Prolonged microgravity degenerates biomechanical properties of the murine caudal intervertebral discs
+ BAILEY, JF; 1 CHENG, KK; 2 HARGENS, AR; 3 MASUDA, K; 1 LOTZ, JC
+1 Dept. of Orthopaedic Surgery, University of California, San Diego, CA; 2 Dept. of Orthopaedic Surgery, University of California, San Diego
jeffrey.lotz@ucsf.edu

INTRODUCTION:
Prolonged exposure to microgravity has adverse effects on the human intervertebral disc (IVD), causing low back pain during spaceflight and an increased incidence of post-spaceflight herniated nucleus pulposus (HNP). Cervical HNP incidence among an astronaut sample population was nearly 5-fold higher compared to a control population, while incidence of lumbar HNP was not significantly different. Theoretically, microgravity increases spinal injury risk by removing diurnal loading that expels IVD fluid that has been osmotically imbibed during bedrest. Discs freely swell throughout the entire flight, leading to increased disc height and spinal stiffness among astronauts.

We propose that degenerative effects of microgravity will vary among spinal regions due to level-dependent differences in range of motion (ROM). Specifically, imposing larger ROM on microgravity stiffened spinal segments could cause accelerated degeneration and increased HNP risk immediately post-spaceflight. As part of the Biospecimen Sharing Program with NASA, we acquired murine lumbar spines and tails from STS-131, a 15-day shuttle mission. We hypothesize the caudal IVD will exhibit a greater difference in biomechanical properties between the spaceflight and ground control mice due to the greater ROM at caudal segments compared to lumbar segments.

METHODS:
Animals
Sixteen female, 16-week-old, wild-type C57BL/C mice were separated into two groups. The spaceflight group (n=8 mice) were exposed to microgravity for 15 days during NASA shuttle mission STS-131. The control group (n=8 mice) was maintained under normal gravitational loads on the ground. Following spaceflight, mice were sacrificed immediately post-landing. Eight caudal specimens (C9/C10) and sixteen lumbar specimens (L4/L5) were utilized for testing.

Specimens radiographed prior to dissection to attain a measure of physiologic disc height. Motion segments were harvested and then dissected by removing extraneous soft-tissue, as well as, posterior elements from the lumbar specimens.

Mechanical Testing
The motion segments were fixed to the testing apparatus (Bose Electroforce 3200) and radiographed again to measure the disc cross-sectional area and initial disc height at the start of the test. Testing included five cycles of compressive creep loading at 0.5 MPa for 20 minutes with 40 minutes recovery at 0.1 MPa. The first four cycles were used for preconditioning and the last cycle was used for data collection and analysis.

Analysis
Resulting displacement vs. time data was then curve fit [Fig 1] to a fluid transport model. The model parameters fit from the curves were: tissue permeability (K), time dependence of annular strain (G), and strain-dependence of swelling pressure (D).

RESULTS: [Fig 2]
Seven of the eight caudal IVDs contributed usable data. Within that set, the space-flight specimens (n=4) demonstrated 32% (p=0.012) decrease in physiologic disc height and 70% decrease in D (p=0.02) compared to the ground control mice (n=3). D was moderately correlated with disc height (R2=0.56, p=0.0013).

Three of the 16 lumbar IVDs contributed usable data. Neither the physiologic disc height nor the D parameter were significantly different between space-flight (n=7) and ground control (n=6) mice.

No statistically significant differences were observed for K and G among both the lumbar and caudal data sets.

DISCUSSION:
The spaceflight caudal IVDs showed significant decreases in physiological disc height and strain dependence (D) compared to the corresponding ground controls. Decreases in either variable is indicative of disc degeneration, indicating that microgravity has an injurious effect on the caudal IVD. By contrast, differences were not noted for lumbar IVDs.

Lumbar spine movement is constrained by the disc, the ligaments, and the facet joints. In the tail however, there are no facets, and as a result, the ROM is larger and constrained principally by the disc. Consequently, when supra-physiologic nuclear swelling from prolonged weightlessness increases disc bending stiffness, this can be more problematical in the tail.

This potentially deleterious interaction between prolonged weightlessness and spine ROM may underlie the increased cervical versus lumbar disc herniation rates observed in crewmembers. In humans, the cervical ROM is significantly greater than the in the lumbar spine for both flexion/extension and axial rotation. The incidence of cervical HNP is 21.4-times higher after spaceflight, while the lumbar HNP was not significantly higher. If these results are confirmed, they suggest countermeasure efforts should focus on protecting spinal movement upon return to Earth’s gravity while nuclear swelling can acclimate to terrestrial conditions.

SIGNIFICANCE:
This study shows that prolonged microgravity could have degenerative effects on IVDs at levels with a greater range of motion. Results could influence potential countermeasures to be used during spaceflight to reduce the occurrence of HNP.

REFERENCES:

ACKNOWLEDGEMENTS:
NASA Grant NNX09AP11G and NASA’s Biospecimen Sharing Program Team.