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 load sharing, intervertebral disc pressures, vertebral stress, and shear loading when ligaments are removed. The model was evaluated in flexion, extension, lateral bending, and axial rotation as each ligament was individually removed from the model.

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]. Previously published experimental data was used to validate the model using cortical strains [2], range of motion [3], quality of motion [4], and disc pressure [2].

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. Applied bending moment magnitudes were 6 Nm in both axial directions, 6 Nm in both lateral directions, 8 Nm in flexion, and 8 Nm in extension. Results for load sharing, intervertebral disc pressure, vertebral stress, shear loading, and range of motion were recorded for the intact condition and used as a control. 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.

RESULTS SECTION:

At maximum flexion and extension, the intervertebral discs carried between 80%-82% of the loading, while the remainder was distributed between the surrounding tissues. Figure 1 shows the load sharing distribution at the L3-L4 spinal level for all of the tissues except the intervertebral discs. Isolated transection of the LF, SSL, or CL resulted in the largest changes in load sharing during flexion. There was also a large increase in loading in the L3 and L4 posterior elements when the ALL was removed during extension.

Removing ligaments generally resulted in an increase of the magnitude of maximum vertebral stress during flexion and extension in pedicles of the L3. The percentage increase of maximum stress in the pedicles at each lumbar level from L2-L5 during extension and flexion can be seen in Figure 2. The largest increases in stress were adjacent to the transected ligament (i.e., L3).

Results showed varying changes in disc pressure and range of motion. Disc pressure generally decreased during extension except for the disc between the L1 and L2. During flexion, disc pressure generally increased except for a large decrease (5.8%) in the disc between the L3 and L4 when the LF was removed. The largest changes in the range of motion occurred at the transected level during flexion when either the LF, ISL, or SSL was removed. Changes in stress, loading and disc pressure were not as large when removing ligaments during axial and lateral rotation.

DISCUSSION:

Ligament transection increases loads in the remaining ligaments, as well as increasing disc pressures, facet loading, vertebral stresses and shear loads on the intervertebral disc. These effects are observed regardless of the ligament transected, but the magnitude of the change is dramatically higher consequent to transection of the LF, SSL, and CL. Biomechanical changes due to ligament transection were not limited to the operative level, but propagated throughout the lumbar spine.

SIGNIFICANCE:

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

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REFERENCES: