

## Case Report

# Effects of Polyaxial Pedicle Screws on Lumbar Construct Rigidity

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**Summary:** Pedicle screw constructs have been shown to increase fusion rates in the lumbar spine. Manufacturers have created pedicle screws with one or two degrees of freedom built into the screw head to allow for easier incorporation of the interlocking rod, but the effects of these screws on construct stiffness has not been tested. The purpose of this study is to compare and contrast the stiffness of lumbar pedicle screw constructs with and without the use of polyaxial pedicle screws. Nontapered, self-taping pedicle screws (6.0-mm diameter × 30-mm length, titanium) were used in the fixation of porcine spines from L3–L5. Group 1 (n = 5) contained six standard pedicle screws from one manufacturer. Group 2 (n = 5) contained six standard pedicle screws from a second manufacturer. Group 3 (n = 5) contained four standard pedicle screws placed at L3 and L5, as well as two polyaxial screws placed at L4. Group 4 (n = 5) contained six polyaxial pedicle screws. A rotational variable differential transformer was used to record angular displacement between vertebrae in the construct as it is loaded in flexion, extension, right bend, left bend, clockwise torque, and counterclockwise torque. Stiffness curves were linear throughout the range of applied force. The average  $r^2$  value for the generated stiffness graphs was 0.94 (SD = 0.06). No construct failure occurred during any of the testing. There were no significant differences ( $p < 0.05$ , two-way analysis of variance) in moment versus angle noted in any of the four groups tested. For torque tests, the all-polyaxial screw constructs showed significantly increased stiffness compared with the other groups. The current study has shown that the incorporation of polyaxial screws in pedicle screw constructs did not significantly decrease the construct stiffness. There is a suggestion that the use of all polyaxial screws may increase the resistance to torque by allowing better purchase of intervertebral rods. **Key Words:** Pedicle screw—Fusion construct—Rigidity.

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The use of pedicle screws in the fixation of the lumbar spine has become common and well accepted. Rigid systems of rods, interlocking bars, and pedicle screws have been designed to decrease or limit motion at the desired levels and to increase fusion rates (1–6). Although the ideal stiffness of constructs is unknown, the use of rigid instrumentation has been shown to aid in the fusion rates of lumbar surgeries (3,5,6). Furthermore, pedicle screw

constructs have been shown to increase fusion rates in the lumbar spine (2,6).

Placement of pedicle screw constructs commonly requires adjustments of the screw's depth of insertion to accommodate rod placement. These adjustments may compromise fixation strength (7). In response to this, manufacturers offer pedicle screw systems designed with screw heads containing one or two degrees of freedom to ease rod accommodation and thereby decrease intraoperative adjustment of screw height. No prior study in the literature has examined the effect these polyaxial screw designs have on construct rigidity.

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TABLE 1. Mean linear stiffness (N-m/deg)  $\pm$  standard deviation as a function of construct  $n = 5$  for all groups

| Group                       | Flexion         | Extension       | Right bend      | Left bend      | Clockwise torque | Counterclockwise torque |
|-----------------------------|-----------------|-----------------|-----------------|----------------|------------------|-------------------------|
| 1: standard <sup>a</sup>    | 23.0 $\pm$ 12.7 | 32.2 $\pm$ 10.5 | 14.9 $\pm$ 7.5  | 14.6 $\pm$ 8.6 | 0.16 $\pm$ 0.03  | 0.17 $\pm$ 0.04         |
| 2: standard <sup>b</sup>    | 22.6 $\pm$ 15.3 | 27.3 $\pm$ 15.5 | 21.5 $\pm$ 12.0 | 20.4 $\pm$ 9.0 | 0.17 $\pm$ 0.11  | 0.18 $\pm$ 0.11         |
| 3: hybrid (polyaxial at L4) | 27.8 $\pm$ 10.4 | 33.4 $\pm$ 16.0 | 24.0 $\pm$ 13.0 | 20.6 $\pm$ 8.9 | 0.14 $\pm$ 0.05  | 0.13 $\pm$ 0.05         |
| 4: all polyaxial            | 22.6 $\pm$ 14.0 | 23.1 $\pm$ 14.6 | 16.5 $\pm$ 12.3 | 19.3 $\pm$ 9.1 | 0.23 $\pm$ 0.07* | 0.26 $\pm$ 0.05*        |

<sup>a</sup>Synthes, Allentown, PA, U.S.A.

<sup>b</sup>Spinal Concepts, Dallas, TX, U.S.A.

\*Significantly different ( $p < 0.05$ ) compared with groups 1, 2, and 3.

fixation ( $p = 0.621$ ) or in the direction of bending ( $p = 0.257$ ). There was no significant interaction between the direction of testing and the fixation type ( $p = 0.916$ ). For the right-bending/left-bending tests, there were no significant differences noted in either the type of fixation ( $p = 0.495$ ) or in the direction of bending ( $p = 0.892$ ). There was no significant interaction between the direction of testing and the fixation type ( $p = 0.948$ ).

For the torque testing, there were no significant differences noted in the direction of torque ( $p = 0.567$ ), but there was a significant interaction with the type of fixation used ( $p = 0.011$ ). The all-polyaxial construct (group 4) had significantly greater torque values than the other three constructs (groups 1, 2, and 3) for both clockwise torque as well counterclockwise torque. There were no significant differences in torque among groups 1, 2, and 3. There was no significant interaction between the direction of testing and the fixation type ( $p = 0.955$ ).

## DISCUSSION

In vitro testing of spinal fixation becomes a challenge because of a lack of a good synthetic model and the poor and varied quality of specimens from cadavers. Cadaver bone can be severely osteoporotic, expensive, and may not be representative of the typical patient undergoing lumbar fusion. Calf bone has been used in numerous trials but, in general, it has been shown to be significantly denser than human bone (9–11). The porcine model has been proven to be a more representative model for mechanical testing in terms of density and pedicle anatomy (9–11).

Instrumentation of lumbar fusion has become increasingly popular. Some studies suggest that rigid fixation with pedicle screws increase fusion rates, although an optimal stiffness has yet to be established (2–6). Many studies have shown that pedicle screw fixation is the most rigid construct available (1,8,12). These systems require precise alignment of screw heads to allow for incorporation of interlocking rods. The difficulty of assembling these systems often requires surgeons to change screws or to adjust screw heights intraoperatively. Some studies suggest that these intraoperative adjustments of pedicle

screws may compromise fixation strength (7). In response, manufacturers have developed pedicle screw systems with screw heads that contain additional degrees of freedom to provide flexibility for the surgeon in the application of the construct. No previous study has assessed how these polyaxial screw heads affect construct rigidity.

The current study compared four construct designs and failed to show a difference between the two standard constructs (group 1 and 2) from different manufacturers or between the standard constructs and the hybrid construct containing standard and polyaxial screws (group 3). No significant decrease in stiffness resulted from the use of polyaxial screws in the hybrid constructs (group 3). This lack of a difference suggests that the stiffness of the titanium rods incorporated into each screw and the titanium interlock overwhelms any micromotion that may be present from the screw heads.

The all-polyaxial construct (group 4) showed no significant difference in flexion/extension and right bending/left bending when compared with groups 1, 2, and 3. However, the all-polyaxial construct (group 4) did show significantly increased torque values when compared with the other three groups. This may be caused by a better purchase on the intervertebral rods made possible by the polyaxial screw heads. It is feasible that the all-polyaxial constructs create a more secure holding environment by permitting better contact between the screw head and the rod. This would result from less relative twisting between the screw head and the rod. In right bending/left bending or in flexion/extension, this effect would be minimal. In bending and flexion/extension, most of the bending is resisted by the rods alone and is more of a pure bending. In torsion, there is more of a combined effect of bending plus shear of the rods, which is reflective of the effects of the clamping. Higher resistance to applied torque will occur if there is more resistance to rotational slippage between the rod and the screw head.

Interpretation of the current study was limited by three main factors. First, forces seen in the lumbar spine are not isolated bending or torque moments but complex combinations of applied loads. Second, like other in vitro biomechanical studies, we experienced large variations in

stiffness within our groups, making any difference difficult to detect. This lack of power in our testing is attributable to our limited number of specimens. However, the model used has been shown to be reproducible and the stiffness estimates generated were linear with  $r^2$  values, on average, being 0.94. Third, our load levels were relatively low compared with the stiffness of the constructs. It is possible that, at these low load levels, the differences between constructs are washed out. These relatively low loads allowed for multiple loading modalities without the possibility of specimen failure so that the individual specimen could act as its own internal control. At low loads, there was no specimen failure and all of the specimen deformation is recoverable. A higher load leading to failure would have prevented us from testing all combinations for a single specimen. Regardless, it is unknown whether differences in construct stiffness result in a difference in fusion rates.

The current study has shown that the incorporation of polyaxial screws in pedicle screw constructs did not significantly decrease the construct stiffness. There is a suggestion that the use of all polyaxial screws may increase the resistance to torque by allowing better purchase of intervertebral rods.

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## REFERENCES

1. Asazuma T, Stokes IA, Moreland MS, et al. Intersegmental spinal flexibility with lumbosacral instrumentation: an in vitro biomechanical investigation. *Spine* 1990;15:1153-8.
2. Lorenz M, Zindrick M, Schwaegler P, et al. A comparison of single level fusions with and without hardware. *Spine* 1991;16(suppl): S455-8.
3. McAfee PC, Farey ID, Sutterlin CE, et al. Device related osteoporosis with spinal instrumentation. *Spine* 1989;14:919-26.
4. McKinley TO, McLain RF, Yerby SA, et al. Characteristics of pedicle screw loading: effect of surgical technique on intrvertebral and intrapedicular bending moments. *Spine* 1999;24:18-25.
5. Vacarro AR, Garlin SR. Pedicle screw fixation in the lumbar spine. *J Am Acad Orthop Surg* 1995;3:263-74.
6. Zdeblick TA. A prospective, randomized study of lumbar fusion: preliminary results. *Spine* 1993;18:983-91.
7. Polly DW, Orchowksi JR, Ellenbogen RG. Revision pedicle screws: bigger, longer shims—what is best? *Spine* 1998;23:1374-9.
8. Markolf KL, Delamarter RB, Fyodorov I, et al. Variables affecting pedicle screw plate fixation of an unstable L3-L4 defect. *Clin Orthop Related Res* 1996;327:283-90.
9. Aerssens J, Boonen S, Lowef G, et al. Interspecies differences in bone composition, density, and quality: potential implications for in vivo bone research. *Endocrinology* 1998;129:663-70.
10. Allen DG, Russell GG, Moreau MJ, et al. Vertebral endplate failure in porcine and bovine models of spinal fracture instrumentation. *J Orthop Res* 1990;8:154-6.
11. Chapman JR, Harrington RM, Lee KM, et al. Factors affecting the pullout strength of cancellous bone screws. *J Biomed Eng* 1996;118: 391-8.
12. Shea M, Edwards WT, Clothiaux PL, et al. Three-dimensional load displacement properties of posterior lumbar fixation. *J Orthop Trauma* 1991;5:420-7.