Three-Dimensional Distribution of Intersegmental Motion on the Entire Intact Thoracolumbar Spine As Measured by a Novel In Vivo/In Vitro Active/Passive Testing Protocol

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ABSTRACT INTRODUCTION:

Advanced image analysis techniques have become available for use in quantifying motion of the spine using plain radiographs (for example, Medical Metrics, Houston, TX). This has allowed quantitative analysis of range of motion and center of rotation of individual motion segments before and after treatment. However, this valuable technology is limited to analysis of static images and also is limited to analyzing the number of levels that are captured on a plain film.

In vitro mechanical testing has historically been used to quantify three dimensional motion of the spine in response to loads. In vitro testing affords repeatability and the opportunity for measuring dynamic three dimensional motion, but the clinical relevance of in vitro testing is limited by the fidelity by which in vitro testing mimics the in vivo environment. Commonly, in vitro testing is conducted by application of arbitrary loads on specimens consisting of three motion segments or fewer. In these cases, the loads may not reflect in vivo conditions and additional motion artifact is introduced because motion is constrained to three (or fewer) levels.

We have established a novel in vivo/in vitro active/passive method for quantifying motion of the entire thoracolumbar spine using a robotic simulator, based on active motion. The purpose of this study was to measure the dynamic three dimensional motion of individual motion segments of the entire intact thoracolumbar spine during active voluntary motion.

METHODS:

We have previously established a library of three dimensional kinematic data mapped from the thoracolumbar spines of normal healthy volunteers during active voluntary flexion/extension, left/right lateral bending, and axial rotation. In the current study, these data were converted to a command set used to drive a six degree-of-freedom PUMA 560 industrial robot (CATS, RPI, Troy, NY) to replicate whole thoracolumbar spine motion. Six human thoracolumbar spines (C7-S1) were harvested fresh and mounted to the robot with C7 mounted to the mobile end-effector and S1 fixed, as shown in Figure 1. Each cadaveric spine was dimensionally matched to one of the data sets in the kinematic library. Three dimensional position and orientation sensors (Flock of Birds, Ascension Technology; Burlington, VT) were attached to eleven levels (T7-L5) of the cadaveric spine to measure the individual kinematics of each vertebra as the intact spine was driven through the prescribed motions. The resultant three dimensional motions were analyzed at each level and plotted to quantify motion in the anatomical planes.

RESULTS:

The sensors were able to accurately capture the full range of motion of the spines as they were moved passively through active voluntary motion. Data were collected from each vertebra at a sample rate of at least 100 samples per second during motion. Three dimensional position and orientation can be extracted from any point in the range of motion data set, as shown in Figure 2. Data at the end points of motion dictate range of motion in the anatomic planes. Mean maximum intersegmental frontal plane motion during lateral bending is shown in Figure 3. As expected, preliminary data indicate a general trend of increasing motion with increasing level of the spine. Three dimensional coupling of motion in multiple anatomic planes was also characterized for all motions.

DISCUSSION:

In this study, we used a novel method to assess the three dimensional motion of the entire intact thoracolumbar spine during dynamic motions. Unlike many traditional in vitro testing protocols, the prescribed movements imposed on the spine specimens were based on active voluntary motions of intact spines. The data characterize the complex interplay of motion between the entire thoracolumbar spine during motion, and are not limited to just the static endpoints of motion. As such, these data are a baseline for comparison to assess changes in dynamic motion (not just static endpoints of motion) resulting from injuries or interventions. Changes in motion at levels adjacent to an operative level indicate altered kinematics and biomechanics at those levels and may be predictive of adjacent level disease.

We have used our novel method to quantify the distribution of motion of the intact thoracolumbar spine following common surgical interventions. Future work will be aimed at quantifying the redistribution of motion following surgical intervention.