Comparing the Fixation of a Novel Hollow Screw Versus a Conventional Solid Screw in Human Sacra Under Cyclic Loading

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Introduction: Pedicle screw loosening in the sacrum is a clinically significant mode of failure. Others have previously shown a novel hollow screw to have superior pullout strength when inserted into the trabecular bone of non-sacral bodies.1 With regards to sacrum testing, several studies have examined the axial pullout capabilities of solid pedicle screws,2,3 but only one is known to have employed cyclic flexion-extension loading.4 The purpose of this study was to determine if a novel hollow screw placed in the S1 pedicle would be more resistant to loosening than a similarly placed solid pedicle screw under cyclic loading.

Materials and Methods: Six fresh-frozen cadaveric sacra (age 72±4 years) were obtained, stripped of soft tissues, and scanned for bone mineral density using quantitative CT. Using a standard posterior technique and fluoroscopic guidance, a solid 7.5x35mm Xia® monoaxial screw was placed in one S1 pedicle and a hollow 10x34mm Aesculap® MACSTL HMA screw was inserted contralaterally in each specimen.

Each sacrum was potted in a custom-designed fixture, and a standard connecting rod was secured to both the screw and to the actuator of a materials testing machine via a ball joint (Figure 1). The distance between the actuator and the screw was 40mm. A sinusoidal loading pattern (1Hz) was used. As this alternating tension-compression load was applied to the rod, the screw was subjected to corresponding flexion and extension bending moments. Flexion moments started at 0.5Nm for the first 1000 cycles and increased by 0.5Nm every 1000 cycle steps until the screw had visibly failed. Extension moments were maintained at 0.5Nm throughout the entire testing protocol. Beads fixed to the rod and the sacrum were used in conjunction with a custom optical tracking system (Camera: Sony DFW-SX910, Japan, Software: Labview Vision Acquisition, National Instruments, TX) to record screw rotation (flexion) relative to bone at 7.5Hz.

The two screws in each specimen were tested independently in a randomized order. Both the magnitude of the applied flexion moment and the required number of loading cycles to cause loosening were analyzed using two-way repeated measures ANOVAs (factors were screw type and degree of screw rotation), followed by post-hoc Student-Newman-Keuls tests with α=0.05.

Results: Visible failure of the screw occurred at 6° of screw rotation relative to bone; thus, the relative screw performances were analyzed at both 3° and 6° of rotation. Overall, the hollow screw required fewer loading cycles (p=0.004) and less applied moment (p=0.003) to achieve the same magnitude of screw rotation as the solid screw. For example, to achieve 6°, the number of loading cycles were 6301±2316 and 11151±4221 for hollow and solid screws, respectively. The corresponding applied flexion moments were 3.5±1.0 Nm and 5.8±2.0 Nm.

Discussion: Lumbar sacral fusion is a common treatment for a variety of spinal conditions including degenerative, traumatic, and deformity pathology.5 High failure rates due to inadequate fixation at the pedicle screw-bone interface are a significant problem for the long-term success of this procedure, particularly following longer lumbar constructs terminating at the sacrum.6 The majority of previous research to examine pedicle screw failure in the sacrum has employed axial pullout for inducing failure. While this method provides valuable comparison data, it is not indicative of the mode of failure seen clinically with screw loosening via the toggle effect. Law et al. showed that cyclic caudo-cephalad toggling creates loosening similar to that of the clinical situation.7 Their method has been adapted in the current model to emphasize the flexion moments, which would typically be larger in long spinal constructs.

Bone mineral density scans showed that the specimens used in the present study were mostly osteoporotic. Due to the repeated-measures design of this study, however, this was not a concern. This also represents the worst-case scenario for fixation.

It had been hypothesized that the hollow screw would perform superiorly to the solid screw in this model due to increased contact with trabecular bone, but the opposite proved to be true. Schramm et al. showed that the HMA hollow screw provided results comparable to a bicortical fixation pedicle screw in an axial pullout test; however, the current study used a more clinically viable failure method in showing the hollow screw to be less effective. The present results are supported by those of Ferguson et al., who also found the hollow screw to be ineffective under cyclic conditions.8 They found the hollow screw experienced excessive displacement in the vertebral body, and had two cases of hollow screw fracture. The current findings would agree with their recommendation to use caution when applying the hollow screw clinically.

In conclusion, the novel hollow screw was less resistant to loosening when compared to a conventional solid pedicle screw in this sacral model under cyclic loading.


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Figure 1: Cyclic loading experimental test apparatus. INSET: (A) Solid screw, (B) Hollow screw.

APPARATUS: (C) Ball joint connected to the actuator of the Instron® materials testing machine, (D) Connecting rod between ball joint and screw, (E) Optical tracking beads (2 on rod, 2 on bone), (F) Sacrum potted in Denstone™ cement with superior portion exposed.