A NOVEL ROBOTIC SIMULATOR FOR ASSESSING THE THREE-DIMENSIONAL KINEMATICS OF THE ENTIRE THORACOLUMBAR SPINE: APPLICATION FOR EVALUATING THE ADJACENT LEVEL EFFECTS OF SPINAL INTERVENTIONS.

By

Erin E. Campbell

An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

Major Subject: BIOMEDICAL ENGINEERING

The original of the complete thesis is on file
in the Rensselaer Polytechnic Institute Library

Approved:

Eric H. Ledet
Thesis Adviser

Rensselaer Polytechnic Institute
Troy, New York

November 2008
(For Graduation December 2008)

Introduction

Low back pain remains the most common type of pain reported by U.S adults, with 75-85% of the US population suffering from back pain at least once in their lives[1]. Traditionally fusions are commonly performed to eliminate severe lower back and leg pain, typically caused by degenerative disc disease (DDD). However, adjacent level disease (ALD) has been identified in long term clinical follow ups of patients who have received spinal fusions. With the discovery of adjacent level disease it has become apparent that in attempts to eliminate pain, fusions may have instead been causing additional pathologies at other levels.

In order to assess the implications of fusion on the kinematics of the spine a methodology to assess the three-dimensional motion of the spine must be created. Current predictive models, while having shown insight, have been limited because they reflect passive motion thus neglecting the contributions of the muscles, ligaments, and tendons to the spine's overall motion capabilities. The purpose of this study was to develop a novel methodology to assess the three dimensional distribution of motion of the entire thoracolumbar spine *in vitro* based on active voluntary *in vivo* motion.

Methods

The Flock of Birds (FOB) electromagnetic tracking sensors were mounted superficial to three vertebrae, C_7, T_{12}, and S_1, on 10 normal and healthy male and female volunteers ranging in age from 20 to 38. All subjects gave their informed consent to participate in this study. The FOB were used to track the position and Euler parameters of each of the volunteers as they move through active voluntary motion (flexion-extension, left-right lateral bending, and axial rotation). These data were used to establish a database of three-dimensional kinematics of the entire thoracolumbar spine. The kinematic data were converted to a command set used to run a PUMA 560 industrial robot manipulator through C_7 to S_1 relative motions. The PUMA 560 is composed of six degrees-of-freedom (DOF)which are controlled by its base that has three DOF's including rotation, linear translation, and tilt, a shoulder joint, elbow joint, and wrist joint.

One fresh, human, cadaveric, thoracolumbar spine (C_7-S_1) was harvested for use. The spine was mounted into the PUMA 560 with C_7 attached to the robot's manipulator and S_1 rigidly potted in a low melting temperature alloy. The cadaveric spine was dimensionally matched to one of the volunteer's kinematic data set. Motion was applied to the spine through the arm of the robot onto the anterior portion of the spine. FOB sensors were attached to six levels (T_{12}-L_5) of the cadaveric spine in order to track the individual kinematics of each vertebra as the spine is driven through the prescribed motions. The resultant 3D motions were analyzed at each level.

Results

The Flock of Birds sensors accurately captured the full range of motion of our subjects as they moved through active voluntary motion. This was validated via video analysis and plain radiographic images.

The motion of the cadaveric spine in the robot replicated with high fidelity *in vivo* motion in all directions. The maximum error produced between the same prescribed motions at different time points was 2.20% while the mean error was 2.11%.

The adjacent level data collected on T12 to L5 via the Flock of Birds demonstrated a larger frontal plane displacement in the superior vertebrae as predicted using other methods. The adjacent level data also demonstrated a tendency to produce larger segmental rotational values at the inferior motion segments of the thoracolumbar spine. Between T12 and L1 the maximum rotation was 4.6°, L1 and L2 a maximum of 6.0°, L2 and L3 a maximum of 8.3°, L3 and L4 a maximum of 8.1°, and L4 and L5 a maximum of 8.9°.

Discussion

The novel method proposed in this study to quantify the three dimensional distribution of motion of the entire thoracolumbar spine provides a means to reflect *in vivo* kinematics using an *in vitro* protocol. The contributions of the complex muscle forces along with the adapting *in vivo* environment are captured in the kinematical data collected from our healthy volunteers.

A better understanding of adjacent level effects following surgical intervention of the lumbar spine helps to guide the surgeon in selecting the most appropriate treatment for patients in jeopardy of developing spinal pathologies at levels adjacent to the surgical intervention. While fusion procedures are likely to exacerbate or accelerate degeneration at adjacent levels, new motion preserving technologies such as total disc replacement or posterior dynamic stabilization are thought to preserve adjacent level kinematics and normal tissue strain. Establishing a model that accurately reflects *in vivo* motion provides a tool for quantitatively comparing the effects of each technique and will provide new insights into the effects of each treatment. This model will also allow for a patient specific clinical assessment of the redistribution of motion following an intervention and thereby provides insight into the development of adjacent level disease for individual cases.