Analysis of the 360 Degree Motion Envelope of Human Lumbosacral Joints

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INTRODUCTION
Knowledge of lumbosacral joint (L5/S1) kinematics is important in understanding the cause of low back pain and in aiding in the diagnosis and subsequent treatment (Bartleson, 2001). In previous studies, the flexibility of the lumbosacral joint under a constant bending moment has been investigated only in three planes; sagittal (flexion/extension), transverse (torsion) and frontal (bilateral bending) (Panjabi et al, 1994), limiting the interpretation of spinal joint kinematics in other planes.

The purpose of the present study was to determine the load response of the lumbosacral joint to pure bending moments in a 360 degree circumference. In particular, we sought to apply such moments in a full motion path envelope to the specimen, and measure the changes in flexibility using a robotic arm and a 6-degrees of freedom (DOF) force/torque transducer.

The goal of this investigation was to analyze the complex motion envelope of a spinal segment in a three dimensional space for better understanding the joint kinematics, pathology of joint disease, and aid in the development of fracture prevention techniques.

METHODS
An intact lumbosacral joint from a 76 year old male donor was prepared for biomechanical testing by detaching the muscular and fatty tissues from the vertebral bodies. The ligamentous structures, facet joints, transverse processes and posterior elements were left intact. To minimize dehydration, saline-soaked gauzes were wrapped around the spinal segment and sprayed with saline solution periodically during sectioning, specimen preparation, and testing. The top and bottom of the spinal segment was permanently potted in PMMA cement. The L5 was mounted to the end of the robotic arm using a custom made connector and the S1 was rigidly fixed to the top of the transducer (Figure 1).

The robotic arm testing system consists of a 6-DOF industrial robotic arm (KR 150, KUKA Robotics Corporation) and a 6-DOF Force/Torque transducer (Omega160, ATI Industrial Automation). The neutral position of the spinal segment was determined by minimizing the forces and moments as measured by the transducer, and the top center of the L5 endplate was assigned as the origin. The specimen was tested in a load feedback control to determine the peripheral path in response to pure moments of 5, 10, and 15 N.m. with and without pure
axial preload of 600-N (total of six loading cases). For each case, the motion path envelope was determined by flexing the specimen in a counterclockwise direction while maintaining the overall bending moment at a fixed value. The full motion path envelope was completed when data was collected for a full path (360 degrees in transverse plane) with approximately one set of data point for each 10 degrees increment. This protocol was repeated for the remaining five loading cases.

RESULTS
Under the application of the mobilization loads, the 360 degree motion path envelopes of lumbosacral joint under each loading regimes were mapped (Figure 2, top). A comparison between preload versus no preload showed a reduction in the projected motion fields area (mm$^2$) up to 35% mostly seen in the anterior portion of the motion field (Figure 2, bottom). No statistically significant decreases in moments were detected after the first loading cycle through the same path.

DISCUSSION
Through the precision and accuracy of the robotic arm, we were able to obtain the full circumferential joint motion envelope in 3-D while applying a rotating pure bending moment. In contrast to previous studies in which range of motions are generally obtained for only four points, two in the sagittal and two in the frontal planes, we were able to determine spinal flexibility in any direction within the transverse plane. In addition, the robotic arm, allowing for simultaneous movement in several axes, determined the path of minimum resistance and the helical axis of motion. Since the posterior elements were intact, restriction in motion caused by zygapophyseal joints resulted a smaller displacement in Z direction for extension than in flexion.

Characterization of such a motion envelope can provide a better understanding of the complex joint kinematics, pathology of joint disease, aid in the development of fracture prevention techniques, and improve the design of new implants with the goal of restoring joint function. A correlation between ergonomic tasks and work related injury can be drawn.

REFERENCES