent segments, but may not provide sufficient fixation for spinal stability, especially in severely unstable injuries. As an alternative, circumferential reconstruction, long constructs (at least 2 levels above and 2 levels below the unstable segment), and screw insertion at the fracture level may provide a stronger and stiffer construction.

For spinal trauma specifically, many studies have provided evidence that short posterior fixation with screws at the fracture level are enough to achieve stability in some injury patterns, such as burst fractures, avoiding the need for circumferential reconstruction and long-segment instrumented fusion.[5] Biomechanical and computational model studies are important because they provide foundational knowledge that precedes clinical studies and motivate future investigations. Given the potential benefits of avoiding unnecessary fusion in mobile healthy spinal segments, we performed a systematic review of biomechanical studies comparing different spinal reconstruction techniques for fractures of the thoracolumbar spine, in an attempt to evaluate if a short fixation may be used in some fracture patterns.

Methods

A systematic literature review was performed in the PubMed Database on October 22, 2017. The following MeSH terms and key words were used: Short [All Fields] AND long [All Fields] AND posterior [All Fields] AND (“spine” [MeSH Terms] OR “spine” [All Fields]) AND (“fractures, bone” [MeSH Terms] OR (“fractures” [All Fields] AND “bone” [All Fields]) OR “bone fractures” [All Fields] OR “fractures” [All Fields]).

Additional searches were performed using the OVID database (January 31, 2018). The following key words were used: fracture, biomechanical, short, and long.

Inclusion criteria were the following: experimental studies comparing the biomechanical differences (such as restriction of range of motion and construction stiffness) between techniques of spine reconstructions, studies investigating the thoracolumbar spine, and studies investigating traumatic conditions. Exclusion criteria were the following: clinical articles, non-English language, studies investigating the cervical spine, and studies investigating nontraumatic conditions.

A total of 171 papers had their title and abstract reviewed by the authors, and 8 were selected and fully included according to the purpose of our review (2 cross-referenced articles and 6 obtained in the main search). A flowchart according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for systematic review of our search mechanism is included (Figure 1).

Results

Two computational biomechanical analysis studies,[6,7] 3 biomechanical studies using human spine specimens,[8-10] 2 studies using fresh-frozen bovine spine specimens,[11,12] and 1 study using fresh-frozen porcine spine specimens[13] are included in this analysis. Tables 1 and 2 illustrate the summary of the 8 studies and their significant results. Figure 2 illustrates different biomechanical scenarios in burst fractures.

Computational Biomechanical Analysis

Elmasry et al[6] performed a 3-dimensional (3D) finite element analysis from T11 to L4 constructed from computed tomography scans of the Visible Human Project. The models were used to simulate the mechanical behavior of 4 different fixation constructs and compared with a baseline intact spine.

The model consisted of 6 vertebrae with their vertebral discs, facet joints, and major ligaments. Material properties for all model constituents of the spine were taken from the literature. Burst fracture was simulated in L1 by removing the anterior and middle spinal columns areas, including the anterior longitudinal ligaments at T12-L1 and L1-2. Additionally, a laminectomy model was performed removing the spinous process, as well as the disrupted supraspinous, interspinous, posterior, and flavum ligaments. The 4 simulated fixation techniques were

1. Pedicle screws at T12-L2 (1 level above and 1 level below)—short-segment posterior fixation (SSPF)
2. Pedicle screws at T12-L2 (1 level above and 1 level below, including screw at the fracture level)—short-segment posterior fixation including screws at the fracture level (SSPFI)
3. Pedicle screws at T12-L2 (2 levels above and 2 levels below)—long-segment posterior fixation (LSPF)
4. Pedicle screws at T12-L2 (2 levels above and 2 levels below including screw at the fracture level)—long-segment posterior fixation (LSPFI)

Models underwent experimental conditions with fixing the inferior endplate of L4 in all directions and loading with a pure moment of 7.5 N·m about the 3 anatomical axes to induce flexion, extension, axial, and lateral bending with a frequency of 0.25 Hz. Mechanical performance was evaluated according to the (*a*) stiffness of the thoracolumbar junction (T12-L2) and (*b*) magnitude and distribution of intradiscal pressure at adjacent intervertebral disc (T12-L1 and L1-2).

For all 4 constructions, the stiffness of the thoracolumbar junction was higher than the intact spine. Long-segment fixations were stiffer than short-segment for most loading conditions and SSPFI had higher stiffness than SSPF, especially in flexion (23%). Of note, LSPF was stiffer than LSPFI in flexion (14%) and extension (5%), although they had the same stiffness in axial and lateral bending. The inclusion of the fracture level tends to a more uniform distribution of the stress along the T12-L1 and L1-2 segments of the posterior rods. The authors concluded that long constructions are stiffer than short ones, and the inclusion of the fracture level increased the stiffness of the short construction by 25%, 13%, 7.5%, and 6.8% in flexion, extension, axial bending, and lateral bending, respectively. Additionally, including the fracture level in the short-segment construct increased the intradiscal pressure at adjacent intervertebral discs, providing greater stability and more support to the anterior column.

On the other hand, the inclusion of the fracture level in long construction produced only minor changes in the value of the stiffness. LSPF was even stiffer than LSPFI and this was attributed to the fact of the 4 versus 5 points of fixation, whereas the additional point of fixation at L1 may act like a pivot point and force the middle segments to bend. Additional points of fixation allow a more uniform stress distribution through the rods.

Hübner et al[7] performed a computational study with numerical simulation (using ANSYS program) with a 3D modeling of a computed tomography scan of the thoracolumbar spine of a man (80 kg and 1.80 m, without previous spinal disease). Dicom images were treated by InVensalius software. The objective of the study was to evaluate the strength of the implants in short (1 level above and below and also the fracture level—T12-L1-2) (SSPF) versus long (2 levels above and below—T11-12-L2-3) posterior fixation (LSPF). The properties of the tissues were estimated using previously published data. The fracture vertebra was simulated by high Poisson's ratio and low modulus of elasticity according to previous published biomechanical data. The numerical analysis of the maximum stress obtained for long fixation (at L2 vertebra with 230 MPa) and short fixation (at T12 with 274.24 MPa) were similar. Authors concluded that, considering the strength of the titanium alloy, the short fixation had similar strength to the long fixation.

Biomechanical Analysis: Fresh-Frozen Bovine Spine Specimens

Sait et al[11] performed a biomechanical study to evaluate the stability of short-segment posterior fixation including the fractured level (SSPFI) to circumferential fixation (CF) in thoracolumbar burst fractures. They created an unstable burst fracture at the L1 vertebra by drop-weight method in 10 fresh-frozen bovine thoracolumbar spine specimens and divided them into 2 groups: group A—specimens received SSPI (1 level above, the fracture level, and 1 level below) and group B—circumferential fixation was performed (an anterior cage held in position under compression using posterior pedicle screws 1 level above and 1 level below). Using Universal Testing Device and stereophotogrammetry, range of motion (ROM) and load-displacement curves were recorded.

In group A (SSPFI), ROM reduced by 46.9% in flexion, 52% in extension, 49.3% in lateral flexion, and 45.5% in axial rotation. Construct stiffness increased by 77.8%, 59.8%, 67.8%, and 258.9% in flexion, extension, lateral flexion, and axial rotation, respectively.

In group B (CF), ROM reduced by 58.1% in flexion, 46.5% in extension, 66.6% in lateral flexion, and 32.6% in axial

Table 1. Eight Studies Comparing the Biomechanical Analysis of Different Spinal Reconstruction Techniques.

Study (Year)	Methods	Comparison	Results
Elmasry et al (2017)[6]	Computational biomechanical analysis	Pedicle 1 level above and 1 below the fracture (SSPF) Pedicle 1 level above and 1 below the fracture, including screws at the fracture level (SSPFI) Pedicle 2 levels above and 2 below the fracture (LSPF) Pedicle 2 levels above and 2 below the fracture, including screws at the fracture level (LSPFI)	– For all 4 constructions, the stiffness of the thoracolumbar junction was higher than the intact spine. – Long-segment fixations were stiffer than short-segment ones for most loading conditions and SSPFI had higher stiffness than SSPF, especially in flexion (23%). – Inclusion of the fracture level tends to a more uniform distribution of the stress along the T12-L1 and L1-2 segments of the posterior rods. – Inclusion of the fracture level in long construction produced only minor changes in the value of stiffness – LSPF was stiffer than LSPFI—this was attributed to the fact that in long fixation, the intermediate screw may act like a pivot point.
Hübner et al (2015)[7]	Computational biomechanical analysis	Pedicle 1 level above and 1 below the fracture (SSPF) Pedicle 2 levels above and 2 below the fracture (LSPF)	– Authors concluded that, considering the strength of the titanium alloy, the short-segment fixation had similar strength to the long-segment fixation.
Sait et al (2016)[11]	Biomechanical analysis—fresh-frozen bovine specimens	Pedicle 1 level above and 1 level below, including the fracture level (SSPFI) Circumferential fusion	– Range of motion (ROM) decrease in lateral flexion was greater in circumferential (66.6%) versus SSPFI (49.3%) ($P > .05$). – There were no differences in decrease sagittal-plane ROM and in construct stiffness between the groups after instrumentation. – SSPFI had comparable stiffness to circumferential fusion for unstable burst fractures.
Bolesta et al (2012)[12]	Biomechanical analysis—fresh-frozen bovine specimens	BF1—stable burst fracture BF2—unstable burst fracture (posterior element resection) BF1—without instrumentation BF1—with 1 screw above and 1 below (SSPF) BF1—with 1 screw above and 1 below and screws at the fracture level (SSPFI) BF1—with 2 screws above and 2 below (LSPF) BF2—without instrumentation BF2—with 1 screw above and 1 below (SSPF) BF2—with 1 screw above and 1 below and screws at the fracture level (SSPFI) BF2—with 2 screws above and 2 below (LSPF)	– Both long- and short-segment constructs with screws in the fractured body significantly reduced ROM compared with the stable and unstable burst fractures in flexion-extension and lateral bending. – Screws inserted in the fracture enhanced construct stability by 68% relative to conventional short-segment posterior fixation and were comparable to long-segment posterior fixation. – Insertion of screws in the fracture level improves construct stiffness and this may be an alternative to long-segment constructs.
McDonnell et al (2016)[10]	Biomechanical analysis—human spine	1 level above and below (SSPF) 1 level above and below, including fracture level (SSPF +L1) 2 levels above and below (LSPF) 2 levels above and below, including fracture level (LSPF + L1)	– In comparison with the intact spine, SSPF did not achieve comparable stability, while LSPF constructs demonstrated increased stiffness compared with both. – Pedicle screws at the fracture level did not improve stability in the short- or long-segment constructs. – No significant differences were found in adjacent segment motion between SSPF and LSPF constructs.
Lazaro et al (2011)[9]	Biomechanical analysis—human spine	Four-level fixation plus cross-link Two-level fixation Two-level fixation plus cross-link	

(continued)

Table 1. (continued)

Study (Year)	Methods	Comparison	Results
		Two-level fixation plus screw at the fracture site Two-level fixation plus screws at the fracture site plus cross-link	– The best restriction of ROM was obtained with long-segment fixation during extension and lateral bending compared with short-segment constructs. – Index screws in short-segment constructs significantly reduced ROM during flexion, lateral bending, and axial rotation ($P < .03$) improving stability by an average of 25%. – Adding a cross-link reduced axial rotation significantly ($P = .001$) but did not affect restriction in other loading directions ($P > .4$).
Mahar et al (2007)[8]	Biomechanical analysis—human spine	One level above and below (SSPF) One level above and below, including fracture level (SSPF + L2)	– Stiffness during axial torsion was significantly higher in constructs including the fracture level ($P < .02$), with no difference in lateral bending and flexion/extension. – Disc pressure fluctuations higher during flexion-extension for constructs including the fracture level ($P < .02$), with no difference in axial torsion and lateral bending.
Gurwitz et al (1993)[13]	Biomechanical analysis—fresh frozen porcine specimens	Short posterior fusion (1 above and 1 below)—SSPF SSPF with an anterior strut Anterior instrumentation with an anterior strut	– In comparison with the intact spine, posterior instrumentation alone was an average of 76% less stiff axially, posterior instrumentation with an anterior strut was 3% more stiff (not significantly different from intact), and anterior instrumentation with an anterior strut was 15% more stiff. – Posterior instrumentation alone was an average of 30% less rigid in torsion, posterior instrumentation with an anterior strut was 26% less rigid, and anterior instrumentation with an anterior strut was 24% less rigid than the intact spine. – The average values of torsional rigidity for the three constructs were significantly lower than for the impact spine ($P < .01$)

rotation. Construct stiffness increased by 80.6%, 56.1%, 82.6%, and 121.2% in flexion, extension, lateral flexion, and axial rotation, respectively.

ROM decrease in lateral flexion was greater in group B (66.6%) vs group A (49.3%) ($P > .05$). However, there were no differences in decrease sagittal-plane ROM and in construct stiffness between the groups after instrumentation. They concluded that SSPFI had comparable stiffness to circumferential fusion for unstable burst fractures.

Bolesta et al[12] performed a biomechanical study to evaluate the effect of inserting a pedicle screw in a burst fracture body compared with conventional short and long-segment posterior fixation. Eight freshen-frozen calf thoracolumbar injuries (T12-L5, aged 18 weeks), were used in their study. They were fixed rostrally at T12 and caudally at L5 and tested under a load protocol of 8 N·m. At L2, a burst fracture was created with multiple burr holes in the anterior and lateral cortex. After that, the vertebral bodies were compressed until both anterior and middle columns were disrupted, resulting in a stable burst fracture—BF I. The posterior column was then disrupted with a scalpel, producing an unstable burst fracture—BF II. Spine range of motion was recorded at L1-3 for flexion-extension, lateral bending, and axial rotation in the following scenarios: BF I without instrumentation, with SF (1 screw above and 1 below), with SF plus screws at the fracture (SSPFI), and with long fixation (2 levels above and 2 levels below) (LSPF). The same 4 situations were performed with BF II (short fixation, short fixation with screw fracture, and long fixation). The authors report that both long- and short-segment constructs with screws in the fractured body significantly reduced ROM compared with the stable and unstable burst fracture in flexion-extension and lateral bending. On average, screws inserted in the fracture enhanced construct stability by 68% relative to conventional short-segment posterior fixation and were comparable to long-segment posterior fixation. They concluded that insertion of screws in the fracture level improves construct stiffness and this may be an alternative to long-segment constructs.

Biomechanical Analysis: Human Spine Specimens

Mahar et al[8] conducted a biomechanical study on human cadaveric spine specimens to compare the stability of segmental (including fracture site) versus nonsegmental (not including fracture site) short-segment fixation in an unstable lumbar burst fracture model. Six specimens (L1-L3) were tested in axial

Table 2. Summary of the Main Findings of the Included Studies.

Study (Year)	Summary of Main Findings
Elmasry et al (2017)[6]	Instrumenting the fracture level increased stiffness in short constructs, but longer constructs remained biomechanically superior for TL burst fractures
Hübner et al (2015)[7]	Short and long titanium alloy constructs found to have similar strengths.
Sait et al (2016)[11]	Short segment construction, including the fracture level, had similar construct stiffness to circumferential fusion for unstable burst fracture.
Bolesta et al (2012)[12]	Instrumenting the fracture level improves construct stiffness, and augmentation of a short-segment construct may provide an alternative to long segment fixation.
McDonnell et al (2016)[10]	Long constructs were found to be the most stable and not associated with increased adjacent segment motion, but instrumenting the fracture level did not improve stability in all constructs.
Lazaro et al (2011)[9]	Thoracic long segment fixation significantly improves stability compared to short segment, with instrumentation of the fractured level also increasing stiffness and cross-linking limiting rotation.
Mahar et al (2007)[8]	Instrumenting the fracture level in short segment fixation improves biomechanical stability.
Gurwitz et al (1993)[13]	Anterior instrumentation with anterior strut was found to have increased stiffness compared to posterior fixation with or without anterior strut.

torsion, flexion-extension, and lateral bending using a custom cantilever beam mechanism within a servohydraulic machine, and L1-2 disc pressures were recorded with a needle-type pressure transducer. Following intact testing, a L2 burst fracture was simulated by removing the caudal aspect of the L2 vertebral body and the L2-3 intervertebral disc, and short-segment fixation was performed using 5.5-mm stainless steel polyaxial pedicle screws and rods. The 6 specimens were tested as both experimental and control groups:

1. Non-segmental L1-L3 fixation, not including fracture level
2. Segmental L1-L3 fixation, including fracture level

The authors found that stiffness during axial torsion was significantly higher in constructs including the fracture level ($P < .02$), with no difference in lateral bending and flexion/extension. Disc pressure fluctuations, an indicator of anterior column stability reflecting the counteracting force of L2, were higher during flexion-extension for constructs including the fracture level ($P < .02$), with no difference in axial torsion and lateral bending. The authors also retrospectively reviewed 12 patients with unstable thoracolumbar burst fractures treated with short-segment posterior fixation including the fracture level and posterolateral fusion using iliac crest bone autograft. They concluded that additional fixation at the fracture level may aid in fracture reduction and kyphosis correction, possibly obviating the need for an accompanying anterior construct.

Lazaro et al[9] performed a biomechanical study with 7 human spine segments (5 from T2 to T8 and 2 from T3 to

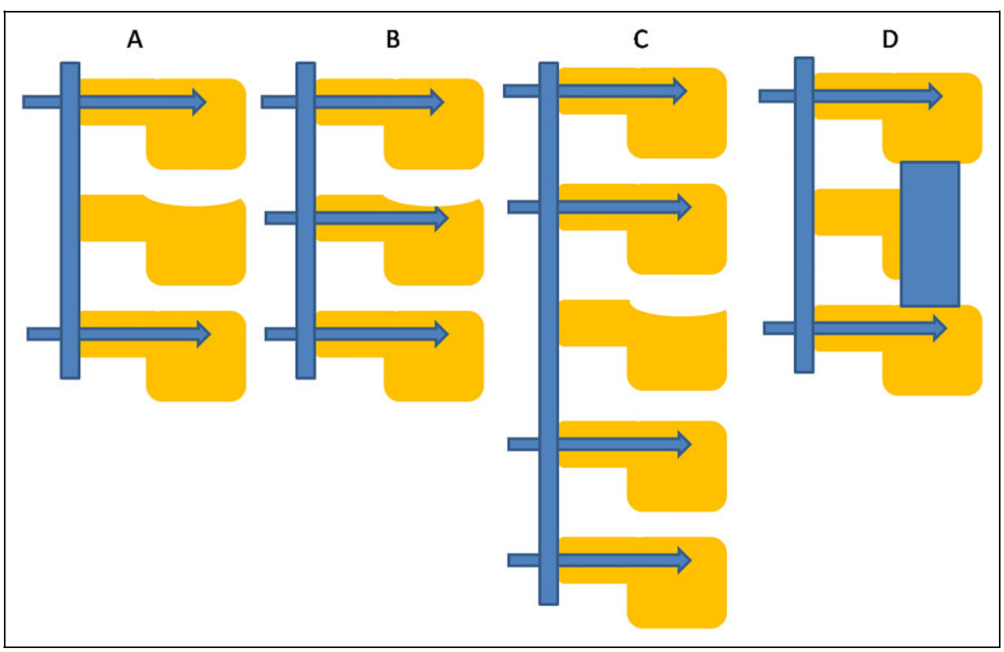

Figure 2. Illustrative examples of (A) short construct (1 level above the fracture and 1 level below), (B) short construct with screws at the fracture level (C) long construct (2 levels above and 2 levels below the fracture, (D) posterior short construction (1 level above and 1 level below) with anterior strut.

T9) to compare the effects of short versus long segments in the thoracic spine. Pure-moment loading of 6 N·m was applied in the spine segments to induce flexion, extension, lateral bending, and axial rotations, with concomitant 3D motion measured optoelectronically. After testing the normal specimens, a wedge fracture was created on the middle vertebra after cutting the spinal posterior elements. Five specific conditions were tested:

Step A—4-level fixation plus cross-link
Step B—2-level fixation
Step C—2-level fixation plus cross-link
Step D—2-level fixation plus screws at the fracture level
Step E—2-level fixation plus screws at the fracture level plus cross-link.

They reported that the best restriction of ROM was obtained with long-segment fixation during extension and lateral bending compared with short-segment constructs. However, index screws in short-segment constructs significantly reduced ROM during flexion, lateral bending, and axial rotation ($P < .03$), improving stability by an average of 25%. Adding a cross-link reduced axial rotation significantly ($P = .001$) but did not affect restriction in other loading directions ($P > .4$).

McDonnell et al[10] also executed a biomechanical study on human spine segments to analyze short- versus long-segment fixation in the treatment of unstable burst fractures. Six specimens from a commercial tissue bank (T10-L4, mean age 64.8 years) were evaluated in flexion-extension, lateral bending, axial rotation, and range of motion using a biaxial servohydraulic load frame and light-emitting diode (LED) flags. Following intact testing, a simulated unstable L1 burst fracture was created and subsequently stabilized using 5.5-mm titanium polyaxial pedicle screws and rods for 4 different constructs:

1. 1 level above and below (SSPF)
2. 1 level above and below, including fracture level (SSPF + L1)
3. 2 levels above and below (LSPF)
4. 2 levels above and below, including fracture level (LSPF + L1).

The authors found that intact specimens had greater ROM than all constructs, and short-segment fixation had significantly greater ROM than long-segment fixation ($P < .01$). They also concluded that short-segment fixation did not achieve the stability of an intact spine, while long-segment fixation exceeded the stiffness of both. Additionally, pedicle screws did not improve either SSPF or LSPF construct stability, and LSPF was not associated with increased adjacent segment motion.

Biomechanical Analysis: Fresh Frozen Porcine Spine Specimens

Gurwitz et al[13] performed a biomechanical study using 6 intact porcine lumbar spines (L1 to L5) to evaluate the axial stiffness and torsional rigidity of different instrumentation procedures. A burst fracture was simulated via corpectomy at L3. Three surgical scenarios were simulated: (1) a posterior instrumentation (VSP screws 7 mm × 40 mm into L2 and L4)—PI, (2) posterior instrumentation with an anterior strut (a wood block)—PIA, and (3) anterior instrumentation with an anterior strut 1 level above and 1 level below the fracture site—AA.

The specimens underwent biomechanical testing with different axial loads. These analyses showed that, in comparison with the intact spine, posterior instrumentation alone was an average of 76% less stiff axially, posterior instrumentation with an anterior strut was 3% more stiff (not significantly different from intact), and anterior instrumentation with an anterior strut was 15% more stiff. Posterior instrumentation alone was an average of 30% less rigid in torsion, posterior instrumentation with an anterior strut was 26% less rigid, and anterior instrumentation with an anterior strut was 24% less rigid than the intact spine. The average values of torsional rigidity for the 3 constructs were significantly lower than for the impact spine ($P < .01$).

Authors did not report any correlation between axial compression and torsional tests. Their model of anterior corpectomy represented the worst-case model for anterior and middle column injury and, in this setting, anterior strut may increase the stiffness of the anterior injured spine.

Discussion

In our review, we found 8 experimental studies comparing different techniques of spinal fixation in the setting of a simulated thoracolumbar spinal trauma. This review identified a number of common findings that may have clinical implications.

Inclusion of Screws at the Fracture Level

As a general result, inclusion of the screws at the fracture level improves overall short-segment construct stiffness in 5 studies that performed this analysis[6,8,9,11,12] and had no effect in 1 study.[10] Sait et al[11] reported that inclusion of screws at the fracture level results in similar comparable stiffness to circumferential fusion for unstable burst fractures. This may be especially useful to decrease the morbidity of an additional anterior approach, especially in patients who do not require an anterior decompression, such as in unstable burst fracture without neurological deficits, despite having significant body comminution.

Sun et al[14] reported the results of 69 patients with thoracolumbar burst fractures treated with SSPF (group A—34 patients, 1 level above and 1 level below with 4 screws) versus SSPFI (group B—35 patients, 1 level above and 1 level below and also screws at the fracture level, i.e., 6 screws). They retrospectively evaluated clinical (visual analog scale [VAS], Oswestry Disability Index [ODI]) and radiological measurements (vertebral wedge angle [VWA] and anterior vertebral height [AVH]). Both groups had similar preoperative characteristics (clinical and radiological). While no differences in the outcome of the 2 groups were documented, SSPF had the advantages of less operative time, blood loss, and hospitalization time. They concluded that SSPF is sufficient to treat burst fractures surgically, regardless of inclusion of the fractured vertebra.

However, Farrokhi et al[15] published a prospective randomized study of 80 patients. They divided patients in 2 groups: group A—SSPF with 42 patients and group B—SSPFI with 38 patients, to evaluate the benefits of included screws at the fracture level. Clinical and radiological outcome was assessed after surgery, with similar baseline characteristics. Group A had a higher rate of failure, with 29% of the patients worsening kyphosis compared with 6% of improvement in kyphosis in group B, especially in Magerl type C injuries (where this effect was most prominent). They recommend SSPFI especially in more unstable injury patterns when short-segment posterior fixation was considered. The differences of Sun et al[14] and Farrokhi et al[15] studies may be attributed to a greater severity of injury patterns in the latter, which may require stronger constructions.

Short-Segment (1 Level Above and Below) Versus Long-Segment (2 Levels Above and Below) Fixation

Elmasty et al[6] and McDonnell et al[10] both report that LSPF has higher stiffness and restricts ROM better than SSPF. However, in the study by Elmasty et al,[6] inclusion of screws at the fracture level in long constructions, paradoxically, decreased stiffness of the fixation, as the intermediate screw was postulated to act like a pivot. Bolesta et al[12] reported that insertion of screws at the fracture level in SSPF may be an alternative to long-segment constructs. This strategy may be used in less unstable scenarios, such as in burst fractures, whereas the LSPF may be used for more unstable scenarios, such as in AO type C fractures, where translation occurs and severe instability is present. Hübner et al[7] reported that, considering the strength of the titanium alloy, in their computational analysis, short fixation had similar strength than the long fixation. This was the only study that did not report the superiority of LSPF over SSPF in restrict motion. This may be due to the fact that computational biomechanical analysis may not reflect real biomechanical studies.

Tezeren and Kuru[16] performed a prospective clinical study with 18 patients with thoracolumbar burst fractures surgically treated divided into 2 groups: group 1 with 9 patients treated with SSPF and group 2, also with 9 patients treated with long fixation (claw hooks attached to second upper vertebra and infralaminar hooks attached to the first upper vertebra and pedicle screws 2 levels below). They reported better radiological outcome in the long fixation group when considering local kyphosis and anterior vertebral height compression ($P < .05$) and less failure rate, even though the long fixation group required a longer operative time and had an increase blood loss. The clinical outcome was similar in both groups. On the other hand, a larger case series evaluated short versus long construction was reported by Dobran et al.[17] Outcome of patients who underwent SSPFI versus those who received LSPF for unstable thoracolumbar junction fractures were compared. A total of 60 patients were divided into 2 groups: group A (SSPFI) with 6 pedicle screws and 30 patients and group B (LSPF) with 8 screws, excluding the fracture level. They measured radiological (local kyphosis angle [LKA], anterior body height [ABH], posterior body height [PBH], ABH/PBH ratio of fractured vertebra), and neurological characteristics (AIS) of both groups. Both groups had similar characteristics regarding age, sex, trauma etiology, fracture level, fracture type, neurologic status, preoperative LKA, ABH, PBH, and ABH/PBH ratio and follow-up ($P > .05$). They reported that posttraumatic kyphosis (assessed with LKA) and restoration of fracture-induced wedge shape of the vertebral body (assessed with ABH, PBH, and ABH/PBH ratio) after surgery were similar in both groups ($P = .234$; $P = 0.754$). The neurological outcome was also similar in both groups. They concluded that SSPFI had similar results than LSPF considering clinical and radiological outcomes. However, SSPFI had the advantages of sparing 2 or more vertebral motion segments. Additionally, the costs of the implants in LSPF are obviously higher than in SSPFI.

Anterior Reconstruction Versus Posterior Fixation

Gurwitz et al[13] compared anterior instrumentation versus SSPF, without adding a screw at the fracture level. They reported that SSPF was less stiff than anterior reconstruction, suggesting that in severe comminuted fractures, anterior reconstruction or SSPFI may be necessary to avoid late kyphosis or hardware failure. However, Sait et al[11] reported that short-segment fixation with a pedicle screw at the fracture site had similar stiffness to circumferential fusion for unstable burst fractures. The only difference was a superior decrease in lateral flexion for circumferential fusion when compared with SSPFI ($P > .05$).

Indeed, clinical context is vital for deciding whether or not to pursue circumferential fusion. McCormack et al[5] reviewed a series of burst fractures treated with short-segment pedicle screw fixation (SSPF) and proposed a classification system based on load sharing in an attempt to predict who would fail with SSPF alone. The proportion of vertebral body damage, spread of fracture fragments, and degree of kyphosis are used to predict failure, suggesting the need for circumferential fusion depending on the circumstances.[5]

SSPFI may be ideally used for unstable burst fractures without neurological deficits. If canal decompression via a posterior approach requires removing the pedicle of at least one side, this may preclude pedicle screw fixation at the fracture level and necessitate long-segment fixation. For more unstable injuries, such as spinal dislocations, long fusions may be a better option due to severe instability.

In a clinical meta-analysis performed by Xu et al,[18] the results of 4 randomized trials and three controlled clinical trials comparing the results of the anterior versus posterior approach for thoracolumbar burst fractures were reported. A total of 179 patients underwent anterior approach versus 152 patients posterior approach and they had no differences between the groups in terms of neurological outcome, return to work, or Cobb angle. However, patients who underwent an anterior approach had longer operative time, greater blood loss, and higher costs than those treated by a posterior approach. In this clinical context, performing short-segment fixation with an instrumented fracture level may avoid the need of a circumferential approach in some selected cases.

Limitations of The Current Analysis

Experimental studies may not reflect the clinical scenarios of real traumatic human spine injuries. This must be taken into consideration when interpreting the results obtained in this systematic review. Additionally, we included two computational biomechanical analyses, which may be even less reproducible than biomechanical studies using animals or human spine specimens. However, this review updates the information obtained in experimental studies that may provide useful information for future clinical trials evaluating the different techniques of spinal reconstruction.

Potential difficulties in planning clinical studies based on experimental models may be attributed to methodological differences in patient selection (such as different injuries patterns—burst fractures vs spinal dislocations, bone quality, etc) and study designed (outcome measurements used, retrospective versus prospective, etc). Thus, such a small group of heterogeneous studies may have limited clinical impact, but further demonstrates the need for high quality future clinical and biomechanical spine studies. Finally, only 3 of the 8 evaluated studies included human spine specimens. For this reason, extreme caution is necessary in extrapolating the results to the human spine, especially in the clinical context.

Conclusions

Our systematic review of experimental studies found that inserting screws at the fracture level in short-segment fixation may improve construction stiffness, and may even be compared with long-segment fixation or circumferential reconstruction in some scenarios, such as unstable thoracolumbar burst fractures. This construct option may be used to enhance stiffness in selected injury patterns, avoiding the needs of an additional anterior approach.

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References

1. Wood KB, Li W, Lebl DS, Ploumis A. Management of thoracolumbar spine fractures. *Spine J*. 2014;14:145-164.
2. Panjabi MM, White AA 3rd. Basic biomechanics of the spine. *Neurosurgery*. 1980;7:76-93.
3. Wood KB, Buttermann GR, Phukan R, et al. Operative compared with nonoperative treatment of a thoracolumbar burst fracture without neurological deficit: a prospective randomized study with follow-up at sixteen to twenty-two years. *J Bone Joint Surg Am*. 2015;97:3-9.
4. Cheng LM, Wang JJ, Zeng ZL, et al. Pedicle screw fixation for traumatic fractures of the thoracic and lumbar spine. *Cochrane Database Syst Rev*. 2013;5:CD009073.
5. McCormack T, Karaikovic E, Gaines RW. The load sharing classification for spine fractures. *Spine (Phila Pa 1976)*. 1994;19:1741-1744.
6. Elmasry S, Asfour S, Travascio F. Effectiveness of pedicle screw inclusion at the fracture level in short-segment fixation constructs for the treatment of thoracolumbar burst fractures: a computational biomechanics analysis. *Comput Methods Biomech Biomed Eng*. 2017;20:1412-1420.
7. Hübner AR, Gasparin D, de Meira Junior AD, et al. Numerical analysis of multi-level versus short instrumentation for the treatment of thoracolumbar fractures. *Eur J Orthop Surg Traumatol*. 2015;25(suppl 1):S213-S217.
8. Mahar A, Kim C, Wedemeyer M, et al. Short-segment fixation of lumbar burst fractures using pedicle fixation at the level of the fracture. *Spine (Phila Pa 1976)*. 2007;32:1503-1507.
9. Lazaro BC, Deniz FE, Brasiliense LB, et al. Biomechanics of thoracic short versus long fixation after 3-column injury. *J Neurosurg Spine*. 2011;14:226-234.
10. McDonnell M, Shah KN, Paller DJ, et al. Biomechanical analysis of pedicle screw fixation for thoracolumbar burst fractures. *Orthopedics*. 2016;39:e514-e518.
11. Sait A, Prabhav NR, Sekharappa V, Rajan R, Raj NA, David KS. Biomechanical comparison of short-segment posterior fixation including the fractured level and circumferential fixation for unstable burst fractures of the lumbar spine in a calf spine model. *J Neurosurg Spine*. 2016;25:602-609.
12. Bolesta MJ, Caron T, Chinthakunta SR, Vazifeh PN, Khalil S. Pedicle screw instrumentation of thoracolumbar burst fractures: biomechanical evaluation of screw configuration with pedicle screws at the level of the fracture. *Int J Spine Surg*. 2012;6:200-205.
13. Gurwitz GS, Dawson JM, McNamara MJ, Federspiel CF, Spengler DM. Biomechanical analysis of three surgical approaches for lumbar burst fractures using short-segment instrumentation. *Spine (Phila Pa 1976)*. 1993;18:977-982.
14. Sun C, Guan G, Liu X, Zhang H, Wang B. Comparison of short-segment pedicle fixation with versus without inclusion of the

fracture level in the treatment of mild thoracolumbar burst fractures. *Int J Surg*. 2016;36(pt A):352-357.
15. Farrokhi MR, Razmkon A, Maghami Z, Nikoo Z. Inclusion of the fracture level in short segment fixation of thoracolumbar fractures. *Eur Spine J*. 2010;19:1651-1656.
16. Tezeren G, Kuru L. Posterior fixation of thoracolumbar burst fracture: short-segment pedicle fixation versus long-segment instrumentation. *J Spinal Disord Tech*. 2005;18:485-488.
17. Dobran M, Nasi D, Brunozzi D, et al. Treatment of unstable thoracolumbar junction fractures: short-segment pedicle fixation with inclusion of the fracture level versus long-segment instrumentation. *Acta Neurochir (Wien)*. 2016;158: 1883-1889.
18. Xu GJ, Li ZJ, Ma JX, Zhang T, Fu X, Ma XL. Anterior versus posterior approach for treatment of thoracolumbar burst fractures: a meta-analysis. *Eur Spine J*. 2013;22:2176-2183.