Development of an *In Vivo/In Vitro* Active/Passive Robotic Simulator to Model the Redistribution of Kinematic Changes of the Thoracolumbar Spine

By

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Introduction

Low back pain is among the most common ailments suffered by Americans with about 50% of the population reporting some instance each year. Degeneration of the intervertebral discs has been identified as part of the natural aging process; however it is not symptomatic in every case. For those who experience pain from disc degeneration, conservative therapy is the first method of treatment. Surgery is another option when conservative therapy fails. The gold standard for surgical treatment of degenerative discs is fusion.

When fusion is successful, the rigid connection limits relative motion between the two vertebrae. Long-term clinical studies of patients with fusions have identified accelerated degeneration at the levels adjacent to the site of surgery.

Adjacent level disease has been tested *in vitro* using many techniques. Due to the current limited knowledge of the *in vivo* environment, the validity of these *in virto* methodologies is unproven. One of the most important limitations of these studies is the load, moment, and/or displacement applied to the model is arbitrary. These inputs have been indirectly measured from *in vitro* models but there is a lack of correlation to the *in vivo* environment. Another important limitation is the number of levels used in previous studies; most studies utilize no more than five motion segments, thus limiting the scope of the effects being measured.

Purpose

The purpose of this research was to develop a system that evaluates the relative change in kinematics of the thoracolumbar spine after various surgical interventions. We hypothesized that there will be a redistribution of motion of the thoracolumbar spine since there is no change in total motion before and after the surgical intervention. We further hypothesized that the greatest changes in motion will occur at levels adjacent to the surgical site.

Methods

Our novel methodology used active *in vivo* data from normal healthy volunteers to drive a cadaveric spine passively *in vitro* through the same range of motion while collecting kinematic data of the entire thoracolumbar spine using a robotic simulator.

Using previously collected active *in vivo* range of motion data from healthy volunteers, we generated a command set for an industrial robot to replicate the motion on an *in vitro* specimen. The data from the healthy volunteer was dimensionally selected to match that of the specimen. The specimen was instrumented with twelve sensors to monitor the vertebral position and orientation in three-dimensional space. The robot then drove the specimen through the same motion as the volunteer while we simultaneously collected data from the sensors. After testing intact, we performed a sequence of seven surgeries, at the L4-L5 level, including pedicle screw fixation. After each surgery was performed the robot drove the specimen through the same motion and data were collected from the twelve sensors. From each specimen we collected one control data set as well as seven experimental data sets (one from each surgical intervention). The data were then post-processed and redistribution of motion was assessed.

Results

We successfully replicated the motion from the healthy volunteers on the cadaveric specimen using a robotic simulator. The results showed a change in the interbody rotations as well as the coronal plane position at the adjacent levels after surgical intervention. An increase in both the interbody rotations and the coronal plane position were also identified at the operative level after a facetectomy (most destabilized state) and a pedicle screw fixation (lest destabilized state).

Discussion

Our testing protocol is uniquely based on the *in vivo* loading environment, and replicates it *in vitro* with high fidelity using an industrial robot. This novel methodology has allowed us to eliminate the use of arbitrary loads, moments, and/or displacements. Our results suggest that for a rigid fixation of a single level, if all non-operative levels have relatively equal compliances, normal bending motion will occur. This normal bending motion will transpire by each superior level moving and rotating slightly more, relative to the inferior level. The operative level, on the other hand, will show no relative movement or rotation due to the rigid fixation of the intervention. However, in a different scenario, if there is early-stage degeneration at another level (i.e. directly caudal to the operative site), there will be increased compliance at that level. When the spine bends, the operative site will have no relative movement or rotation, due to the

rigid fixation, and the levels superior to the operative site will have small changes in movement and rotation. In this instance, the majority of the motion will occur at the degenerated level due to its increase in compliance. With more testing of specimens, these hypotheses can be tested.