Assessing the Ability of Pressure Sensors Inserted into Intervertebral Discs to Detect Compression, Flexion, and Combined Flexion + Compression Loading

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Objective

Research on evaluating human response in simulated vehicle crash environments using postmortem human subjects (PMHS) is ongoing (Richardson et al., 2020; Somasundaram et al., 2022). Unfortunately, force and moment responses in the lumbar spine are difficult to measure directly during sled testing without major tissue disruption. However, indirect measurement may be possible by inserting a pressure sensor into the intervertebral disc (IVD). This sensor has been used to detect pressure changes useful in determining local event timing such as vertebral fracture (Shin et al., 2023), but relation to loading is uncertain. This study utilizes a controlled loading environment to evaluate the ability of IVD pressure sensors to detect changes in lumbar spine loading, specifically compression and flexion.

Methodology

Pressure transducers were inserted into the nucleus pulposus of the IVD of seven PMHS whole lumbar spines (T10-Sacrum) using a bore needle apparatus at the T12-L1 and L4-L5 levels to a depth determined in CT analysis (Figure 1). Sensor insertion was completed without major disruption (e.g. coring, fluid leakage) to the surrounding tissue. A 6 degree-of-freedom (DOF) robotic test device applied flexion both with and without compression to the lumbar spine. Axial compression was applied by a follower load mechanism. A loading scheme where compressed and non-compressed cases were evaluated at increasing flexion angles was used. Loads were applied to the superior end of the spine while reaction forces and moments were recorded by a load cell fixed inferior to the sacrum.

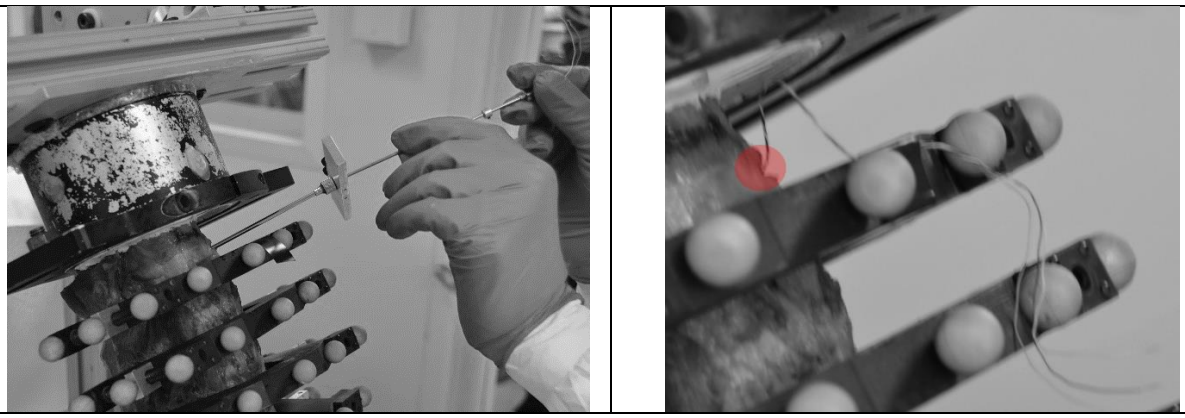

Figure 1: Top Left) Pressure sensor depth measurement from CT with depth outlined in red. An ellipse was drawn around the vertebral body and a measurement was made between the insertion point and the middle of the disc. Bottom Left) Pressure transducer insertion process. Bottom Right) Inserted pressure transducer with wires of pressure transducer protruding from the insertion point highlighted in red.

Included Data

Forces, moments, translations, and rotations of the lumbar spine were recorded and time-synched with IVD fluid pressures from the sensors over the test duration. Selected trials will be shown indicating the ability of IVD pressure sensors to detect changes in the compression and flexion states of the lumbar spine. Placement diagrams for the desired and final locations of the sensors will be included along with an analysis of how placement impacted data quality. Additionally, cross-sectional area analysis for relation between pressure and force will be included.

Results and conclusions

Results indicate detectable changes in IVD pressure due to applied compression and flexion. Importantly, we observed proper sensor placement is critical for the trustworthiness of pressure data in the IVD. A linear increase in compression force resulted in increasing measured IVD pressure. Similarly, decreasing compression force decreased pressure. Applied flexion generally increased observed IVD pressure, but the relation was not as consistent as compression and depended on sensor placement within the IVD. Notably, pure flexion had much lower IVD pressures than combined compression and flexion loading. From this study we can better link observed IVD pressures from sled tests to applied loadings, but differentiating between these loads remains the focus of future work.