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Pedicle Screws With High Electrical Resistance

A Potential Source of Error With Stimulus-Evoked EMG

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Study Design. Clinically relevant aspects of pedicle screws were subjected to electrical resistance testing.

Objectives. To catalog commonly used pedicle screws in terms of electrical resistance, and to determine whether polyaxial-type pedicle screws have the potential to create a high-resistance circuit during stimulus-evoked electromyographic testing.

Summary of Background Data. Although stimulus-evoked electromyography is commonly used to confirm the accuracy of pedicle screw placement, no studies have documented the electrical resistance of commonly used pedicle screws.

Methods. Resistance measurements were obtained from eight pedicle screw varieties (5 screws of each type) across the screw shank and between the shank and regions of the screw that would be clinically accessible to stimulus-evoked electromyographic testing with a screw implanted in a pedicle. To determine measurement variability, resistance was measured three times at each site and with the crown of the polyaxial-type screw in three random positions.

Results. Resistance across the screw shank ranged from 0 to 36.4 ohms, whereas resistance across the length of the monoaxial-type screws ranged from 0.1 to 31.8 ohms. Resistance between the hexagonal port and shank of polyaxial-type screws ranged from 0 to 25 ohms. In contrast, resistance between the mobile crown and shank of polyaxial-type screws varied widely, ranging from 0.1 ohms to an open circuit (no electrical conduction). Polyaxial-type screws demonstrated an open circuit in 28 of 75 measurements (37%) and a high-resistance circuit (exceeding 1000 ohms) in 5 of 75 measurements (7%).

Conclusions. Polyaxial-type pedicle screws have the potential for high electrical resistance between the mobile crown and shank, and therefore may fail to demonstrate an electromyographic response during stimulus-evoked electromyographic testing in the setting of a pedicle breech. To avoid false-negative stimulus-evoked electromyographic testing, the cathode stimulator probe should be applied to the hexagonal port or directly to the screw shank, and not to the mobile crown. [Key words: EMG, implant, lumbar, neurophysiology, pedicle, spine] **Spine 2002;27:1577–1581**

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Pedicle screw systems have become an accepted adjuvant to spinal reconstructive surgery. The vertebral pedicle is the strongest site for fixation and allows correction and maintenance of the spine in an optimal position, improving the rates of successful fusion.[22] The vertebral pedicle, however, is intimately associated with the adjacent neural elements, and thus leaves little margin for error with pedicle screw placement. Pedicle screw insertion is a technically demanding task with a steep learning curve.[9,18,22,25,28] Misplacement of a pedicle screw implant can result in neurologic injury or pain.[7] Cadaveric studies have demonstrated rates of malpositioned screws as high as 21%.[23] In clinical studies, irritation or injury of adjacent nerve roots has been reported in 1.6% to 5% of cases.[4,9,25,28] For this reason, a variety of techniques have been developed to detect pedicle wall violation and prevent pedicle screw misplacement.[1,6,15,17,24]

Stimulus-evoked electromyographic (stEMG) monitoring has emerged as one of the most clinically useful means for detecting a pedicle wall violation.[2–4,12,15,20,24,26] The primary principle underlying stEMG monitoring is that cortical bone has a high resistivity (low conductivity) to electrical current flow, whereas soft tissue has a low electrical resistivity. To perform stEMG monitoring, a simple circuit is created by applying a voltage potential between a stimulating cathode (used to stimulate the inner surface of the pedicle) and an anode, usually a needle electrode placed in exposed paraspinal muscle on the contralateral side. The body tissue provides a current path between these two respective electrodes. When the pedicle wall is intact, the high electrical resistivity of cortical bone will diffuse the current flow throughout the bone. Thus, the flow of current reaching an adjacent spinal nerve root will be at a level below that required to provoke depolarization. If, on the other hand, there is a break in the bony pedicle wall, sufficient electrical current will flow through the soft tissue adjacent to the pedicle to cause depolarization of a nearby nerve root. Such depolarization will result in contraction of muscle tissue supplied by the stimulated nerve root, which is easily recorded as a compound action potential using commercially available EMG instrumentation.

This stEMG monitoring paradigm has been widely used as a simple, rapid method for detecting pedicle violation when metallic pedicle screws are implanted. Several important factors, however, have been identified that interfere with the conduction of electrical current or elevate the nerve root depolarization threshold, and may lead to an erroneous stEMG testing result. Neuromuscular blocking agents have been shown to raise the thresh-

Table 1. Properties of the Pedicle Screws Used in This Study

Screw Manufacturer	Screw Type	Screw Material	Monoaxial or Polyaxial	Screw Size (mm)
Depuy Acromed Inc.	Isola	Stainless steel	Mono	7 × 40
Depuy Acromed Inc.	Moss-Miami	Titanium alloy	Poly	7 × 40
Medtronic Sofmor Danek Inc.	Multiaxial	Titanium alloy	Poly	7 × 40
Stryker Spine Inc.	Xia	Titanium alloy	Poly	7.5 × 40
Spinal Concepts Inc.	BacFix–Multiaxial	Titanium alloy	Poly	7 × 40
Spinal Concepts Inc.	BacFix–Flexible angle	Titanium alloy	Mono	7 × 40
Synthes Inc.	USS	Titanium alloy	Mono	7 × 40
Synthes Inc.	Click'x	Titanium alloy	Poly	7 × 40

old for nerve root stimulation and may produce a false-negative stEMG test.[5,14] In addition, chronically compressed nerve roots may have an elevated threshold for depolarization and thus fail to produce EMG activity within the standard stimulation voltages.[11] Both of these nonsurgical factors have the potential to diminish the sensitivity of stEMG, leading to a false-negative result in the setting of a pedicle wall violation.

Another possible variable that may lead to a false-negative stEMG result is high resistance of a pedicle screw implant. Electrical resistance is a property that impedes current flow and results in the dissipation of power. Resistance values can vary as a function of the material properties, size, or structural form of an object. Standard voltage thresholds commonly used in clinical stEMG monitoring assume a low or negligible resistance value for the pedicle screw implant. High resistance, on the other hand, will increase the voltage potential that must be applied to achieve current flow and thus stimulate and depolarize an adjacent nerve root in the setting of a pedicle wall breech. Clinically, the authors have observed that pedicle screw implants with mobile connections between the screw crown and shank, commonly referred to as polyaxial screws, may demonstrate high resistance values or even an open circuit when subjected to resistance testing.

This study aimed to measure and catalog the resistance values across clinically relevant regions of commonly used monoaxial- and polyaxial-type pedicle screw models. In addition, this study was intended to confirm whether there was indeed the potential for high electrical resistance between the mobile crown and shank of polyaxial-type pedicle screws that ultimately could cause failure of stEMG testing to detect a misplaced pedicle screw implant.

■ Methods

Direct current electrical resistance measurements were obtained from eight commonly used monoaxial and polyaxial pedicle screws with a commercially available Fluke multimeter (Model 12; John Fluke Manufacturing, Everett, WA). The specific screw types tested are listed in Table 1.

Five different screws of each type were selected for resistance testing. Resistance measurements were obtained by securing each screw in a nonconductive jig and placing alligator clip electrodes at specific locations so as to test the resistance across clinically relevant regions of the screw. Resistance was measured across the screw shank and across the length of the screw in the case of monoaxial screws, or across the screw shank, between crown and shank, and between the hexagonal port and shank in the case of polyaxial screws. The location of electrode placement is shown in Figures 1 and 2.

Each portion of the screw was tested three times. Between each screw measurement, the multimeter was zeroed (at the contact points of the anode and cathode electrode to ensure that a zero resistance value was obtained). The crown-to-shank measurements for polyaxial screws were obtained with the mobile crown in three random positions. The mobile crowns were not fixed in any way so that they would most closely simulate intraoperative testing conditions after implantation of the screw.

■ Results

Resistance values measured for the monoaxial and polyaxial screws are summarized in Tables 1 and 2. The shank resistance for all the tested screws fell within the range of 0 to 36.4 ohms. The proximal-to-distal resistance of the monoaxial screws had a range of 0.1 to 31.8 ohms, whereas the hexagonal port-to-shank resistance of polyaxial screws was found to range between 0 and 25 ohms. In contrast, the crown-to-shank resistance of the

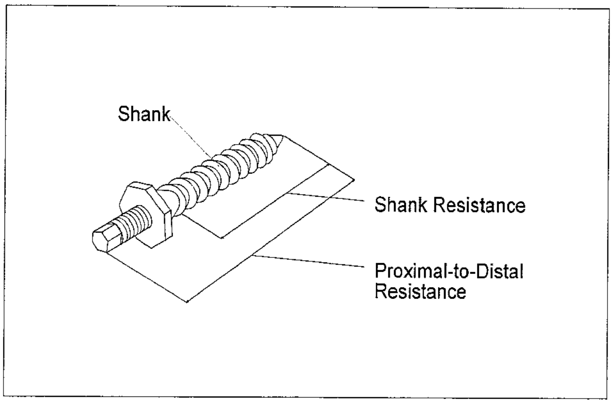

Figure 1. Diagram of a monoaxial pedicle screw showing the location of electrode placement during electrical resistance testing.

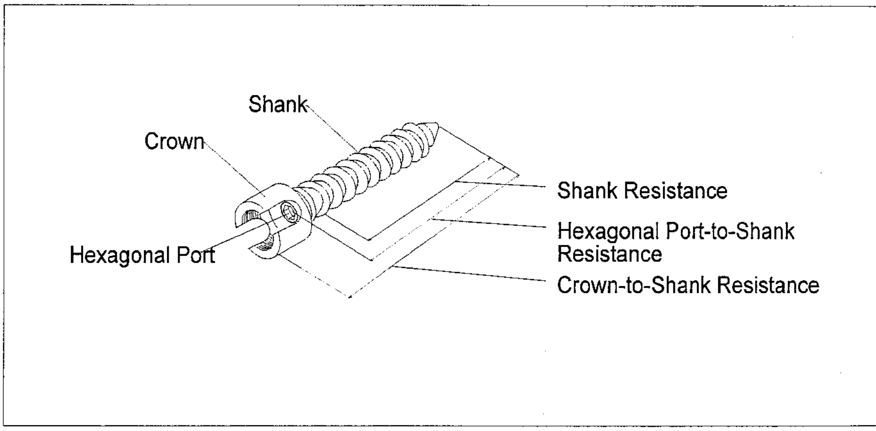

Figure 2. Diagram of a polyaxial pedicle screw showing the location of electrode placement during electrical resistance testing.

polyaxial screws demonstrated wide variability, ranging from 0.1 ohms to an open circuit (no electrical conduction). Overall, an open circuit was found with crown-to-shank resistance testing in 28 of 75 measurements (37%), and a high resistance circuit (exceeding 1000 ohms) was found in 5 of 75 measurements (7%).

■ Discussion

The rate of neurologic injury after pedicle instrumentation has been shown to be 0% to 15% in various studies.[4,9,13,18,24,25,26,27,28] To prevent nerve root injury, investigators have sought ways to ensure that pedicle screws are confined within the bony cortex of the pedicle. Based on the impedance differences between cortical bone (16,000 ohm/cm) and soft tissue,[10] Myers et al proposed using electrical impedence measurements to determine whether a pedicle implant is surrounded by intact cortical bone. In a porcine model, they found this technique to have an accuracy of 95%.[16] In a follow-up study on humans, however, Darden et al[6] were unable to correlate measured impedance with the presence of a pedicle wall breech.

Neurophysiologic monitoring has become standard for scoliosis surgery and has lowered the risk of catastrophic neurologic injury during deformity correction.[8,19,20,21] Calancie et al[2,3] was the first to describe the use of stEMG for the detection of pedicle integrity. First in a porcine model, and then in human testing, the technique was shown to have high sensitivity, specificity, and predictive value for detecting pedicle cortex fracture. Calancie et al[2,3] reported no clinical nerve root injuries, despite a 32% incidence of pedicle wall violation, in 18 patients receiving 102 pedicle screws.[3] Other investigators have subsequently validated the efficacy of stEMG testing for detecting improperly placed pedicle implants.[4,12,29]

Stimulus-evoked EMG testing for a pedicle breech depends on the ability of the pedicle implant to conduct an applied electrical current. Electrical conductance is the inverse of resistance and represents a measure of a material's ability to conduct electricity. The conductance of various materials is shown in Figure 3. Note that the conductance of stainless steel and of titanium alloy are similar, but lower than that of other common metals.

Both titanium and stainless steel screws tested in this study demonstrated relatively low resistance across all regions of the screw except across the mobile crowns. Certain screw models, such as the Synthes USS, the Synthes Click'x, and the Danek multiaxial, demonstrated more variability in resistance testing than other models (Table 3). This may be due to anodized coatings on these implants, which can variably impede the conductivity of electrical current between the applied electrode and the metallic core of the screw. Because an alligator clip electrode was used in testing of the implants, the authors do not believe that the observed variability was due to differences in contact pressure between the implant and electrode. However, excluding resistance across the mobile crown–shank connection, the highest resistance

Table 2. Resistance Data for Monoaxial Pedicle Screws

Manufacture/Screw Type	Test Trial	Shank Resistance of 5 Screws Tested ohms					Proximal-to-Distal Resistance of 5 Screws Tested ohms				
Depuy Acromed/Isola	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	2	0	0.2	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1
	3	0	0.2	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1
Spinal Concepts/Flexible Angle	1	0.1	0.1	0.3	0.3	0.1	0.5	0.5	0.1	0.5	0.6
	2	0.1	0.1	0.2	0.1	0.1	0.5	0.5	0.1	8.7	0.2
	3	0.1	0.1	0.2	0.1	0.1	0.4	0.4	0.3	2.6	0.3
Synthes/USS	1	1.4	0.7	5.5	2.4	4.2	0.9	5	2.4	31.8	17.2
	2	0.9	0.7	9.5	36.4	21.5	5.8	1.1	1.5	21.5	3.4
	3	1.8	1	4.2	2.6	6.2	20.1	0.9	1.2	8.4	2.7

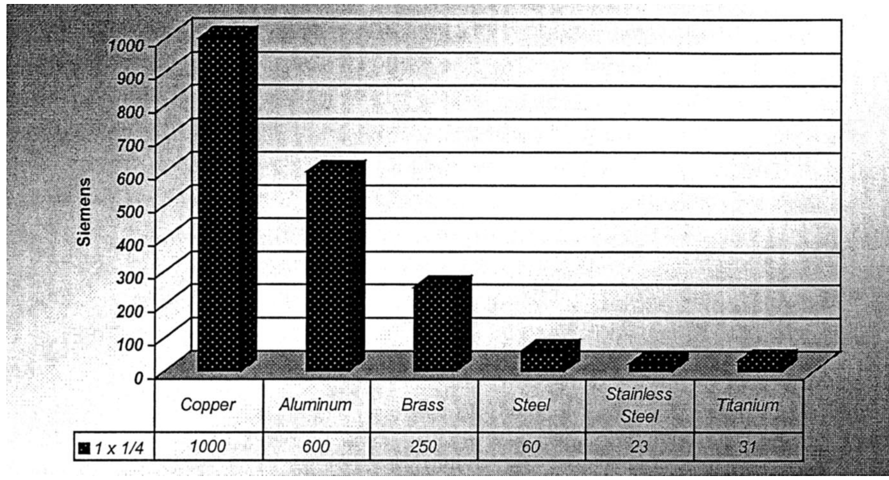

Figure 3. Conductance of common metals.

Table 3. Resistance Data for Polyaxial Pedicle Screws

Manufacturer/Screw Type	Trial	Shaft Resistance of 5 Screws ohms					Crown-to-Shank Resistance of 5 Screws ohms					Hexagonal Port-to-Shank Resistance of 5 Screws ohms				
DePuy Acromed/Moss-Miami	1	0.2	0.2	0.1	0.1	0.1	0.3	Open	5.5	2.6	0.2	0.3	0.4	0.3	0.4	0
	2	0.2	0.1	0.1	0.1	0.1	0.3	2	3.9	0.1	2	0.4	0.4	0.2	0.3	0
	3	0.3	0.1	0.1	0.1	0	0.6	Open	11	0.2	12	0.3	0.4	0.2	0.4	0.1
Sofmor Danek/Multiaxial	1	1.4	2.7	0.6	7.5	4	57	2.7M	Open	Open	Open	1.1	9.2	1.7	1.7	1.5
	2	0.2	4.7	1	1.1	1.9	7.9	17M	Open	Open	Open	1.3	19	2.5	2.1	1.9
	3	13	1.4	0.8	1.1	5.5	Open	Open	0.7K	Open	Open	1.8	18	2.5	25	1.6
Stryker/Xia	1	0.1	0	0.1	0.2	0.1	6.2	0.4	0.7	1.4	0.4	0	0	0.2	0.1	0.1
	2	0.1	0	0	0.1	0	0.4	0.9	0.3	4	1	0	0	0.2	0.1	0.1
	3	0.1	0	0	0.1	0	0.7	1.5	7	5.1	0.2	0	0	0.2	0.2	0.1
Spinal Concepts/BacFix Multiaxial	1	0.1	0.1	0.1	0.2	0.1	13	52K	Open	76	Open	0.5	0.4	0.2	0.5	2
	2	0.1	0.2	0.3	2	0.2	Open	Open	3M	Open	13	0.5	0.5	0.8	2.1	1.3
	3	0.1	0.3	0.1	0.1	0.1	Open	Open	21	Open	4	0.4	0.4	0.7	0.2	0.4
Synthes/Click'x	1	0.4	3.4	0.9	1.3	1.4	0.9	Open	Open	76	32	0.5	9.6	1.5	2.6	12
	2	0.4	2.9	1.2	0.5	0.4	94	20K	Open	.5K	Open	5.4	7.2	6.7	11	2
	3	0.3	3.3	1	1.2	1.1	Open	Open	35	Open	Open	6.4	2.5	1.4	4.5	1.2

measured was 36.4 ohms. This level of resistance is not clinically significant because most constant-current stimulators are able to provide adequate current flow for clinical accuracy up to a circuit resistance of at least 1000 ohms. However, circuit resistances greater than 1000 ohms may exceed the limits of accuracy for stEMG stimulators.[15]

This is the first study to demonstrate that the resistance of a pedicle implant can vary significantly if the testing electrode is applied to the mobile crown. In this study, the resistance varied from negligible to an open circuit (infinite resistance) depending on the position of the crown. High resistance apparently is the byproduct of poor contact between the crown and shank in certain positions. Unfortunately, the mobile crown is the most accessible site for stimulator placement during testing of an inserted screw, and thus may be used by surgeons unaware of the potential for a high-resistance circuit. Ultimately, this may lead to a false-negative result, with failure to recognize a misplaced screw. To avoid the possibility of false-negative testing results, the authors recommend testing polyaxial pedicle screws by applying the cathode stimulator to the hexagonal port or the screw shank and not to the mobile crown when stEMG is performed.[16,27,29]

■ Key Points

- Although pedicle screw resistance can vary, titanium and stainless steel screws demonstrate similar resistance values.
- Polyaxial-type pedicle screws may have very high resistance across the mobile connection between the crown and shank of the screw.
- In performing stEMG, stimulation of the mobile crown of a polyaxial-type pedicle screw may lead to false-negative testing results.
- The polyaxial-type pedicle screw should be tested by placing the probe in contact with the hexagonal port or directly with the screw shank.

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