Changes in Lumbar Spinal Ligament Stress Due to Isolated Transected Ligaments

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ABSTRACT INTRODUCTION:

Virtually all spinal surgeries induce iatrogenic damage to spinal ligaments and some require complete ligament transection. Although many studies have been done (and are ongoing) to determine the effectiveness of these treatments in relieving or reducing lower back pain, comparatively little research has been done to determine how the mechanics of the lumbar spine are changed by damaging or removing spinal ligaments.

In the present work, a validated, three dimensional, nonlinear finite element model of the lumbar spine (T12-S1) was used to predict changes in the mechanics of the lumbar spine following spinal ligament transection. The purpose of this work was to identify changes in stress of the remaining ligaments when a ligament is removed or damaged.

Figure 1
Hexahedral finite element model of a ligamentous lumbar spine based on quantitative computed tomography of a cadaveric spine.

METHODS:

A hexahedral finite element model of T12-S1 (234,011 elements) was created using a commercial finite element preprocessor (TrueGrid, XYZ Scientific Applications, Inc., Livermore, CA) based on CT scan data from a 65 y.o., cadaveric lumbar spine (Figure 1). Vertebral geometry was semi-automatically segmented from the CT data using Analyze (Mayo Clinic, Rochester, MN). The ligaments and the cortical bone on the surfaces of the vertebral bodies were created with shell elements. Material formulations and properties for each were similar to that used in prior work [1]. Boundary conditions for the FE simulations consisted of pure bending moments applied at the T12 vertebra, with an applied compressive load of 440 N. The S1 vertebra was fixed against both translation and rotation. The ALL between the L3 and L4 was removed from the model and the six tests were run again and data was recorded. The ALL was then replaced and the PLL between the L3 and L4 was removed from the model. The six tests were executed again, and data was recorded. The same process was repeated for the CL, LF, ISL and SSL.

VALIDATION:

In order for the model to correctly predict spinal behavior, the model was stress converged to test mesh resolution. Another model of the same geometry was created with twice as many elements in order to verify stress convergence and mesh discretization. This model contained 465,082 elements compared to the 234,011 in the model used for testing. Both modeled were compressed and maximum stresses were within 5%. The stress converged model was validated by comparing data to experimental data presented in the literature. The following parameters were used for comparison:

Range of motion – Loading moments were applied to the T12 while fixing the S1 in flexion/extension, lateral bending and axial rotation. Kinematic data of the model were compared against reported experimental studies [2] as well as experimental data of the same cadaver from our lab.

Quality of motion – To insure an even more accurate prediction of spinal kinematics, the applied moment was plotted against the angular displacement to verify the data followed a physiologic nonlinear path as presented in the literature [1,3].

Disc Pressure – After the model was compressed, disc pressure data was collected by averaging the pressure of a small spherical region of elements located in the center of the nucleus pulposus. This average simulates the experimental data collected by probes. The disc pressures were compared to data presented in literature [4].

Cortical Strains – Cortical strain comparisons were made by comparing the maximum principal strains from the model to the experimental data in eight different locations of the vertebral bodies [4].

Instantaneous Axes of Rotation – The axes of rotation for each of the functional spinal units during flexion/extension were calculated and compared to locations found in the literature [5].

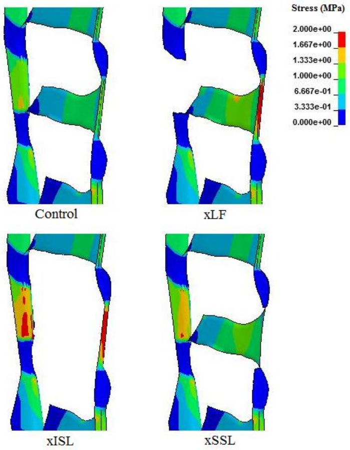

Figure 2
Stress contours are represented for the ISL, SSL, and LF during flexion.

RESULTS SECTION:

The areas that are of most concern occur during the removal of the LF, ISL, or SSL during flexion between the L3 and L4. The removal of one of the ligaments creates large increases in stress in the other two ligaments. Figure 2 shows the stress contours of these three ligaments during flexion. The removal of the LF during flexion also caused a large increase in stress in the PLL. The removal of the SSL or the ISL also caused increases in stress in the LF during axial rotation and lateral bending.

DISCUSSION:

Ligament transection necessarily increases loading in the remaining spinal elements and can lead to overload or fatigue damage. The potential for an increase of ligament fatigue damage is greatest in the posterior ligaments at the level of the transected ligament. However, transected ligaments still may increase the chance of ligament fatigue in the other ligaments as well as the ligaments on adjacent levels.

SIGNIFICANCE:

This study speaks to the clinical consequences of ligament transection during lumbar spine surgery and specifically identifies the consequent changes in spinal biomechanics.

ACKNOWLEDGMENTS:

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