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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.

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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The purpose of the current study was to examine the effect of pedicle screws with single degree of freedom heads on the rigidity of lumbar constructs. Construct rigidity was measured by using a custom designed fixation system similar to one used previously by Markolf et al. (8). Linear regression analysis was used to determine stiffness (Nm/degree) as the slope of the linear loading curves. Stiffness was analyzed for six separate tests: flexion, extension, right bending, left bending, clockwise torque, and counterclockwise torque.

METHODS

Twenty, fresh-frozen, lumbar vertebrae were harvested from mature hogs weighing 200 lb each. These vertebrae were harvested before the processing of the animals. The lumbar vertebrae from L3 to L5 were dissected free of all soft tissue and frozen immediately.

Instrumentation consisted of 6.0-mm diameter × 30-mm long, titanium, self-taping, cylindrical screws supplied from two manufacturers. All screws incorporated a 10-mm diameter head. The polyaxial screws permit head rotation in the axial plane. This allows the head to swing medial–lateral for easier rod incorporation. All constructs used two 6.0-mm titanium rods and a single interlocking device connecting the rods as per manufacturers' suggested use.

Specimens were randomized into one of four groups. Group 1 ($n = 5$) served as the community standard and contained six standard pedicle screws (Synthes, Allentown, PA, U.S.A.) placed at the L3, L4, and L5 levels. Group 2 ($n = 5$) contained six standard pedicle screws from another manufacturer (Spinal Concepts, Dallas, TX, U.S.A.) placed at the L3, L4, and L5 levels. Group 3 ($n = 5$) contained four standard pedicle screws (Spinal Concepts) placed at L3 and L5, as well as two "polyaxial" screws (Spinal Concepts) placed at L4. Group 4 ($n = 5$) contained six polyaxial pedicle screws (Spinal Concepts) placed at L3, L4, and L5.

The gross specimens were cleaned of soft tissue and securely placed in a clamp for instrumentation. A single author (J. C. W.) used a standard pedicle finder to establish the path of each pedicle screw. All screws were placed according to the recommendations of the respective manufacturer. All screws were placed a single time and were not backed out or replaced. For all screws, care was taken to ensure that all threads were incorporated in bone.

Construct rigidity was measured by using a material testing machine (MTS model 812; MTS Systems, Minneapolis, MN, U.S.A.) and by a custom apparatus as described previously by Markolf et al. (8) The L3 and L5 vertebrae were potted in cylindrical molds of methylmethacrylate to ease fixation in the loading apparatus. The potted ends of each specimen were clamped within a metal cylinder. The L3 end was rigidly fixed to the crosshead of the MTS machine. The L5 potted segment was placed within a metal cylinder that has two pulleys mounted on each of its sides at midline. A drive cable on each side is fixed superiorly to the apparatus, passed through these pulleys, and connected to the load cell mounted on the actuator of the MTS inferiorly. As the actuator displaces inferiorly, developing a maximum force of 15 N, a pure bending moment is applied to the specimen, causing the L5 end to deflect inferiorly. This arrangement allows the specimen to be fixed in 90-degree increments about its spinal axis so that this moment can be applied as flexion, extension, right bend, or left bend. A rotational variable differential transformer (RVDT) mounted on a four-bar linkage is attached to the vertebral bodies (either L3–4 or L4–5) to record intervertebral rotation. For torque measurements, a single cable is passed from the apparatus superiorly through one side of pulleys, through the pulleys on the load cell inferiorly, and again passed superiorly to the contralateral side of the metal cylinder and fixed. In this case, the RVDT is mounted to the end of L5 metal cylinder via a four-bar linkage to record the angular rotation of the L5 segment as torque is applied. A counterbalance system was used to negate the effects of the weight of the specimen and fixtures.

The RVDT was used to record the angular displacement versus moment or torque depending on the test. Angular displacements and force were recorded continuously for each test conducted. Force values were converted to moment or torque as appropriate for the type of test conducted. Stiffness (Nm/degree) was determined by linear regression analysis as the slope of the linear loading curves. Stiffness was analyzed for six separate tests: flexion, extension, right bending, left bending, clockwise torque, and counterclockwise torque. All tests were conducted without specimen destruction.

Comparison of stiffness values was based on two variables (construct design, direction of loading) and was performed using a two-way analysis of variance with Student-Neuman-Keuls post hoc test. Level of significance was set at $p < 0.05$. To assess the linearity of the plots, r^2 analysis of the stiffness curves was performed.

RESULTS

Stiffness curves were linear throughout the range of applied force. The average r^2 value for the generated graphs was 0.94 (SD, 0.06). No failure of the fixation construct occurred for any of the specimens.

Mean stiffness values of the four construct groups are shown in Table 1. For flexion–extension testing, there were no significant differences noted in either the type of

TABLE 1. *Mean linear stiffness (N-m/deg) ± 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[a]	23.0 ± 12.7	32.2 ± 10.5	14.9 ± 7.5	14.6 ± 8.6	0.16 ± 0.03	0.17 ± 0.04
2: standard[b]	22.6 ± 15.3	27.3 ± 15.5	21.5 ± 12.0	20.4 ± 9.0	0.17 ± 0.11	0.18 ± 0.11
3: hybrid (polyaxial at L4)	27.8 ± 10.4	33.4 ± 16.0	24.0 ± 13.0	20.6 ± 8.9	0.14 ± 0.05	0.13 ± 0.05
4: all polyaxial	22.6 ± 14.0	23.1 ± 14.6	16.5 ± 12.3	19.3 ± 9.1	0.23 ± 0.07*	0.26 ± 0.05*

[a] Synthes, Allentown, PA, U.S.A.
[b] 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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