A Biomechanical Model Simulating Proximal Pedicle Pullout with Long Fusion Spinal Hardware

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Disclosures:

Introduction: Proximal pedicle screw pullout is a commonly observed clinical occurrence after long fusion hardware implantation. Recent novel spinal hardware and surgical techniques have been developed to alleviate this complication [1]. Current methods, such as multiaxial bending moment range-of-motion testing [2] do not consistently replicate this failure modality. Additionally no biomechanical model currently exists to accurately replicate this mode of failure in vitro to adequately evaluate new strategies under rigorous laboratory testing. Standard pure moment loading and range of motion testing do not consistently reproduce this failure modality [3][5]. Additionally, the majority of proximal pedicle screw pullouts have been observed clinically, outside the laboratory setting [3]. It is hypothesized that a combination of anterior-posterior (AP) shear, compressive force, and flexion moment is required to induce screw pullout with clinically similar fatigue patterns. The goal of this preliminary study is to develop a biomechanical model to consistently replicate clinically observed proximal pedicle screw pullout.

Methods: Testing was conducted using a custom-built adjustable slide angle shear plate and custom variable-length moment arm fixture fixed at the cranial aspect of each specimen (Figure 1). Proximal AP shear was induced by modulating compressive angle from 0 - 50 degrees; proximal moment was induced by modulating moment arm from 0 - 80 mm. Two cadaver spines (T12-L4) implanted with bilateral posterior fusion hardware (from L1 to L4) underwent fatigue testing under (A) 10 Nm flexion and (B) 20 Nm flexion moment, 0 - 400N AP shear for 10,000 cycles. Fatigue testing was conducted under a mean 200N compressive load with amplitude of 200N and testing frequency of 1 Hz. Bilateral fusion hardware was potted caudally with the specimens. Proof testing and x-ray imaging were used to test for proximal pedicle screw pullout every 1,000 cycles. Proof testing consisted of decoupling the pedicle screw from the fusion rod to allow any posterior axial translational movement. The screw was then attached to a Mark 10 2DOF load cell and pulled to 20N to test screw purchase and surrounding bone integrity. X-rays were obtained of both the unloaded and loaded screw with surrounding spine using a Philips BV Pulsera C-Arm. Pullout was evaluated at an axial displacement of 1 pitch length relative to the specimen and was identified under x-ray imaging. Windshield wiper was considered to be any observable transverse sagittal motion relative to the spine under 20N transverse loading and similarly observed under real-time x-ray image streaming. Specimens (Specimens (C), (D), and (E)) and relevant data from a previous experiment [6] was additionally included with this study and had been subjected to a different fatigue protocol. Testing was conducted with a 1:10 min:max compression ratio and 1:1 compression:shear ratio at 2 Hz. Specimens then underwent step-wise compression from 250 - 600N in 50 - 100N increments every 10,000 - 30,000 cycles.

Results: For this study, fatigue loading conditions for both (A) and (B) resulted in loss of purchase and windshield wiper. Specimen (A) experienced loss of purchase and windshield wiper after 6,000 cycles at 400N (Figure 2). Specimen (B) lost purchase following 2,000 cycles, exhibiting additional 2nd proximal and 3rd proximal screw windshield wiper after 3,000 and 4,000 cycles, respectively. From [5], Specimen (C) exhibited proximal screw pullout after 837 cycles at 600N and prior fatigue loading. Specimens (D) and (E) did not exhibit pullout under fatigue loading conditions until _ cycles runout. Specimen (D) exhibited significant 40,000 cycles at 800N. Specimen (E) was tested for 220,000 cycles and only exhibited pullout and loss of purchase at 800N.

Discussion: Comparing results from the present study and [6] indicate proximal pedicle pullout can be replicated in vitro by a combination of AP shear and moment (approximately a 20:1 AP shear:moment ratio in this preliminary study, given 400N compressive load on the specimen). Two of the two (100%) specimens undergoing joint AP shear and moment fatigue loading in the present study exhibited loss of purchase and windshield wiper. Specimen (B) further demonstrated this order of failure to occur proximally to distally under further cycling, replicating clinically observed patterns of failure. By comparison, only one of the three (33%) specimens undergoing AP shear and moment loading in [5] exhibited loss of purchase, indicating that a high AP shear:moment ratio (heavily shear-dominated ratio) is capable of producing screw pullout, but not necessarily consistently. The failure modality observed in specimens (A) and (B) support the hypothesis that an approximately 20:20:1 compression:shear:moment ratio can consistently replicate proximal pedicle screw pullout in 3-level lumbar spines with bilateral posterior fusion hardware. Future biomechanical model studies will conduct fatigue testing over a larger sample size and focus on inducing a pure shear to isolate the contribution of shear to proximal pedicle screw pullout and loss of purchase.

Significance: The present study suggests that a combination of anterior-posterior shear and moment are required to reproduce
clinically observed proximal pedicle pullout and presents a biomechanical loading model capable of reproducing proximal pedicle screw pullout. These results provide an instrumental in vitro testing basis for developing novel spinal hardware to reduce the probability and occurrence of proximal pedicle screw pullout.

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