International Journal of Research in Orthopaedics
Sait A et al. Int J Res Orthop. 2023 May;9(3):501-505
http://www.ijoro.org

DOI: https://dx.doi.org/10.18203/issn.2455-4510.IntJResOrthop20231050

Original Research Article

Biomechanical analysis of the effect of ‘intermediate screws’ in short segment posterior fixation of unstable burst fractures of thoracolumbar spine in calf spine model

Azad Sait[1], Monosha Priyadarshini[1], N. Arunai Nambi Raj[1]*, Kenny Samuel David[2]

[1]School of Advanced Sciences, Vellore Institute of Technology, Vellore, Tamil Nadu, India
[2]Spinal Disorders Surgery Unit, Department of Orthopaedics, Christian Medical College Vellore, Tamil Nadu, India

Received: 22 March 2023
Revised: 04 April 2023
Accepted: 07 April 2023

***Correspondence:**
Dr. N. Arunai Nambi Raj,
E-mail: narunainambiraj@vit.ac.in

ABSTRACT

Background: Efforts in preserving motion levels in unstable thoracolumbar burst fractures steered to short segment fixation. However, short segment spanning fixation in clinical scenario reported high failure rates. Augmentation of spanning fixation by inserting intermediate screws into the fracture level is proposed to enhance stability. An experimental comparative study was performed to assess the biomechanical role of the ‘intermediate screws.’
Methods: Five calf spine specimens were freshly prepared to record the biomechanical characteristics, range of motion (ROM), and stiffness. CT scan confirmed an unstable burst fracture in each specimen. Each specimen was instrumented with short-segment posterior fixation with an intermediate screw. The same test protocols were repeated with and without intermediate screws.
Results: Intermediate screws contribute to 20.2%, 16.5%, 14.5% and 23% decrease in ROM and 15.4%, 25.6%, 48.3%, and 160.2% increase in construct stiffness.
Conclusions: Intermediate screws significantly increase the construct stiffness and decrease the ROM.

Keywords: Bending moment, Pedicle screw, Load, Displacement curve, Universal testing device, Posterior instrumentation

INTRODUCTION

Unstable burst fractures are commonly seen in young individuals in the thoracolumbar region due to high energy trauma.[1,2] Approximately fifty percent of the affected population are estimated to have neurological deficits.[3-5] The affected individual is usually poly-traumatized, and the associated injuries warrant a quick surgical stabilization of the spine to aid early rehabilitation.

Short segment instrumentation was preferred in young individuals because of the preservation of motion levels. Posterior short segment spanning fixation (SSSF) depends on the integrity of the anterior column and is not reliable in an unstable burst situation.[6,7] Although circumferential fixation provides reliable and stable short segment constructs, it adds to the further morbidity of an already poly traumatized individual.[8] Various augmentation techniques to SSSF have been described in the literature such as percutaneous balloon vertebroplasty, use of laminar hooks, and insertion of screws into the fractured level commonly termed as ‘intermediate screws’.[9-11] The short segment posterior fixation with intermediate screws (SSPI) was performed through the posterior approach familiar to most spine surgeons, and the associated morbidity was less. Our study aims to evaluate the biomechanical advantages of intermediate screws in experimentally induced unstable burst fractures in the calf spine model.

METHODS

This experimental study was conducted at the School Of Advanced Sciences, Vellore Institute Of Technology, Tamil Nadu, India between September 2014 and October 2015.

Institutional review board and ethics committee approved the study.

Specimen collection and preparation

Five calf spine specimens (all males, aged 4 to 6 months), including the last two thoracic and first three lumbar vertebrae, were freshly harvested from a local slaughterhouse. Plain radiographs were obtained to rule out any gross pathology. The specimens were double packed in polythene bags and stored at -70ºC. Before biomechanical testing, each specimen was thawed overnight, and all muscle tissue was cleared carefully, retaining the bony and discoligamentous anatomy. The end vertebrae were trimmed to fit the mounting cup and mounted using dental resin.

Biomechanical testing

Specimens were put to test for flexion extension, right-left lateral flexion, and axial rotation in clockwise and anticlockwise directions. The intact specimen was first examined. The same test protocol was repeated for the instrumented specimens with and without ‘intermediate screws’.

The mounted specimen was firmly fixed to the testing fixture on either end using four screws drilled through it. An electromagnetic three-dimensional motion tracking system (Polhemus, Inc., Colchester, VT) was used to record the orientation of the spine in space (Figure 1). The 6 degrees of freedom sensors were attached to the vertebrae above and below the index level. Neutral Point (NP) coordinates were measured for each test direction before loading. The non-destructive unidirectional bending moment was applied for each test direction with a servohydraulic universal testing machine (Tinius, Oslen, PA, USA) using a system of cables and pulleys.[12] The test direction was determined by the relative orientation of the specimen to the cables and pulleys. Flexion-extension was tested by orienting the cable sagittal to the specimen, while lateral flexion was tested by orienting the cable coronal to the specimen. Axial rotations were 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 mode of 5mm/s to correspond roughly to a bending moment of 7.5 Nm.[13] 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.[14] The stiffness of the construct was calculated from the slope of the elastic zone of LDC (Figure 2) and was expressed in N/mm.[15] 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 custom-made software. The Range of Motion (ROM) was calculated as the angular difference between the NP and the end of the peak loading.[16,17] After completing the test for each direction, the apparatus was reconfigured for testing in another direction.

Creation of unstable burst fracture

After testing the intact spine biomechanically, an unstable burst fracture was created at the first lumbar vertebra using a previously described method.[18] In short, the index vertebra L1 was weakened by making osteotomies 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 meters onto the upper end of the mounted specimen, keeping in mild flexion. The specimen was then wrapped in saline-soaked gauze and immediately taken for computerized tomography (CT) scan. The fracture pattern was studied in detail with the help of CT with 3D reconstruction.

Instrumentation

Once the CT scan was done of the created fracture, the specimen was immediately instrumented with SSPI. Pedicle screws were inserted in the standard freehand manner [Figure 3]. Instrumentation was done for all specimens using titanium monoaxial pedicle screws of 5mm diameter and 34 to 38 mm length (Jayon, India). There were no visible pedicle violations during instrumentation, nor was there a need for screw repositioning. Plain radiographs of all specimens were obtained following instrumentation. Once the biomechanical testing was completed, the intermediate screw was removed and the resulting SSSF construct was again tested biomechanically following the same test protocol.

RESULTS

Instrumentation using SSPI has significantly decreased the ROM and increased the construct stiffness in all test directions. On testing the SSSF after removing the intermediate screws; ROM was found to increase significantly in all test directions-20.2% in flexion, 16.5% in extension, 14.5% in lateral flexion, and 23% in axial rotation (Figure 4). Moreover, the intermediate screws were found to significantly contribute to the construct stiffness-15.4%, 25.6%, 48.3%, and 160.2%, respectively, in flexion, extension, lateral bending, and axial rotation (Figure 5).

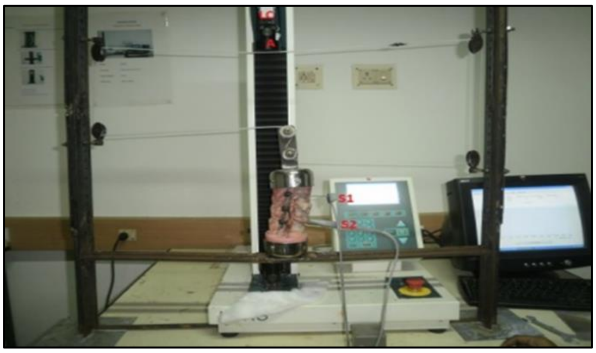

Figure 1: The test set-up consisted of the specimen fitted on to the mounting frame with 6 -degree-of freedom electromagnetic motion tracking sensors (S1 and S2) mounted above and below the fractured level. The actuator arm (A) of the servohydraulic univers.

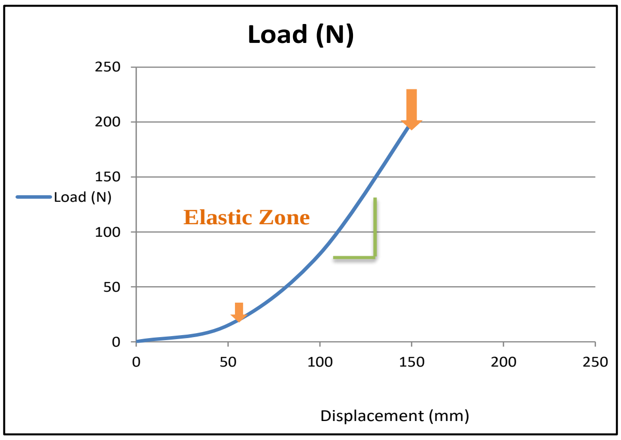

Figure 2: Load displacement curve of un-instrumented specimen in flexion indicating elastic zone.

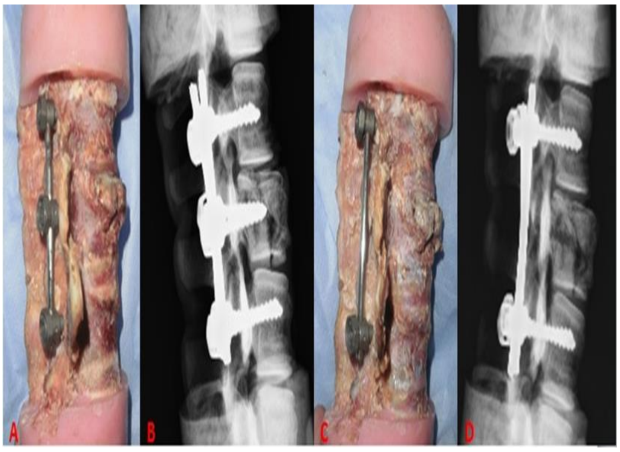

Figure 3 (A-D): Radiograph of a specimen instrumented with SSPI. Same specimen was re-instrumented after removal of intermediate screws to represent SSSF.

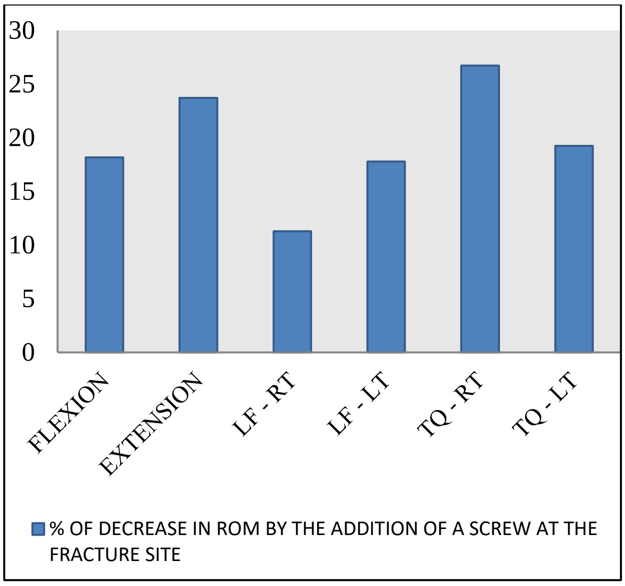

Figure 4: The contribution of intermediate screws in decreasing the ROM.

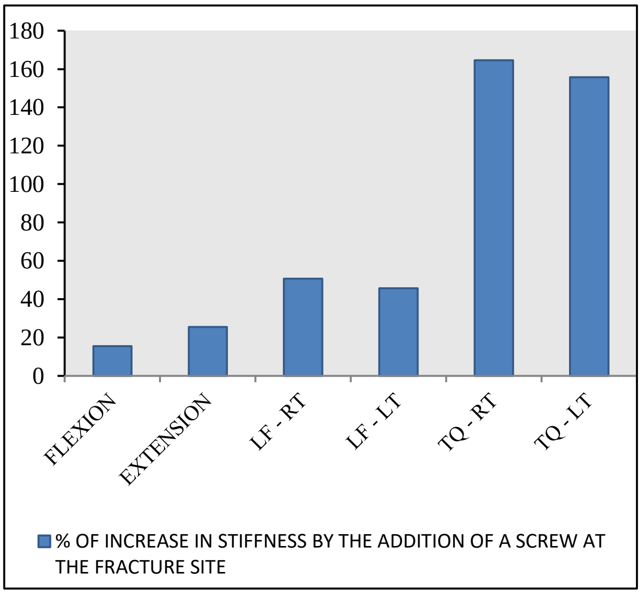

Figure 5: The contribution of intermediate screws in increasing the construct stiffness.

DISCUSSION

Traditionally, long segment fixation was used for stable fixation of an unstable burst fracture. Posterior long segment spanning fixation was used when instrumentation has relied only on the posterior fixation points. Long constructs work on the principle of three points bending when the load is applied.[7] Later, with the advent of pedicle screws by Roy Camillie, transpedicular three-column fixation became popular.Although biomechanically superior to posterior anchoring devices, multilevel fixation using pedicle screws is associated with the high possibility of spontaneous fusion of joints spanned and not included in the arthrodesis.[19,20] Moreover, placing pedicle screws in the upper 155 thoracic level is challenging given the great variability in pedicle size, orientation, and surrounding vital anatomy.[21,22]

Considering the biomechanical superiority of pedicle screw fixation over posterior-only fixation devices, Dick et al. popularised short segment spanning fixation (SSSF) of the fractured vertebra to decrease the instrumented motion segments.[7,23] SSSF works on the principle of cantilever bending or anterior column integrity.[7] The pedicle screws spanning the fractured vertebra act as “fixed beams” through transpedicular three-column fixation imparting superior stability.[7] However, later studies revealed the inadequacy of SSF with implant failure and progressive kyphosis.[7,23-24] McLain et al illustrated the mechanism of early failure of the SSSF.[27] This led to the implementation of other techniques of stable fixation preserving the motion segments.

Circumferential fixation reconstructs the anterior column with a stable device such as a cage to allow for a reliable stable short segment construct and aids indirect decompression of the neural canal. However, not many surgeons are familiar with this approach and the associated morbidity restricts its use in a poly-traumatized patient. Posterior augmentation of SSSF with intermediate screws gained popularity with its promising clinical results. SSSPI is a less morbid procedure that offers indirect spinal canal decompression and correction of kyphosis by ligamentotaxis.[22,23] SSSPI offers an additional anchoring point to fixation and decreases the progression of kyphosis.

Farrokhi et al in their prospective randomized study in 80 patients with burst fractures treated with SSSF and SSSPI concluded that inclusion of fracture level into the construct offered a better kyphosis correction, fewer instrument failures, lesser complications, and good functional outcome.[11] Butt et al in their review of 50 patients observed a reasonable correction of the deformity and neurologic recovery.[25] Previous biomechanical studies also have signified the role of intermediate screws. Lazzaro et al. estimated the average stability offered by the intermediate screws as 25% and established its superiority over cross-links in augmenting SSSF.[28] Wang et al compared the biomechanical strength of SSSF and SSSPI using monoaxial and polyaxial pedicle screws.[29] It concluded that there was no significant difference in instability with the SSSPI constructs using monoaxial and polyaxial screws. However, the construct stability was significantly high with SSSF in the sagittal plane using monaxial pedicle screws.[29] Both these biomechanical studies used a decrease in ROM recorded while loading using a 3D motion tracker as the stability parameter and did not calculate the stiffness of the construct from the LDC. Anekstein et al used the offset loading method using a universal testing device to apply the load and displacement was recorded using an extensometer mounted on the vertebrae above and below the index vertebra to record an LDC. They calculated the construct stiffness from the slope of LDC and ROM from the amplitude of the LDC.[2] Offset loading is not a method to apply pure unidirectional bending moments as it has an axial load vector which is also acting on the vertebrae. The ROM recorded in their study is only a displacement change rather than an angular change.

The primary limitation of this study was the use of calf spine models instead of human cadaveric spines, which was due to the restricted availability of human spines. Another limitation was the inability to apply a follower load, as the impact of such a load on a habitually quadrupedal animal has not been investigated. Nonetheless, the study offers valuable insight into the role of intermediate screws in short segment fixation.

CONCLUSION

Our study has the limitation of using calf spine instead of the human cadaveric spine. Easy availability, expandability, and matching motion kinetics as like the human cadaveric spine prompted us to use the calf spine model. The study results reflect the immediate post-fixation stability of the constructs. The durability of the fixation needs to be tested further using cyclical loading tests. We did not use a follower load to simulate the compressive load acting on the vertebral column due to the weight of the trunk because we were not sure about its effect on the vertebral column of a habitual quadruped animal. Intermediate screws reliably augment the construct stiffness of a short segment spanning fixation and contribute significantly to decrease the ROM.

ACKNOWLEDGEMENTS

Author would like to thanks to the fluid research grant IRB (EC)-ER-1-27-11-2013 for funding and making the work flow easy and success.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee

REFERENCES

1. Wettstein M, Mouhsine E. Operative compared with nonoperative treatment of a thoracolumbar burst fracture without neurological deficit. J Bone Joint Surg Am. 2004;86(3).
2. Anekstein Y, Brosh T, Mirovsky Y. Intermediate screws in short segment pedicular fixation for thoracic and lumbar fractures: A biomechanical study. J Spinal Disord Tech. 2007;20(1):72-7.
3. Denis F. The Three Colum Spine and Its Significancve in the Classification of Acute Thoracolumbar Spinal Injuries. Spine. 1983;8:817-31.
4. Braakman R, Fontijne WPJ, Zeegers R, Steenbeek JR, Tanghe HLJ. Neurological deficit in injuries of the

thoracic and lumbar spine-A consecutive series of 70 patients. Acta Neurochir (Wien). 1991;111:1-2:11-7.

5. Limb D, Shaw DL, Dickson RA. Neurological Injury in Thoracolumbar Burst Fractures. J Bone Joint Surg.1995;774-7.
6. Kanna RM, Shetty AP, Rajasekaran S. Posterior fixation including the fractured vertebra for severe unstable thoracolumbar fractures. Spine J. 2015;15(2):256-64.
7. McLain RF. The biomechanics of long versus short fixation for thoracolumbar spine fractures. Spine (Phila. Pa. 1976). 2006;31(11):70-9.
8. Esses S. Posterior short-segment instrumentation and fusion provides better results than combined anterior plus posterior stabilization for mid-lumbar (L2 to L4) burst fractures: Commentary. J Bone J Surg. 2006;88(10):2311.
9. Afzal S, Akbar S, Dhar SA. Short segment pedicle screw instrumentation and augmentation vertebroplasty in lumbar burst fractures: An experience. Eur Spine J. 2008;17(3):336-41.
10. Chiba M, McLain RF, Yerby SA, Moseley TA, Smith TS, Benson DR. Short-segment Pedicle Instrumentation. Spine. 1996;21(3):288-94.
11. 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(10):1651-6.
12. Crawford NR, Brantley G, Dickman CA, Koeneman EJ. An apparatus for applying pure noncnstraining moments to spine segments *in-vitro*. Spine. 1995;20(19):2097-100.
13. Acosta FL, Buckley JM, Xu Z, Lotz JC, Ames CP. Biomechanical comparison of three fixation techniques for unstable thoracolumbar burst fractures: Laboratory investigation. J Neurosurg Spine. 2008;8(4):341-6.
14. M. M. Panjabi, “The stabilizing system of the spine.Part II. Neutral zone and instability hypothesis. J Spinal Disorders. 1992;5(4):390-7.
15. Wilke HJ, Wenger KH, Claes LE. Load-displacement properties of the thoracolumbar calf spine: experimen Load-displacement properties of the thoracolumbar calf spine: experimental results and comparison to known human data. Eur Spine J. 1997;129-37.
16. Goel VK, Panjabi MM, Patwardhan AG, Dooris AP, Serhan H. Test protocols for evaluation of spinal implants. J Bone J Surg. 2006;88(2):103-9.
17. Wilke HJ, Wenger K, Claes L. Testing criteria for spinal implants: Recommendations for the standardization of in vitro stability testing of spinal implants. Eur Spine J. 1998;7(2):148-54.
18. Sekharappa V, Sait A. Simple and economical method to create thoracolumbar burst fracture in a calf spine model. Asian Spine J. 2016;10(1):6-13.
19. Kahanovitz N, Bullough P, Jacobs RR. The effect of internal fixation without arthrodesis on human facet joint cartilage. Clin Orthop Relat Res. 1984;189:204-8.
20. Akbarania BA, Crandall DG, Burkus K, Matthews T, Missouri L. Use of Long Rods and a Short Arthrodesis for Burst of the Thoracolumbar spine. J Bone Joint Surg. 1994;76(11).
21. Panjabi MM, O’Holleran JD, Crisco JJ, Kothe R. Complexity of the thoracic spine pedicle anatomy. Eur Spine J. 1997;6(1):19-24.
22. Vaccaro AR. Placement of pedicle screws in the thoracic spine: Part II: An anatomical and radiographic assessment. J Bone J Surg. 1995;77(8):1200-6.
23. Dick W, Kluger P, Magerl F, Woersdörfer O, Zäch G. A new device for internal fixation of thoracolumbar and lumbar spine fractures: The ‘fixateur interne. Paraplegia, 1985;23(4):225-32.
24. Been HD, Bouma GJ. Comparison of two types of surgery for thoraco-lumbar burst fractures: Combined anterior and posterior stabilisation vs. posterior instrumentation only. Acta Neurochir. 1999;141(4):349-57.
25. Butt MF, Farooq M, Mir B, Dhar AS, Hussain A, Mumtaz M. Management of unstable thoracolumbar spinal injuries by posterior short segment spinal fixation. Int Orthop. 2007;31(2):259-64.
26. Yu SW, Fang KF, Tseng IC, Chiu YL, Chen YJ, Chen WJ. Surgical outcomes of short-segment fixation for thoracolumbar fracture dislocation. Chang Gung Med J. 2002;25(4):253-9.
27. McLain R, Sparling E, Benson D. Early Failure of Short-Segment Pedicle Instrumentation for Thoracolumbar Fractures. J Bone Joint Surg. 1993;75:2.
28. Lazaro BCR. Biomechanics of thoracic short versus long fixation after 3-column injury: Laboratory investigation. J Neurosurg Spine. 2011;14(2):226-34.
29. Wang H, Li C, Liu T, Zhao WD, Zhou Y. Biomechanical efficacy of monoaxial or polyaxial pedicle screw and additional screw insertion at the level of fracture, in lumbar burst fracture: An experimental study. Indian J Orthop. 2012;46(4):395-401.

Cite this article as: Sait A, Priyadarshini M, Raj NA, David KS. Biomechanical analysis of the effect of ‘intermediate screws’ in short segment posterior fixation of unstable burst fractures of thoracolumbar spine in calf spine model. Int J Res Orthop 2023;9:501-5.