Long-duration spaceflight affects passive and active lumbar stabilization and health: an imaging study on NASA crew

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INTRODUCTION: Under normal gravitational force, the lumbar spine bears the load of the upper body in upright posture and is stabilized by passive and active mechanisms. Prolonged microgravity removes physiological diurnal loads from the lumbar spine. Microgravity is known to cause muscle atrophy and bone loss. Previous animal studies show microgravity may have deleterious effects on disc material properties[1,2] and bone strength at the bone/disc interface[3]. NASA crewmembers in prolonged microgravity experience localized low back pain (~43% incidence)[4] and heightened risk of lumbar disc herniation following spaceflight (4.3x)[5]. How prolonged microgravity on the lumbar spine disrupts passive and/or active stabilization mechanisms is unclear.

We hypothesize that prolonged unloading on the lumbar spine alters both passive and active stabilization resulting in lumbar spine flattening and higher stiffness, which may then heighten post-flight herniation risk. We investigated the impact of six months spaceflight on lumbar health by collecting pre- and post-imaging data on volunteer crewmembers, including MRI and dynamic fluoroscopy.

METHODS: Data from 3T MRI and dynamic fluoroscopy are reported from two time-points: 1) within 90 days prior to launch (pre) and 2) one day following six months spaceflight (post). From 3T MRI, we measured lumbar lordosis (sagittal angle between L1-S1 cranial endplates), individual disc and vertebral wedging angles in sagittal plane, disc height (averaged between anterior and posterior edges), water content (T2-weighted intensity), the presence/absence of endplate irregularities, and functional cross-sectional area (FCSA) of lumbar spine extensor muscles (*multifidus* and *erector spinae*) at L3/L4. From dynamic fluoroscopy, we measured controlled flexion, extension and lateral bending for each lumbar disc segment in standing subjects (Orthokinematics, Inc. Austin, TX). Additionally, we have pre and post-flight Biering Sorensen tests for trunk muscle strength, pain questionnaires and spine health reports from flight surgeons.

RESULTS: Five NASA crewmembers participated in our study to date. MRI data are available for 5/5 crewmembers and dual fluoroscropy data are available for 4/5 crewmembers. In 4/5 subjects, lumbar spine extensor FSCA decreased following spaceflight (average change: -11.4%) and lumbar spine extensor strength decreased in 5/5 subjects (average decrease in time holding Biering Sorensen: -28%). In 5/5 subjects, lumbar lordosis decreased (flattened) following spaceflight (average change: -10.7%). Among subjects, pre- to post-flight changes in *multifidus* strongly correlated with changes in supine lordosis (r^2=0.97; Figure 1).

In 2/5 subjects, total lumbar vertebral wedging decreased by -8° and -9°, meaning the vertebral bodies lost height on the anterior boarder relative to the posterior boarder. For these two subjects, vertebral wedging changes contributed to loss of lordosis for both standing and supine measures by 10-38%. In 4/5 subjects, total lumbar disc wedging decreased (average change: -6.1%). Disc height (summed over all 5 lumbar discs per subject) showed negligible changes (<1mm) between pre and post-flight time-points. Changes in water content varied inconsistently among crew and spine levels. In 2/5 subjects, total lumbar disc water content decreased following spaceflight and these two subjects included both our healthiest and most degenerated lumbar spines.

Based on the sum of segmental motion in three mid-lumbar discs (between L2-L5), we observed that: lateral bending and flexion decreased in 3/4 subjects while extension increased in 4/4 subjects (Figure 2).

Lumbar endplate irregularities were present in 2/5 subjects, while completely absent in the lumbar endplates of the other 3/5 subjects. Following spaceflight, the number of irregularities increased within the two affected subjects. These same 2/5 subjects had prolonged and severe low back pain after spaceflight and one of which experienced a herniated lumbar disc.

DISCUSSION: Our results indicate that prolonged spaceflight disrupts both active (muscles) and passive (vertebra and intervertebral disc) lumbar spine stabilizers. We observed that lumbar spine extensor muscles, responsible for keeping the lumbar spine supported in upright posture under gravity conditions, atrophy following microgravity despite in-flight strengthening programs. Furthermore, we observed that post-flight atrophy of *multifidus*, specifically, is strongly correlated with a decrease in post-flight lumbar lordosis. Proposed countermeasures should include in-flight exercises to maintain the strength of *multifidus*.

We observed vertebral wedging changes in two crewmembers, which may be caused by decreased bone density and loss of lordosis from muscle atrophy. Further validation for characterizing these vertebral changes is underway. We did not observe anticipated flight-induced increases in disc water content or disc height. However, the dynamic fluoroscopy results are supported by prior cadaveric work on the effects lordosis changes on disc motion[6], where we reported a reduction of flexion and lateral bending along with an increase in extension range of motion with lumbar flattening.

We observed that the two crewmembers with advanced degeneration and lumbar endplate irregularities were the only two subjects to experience severe low back pain and disc injury following spaceflight. This association between endplate irregularities and back pain is consistent with reports from terrestrial populations, and may indicate that overall lumbar health is a major factor in predicting spine ailments resulting from prolonged microgravity.

SIGNIFICANCE: This is the first spine imaging study to involve NASA crewmembers and provides a unique and valuable insight into the effects of prolonged microgravity on the human lumbar spine. Our results showing that microgravity disrupts passive and active stabilization of the human lumbar spine supports some previously hypothesized mechanisms (muscle atrophy, spinal flattening) and potentially dispels others (discs may not be more swelled following spaceflight).

REFERENCES: [1]Bailey JF et al., *Grav Space Biol* 2012; [2]Bailey JF et al., *J Biomech* 2014; [3]Berg-Johansen B et al., *J Orthop Res* 2015 (*in press*); [4]Kerstman EL et al., *ASEM* 2012; [5]Johnston SL et al., *ASEM* 2010; [6]Laws et al., *Euro Spine J* 2015 *(in press)*

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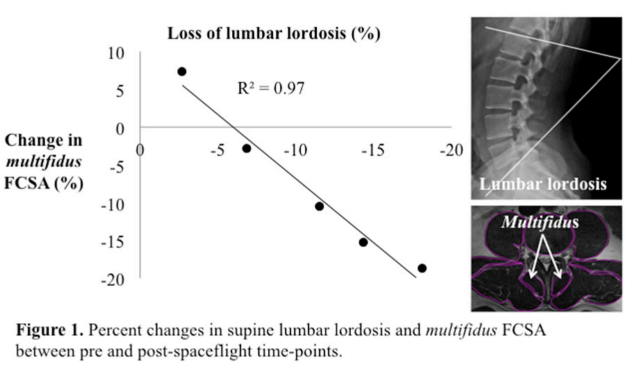

Figure 1. Percent changes in supine lumbar lordosis and *multifidus* FCSA between pre and post-spaceflight time-points.

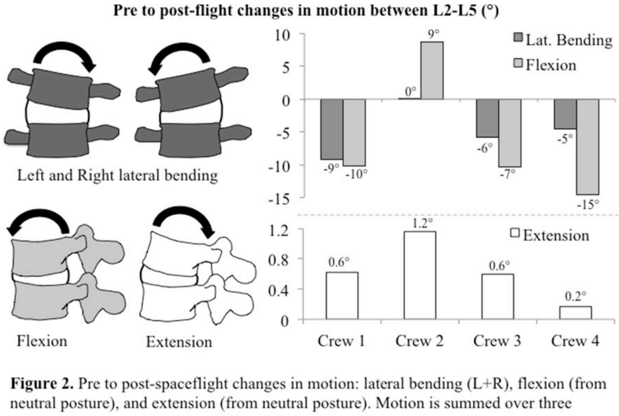

Figure 2. Pre to post-spaceflight changes in motion: lateral bending (L+R), flexion (from neutral posture), and extension (from neutral posture). Motion is summed over three lumbar disc segments between L2 and L5 vertebrae.