Fatigue Behavior of Cortical Versus Traditional Pedicle Screws in a Paired Cadaveric Model of Severe Lumbar Instability

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INTRODUCTION:

Cortical bone trajectory (CBT) screw fixation has emerged as a promising alternative to traditional pedicle screws (TPS) for lumbar spinal stabilization, offering potential advantages including smaller incision requirements, reduced muscle dissection, and stronger cortical purchase. While several biomechanical studies have explored insertional torque, construct stiffness, and pullout strength, most comparisons between CBT and TPS constructs have relied on static loading paradigms. Clinical reports of early failure, particularly following interbody reduction maneuvers or in osteoporotic bone, raise concerns about the cyclic durability of CBT screws. There remains limited in vitro data examining how CBT constructs behave under repetitive physiologic loading in scenarios that reflect severe segmental destabilization. The goal of this study was to directly compare CBT and TPS fatigue behavior using a cadaveric model simulating anterior column deficiency and dynamic flexion-compression loading.

METHODS:

L2-L3 and L4-L5 motion segments were harvested from seven fresh-frozen human cadaveric lumbar spines (mean age 67 ± 5 years). Each spine underwent dual-energy X-ray absorptiometry (DXA) to quantify bone mineral density (BMD). A paired design was used such that one level was instrumented with CBT screws and the other with TPS screws using fluoroscopic guidance. All screws were 5.0 mm diameter polyaxial screws of equal length (35 mm) to minimize construct variability. Segments were potted in PMMA with custom screw placement to allow unconstrained rotation and simulate flexion-compression moments.

Specimens were tested in three states: intact, destabilized and instrumented, and post-cyclic. Destabilization involved bilateral facetectomy and subtotal discectomy with removal of the anterior longitudinal ligament, mimicking a high-grade spondylolisthesis scenario. Each segment underwent static anterior offset loading (750 N with 10 mm anterior bias), followed by 50,000 cycles of dynamic loading between 200-750 N at 2 Hz. Motion tracking was performed using an optical 3D system. End-range flexion stiffness and range of motion (ROM) were extracted from moment-angle curves during static loading. Failures were classified based on the cycle of occurrence and mode of failure, and surviving constructs were retested post-cyclic. Statistical analyses used Wilcoxon signed-rank tests and Spearman correlation for stiffness, ROM, and BMD associations.

RESULTS:

All 14 motion segments completed intact and instrumented testing. Following cyclic loading, 6 of 14 specimens failed prematurely (3 CBT, 3 TPS), resulting in 8 post-cyclic constructs. No significant difference in survival was observed ($p = 0.71$), although CBT constructs trended toward higher cycle resistance (mean 19,500 ± 13,026) compared to TPS (5,625 ± 6,419). Failure mechanisms differed between groups. TPS constructs failed via screw toggling or vertebral fractures near the screw tip, while CBT failures were more variable, including pedicle fracture, cutout, or toggling.

In the intact state, CBT and TPS constructs did not differ significantly in flexion stiffness (5.2 ± 2.5 Nm/deg vs. 3.4 ± 0.8 Nm/deg, $p = 0.156$) or ROM (3.7 ± 2.3° vs. 4.6 ± 1.5°, $p = 0.297$). After instrumentation, CBT constructs showed significantly reduced ROM (3.6 ± 1.4° vs. 5.4 ± 1.9°, $p = 0.047$), with similar stiffness values (2.8 ± 1.3 Nm/deg vs. 2.1 ± 0.9 Nm/deg, $p = 0.219$). Post-cyclic testing revealed increased stiffness in both groups: CBT rose to 6.5 ± 3.2 Nm/deg, TPS to 4.0 ± 1.0 Nm/deg. Correlation analysis revealed that stiffness positively correlated with BMD ($\rho = 0.65$, $p = 0.011$) and negatively with ROM ($\rho = -0.72$, $p = 0.004$).

DISCUSSION AND CONCLUSION:

This study presents the first direct comparison of CBT and TPS fatigue behavior in a paired cadaveric model of severe lumbar destabilization. Under physiologically relevant cyclic flexion-compression loading, CBT constructs demonstrated comparable survival and stiffness to TPS constructs. Although not statistically significant, CBT constructs withstood more cycles and failed via more diverse mechanisms, suggesting greater resistance to early failure but potential vulnerability to surgical technique or bone quality. The increased ROM restriction observed in CBT-instrumented segments may reflect the medialized and upward screw trajectory, which alters the instantaneous axis of rotation and provides enhanced anterior column constraint.

These findings emphasize that CBT screws are not inherently inferior but may be more technically sensitive. While CBT constructs performed robustly when properly placed, deviations in trajectory or suboptimal cortical purchase may predispose to failure. Spine surgeons considering CBT should account for this technical nuance, especially in cases of poor bone quality or complex reductions.

Our model offers a controlled and reproducible method to simulate clinical fatigue conditions in high-grade instability, and future work should build upon this design to incorporate interbody devices and assess multilevel constructs. This study supports the mechanical viability of CBT constructs under demanding cyclic conditions, contributing valuable evidence to guide construct selection in challenging lumbar pathology.