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Basic Science

The biomechanical influence of the facet joint orientation and the facet tropism in the lumbar spine

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Abstract

BACKGROUND CONTEXT: Facet joint orientation and facet tropism (FT) are presented as the potential anatomical predisposing factors for lumbar degenerative changes that may lead in turn to early degeneration and herniation of the corresponding disc or degenerative spondylolisthesis. However, no biomechanical study of this concept has been reported.

PURPOSE: To investigate the biomechanical influence of the facet orientation and FT on stress on the corresponding segment.

STUDY DESIGN: Finite element analysis.

METHODS: Three models, F50, F55, and F60 were simulated with different facet joint orientations (50°, 55°, and 60° relative to coronal plane) at both L2–L3 facet joints. A FT model was also simulated to represent a 50° facet joint angle at the right side and a 60° facet joint angle at the left side in the L2–L3 segment. In each model, the intradiscal pressures were investigated under four pure moments and anterior shear force. Facet contact forces at the L2–L3 segment were also analyzed under extension and torsion moments and anterior shear force. This study was supported by 5000 CHF grant of 2011 AO Spine Research Korea fund. The authors of this study have no topic-specific potential conflicts of interest related to this study.

RESULTS: The F50, F55, and F60 models did not differ in the intradiscal pressures generated under four pure moments: but under anterior shear force, the F60 and FT models showed increases of intradiscal pressure. The F50 model under extension and the F60 model under torsion each generated an increase in facet contact force. In all conditions tested, the FT model yielded the greatest increase of intradiscal pressure and facet contact force of all the models.

CONCLUSIONS: The facet orientation per se did not increase disc stress or facet joint stress prominently at the corresponding level under four pure moments, but FT could make the corresponding segment more vulnerable to external moments or anterior shear force.

Keywords: Spondylolisthesis; Facet joint orientation; Facet tropism; Finite element model

FDA device/drug status: Not applicable.

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Introduction

Degenerative changes in the spine may potentially cause back pain and various spine pathologies [1]; hence, to prevent degenerative spinal disease and select appropriate treatments, it is important to identify factors that promote the degenerative process. As anatomical factors that promote spinal degeneration, the facet joint orientation and facet tropism (FT) have been suggested; from these internal factors, herniation of the corresponding disc or degenerative spondylolisthesis may result [1–7].

Facet orientation is the angle of the facet joint in the transverse view relative to the coronal plane [3]. Many previous studies have focused on facet joint orientation as a pre-existing morphological factor in degenerative spondylolisthesis [1–3]. Biomechanically, the facet joints primarily share the load in compression, extension, and torsion of the lumbar spine and protect the disc against torsion [8]. It is therefore proposed that a more sagittal orientation of the facet joint promotes anterior gliding by reducing resistance to anterior shear forces [2,9]. Facet joint tropism is defined as asymmetry between the left and right facet joint angles, with one joint having a more sagittal orientation than the other [3,10]. This was proposed to increase risk for degenerative diseases in the corresponding disc, such as disc herniation and rotational instability of the spinal segment [4–7].

However, there is some controversy concerning the correlation of facet joint sagittal orientation or tropism and degenerative disc disease. Several previous studies reported that a more sagittal facet joint orientation arose secondary to osteoarthritic remodeling or as the result of osteoarthritis and facet joint effusion [11,12]. Moreover, some studies found no association between facet joint tropism and disc degeneration [10,13]. Although many clinical studies attempt to associate facet orientation/FT with disc degeneration, no biomechanical test of this concept has been reported. Therefore, we conducted this study to investigate the biomechanical association between facet orientation and FT and stress on the corresponding disc and/or facet joint. For this purpose, we used a finite element (FE) model of the lumbar spine.

Materials and methods

An FE model of intact lumbar spine (L2–L5)

We developed a three-dimensional nonlinear FE model of the lumbar spine that consisted of four lumbar vertebrae, three intervertebral discs, and associated spinal ligaments. Geometrical details of the human lumbar spine (L2–L5) were obtained from high-resolution computed tomography images of a 46-year-old male subject who had no spinal deformities. Digital computed tomography data were imported to a software program (Mimics; Materialise Inc., Leuven, Belgium) that was used to generate the three-dimensional geometrical surface of the lumbar spine. Initial Graphic Exchange System files exported from the Mimics software were input into Unigraphics NX 3.0 (Siemens PLM Software, Torrance, CA, USA) to form solid models for each vertebral segment. The solid model was then imported into Hypermesh 8.0 (Altair Engineering, Inc., Troy, MI, USA) to generate FE meshes. The FE method was analyzed with commercially available software (ABAQUS 6.6-1; Hibbitt, Karlsson and Sorenson, Inc., Providence, RI, USA).

Three-dimensional homogenous and transversely isotropic solid elements were used to model the cortical and cancellous cores, the posterior bony parts of the vertebrae. The anterior longitudinal ligament, posterior longitudinal ligament, intertransverse ligament, ligament flavum, capsular ligament, interspinous ligament, and supraspinous ligament were modeled using tension-only truss elements.

Material properties

Material properties were selected from various sources in the literature (Table) [14–18]. The cortical and cancellous regions of the vertebrae were modeled independently. Differentiation between cortical and trabecular bone in the posterior region was difficult to delineate; therefore, the posterior elements were all assigned a single set of material properties.

The annulus fibrosus was modeled as a composite of a solid matrix with embedded fibers (using the REBAR parameter) in concentric rings surrounding a nucleus pulposus, which was considered to be an incompressible inviscid fluid. Element members with hybrid formulation (C3D8H) combined with low elastic modulus and large Poisson ratio definitions were applied to simulate the nucleus pulposus. Eight-node brick elements were used to model the matrix of the ground substance. Each of four concentric rings of ground substance contained two evenly spaced layers of annulus fibers oriented at ±30° to horizontal [19]. The reinforcement structure annulus fibers were represented by truss elements with modified tension-only elasticity. In the radial direction, four double cross-linked fiber layers were defined, and those fibers were bounded by the annulus ground substance and both end plates. In addition, these fibers had proportionally decreased elastic strength from the outermost (550 MPa) to the innermost (358 MPa) layer [19,20].

The articulating facet joint surfaces were modeled using surface-to-surface contact elements in combination with the penalty algorithm with normal contact stiffness of 200 N/mm and a friction coefficient of zero [21]. The thickness of the cartilage layer of the facet joint was assumed to be 0.2 mm [21]. The initial gap between the cartilage layers was assumed to be 0.5 mm [15,21]. The cartilage was assumed to be isotropic, linear elastic with a Young's modulus of 35 MPa and a Poisson's ratio of 0.4 [21]. Nonlinear material properties were assigned to spinal ligaments.