The Effect of Posterior Spinal Instrumentation on the Stability of Inter-Body Fusion Cages under Cyclic Loading

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Introduction: Compared to conventional posterolateral fusion methods, interbody fusion using interbody cages for transforaminal lumbar interbody fusion (TLIF) or posterior lumbar interbody fusion (PLIF) approach offers preservation of disc space height, anterior column support, increased foraminal area and improved restoration of lumbar lordosis leading to decreased incidence of “flat back syndrome”. Although use of pedicle screws has won wide-spread adoption, subsidence at the fused level and, in more severe cases, dislocation brachium through the endplates of the implants, remains a clinical concern. Over time, degradation of the cage-bone interface negatively affects mechanical stability, degree of distraction achieved for foraminal size and any correction of sagittal balance, thus adversely affecting the surgical outcome. This study investigated effects of cage design on the performance of three TLIF cage designs in human lumbar segments in response to a cyclic loading regime simulating functional loading regime likely to occur during the first few weeks post surgery.

Significance: This study demonstrated the dominant role of the posterior spinal instrumentation in determining the degradation profile of the interbody cage and vertebral bone under complex dynamic loading conditions.

Methods: Three cage designs, the Brantigan™, the Concord™ and the Leopard™ were compared (Fig 1). Nine cadaveric thoracolumbar (T12 to L4) human spines aged 43 to 72 years, were radiographed (Faxitron 43855A, HP, OR) to exclude pathology or evidence of structural deformity. Musculature tissue was dissected clean with the intervertebral disc, facet joints and all spinal ligaments preserved. The spine were segmented to obtain, T12-L1, L1-L2, L2-L3 and L3-L4 functional spinal levels and each level shallow embedded in cement using an alignment device. A lumbar interbody fusion procedure was performed in accordance to manufacture instructions (Fig 1), the pedicles of each vertebra instrumented with trapedicular screws (6mm, DePuy spine, Raynam, MA), intradiscal distractors used to achieve appropriate height restoration. Instrumentation was completed by securing vertical rods to the screws, compression impart to the interspace and the system secured.

Fig 1. Illustration of the cages compared for this study. All of the designs were manufactured from PEEK (DePuy Spine, Inc. Raynam, MA). The instrumented spines are shown for the Brantigan and Concord designs.

Mechanical testing: For each instrumented spine, a custom device secured to a hydraulic test system (DDC 4000, Interlaken, MN), Fig 2, was employed to find the instrumented spine center of rotation (CAR). Under force control, and spine was loaded to a value of 400N compressive force, followed by a half-sine load waveform (400 - 1200, R= 800N) under force control at a loading rate of 2Hz for the duration of 20,000 cycles. The test was terminated if either completed, or the system recorded a cross head displacement equal to 10mm.

Fig 2. Illustration of the testing device used for CAR and subsequent cyclic testing. A six degree of Freedom load cell (AMTI, MC-5, MA) was used to measure force and moment response with LabView (2009, NI, TX) used to record the output at 10Hz.

Analysis: The response of each cage was plotted at: 1, 10, 500, (1, 2, 5, 10, 15, 20) x10⁴ load cycles. Linear models were fitted to for the loading (-600N to -800N) and unloading (-800N to -1000N) phases to compute stiffness values of the cage-bone interface. Response Hysteresis was computed as the difference between the loading and unloading phases at mean value (-800N). Cage subsidence was computed from the difference between the maximum point of cage excursion into the bone at the first load cycle and successive load cycle used compute change in stiffness. Repeated Measure analysis was used to investigate the effects of cage design (in-between) and vertebral level (between), on the change in the load-displacement behavior of the cages and the degree of cage subsidence. Post hoc testing was used to compare for differences at each cycle # with statistical significance set at the 5% level.

Results: Independent of cage design, compressive compliance decreased significantly during the first 500 cycles, p<0.01. Fig. 3. Thereafter, the compressive compliance did not show statistically changes between consecutive sampled intervals with post-test comparisons revealing no statistically significant difference between the designs. Examining the compliance for the unloading response showed the Brantigan cage to demonstrate consistently a higher compliance in comparison to both the Concord and the Leopard designs (p<0.05). Fig. 3. Mirroring the compliance results, response hysteresis decreased significantly for the first 500 cycles, p<0.05, whilst changing little for the remaining cycles, p<0.05, Fig 4. No statistically significant differences could be found between the different cage designs. All cages were observed to subside at an accelerated rate during the initial 1000 cycles with the rate decreasing thereafter. Statistical comparisons revealed this difference to be statistically significant (p<0.01). Comparison between the cages, showed the Leopard and particularly, the Concord design, to appear to subside at a higher rate than that of the Brantigan cages. However, due to large variation in the measurement, no statistically significant differences could be observed.

Discussion: Despite the use of pedicle screws to augment interbody fusion systems, subsidence of interbody cages and failure of the cage-endplates interface remains a clinical concern. This study has shown that the use of posterior instrumentation renders the change in cage geometry and the location of the cage within the disc space, ineffective in reducing mechanical degradation of the cage-bone interface. Our result further demonstrates the relative inability of the posterior instrumentation to arrest the process of cage subsidence, supporting the clinical finding regarding the degradation of the cage-bone interface which adversely affects surgical outcome. These results suggests that to improve the performance of inter-body cages, the co-development of posterior instrumentation better able to support the cage-bone interface in response to complex loading may be required.

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