Effects of lumbar spinal fusion on the other lumbar intervertebral levels (three-dimensional finite element analysis)

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Abstract The risk of accelerating the degeneration of adjacent disc levels after lumbar spinal fusion is a controversial issue. A finite element model consisting of L1 to L5 lumbar spines was used to assess the effect on adjacent disc level after lumbar spinal fusion. We compared intact, L4/5 posterior interbody fusion (PLF), and L4/5 posterior lumbar interbody fusion (PLIF) models. The loading conditions applied were compressive force, compressive force plus flexion moment, and compressive force plus extension moment. Evaluations were made for von Mises stress on each vertebral end-plate, Tresca stress of all the annulus fibrosus, and Tresca stress of the annulus fibrosus from the posterior surface of the disc to the neural foramen. As the result, the von Mises stress adjacent to the fusion level was higher than the other nonfusion levels; it was higher under conditions of flexion moment loading plus compression loading [112% (2.59 PMa) in the PLF model and 117% (2.72 Mpa) in the PLIF model] than in the intact model. The Tresca stress of all the annulus fibrosus adjacent to the fusion level was higher than that on other nonfusion intervertebral levels; it was higher under conditions of flexion moment loading plus compression loading [127% (0.57 PMa) in the PLF model and 209% (0.89 Mpa) in the PLIF model] than in the intact model. The Tresca stress of the annulus fibrosus from the posterior surface of the disc to the neural foramen adjacent to the fusion level was higher than that on other nonfusion intervertebral levels; and it was higher under conditions of flexion moment loading plus compression loading [107% (1.48 PMa) in the PLF model and 112% (1.54 Mpa) in the PLIF model] than in the intact model. These findings demonstrate that with lumbar fusion, stresses on the vertebral end-plate and the annulus fibrosus were high adjacent to the fusion level; furthermore, stresses were higher in the PLIF model than in the PLF model. These results suggested that lumbar spinal fusion might bring with it a risk of damage to the annulus fibrosus and the vertebral end-plate adjacent to the fusion level.

Key words Finite-element method · Adjacent segment · Posterolateral lumbar fusion (PLF) · Posterior lumbar interbody fusion (PLIF)

Introduction

Various fusion techniques are undertaken for unstable lumbar spines. Spinal fusion has been suggested to have the risk of promoting degeneration at the other intervertebral levels due to the rigidity of the fusion area.12 Seitsalo et al.15 however, reported that spinal fusion did not accelerate adjacent-segment degeneration.

Several reports regarding the influence on the motion of adjacent segments after in vivo spinal fusion in humans,5,8,9 but no in vivo studies have detailed stress changes in relation to the annulus fibrosus. There are some in vitro studies regarding the influence on adjacent motion segments in fusion models17,21 using an instrument that makes the initial fusion more rigid than can be obtained by autogenous bone fusion. No reports have been presented about the influence of autogenous bone fusion on the adjacent motion segments. This could be because evaluations of such influences in a bone-fused state are difficult in cadaver experiments. If a model in a bone-fused state after lumbar spinal fusion could be produced by the three-dimensional finite element method, however, numerical analysis would be possible.

Data on the material constants of the vertebral body are indispensable for producing models for finite element analysis, but, there are no measurement values that give accurate material constants for the intact nucleus pulposus. Given this, an accurate model of the intervertebral disc could not be made.

In previous studies, models of the intervertebral disc have been produced by conferring viscoelastic20 or
poroelastic\textsuperscript{18,23} characteristics on the elements of the disc, with analyses performed using virtual intervertebral disc models. In a previous study, we did not venture to express the nucleus pulposus in terms of elements and so produced a lumbar spine model by directly inputting the intradiscal pressure of the lumbar spine with no abnormalities of the nucleus pulposus. We then analyzed changes in stress on the disc utilizing the three-dimensional finite element method.\textsuperscript{5} In the present study, a model of the entire lumbar spine (L1-L5) has been produced by this method, and the influence of L4/5 fusion on the vertebral end-plate and the annulus fibrosus of the intervertebral disc at the other intervertebral levels has been evaluated by three-dimensional finite element analysis.

Material and methods

We performed finite element analysis to investigate biomechanical changes induced by posterolateral interbody fusion (PLF) and posterior lumbar interbody fusion (PLIF). Three finite element models (FEMs) of the lumbar spine consisting of the five vertebral bodies and the four discs from L1 to L5 were established. A commercially available finite element program, COSMOS/M 2.5 (Structural Research and Analysis Corporation, Los Angeles, CA, USA), was used to model the spinal segments. The models and the loading and boundary conditions are described here.

Intact model

For the analytical model (Fig. 1a) computed tomography (CT) scanning was performed at slice widths of 2 mm in a 29-year-old man with no clinical or roentgenological abnormalities. This model contains elements of cortical and cancellous bone, annulus fibrosus, and anterior longitudinal, posterior longitudinal, supraspinous, interspinous, and intertransverse ligaments.

A three-dimensional isotropic eight-nodal solid element was used for modeling the cortical and cancellous bones, the end-plate, and ground substance of the disc. The material properties of each element were determined according to the literature (Table 1).\textsuperscript{1,2,4,7,10,11,13,16,19,22}

When modeling the disc, the annulus was regarded as composite material consisting of fiber embedded in the ground substance. Annular fibers were modeled using a three-dimensional cable element with pure tensile force.

The facet joints (L1/2, L2/3, L3/4, L4/5) were treated as in three-dimensional contact with a total of 139 individual gap elements. This model was symmetrical in the sagittal plane and was separated into 31,948 total elements and 33,035 total nodal points, as shown in Fig. 1.

Posterolateral lumbar fusion model

For PLF, bone graft was placed between the transverse process of the adjacent two vertebrae. The PLF model (Fig. 1b) consisted of the bone graft and the intact