BIOMECHACAL ANALYSIS OF THE LUMBOSACRAL SPINE UNDER VARIOUS LOADINGS AND GESTURES —A THREE-DIMENSIONAL FINITE ELEMENT STUDY

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INTRODUCTION

Although many finite element (FE) models[1-13] have been used to explore the biomechanical behavior of the lumbar spine , nevertheless , few researches[3,9,11] concerned with the whole lumbosacral (L1-S5) spine, and also few studies took more attention on the geometry of the highly irregular vertebra, especially at the posterior part. This study developed an accurate finite element model based on CT scans and considered the effect of ligaments and contacting friction in facet joints on the behavior of the lumbosacral spine under various loadings and postures.

METHODS

302 CT images 1mm spaced were depicted for the contour of each image on its bony boundary outline filtered by image grayvalue threshold, these contour lines then were stacked by software 3D-DOCTOR, and a three-dimensional STL format surface model was developed. Without loss of the accurate geometry of the irregular bony structure and preserving the efficiency of performance of the model on computers, this study used solid tetrahedral elements instead of hexahedral ones and triangular shell elements with element side in the range 1-3 mm to simulate the posterior bone and cortical shell, respectively. After convergence tests were conducted by limiting volume error and relative displacement error of L1 body less than 2% and 0.33%, respectively, a total amount of 136362 mixed elements were used to execute analyses of the FE model .

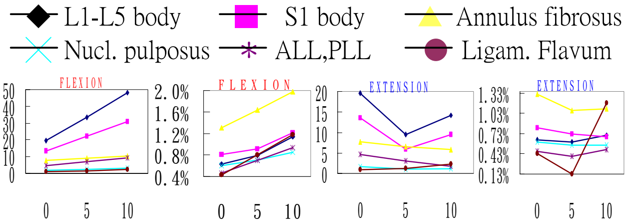
The vertebra consists of three components, cancellous bone, cortical shell (1 mm thickness) and posterior bone, and each disc is composed of nucleus pulposus, two layers of (inner and outer) annulus fiber, annulus ground matrix and end plates (1.5 mm thickness). All these were modeled as isotropic linear elastic materials, while ligaments except facet capsulary ligament were set as bilinear materials.

This study analyzed various loading conditions of uniformly distributed load (total 300N downward) over the top surface of L1 body, lateral bending/rotation moments (5Nm, 10 Nm) and forward/backward traction forces (100N, 200N, 300N) for the movement gestures including flexion, extension, left / right lateral bending and rotation, and fixed the sacroiliac joints.

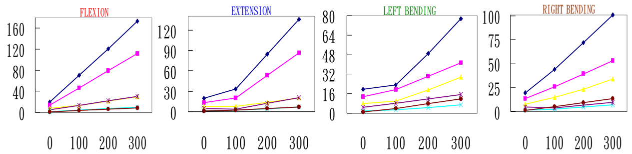
RESULTS AND DISCUSSION

The results showed a downward tendency of increasing stress/strain in the lumbosacral spine reaching the maximum value in the L5/S1 segments as previous studies mentioned, and other detailed items were extracted as follows:

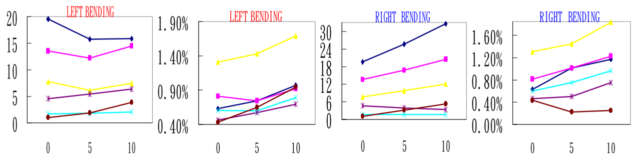
- Von-Mises stress/strain increased with larger bending moment in flexion, while they reduced temporarily in extension, especially in the ligamentum flavum (figs. 1-4); in cases of traction forces, stress increased not only in flexion/extension but also in bending. (figs.5-8)
- In the left/right lateral bending, there existed some differences in the von-Mises stress/strain despite nearly symmetry of the vertebra with respect to the sagittal plane. (figs.9-12)
- Left/right axial rotation also exhibited the asymmetry in the spine, especially in the case of right rotation, and small reduction in stress appeared transiently while larger reduction in strain arose.(figs.13-16)



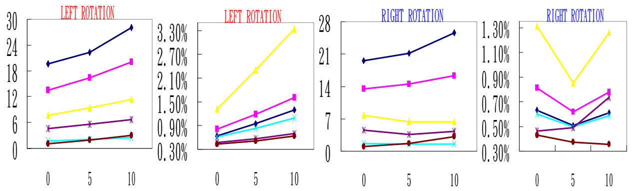
Figs.1-4 Von-Mises stress(MPa)/von-Mises strain in flexion and in extension under bending moments 0, 5, 10 (Nm)



Figs.5-8 Von-Mises stress(MPa) in flexion, extension, left/ right lateral bending under traction forces 0, 1, 2, 3 (×100N)



Figs.9-12 Von-Mises stress(MPa)/von-Mises strain in left/ right lateral bending under bending moments 0, 5, 10 (Nm)



Figs.13-16 Von-Mises stress (MPa)/von-Mises strain in left/ right axial rotation under rotation moments 0, 5, 10 (Nm)

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