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Physical Characteristics of Polyaxial-Headed Pedicle Screws and Biomechanical Comparison of Load With Their Failure

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Study Design. Pedicle screw strength or load to failure was biomechanically evaluated, and the geometric characteristics of pedicle screw instrumentation systems were compared.

Objectives. To compare the features of pedicle screw systems, and to demonstrate the failure point of the polyaxial pedicle screw head.

Summary of Background Data. Many pedicle screw instrumentation systems are currently available to the spine surgeon. Each system has its unique characteristics. It is important for the surgeon to understand the differences in these pedicle screw systems. Pedicle screw load to failure has not been subjected to a comparison study.

Methods. The physical characteristics of each pedicle screw instrumentation system were determined. Features of rods, instruments, and pedicle screws were cataloged. Biomechanical testing of the pedicle screw construct was performed to determine the site and force of the load to failure. Nine pedicle screw systems were evaluated. Testing was performed with a pneumatic testing system under load control. Three polyaxial screws were used for each test at a load rate of 100 N/second. The load failure value was the force at which the pedicle screw or polyaxial head–screw interface initially deflected.

Results. Biomechanical testing demonstrated in all instances that the polyaxial head coupling to the screw was the first failure point. Although there have been subtle design differences in the instruments over time, the features of the pedicle screw instrument sets have become remarkably similar.

Conclusions. Biomechanical pedicle screw load-to-failure data demonstrated that the polyaxial head coupling to the screw is the first to fail and may be a protective feature of the pedicle screw, preventing pedicle screw breakage. Knowing the physical characteristics of the available pedicle screw instrumentation systems may allow the choice of pedicle screw best suited for a given clinical situation. [Key words: biomechanics, equipment design, pedicle screws, spinal fusion/instrumentation, surgery] **Spine 2003;28:470–473**

Polyaxial heads have made the pedicle screw more versatile, particularly improving ease of connecting rod application. Clinically, the senior author has observed that the incidence of broken pedicle screws has diminished over the past several years coincidentally with the usage of polyaxial screws. A hypothesis was developed to explain the decreased breakage of pedicle screws. It may be that there is a subtle loosening or failure of the polyaxial head that removes some of the stress from the pedicle screw. By decreasing the stiffness in the coupling of the polyaxial head to the pedicle screw, the bending stresses on the pedicle screw would be lessened. A MEDLINE search showed no biomechanical evidence in the English spine literature regarding the testing of polyaxial screws. In addition, polyaxial-headed pedicle screw load-to-failure testing has not been subjected to a comparison study.

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Methods

Nine pedicle screw systems were evaluated: the Silhouette (Sulzer Spine-Tech, Minneapolis, MN), Blackstone (Blackstone Medical, Springfield, MA), Click-X (Synthes, Paoli, PA), Xia (Stryker-Howmedica, Warsaw, IN), M8 (Sofamor-Danek, Memphis, TN), Miami-MOSS, Monarch, and Magnum (Depuy-AcroMed, Cleveland, OH), and the SD-90 (Surgical Dynamics, Memphis, TN). Not all of the commercially available pedicle screws were available for testing. The screw lengths were standardized at 45 mm, and the diameters varied from 6 to 7.5 mm.

Each tested screw was mounted perpendicularly on the appropriate rod provided by the vendor at the manufacturer's recommended torque settings. The distal half of the screw body was potted in the shape of a ceramic cylinder to enhance contact with the MTS machine. Testing was performed with a materials testing system (Model 1321; Instron, Canton, MA) (Figure 1). The MTS force was applied at a point 30 mm from the rod perpendicular to the long axis of the screw. The MTS compressed the screw at a load rate of 100 N/second until failure occurred. The load failure value was the force at which the pedicle screw initially deflected or uncoupled from the polyaxial head.

Results

The geometry of the coupling between the screw and head shows a conforming hemispherical interface that allows for polyaxial motion of the head on the screw. The fixation of the polyaxial head to the rod is with an internal screw, external nut, or both, pushing the rod into the slot of the head. The Silhouette has an external nut securing the rod into the head of the screw, whereas the Miami MOSS and the Magnum have an inner screw head and an external nut both securing the rod into the screw head. The other five systems have an internal screw device securing the rod to the pedicle screw head. To gain

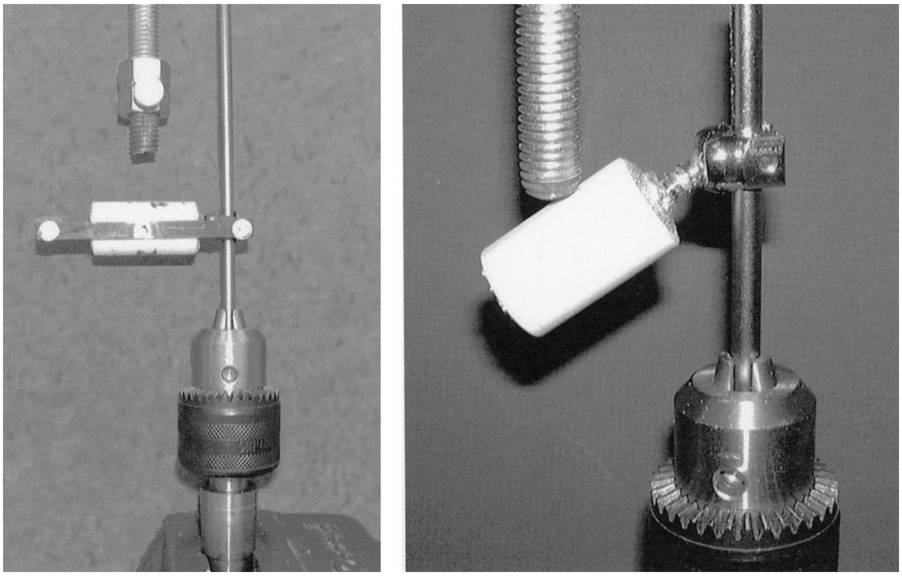


Figure 1. Setup of the Instron MTS. The pedicle screw is encased in a ceramic cylinder, and the rod construct is held in a large chuck in a vise. The screw then is compressed at a load rate of 100 N/second until failure occurs.

final fixation, all the screws and nuts require torque to specified levels except the Surgical Dynamics SD-90. The SD-90 has a helical wedge that requires only a 90° turn of the inner screw to gain the final fixation. The Monarch also has a dovetail top with a center screw that locks the head to the rod.

The Silhouette had the lowest mean failure load of 213 N, whereas the Magnum was the highest at 486 N. The full results from load-to-failure testing of the pedicle screws are shown in Table 1. Figure 2 shows that the statistical differences ranged from a P of 0.13 to a P of 0.0009. The statistical power was limited in some cases by the small sample size.

Discussion

Pedicle screw systems have undergone continual modifications over the past several years. As recently as 1 to 2 years ago, there were substantial differences in the design features of these sets. However, the systems have evolved to match the strengths of each other such that there currently are very few differences between instrument sets (Table 2). There have been design changes in the screws themselves. The crosslink systems have been updated, and there currently is a wide selection of screw diameters, lengths, and sizes of cross-links. Two of the systems do offer more than one rod diameter.

The results from the load-to-failure testing of the polyaxial pedicle screws demonstrates that the weakest point of the construct is the head-to-screw coupling (Table 1 and Figure 2). This failure of the polyaxial head may be a protective factor for the pedicle screw shaft, preventing early breakage.

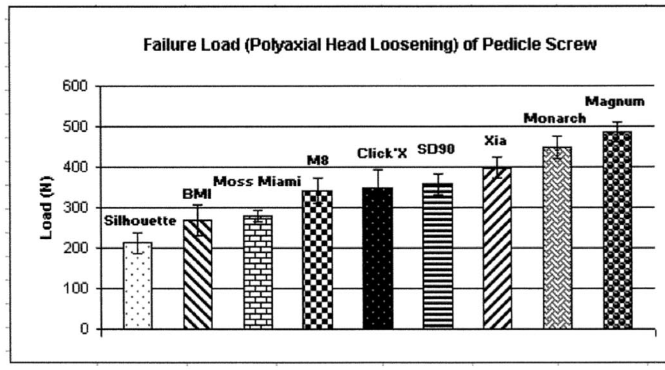
The polyaxial head has three tasks: 1) to secure the rod to the head, 2) to prevent the head from deforming in diameter, and 3) to secure the polyaxial head to the pedicle screw. The outside nut, pin-nut, helical or dovetail wedges, and thicker walled polyaxial head are designed to prevent the head from deforming. The inner screw locks the rod in the head and the head to the screw. The helical wedge actually can do all three tasks with one locking device. All pedicle screw heads have some method to stabilize the diameter of the head and a method to hold the rod in the head. The single outside nut–locking mechanism was statistically weaker than any other design.

Biomechanical tests of pedicle screw constructs have demonstrated the fundamental importance of the bone implant interface, bone density, and screw pullout strength.[4,5,7,9,11,12,15,16] The essential need for fit and fill of the screw in the isthmus of the pedicle has been proved.[7,15] The direct relation between pullout strength and insertional torque has been well demonstrated,[5,6] and the fundamental improvement in pullout strength obtained by cross-linking has been documented.[14] The stabilizing influence of using converging screws has been shown.[1] The major diameter of a pedicle screw has been shown to control pullout strength.[2,3] Bicortical purchase increased pullout strength fundamentally both in individual vertebrae and in the sacrum. However, bicortical

Table 1. Load to Failure of Polyaxial Head of Pedicle Screw

Screw System	Mean (N)	SD	Screw Diameter (mm)
Silhouette	213.21	25.71	6.5
BMI	268.88	38.06	6.5
Moss Miami	280.02	13.31	6
M8	340.57	31.18	6.5
Click’X	349.54	42.53	7
SD90	357.99	25.44	6.75
Xia	397.72	25.5	7.5
Monarch	447.67	28.38	7
Magnum	486.24	24.05	7

SD = standard deviation.



Statistical Analysis (One Way ANOVA)

	Silhouette	BMI	Moss Miami	M8	Click'X	SD90	Xia	Monarch	Magnum
Silhouette		p=0.13	p=0.016	p=0.005	p=0.008	p=0.002	p=0.0009	p=0.0004	p=0.0002
BMI			p=0.65	p=0.101	p=0.121	p=0.048	p=0.018	p=0.008	p=0.0039
Moss Miami				p=0.036	p=0.054	p=0.009	p=0.002	p=0.0007	p=0.0002
M8					p=0.782	p=0.495	p=0.069	p=0.012	p=0.003
Click'X						p=0.782	p=0.167	p=0.029	p=0.0084
SD90							p=0.128	p=0.015	p=0.0032
Xia								p=0.086	p=0.012
Monarch									p=0.147
Magnum									

Figure 2. Comparison of load-to-failure data for nine pedicle screw systems.

Table 2. Pedicle Screw Sets Characteristics

	Screw Diameter (mm)	Rod Diameter (mm)	Screw-rod Locking Mechanism
Danek CDH	4.5, 5.0, 5.5, 6.5, 7.5, 8.5	4.5, 5.5, 6.35	Inner set screw, Buttress thread
Surgical Dynamics SD-90	4.75, 5.75, 6.75, 7.75, 8.75	5.5	Twisting saddle nut
Depuy Miami-MOSS	4.35, 5.0, 6.0, 7.0, 8.0	5.0, 5.5, 6.35	Inner pin nut in 5.5 mm diameter rod.* Inner and outer nut for 5.0 and 6.35 mm rod
Monarch	4.75, 5.5, 6.25, 7, 7.75, 8.5	5.5	Dove tail cap with prethreaded set screw
Magnum	6-7-8	6.35	Inner set screw and Outer nut
Blackstone	4.5, 5.5, 6.5, 7.5, 8.5	5.5	Inner set screw
Spine-Tech Silhouette	4.5, 5.5, 6.5, 7.5, 8.5	5.5	Outer nut
Synthes Click-X	5.2, 6.2, 7.0, 8.0, 9.0	6.0	Inner set screw
Stryker XIA	4.5, 5.5, 6.5, 7.5, 8.5	6.0	Inner set screw, Buttress thread

* Currently the Miami Moss 5.5 Titanium system uses the pin nut, while 5.0 and 6.35 mm rods in both steel and Titanium use the inner screw and outer nut locking mechanism.

purchase, except at the sacrum, has not been widely adopted by surgeons because of the risk for vascular injury.[8,10,13] Nevertheless, bicortical sacral purchase has been proved extremely safe and has gained widespread acceptance.[8,10,13]

Biomechanical testing of the load characteristics of the polyaxial pedicle screw was not reported in the literature reviewed for this study. This testing has further detailed the biomechanical characteristics of the polyaxial pedicle screw. The results of this testing demonstrate a range of load tolerances for the various systems. Although the testing does show that some polyaxial pedicle screws are stronger, it is important to note that it is not clear whether a stronger coupling of pedicle screw to head is better. There may be instances in which more or less rigid fixation is preferable. Further study is needed to investigate the physical properties and their clinical application.

■ Conclusions

Biomechanical pedicle screw load-to-failure data demonstrated that the polyaxial head coupling to the screw was the first failure point and may be a protective feature of the pedicle screw and rod, preventing pedicle screw or rod breakage. Knowing the physical characteristics of the available pedicle screw instrumentation systems may allow the choice of pedicle screw best suited for a given clinical situation.

■ Key Points

- The polyaxial head coupling of the pedicle screw is the first feature to fail.
- This may protect the pedicle screw from breaking.
- There is a wide range of pedicle screw construct failure loads.

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