ABSTRACT INTRODUCTION:
For patients with low back pain who fail conservative therapy, surgery is an option. Every surgical procedure alters the native environment in the spine due to the inherent tissue disruption. Procedures with less tissue disruption such as microdiscectomy are less likely to alter the biomechanics and kinematics of the spine following surgery, whereas fusions, which eliminate (or alter) intersegmental motion, are more likely to alter spine kinematics and biomechanics. Long term clinical follow up of fusion patients has led to the identification of adjacent level disease (ALD). However, the relationship between adjacent level disease and surgical intervention remains controversial. Procedures with less tissue disruption, and motion preserving and dynamic stabilization therapies purport to eliminate deleterious effects on adjacent levels, but these assertions have not been confirmed with long term clinical trials. Current analyses are limited short term outcomes and predictive models. In vitro testing affords repeatability and the opportunity for relative comparison between treatments, but the clinical relevance of in vitro testing that is not based on in vivo loads or motions remains questionable.

We have established a novel in vivo/in vitro 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 three-dimensional redistribution of motion of the entire thoracolumbar spine following surgical intervention as a means of predicting adjacent level disease.

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.\(^1\) 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. 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 spine was driven through the prescribed motions. The spine was tested (a) intact, (b) after microdiscectomy, (c) after laminectomy, (d) after facetectomy, (e) after facet screw fixation, and (f) after pedicle screw fixation all at the L4-L5 level. The resultant 3D motions were analyzed at each level and compared to intact.

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. Absolute motion of levels adjacent to the surgical interventions during left and right lateral bending are shown in Figure 1. A comparison of intact data to facetectomy (the most unstable condition) and to pedicle screw fixation (the most rigid condition) are shown in Figure 2. Preliminary data indicate that frontal plane motion during lateral bending at the L4-L5 (operative) level increased following facetectomy. Motion at all super-adjacent levels (L3-L4 through T7-T8) also increased compared to intact. Placement of pedicle screw fixation following facetectomy resulted in a marked reduction in motion at L4-L5 (the operative level) to less than intact motion and a reduction in motion at the super-adjacent level (L3-L4) compared to intact. However, there was little reduction in motion at all other adjacent levels and in some specimens, the motion following pedicle screw fixation at all levels superior to L3-L4 was increased relative to the intact state.

DISCUSSION:
In this study, we used a novel method to assess the three-dimensional motion of the entire thoracolumbar spine following surgical intervention at the L4-5 level. Changes in motion at levels adjacent to the operative level indicate altered kinematics and biomechanics at those levels and may be predictive of adjacent level disease.

Preliminary results indicate a reduction in motion at the operative and super-adjacent level. At all other levels, motion is increased compared to intact, even following pedicle screw fixation. The increased motion at other levels may be compensation for the reduced motion at the operative and adjacent level. This is necessary if the overall motion of the trunk is does not change substantially following surgical intervention (i.e. loss of motion at one level must be made up by increased motion at another).

We have used a novel method to quantify the redistribution of motion of the thoracolumbar spine following common surgical interventions. New motion preserving technologies such as total disc replacement or posterior dynamic stabilization are thought to preserve adjacent level kinematics. Future work will include investigation of motion preservation and dynamic stabilization systems.