Identifying incipient injury from flexion-compression loading of porcine lumbar intervertebral disc

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Introduction

Low back pain (LBP) is a global issue, affecting 50-80% of adults in their lifetimes. Approximately 85% of patients reporting LBP are diagnosed with ‘nonspecific LBP,’ which is denoted when no particular pathology can be determined, resulting in generic treatment options with small effect sizes. There is a critical need to identify low-level incipient lumbar spine injury to improve diagnosis and treatment. Recent studies show repeated loading and flexion increase injury risk and those exposed to repeated flexion-compression loading (i.e. helicopter pilots) are particularly susceptible to LBP. The objective of this study is to identify incipient lumbar injury due to prolonged flexion-compression loading using high-resolution microCT.

Methodology

Five porcine lumbar functional spinal units from three pigs were loaded quasistatically in combined flexion-compression until material failure, defined as an inflection in the creep displacement profile. This signified structural character change in the intervertebral disc (IVD). Specimens were loaded in an environmental chamber held at 37°C and saturated humidity to simulate in vivo temperature and humidity conditions. Test specimens were subject to constant flexion at 3° and constant compression (ranging 8-401345N) below the bony failure threshold. The control specimen was prepared identically, held at the same environmental conditions for 60 minutes, but was not subject to loading. All specimens were imaged with a high-resolution x-ray CT (80-100 μm voxel size) prior to and after testing to analyze injury.

Results and Conclusions

No endplate or bone fractures were observed in post-test CTs for all specimens, which was expected from the low compressive loads relative to endplate fracture tolerance. However, the high-resolution images showed microdamage to annulus fibrosis (AF) fibers in the IVD for all test specimens compared to pre-test images and the control specimen. Figure 1 shows the control specimen before (A) and after (B) preparation procedures, including heat and humidity exposure. Here, the annulus fibers are tightly aligned, as expected in a healthy IVD. However, when exposed to prolonged loading, discs showed separation between AF fibers, particularly on the lateral and anterior disc regions (Figure 2). Figure 3 shows a larger magnification to highlight this fiber separation. Mechanically, these regions would likely experience failures first. Lateral AF regions are under greater strain compared to other disc regions due to porcine endplate curvature and flexion applies greater strain to the anterior AF.

These results, facilitated by high-resolution imaging, are potentially demonstrating incipient failure caused by flexion-compression loading that leads to larger, more serious disc injury with subsequent loading. This damage would not be resolvable in standard clinical CT imaging (0.5-1.5 mm voxel size) with at least 200X lower volumetric resolution, so it is difficult to assess whether this incipient damage is associated with clinical presentation of pain. Further, it is unknown whether this low-level AF damage is susceptible to healing in vivo or if this damage is irreversible, initiating greater damage over time. However, proteoglycan turnover in the spine has been measured at ~400 days in dogs. More tests are needed at a wider range of loads to develop an injury risk for this low-level incipient failure.