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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

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OBJECTIVE There has been a transition from long- to short-segment instrumentation for unstable burst fractures to preserve motion segments. Circumferential fixation allows a stable short-segment construct, but the associated morbidity and complications are high. Posterior short-segment fixation spanning one level above and below the fractured vertebra has led to clinical failures. Augmentation of this method by including the fractured level in the posterior instrumentation has given promising clinical results. The purpose of this study is to compare the biomechanical stability of short-segment posterior fixation including the fractured level (SSPI) to circumferential fixation in thoracolumbar burst fractures.

METHODS An unstable burst fracture was created in 10 fresh-frozen bovine thoracolumbar spine specimens, which were grouped into a Group A and a Group B. Group A specimens were instrumented with SSPI and Group B with circumferential fixation. Biomechanical characteristics including range of motion (ROM) and load-displacement curves were recorded for the intact and instrumented specimens using Universal Testing Device and stereophotogrammetry.

RESULTS In Group A, ROM in flexion, extension, lateral flexion, and axial rotation was reduced by 46.9%, 52%, 49.3%, and 45.5%, respectively, compared with 58.1%, 46.5%, 66.6%, and 32.6% in Group B. Stiffness of the construct was increased by 77.8%, 59.8%, 67.8%, and 258.9% in flexion, extension, lateral flexion, and axial rotation, respectively, in Group A compared with 80.6%, 56.1%, 82.6%, and 121.2% in Group B; no statistical difference between the two groups was observed.

CONCLUSIONS SSPI has comparable stiffness to that of circumferential fixation.

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KEY WORDS burst fracture; posterior short-segment fixation; circumferential fixation; biomechanical study; lumbar spine

Burst fractures commonly occur in young adults due to road traffic accidents or a fall from a height,[19,39] and they represent 10%–20% of all injuries in the thoracolumbar region.[9] Because these fractures are commonly encountered in the younger age group, there is a significant economic burden on the family and society owing to loss of work, disability related to neurological deficits, and treatment expenses.

Burst fractures are considered unstable when there is more than a 50% loss of vertebral body height[26] or when there is more than 20° of angulation at the thoracolumbar junction.[26,29] Instrumented surgical stabilization is currently the treatment of choice for unstable burst fractures.[18,32,40] Since the advent of pedicle screws, the posterior approach has been increasingly favored in the treatment of these injuries. Long posterior constructs offer greater mechanical

ABBREVIATIONS BMD = bone mineral density; LDC = load displacement curve; LSC = Load Sharing Classification; NP = neutral point; ROM = range of motion; SSPI = short-segment posterior fixation including the fractured level.

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stability, but their placement entails longer surgical exposures and the immobilization of a greater number of motion segments. There has been a transition from long- to short-segment instrumentation in efforts to preserve motion segments.[11,16] However, posterior short-segment fixation constructs spanning one level above and one below the fractured vertebra can lead to early implant failure and kyphosis in unstable burst fractures.[4,27,41] Various techniques have been described to augment the stability provided by short posterior pedicle screw constructs. These include percutaneous balloon vertebroplasty,[2] supplementation with sublaminar hooks,[6] addition of cross-links,[10,22] and insertion of a screw into the fractured vertebra.[12,14,24] Insertion of pedicle screws into the fractured level in addition to fixing one level above and one below has shown promising clinical results, with a lower incidence of implant failure and kyphosis.[12,16] This is a less morbid and less time-consuming technique and helps in rapid rehabilitation.

Circumferential fixation using combined anterior and posterior approaches aids in direct decompression of the neural canal and reconstructs the unstable anterior and middle column using a stable mechanical device such as Harms cage, which is secured in compression by the posterior instrumentation. It allows for the use of a stable short-segment construct and preserves motion levels,[1,26] but it is associated with higher morbidity rate and operative complications.[19]

To our knowledge, there are no biomechanical studies directly comparing these two clinically successful fixation techniques. If both fixation techniques provide comparable stability under physiological loads, the one that causes less morbidity and is familiar to most surgeons can be chosen as a viable alternative to the other in treating unstable burst fractures. Our study is aimed at comparing the biomechanical stability achieved by short-segment posterior fixation including the fractured level (SSPI) to circumferential fixation.

Methods

Study Design: Experimental Comparative Study

Specimen Collection and Preparation

Institutional review board and ethics committee approvals were obtained. Ten spine specimens including the last two thoracic and first three lumbar vertebrae were harvested fresh from dairy calves of 4 to 6 months age. Specimens were obtained from a local slaughterhouse. Plain radiographs were obtained to rule out any gross pathology. Specimens were weighed and a DEXA (dual energy x-ray absorptiometry) scan was obtained to ensure that there is no gross difference among the specimens. Specimens were assigned to one of two groups—A or B (Table 1)—depending on the weight and bone mineral density (BMD). Specimens were labeled, double-packed in polythene bags, and stored in a deep freezer at –70°C.

One specimen was tested at a time. Before testing, the specimen was thawed over night at room temperature. The residual soft tissues were removed carefully, preserving the bony and discoligamentous anatomy (Fig. 1A–C). The end vertebrae were trimmed to fit the mounting cup and mounted using dental resin.

TABLE 1. Grouping of the specimens based on weight and BMD

Specimen No.*	Weight (g)	BMD (g/cm^2)
A1	430	0.912
B1	410	0.927
A2	390	0.877
B2	390	0.865
A3	450	0.768
B3	460	0.783
A4	360	0.686
B4	350	0.651
A5	390	0.812
B5	400	0.835

* A = Group A specimen; B = Group B specimen.

Creation of Unstable Burst Fracture

After the intact spine was biomechanically tested, an unstable burst fracture was created at the L-1 vertebra by drop-weight method. The index vertebra, L-1, was weakened by making drill holes in the upper third in an H-shaped fashion. A weight of 4.5 kg was dropped along a rail from a height of 1.25 m on to the upper end of the mounted specimen, which was kept in mild flexion.[3,28,33] The specimen was then wrapped in saline-soaked gauze and immediately taken for CT scanning. The fracture pattern was studied in detail with the help of 3D reconstructed CT scans (Fig. 2A–C).

Instrumentation

Once the fracture had been created and the CT scan had been taken, the specimen was immediately instrumented. Group A specimens were instrumented with SSPI (Fig. 3A and B). Group B specimens, after anterior corpectomy, were instrumented with circumferential fixation involving an anterior cage that was held in position under compression using pedicle screws one level above and below the index vertebra, simulating a combined anterior-posterior procedure (Fig. 3C and D). All specimens were instrumented using 5-mm-diameter, 34- to 38-mm-long. monoaxial pedicle screws (Jayon). The corresponding specimens in each group were instrumented using pedicle screws of the same length. Instrumentation was placed in the standard fashion. There was no visible pedicle violation during instrumentation, nor was there a need for screw repositioning. Plain radiographs obtained following instrumentation showed hardware was well positioned.

Biomechanical Testing

Specimens were tested in flexion-extension, right-left lateral flexion, and axial rotation in clockwise and anticlockwise directions. The intact specimen was tested first. followed by instrumented specimen after creating a burst fracture. The mounted specimen was firmly fixed to the testing fixture on either end using 4 screws drilled through it. An electromagnetic 3D motion tracking system (Polhemus, Inc.) was used to record the orientation of the spine in space. The 6 degree-of-freedom sensors were attached to the vertebra above and the vertebra below the index

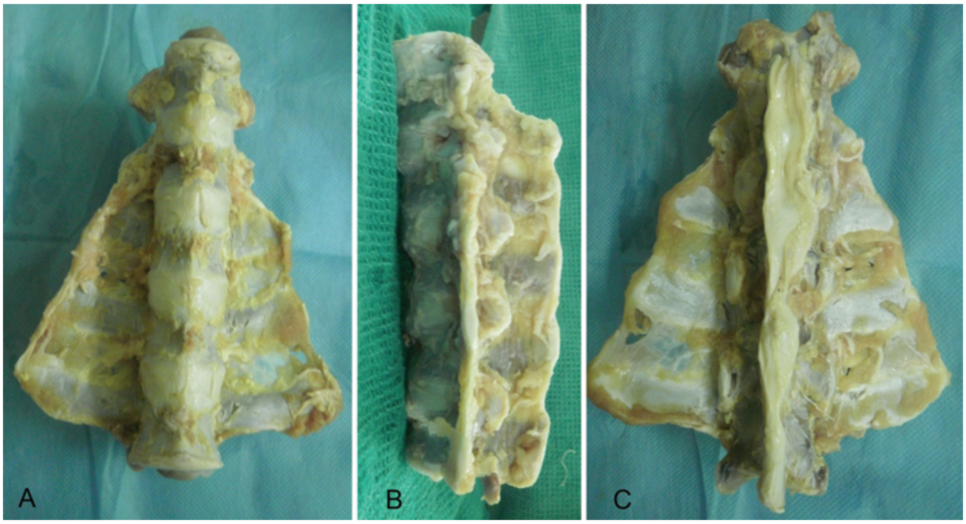

FIG. 1. Anterior (**A**), lateral (**B**) and posterior (**C**) photographs of the prepared specimen showing the retained bony and discoligamentous anatomy after soft-tissue clearance. Figure is available in color online only.

level. Neutral point (NP) coordinates were measured for each test direction before loading. A nondestructive, unidirectional bending moment was applied in each test direction using a Servohydraulic Universal Testing Machine (Tinius, Oslen) having a system of cables and pulleys[8] (Fig. 4). The test direction was determined by the relative orientation of the specimen to the cables and pulleys. Flexion-extension was tested by orienting the cables sagittally to the specimen, while lateral flexion was tested by orienting the cables coronally. Axial rotation was tested by the horizontal arrangement of the pulleys attached to the upper mounting fixture.

Three preconditioning loading cycles of 200 N were applied in the test direction at a displacement control

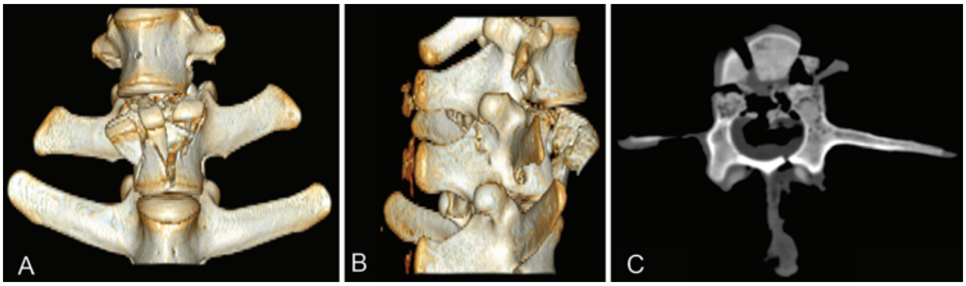

FIG. 2. CT images of a specimen showing the features of an unstable burst fracture: anterior and middle column comminution (**A**) and vertical laminar fracture (**B** and **C**). Figure is available in color online only.

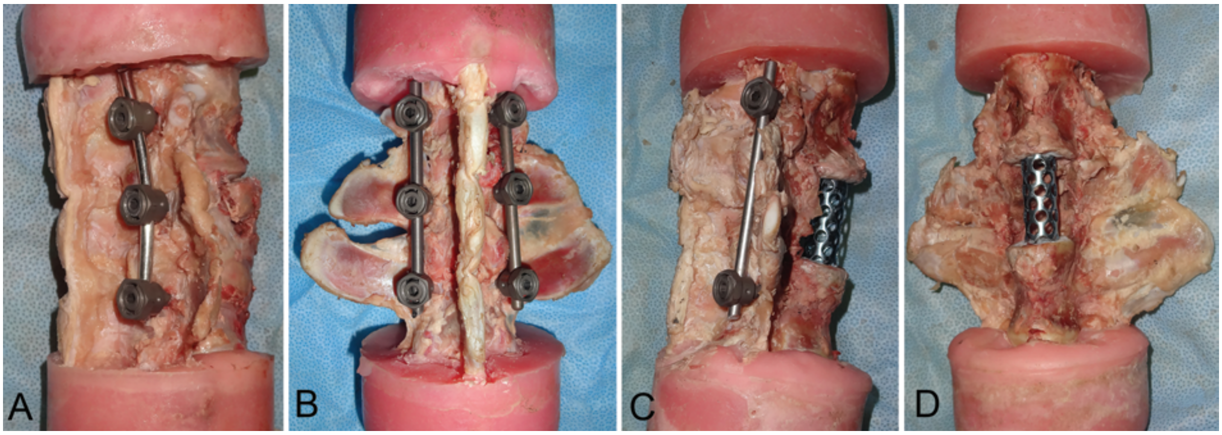

FIG. 3. Instrumented specimens: Group A specimen instrumented with SSPI (**A** and **B**) and Group B specimen instrumented with circumferential fixation (**C** and **D**). Figure is available in color online only.

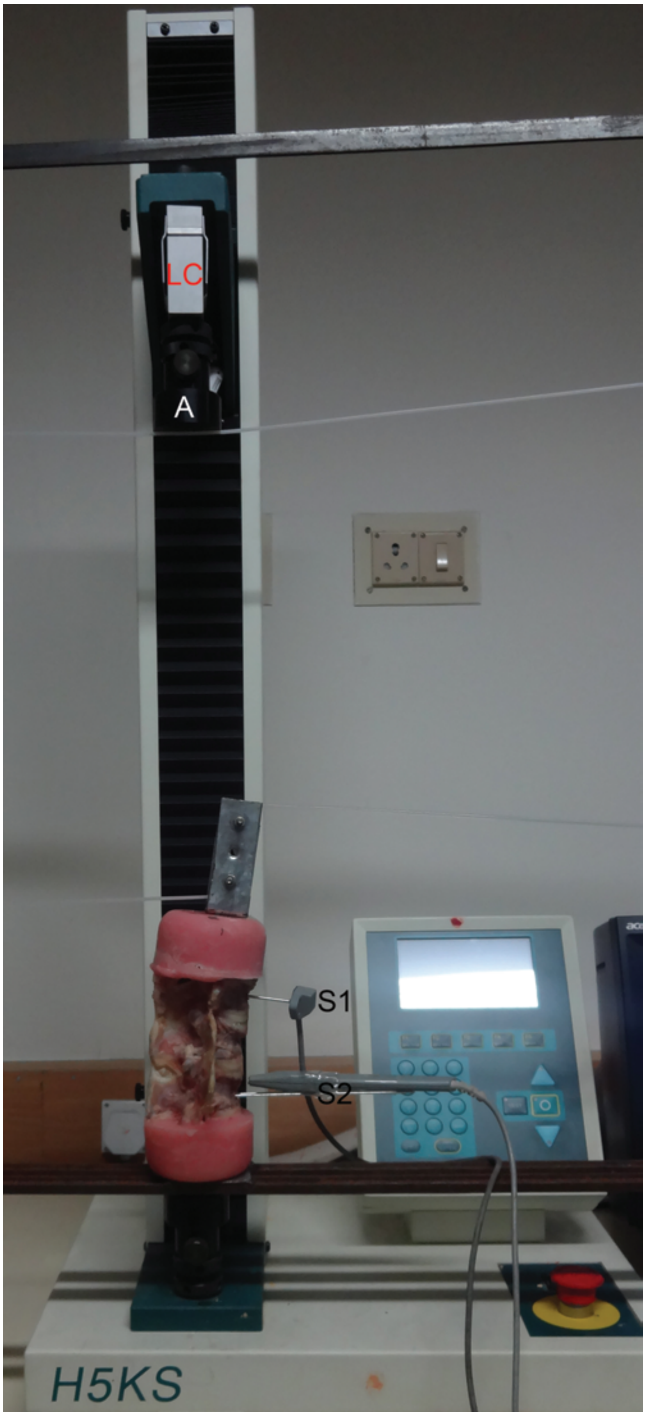

FIG. 4. The test setup for flexion moment. A = actuator; LC = load cell; S1 and S2 = 6-d.f. motion sensors. Figure is available in color online only.

mode of 5 mm/sec to correspond roughly to a bending moment of 7.5 Nm.[1] Coordinates were recorded after the third preconditioning cycle. The angular change between the NP and the end of the preconditioning cycle was taken as the neutral zone.[31] The load displacement curve (LDC) obtained from the fourth cycle was used to calculate the stiffness of the construct. The applied load, which was recorded by the load cell placed on the actuator arm of the testing device, was plotted against the displacement of the actuator arm to obtain the LDC.[37] The stiffness of the construct was calculated from the slope of the elastic zone of LDC and was expressed in newtons/millimeter. A continuous record of the relative motion of the vertebrae in space was obtained for the fourth loading cycle until the peak loading value of 200 N was reached. The coordinate values were converted into angles using a custom-made software. The range of motion (ROM) was calculated as the angular difference between the NP and the end of the peak loading.[13,38] The angular difference between the starting point and the end of the fourth loading cycle was taken as the elastic zone of ROM. After the test was completed for each direction, the apparatus was reconfigured for testing in another direction.

Outcome Measures and Statistical Analysis

The ROM and stiffness of the construct were the primary outcome measures used to determine the stability after placement of the instrumentation.[38] These two parameters were calculated for each specimen in each test direction, and the values were compared before and after instrumentation for each group using paired t-test. The mean decrease in ROM and the mean increase in the stiffness of the construct after instrumentation were compared between Group A and B for each test direction by using comparison of means.

Results

Instrumentation significantly reduced ROM and increased construct stiffness for all test directions in both Group A and Group B (Fig. 5). In Group A, ROM in flexion and extension was reduced by 46.9% and 52%, respectively, compared with 58.1% and 46.5%, respectively, in Group B. ROM in lateral flexion was reduced by 49.3% and axial rotation by 45.5% in Group A, whereas it was reduced by 66.6% and 32.6%, respectively, in Group B (Fig. 6). The ROM decrease in lateral flexion was significantly greater in Group B, while the ROM decrease in axial rotation was significantly greater in Group A ($p > 0.05$). However, there was no significant difference between the two groups in the decrease in sagittal-plane ROM. Construct stiffness was increased by 77.8% in flexion, 59.8% in extension, 67.8% in lateral flexion, and 258.9% in axial rotation in Group A and by 80.6%, 56.1%, 82.6%, and 121.2% in Group B, respectively (Fig. 7). There was no significant intergroup difference in the increase in construct stiffness after instrumentation.

Discussion

Treatment of unstable burst fractures has evolved from the use of long- to short-segment fixation in efforts to preserve motion segments. Traditionally, multilevel instrumentation involving 2–3 levels cranially and caudally was used when posterior fusion was performed using hooks and wires, which relied only on posterior fixation points. The advent of pedicle screws that offered transpedicular three-column fixation popularized the short-segment construct, which used the ligamentotaxis to indirectly restore

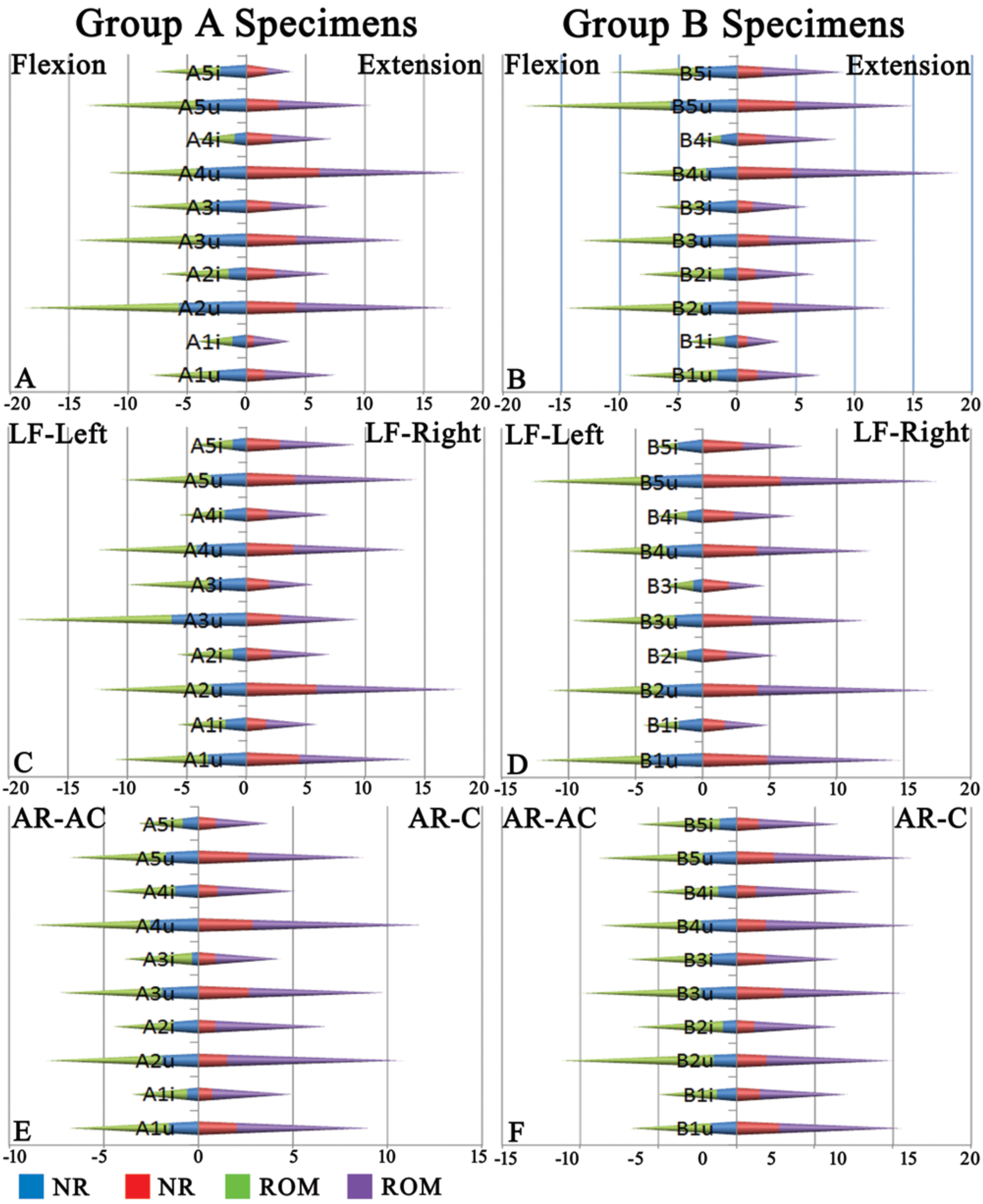

FIG. 5. Graphs depicting ROM for each specimen in Groups A and B before and after instrumentation for coronal (**A** and **B**), sagittal (**C** and **D**) and axial planes (**E** and **F**). A1–A5 and B1–B5 represent specimens in Group A and B. AC = anticlockwise; AR = axial rotation; C = clockwise; i = instrumented; LF = lateral flexion; NR = neutral range; u = uninstrumented. Figure is available in color online only.

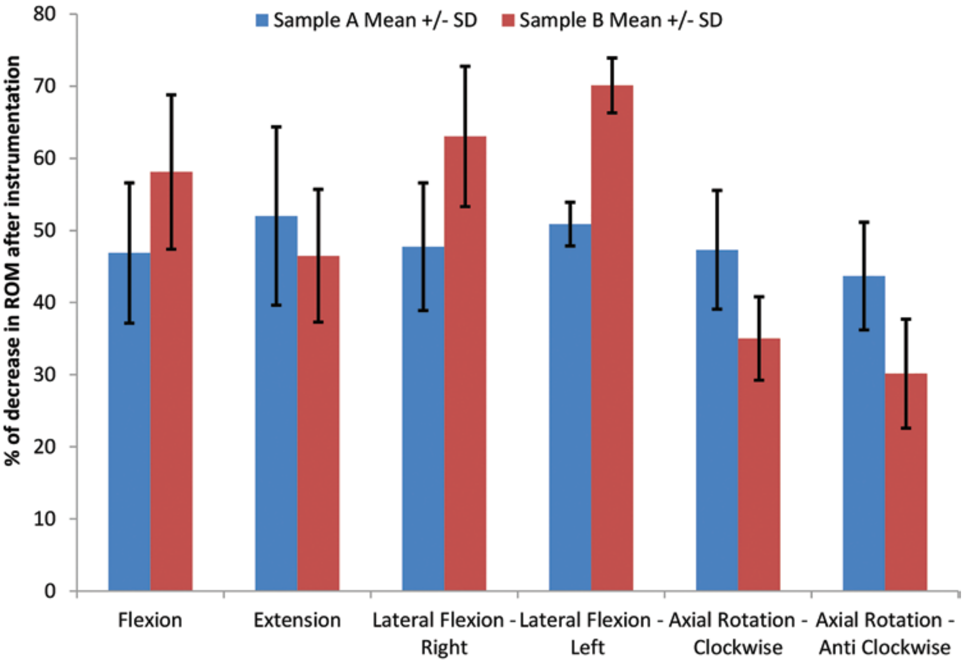

FIG. 6. Graph comparing the percentage of decrease in ROM for each test direction after instrumentation between Group A and Group B. Figure is available in color online only.

the vertebral body height and decompress the neural canal.[11] Later clinical and biomechanical studies revealed the inadequacy of such a construct, as the short spanning constructs often failed in kyphosis.[3,5,12,20,27] McCormack et al. pointed out the relevance of anterior column integrity in successful treatment with a short-segment construct[25] and recommended circumferential fixation in burst fractures that involved severe anterior column disruption.

Circumferential fixation replaces the unstable comminuted anterior column with a stable anterior construct that transmits load across the anterior column in burst fractures with a Load Sharing Classification (LSC) score > 7 proposed by McCormack et al.[25] This greatly reduces the cantilever bending of the posterior spanning screws and prevents kyphotic collapse.[26] Circumferential fixation also allows the addition of an anterior fixation device to resist the sagittal-plane forces. Despite the mechanical advantages, its lack of surgeon familiarity, longer operating time, associated blood loss, and complications limit its use, especially in patients with multiple injuries.

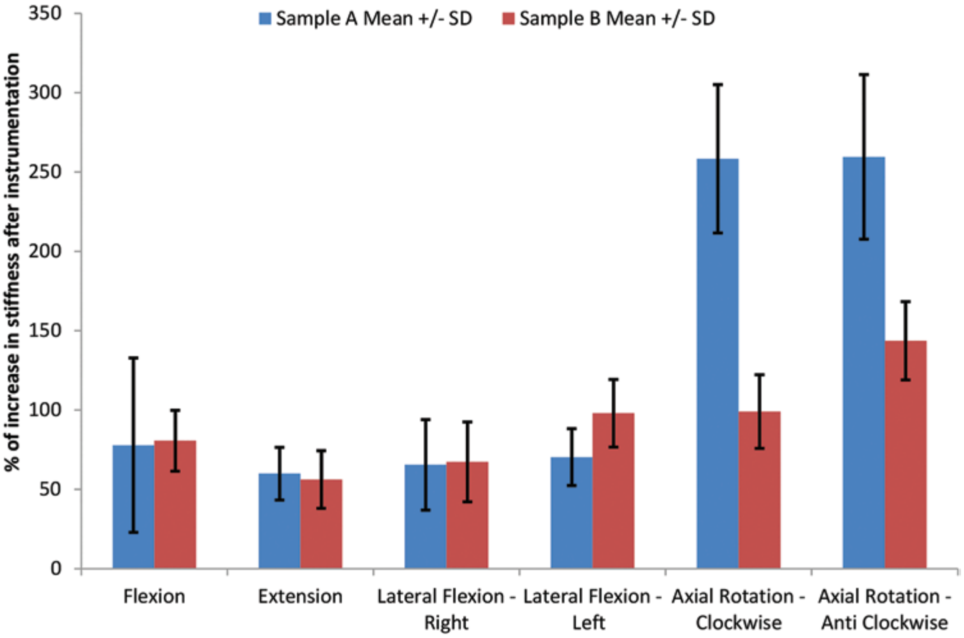

FIG. 7. Graph comparing the percentage of increase in stiffness for each test direction after instrumentation between Group A and Group B. Figure is available in color online only.

The role of intermediate screws in the long-term maintenance of kyphotic correction in burst fractures with severe anterior column comminution has been well acknowledged in clinical studies.[12,16] In a recent retrospective review of unstable burst fractures classified as LSC ≥ 7 in 32 patients who underwent SSPI, Kanna et al. reported good maintenance of kyphotic correction in a minimum follow-up period of 2 years. The authors questioned the relevance of LSC in predicting implant failure in cases involving intermediate screw fixation.[16] The biomechanical role of an intermediate screw inserted into the fractured vertebra to augment a short-segment construct is well recognized.[3,10,30,35] The biomechanical stability conferred by the intermediate screw is based on the fact that most of the stiffness of the construct and the pullout strength of the pedicle screw are derived from the screw's purchase within the pedicle[15,21] and from the fact that the pedicle is usually intact in a burst fracture of Magerl[23] Grades A.3.1 to A3.3. The addition of another posterior fixation point might also provide an alternative path for load transfer and could theoretically reduce the stress on the individual components of the whole instrumented unit. Intermediate screws may also stiffen the construct by splitting the length of the rod into two half-length parts, thus decreasing motion at the bone-screw interface.[3]

The "intermediate screw" technique is performed via the posterior approach, which is familiar to the majority of spine surgeons. Operating time, blood loss, incidence of intraoperative complications, and duration of hospital stay have all been shown to be significantly lower with this approach.[4,19] Our results show that both circumferential fixation and short-segment posterior fixation with intermediate screws decrease the ROM significantly and that the construct stiffness does not differ significantly between the two techniques. Considering the relatively superior safety profile of the posterior-only approach, we believe that short-segment posterior fixation in which intermediate screws are placed into the fracture site is a viable alternative to circumferential fixation for stabilizing burst fractures of the thoracolumbar spine.

The use of the calf spine rather than human cadaveric specimens is a potential limitation of our study. However, the calf spine has been shown to best match the anatomy and motion characteristics of the human spine in the thoracolumbar region and is widely used to test pedicle screw systems.[7,36] Its comparable equivalent BMD, compressive strength, and compressive modulus to that of young human vertebrae make it a good model for young nonosteoporotic human spine[34] in which burst fractures are commonly encountered. The load-displacement properties and ROM of calf spine specimens have been compared with those of human cadaveric spine specimens in previous biomechanical studies, and calf spine specimens have been proven to be suitable for testing rigid fixation systems using pedicle screws for in vitro flexibility tests.[17,37] We therefore chose to use calf spines for this comparative study, in part also because they are easily attainable and possess low interspecimen variability.

The use of a fixed pulley system for applying unidirectional bending moments has the potential to create an element of constant deformation termed "impure moment" acting on the spine in all test directions. This necessitates moving the pulleys repeatedly to achieve parallelism of the pulleys and thereby reducing the impure moment acting on the construct.[30] We avoided readjusting the pulley system repeatedly to minimize the effect on the sensors, which were continuously recording the coordinate points. Moreover, the deformation effect seen was almost identical in all specimens. In the present study we did not evaluate the role of anterior fixation devices in the circumferential construct, although most surgeons performing an anterior approach would prefer to place the hardware anteriorly. Further biomechanical studies are required to compare SSPI to circumferential fixation with additional anterior fixation. Finally, this study compared only the immediate postfixation stability in both groups. The durability of these fixation constructs need to be evaluated using cyclical loading tests. However, we believe the results of this study can be clinically applied in the immediate postoperative rehabilitation of patients who are undergoing short-segment fixation.

Conclusions

Short-segment fixation with intermediate screws achieves comparable stiffness to that of circumferential short-segment fixation and may be used as an alternative to circumferential fixation in unstable burst fractures of thoracolumbar spine considering the clinical safety of this procedure.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: all authors. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: Sait, Prabhav, Sekharappa, David. Statistical analysis: Sait, Prabhav, Rajan, Nambi Raj, David. Administrative/technical/material support: Sait, Prabhav. Study supervision: Sait, Prabhav, Nambi Raj, David.

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