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Basic Science

Primary stability of pedicle screws depends on the screw positioning and alignment

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Abstract

BACKGROUND CONTEXT: There is no universal consensus regarding the biomechanical aspects and relevance on the primary stability of misplaced pedicle screws.

PURPOSE: The study is aimed to the determination of the correlation between axial pullout forces of pedicle screws with the possible screw misplacement, including mild and severe cortical violations.

METHODS: Eighty-eight monoaxial pedicle screws were implanted into 44 porcine lumbar vertebral bodies, paying attention on trying to obtain a wide range of placement accuracy. After screw implantation, all specimens underwent a spiral computed tomography scan, and the screw placements were graded following the scales of Laine et al. and Abul Kasim et al. Axial pullout tests were then performed on a servohydraulic material testing system.

RESULTS: Decreasing pullout forces were determined for screws implanted with increasing cortical violation. A smaller influence of cortical violations in the medial direction with respect to the lateral direction was observed. Screws implanted with a large cortical violation and misplacement in the craniocaudal direction were found to be significantly less stable than screws having comparable cortical violation but in a centered sagittal position.

CONCLUSIONS: These results provide adjunctive criteria to evaluate more accurately the fate of a spine instrumentation. Particular care should be placed in the screw evaluation regarding the craniocaudal positioning and alignment.

Keywords: Pullout; Pedicle screw; Screw misplacement; Stability; Porcine

Introduction

The use of pedicle screws is widespread in spinal surgery for degenerative, traumatic, and oncological diseases and is considered a growing field of spine surgery. Many concerns are referred regarding the screw misplacement, as documented to the continuous research in technological innovation (ie, electrical conductivity measuring devices and image-guided surgery) [1–4] to reduce the rate of cortical violations. However, there is no universal consensus regarding both the definition and the classification of the position of the screws and the anatomo-biomechanical aspect of the misplaced screws. In fact, the current evaluation criteria for the results of an instrumented spinal fixation are a personal choice of the surgeon, mainly dictated by clinical evaluation and own experience.

The principal criterion for revision surgery in the presence of misplaced screw is the development of neurological deficit, which usually is recognized with pedicle perforation by at least 4 mm [5]. It is also well accepted that totally misplaced pedicle screws will lead to major stability

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problems. Loosening because of fatigue loading and screw breakage are commonly cited reasons for failure [6–8]. To date, biomechanical studies included parameters of analysis, dimension, and type of the screws, bony preparation (drilling or probing the pilot hole), coupling, angular insertion, and augmentation with bushings and poly(methyl methacrylate), whereas there are few studies that analyzed the biomechanical behavior of a misplaced screw. In particular, in case of minor to mild cortical violation, up to now there are no definitive data in literature about the stability behavior of screws. Using image-guided surgery, such as neuronavigation based on an intraoperative computed tomography (CT) scan (which actually is the tool providing the best results), the rate of these misplaced screws (<4 mm) is about 3% to 5% [4,9,10] that still represents a considerable number of implant worldwide.

To estimate the stability of misplaced screws with respect to correctly implanted screws, we performed a biomechanical study testing the axial pullout forces of pedicle screws placed in porcine lumbar vertebral specimens, implanted correctly or with both mild and severe cortical violations. The pullout forces were correlated with the position of each screw classified according to different CT-based classification systems.

Materials and methods

Specimen description, conservation, and preparation

Eighty-eight monoaxial self-tapping pedicle screws (Expedium 5.5 Monoaxial Screw SI: diameter 4.35 mm, length 30 mm; DePuy Spine, Raynham, MA, USA) were implanted into 44 porcine lumbar vertebral bodies. Once the entry point was recognized (lateral facet joint at the level of the junction of the base of transverse process), the superficial part of the cortical bone was removed with a rongeur to facilitate the direction control. We used an awl to prepare the entry point and prepared the initial part of the trajectory with a probe. A tap (regular Expedium—DePuy Spine instrumentation) was used to complete the trajectory of the pedicle. During this phase, the tap and later the screw itself were used carefully, especially when the cortical bone was violated, to avoid the fracture of the bone. To obtain a wide range of screw placements, we tried to implant the screws in various directions (superior, inferior, medial, lateral) in different combinations. However, the final screw positioning can be considered randomized.

After screw placement, all specimens underwent a spiral CT scan (SOMATOM Volume Zoom; Siemens Healthcare, Erlangen, Germany), and the screw placements were graded following the scales of Laine et al. [11] (Table 1) and Abul Kasim et al. [12] (Table 2).

To preserve mechanical properties of the biological specimens, all spines were kept in a freezer at a temperature of −20°C after implantation. Each spine was thawed 4 hours before testing (Fig. 1, Left), and each vertebral body was carefully cut to obtain two specimens comprising a screw and the surrounding biological tissues (Fig. 1, Middle).

Table 1
Grading scale of Laine et al. [11] and numbers of screws classified for each grade

Laine classification	Screws
Cortical violation	
0: no violation	30 (34%)
1: <2 mm	23 (26%)
2: 2–4 mm	10 (11%)
3: 4–6 mm	12 (14%)
4: >6 mm	13 (15%)
Position	
S: superior	15 (17%)
I: inferior	7 (8%)
M: medial	27 (31%)
L: lateral	24 (27%)

Testing setup

Tests were performed on an MTS 858 Bionix servohydraulic testing machine (MTS, Minneapolis, MN, USA). The testing machine was equipped with an axial-torsional hydraulic actuator, with 25 kN axial capacity and 250 Nm torsional capacity, respectively. The applied loads were measured by an MTS axial/torsional load cell (model 662.20D-05, ±25 kN maximum axial load, ±250 Nm maximum torsional load). Tests were conducted in air at room temperature (24°C±2°C).

Each specimen was cemented into an aluminum cylindrical pot assured to the inferior grip of the testing machine through a pin inserted in a threaded hole located in the center of its inferior face (Fig. 1, Right). A purposely made threaded pin was manufactured as to be gripped, on one hand in the upper jaw of the testing machine and on the other hand to be connected to the threaded house present in the head of the screw. Such a configuration guaranteed that each specimen was perfectly aligned to the vertical axis of the testing machine. The pin-specimen complex was

Table 2
Grading scale of Abul Kasim et al. [12] and numbers of screws classified for each grade

Abul Kasim classification	Screws
Axial plane	
A: normal	51 (58%)
B: medial cortical perforation, Grade 1	7 (8%)
C: medial cortical perforation, Grade 2	10 (11%)
D: lateral cortical perforation, Grade 1	8 (9%)
E: lateral cortical perforation, Grade 1	6 (7%)
F: lateral cortical perforation, Grade 1	6 (7%)
G: lateral cortical perforation, Grade 2	0 (0%)
H: lateral cortical perforation, Grade 2	0 (0%)
I: anterior cortical perforation	
Sagittal plane	
J: normal	66 (75%)
K: foraminal perforation	9 (10%)
L: perforation of the superior end plate	13 (15%)