

Monitoring the Mechanical State of Lumbar Fusion Constructs with Rod-Mounted Strain Sensors and Sensor-integrated Interbody Cages

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Introduction

Lumbar interbody fusion is an established treatment for spinal pathologies. However, postoperative complications such as pedicle screw loosening and cage subsidence may occur. Conventional radiography or CT is typically symptom-driven, affected by implant artifacts, and shows limited sensitivity for early loosening and substantial interobserver variability. Sensor-equipped implants may enable continuous, objective inference of the construct's mechanical state. We therefore investigated whether progressive fusion and common mechanical complications can be detected in vitro through changes in rod and cage sensor outputs.

Materials and Methods

Twelve lumbar spinal segments (T12/L1, L2/3, L4/5; six fresh-frozen cadavers) were instrumented with four pedicle screws, two fixation rods equipped with rod-mounted strain sensors, and a posterior lumbar interbody fusion cage integrating two load cells. Specimens underwent cyclic uniaxial compression (150–1000 N, 1 Hz). Screw loosening was simulated by stepwise reduction of screw diameter. Cage subsidence was induced by cranial endplate disruption. Fusion progression, including facet fixation, intervertebral PMMA fusion, and anterior bridge fusion, was simulated sequentially. Cage load, rod sensor strain, and segment axial stiffness were compared between conditions.

Results

Rod-mounted sensors detected consistent changes across all conditions. Without additional interventions, rod output decreased by 4.1% and a further 22.2%, while cage load increased by 11.5% and 3.4% after low- and high-level screw loosening, respectively (n=12). Cage subsidence increased rod output by 60.2% and decreased cage load and axial stiffness by 51.5% and 12.3%, respectively (n=6). During simulated fusion, rod sensor output decreased by 13.7%, 33.1%, and 12.9%, and cage load decreased by 3.4%, 48.6%, and 18.5% after facet, intervertebral, and bridge fusion, respectively (n=6). Rod sensors successfully detected 85% (41/48) of selected interventions versus 69% (33/48) for cage sensors.

Conclusion

Rod-mounted sensors provided consistent detection of screw loosening, cage subsidence, and fusion progression. Cage force sensing added complementary information, particularly for subsidence and fusion-related changes. These findings support the potential of instrumented spinal implants for objective monitoring of implant function and fusion progression.