BIOMECHANICAL ANALYSIS OF THE LUMBAR SPINE ON THE FACET JOINT FORCE AND INTRADISCAL PRESSURE—A REALISTIC FINITE ELEMENT STUDY

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INTRODUCTION

The lumbar spine often leads to a high incidence of disc diseases, such as herniated disc, sciatica and low back pain. Biomechanical analyses of lumbar spine have been used to explore the related problems using in vitro studies or finite element simulations. Most of the previous FE studies have used simplified models such as a quarter of the vertebrae and discs, a half of the vertebrae, or a simple whole spine model. This study developed and validated an FE model of the lumbosacral spine with a realistic geometric shape to simulate the lumbar spine subjected to several loading conditions. The effects of symmetric postures such as left and right axial rotations on the facet joint forces at various levels of the lumbar spine were compared. In addition, we investigated the effect of postures on the intradiscal pressures in the nuclei pulposi.

METHODS AND PROCEDURES

CT images were acquired from scanning a specimen of a lumbosacral spine model. Bony boundary outlines were depicted from each DICOM image filtered using a gray value threshold, and then a smooth surface model was created by smoothing the sawtooth shapes of the boundary outlines and stacking. The surface model was further preprocessed with PATRAN to retain the accurate geometry of the lumbosacral spine (Fig. 1). Properties of the materials used in this study are listed in Table 1. The contact behavior of facet joints was simulated by setting the coefficient of friction to 0.1. The model used solid tetrahedral linear elements instead of hexahedral ones to simulate the posterior bone, cancellous bone, and annulus ground substance, near incompressible tetrahedral elements for the nucleus pulposus, triangular shell elements for the cortical shell, endplate, and annulus fiber layers, and narrow strip-shaped bilinear membrane elements for the ligaments under the control of no resistance in compression. Several loading conditions included an evenly distributed load of 300, 460, or 600 N, and combinations of a preload of 300, 460, or 600 N with bending or rotation moment of 5, 10, 15, or 20 Nm on the superior surface of the L1 vertebral body. The boundary condition imposed in the model involved setting the sacroiliac joint to fully constrained in all directions.

Figure 1. A realistic finite element model of the lumbosacral spine. (under a preload of 460 N; left/right for stress/strain distribution.)
<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s (MPa)</th>
<th>Poisson ratio, ν</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical shell</td>
<td>12000</td>
<td>0.3</td>
</tr>
<tr>
<td>Cancellous bone</td>
<td>100</td>
<td>0.2</td>
</tr>
<tr>
<td>Endplate</td>
<td>12000</td>
<td>0.3</td>
</tr>
<tr>
<td>Posterior bone</td>
<td>3500</td>
<td>0.25</td>
</tr>
<tr>
<td>Nucleus pulposus</td>
<td>1</td>
<td>0.4999</td>
</tr>
<tr>
<td>Ground substance</td>
<td>4.2</td>
<td>0.45</td>
</tr>
<tr>
<td>Fiber (inner/outer)</td>
<td>(360/550)</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 1. Material properties of this model.

RESULTS

Figure 2 indicates that the facet joint forces were affected slightly by the preloads in the range of 300 to 600 N, particularly in right rotation. Left rotation resulted in a larger facet joint force in the contralateral (right) facet joint than that in the homolateral (left) joint at the same level, and vice versa. Figure 3 shows that intradiscal pressures in the nuclei pulposi increased with preloads and became more noticeably with flexion than with extension or left/right rotation.

DISCUSSION AND CONCLUSIONS

With regard to the facet joint forces, forward/backward bending and axial rotation produced asymmetric responses in the facet joints. It appeared that the influence of the magnitude of preloads on the facet joint force was less important than that due to the various postures. The intradiscal pressures, in extension postures, decreased temporarily at levels L2/L3, L3/L4, and L4/L5 under different preloads, and considering all levels of the lumbar spine, it showed that the pressure at level L1/L2 was greatest for the various postures — flexion, extension, and axial rotation.

REFERENCES