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Basic Science

The influence of facet joint orientation and tropism on the stress at the adjacent segment after lumbar fusion surgery: a biomechanical analysis

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Abstract

BACKGROUND CONTEXT: Facet joint orientation and tropism influence the biomechanics of the corresponding segment. Therefore, the sagittal orientation or tropism of the facet joint adjacent to the fusion segment seems a potential risk factor for adjacent segment degeneration. However, there have been no biomechanical studies regarding this issue.

PURPOSE: To investigate the association between adjacent facet orientation and facet tropism and stress in adjacent disc/facet joints using finite element (FE) analysis.

STUDY DESIGN: An FE analysis.

METHODS: Four intact (F50, F55, F60, and FT [facet tropism]) and matched L3–L4 fusion (F50, F55, F60, and FT fusion) models with different facet joint orientation (50°, 55°, 60° relative to the coronal plane, and facet tropism, respectively) at both L2–L3 facet joints were simulated. In each model, intradiscal pressures and facet contact force at the L2–L3 segment were investigated under pure moments and anterior shear force.

RESULTS: Compared with the matched-intact model, the F60 fusion model yielded the highest and largest percentage increase of intradiscal pressure at the L2–L3 segment under flexion, torsion moment, and anterior shear force among the F50, F55, and F60 fusion models. F60 fusion model also demonstrated the largest facet contact force under torsion moment among the F50, F55, and F60 fusion models. In all conditions tested, the FT fusion model demonstrated the highest intradiscal pressure and facet contact force of all the models.

CONCLUSIONS: Facet joint orientation and tropism at the adjacent segment influences the overstress of the adjacent segment, especially under the clinical circumstance of increased anterior shear force. © 2015 Elsevier Inc. All rights reserved.

Keywords: Facet orientation; Facet tropism; Adjacent segment degeneration; Lumbar fusion; Finite element analysis; Anterior shear force

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Introduction

Adjacent segment degeneration (ASD) refers to the radiographic deterioration of disc or facet joints adjacent to a fusion segment, with or without clinical symptoms, after lumbar arthrodesis surgery [1,2]. Potential risk factors contributing to ASD include instrumentation, posterior lumbar interbody fusion, injury to the facet joint of the adjacent segment, fusion length, age, previous facet arthritis, and sagittal alignment [3–5].

Facet joint orientation and tropism significantly influence the biomechanics of the corresponding segment [6–10]. A more sagittal orientation of the facet joint leads to anterior gliding because of reduced resistance to anterior shear forces, which results in anterolisthesis [10,11]. Facet tropism, defined as asymmetry between the left and right vertebral (apophyseal) facet joint angles [6,9], causes biomechanical vulnerability at the corresponding joint and intervertebral disc degeneration and/or herniation [7,8,12,13].

Because facet joint orientation and tropism influence the biomechanics of the corresponding segment, the sagittal orientation or tropism of the facet joint adjacent to the fusion segment seems a potential risk factor for ASD. However, there have been no biomechanical studies regarding this issue. Therefore, the purpose of this study was to investigate the association between adjacent facet orientation and facet tropism and stress on adjacent disc/facet joints. For this biomechanical analysis, a finite element (FE) model of the lumbar spine was used.

Materials and methods

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

In the present study, we used a previously validated three-dimensional nonlinear FE model of the lumbar spine consisting of four lumbar vertebrae, three intervertebral discs, and associated spinal ligaments [14]. Detailed methods of model development have been described in previous study [14]. Three-dimensional homogenous and transversely isotropic solid elements were used to model 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) [15–19]. The cortical and cancellous regions of the vertebrae were modeled independently. It was difficult to delineate the differences between the cortical and trabecular bones in the posterior region; therefore, all posterior elements were 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 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° horizontal.

Table
Material properties in the present FE models

Component	Young modulus (MPa)	Cross-section (mm^2)	Poisson ratio
Cortical bone	E_x=11,300		υ_{xy}=0.484
	E_y=11,300		υ_{xz}=0.203
	E_z=22,000		υ_{yz}=0.203
	G_x=3,800		
	G_y=5,400		
	G_z=5,400		
Cancellous bone	E_x=140		υ_{xy}=0.45
	E_y=140		υ_{xz}=0.315
	E_z=200		υ_{yz}=0.315
	G_x=48.3		
	G_y=48.3		
	G_z=48.3		
Posterior elements	3,500		0.25
Disc			
Nucleus pulposus	1.0		0.4999
Annulus (ground substance)	4.2		0.45
Annulus fiber	358–550		0.30
Cartilaginous end plate	24.0		0.40
Ligaments			
Anterior longitudinal	7.8(<12%) 20(>12%)	63.7	
Posterior longitudinal	10(<11%) 20(>11%)	20.0	
Ligamentum flavum	15(<6.2%) 19.5(>6.2%)	40.0	
Capsular	7.5(<25%) 32.9(>25%)	30.0	
Interspinous	10(<14%) 11.6(>14%)	40.0	
Supraspinous	8.0(<20%) 15(>20%)	30.0	
Intertransverse	10(<18%) 58.7(>18%)	1.8	

FE, finite element.

The reinforcement structure annulus fibers were represented by truss elements with modified tension-only elasticity. Radially, four double-cross-linked fiber layers were defined, and those fibers were bound 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 [14,20,21].

The articulating facet joint surfaces were modeled using surface-to-surface contact elements in combination with the penalty algorithm, with a normal contact stiffness of 200 N/mm and a friction coefficient of zero [22]. The thickness of the cartilage layer of the facet joint was assumed to be 0.2 mm [22]. The initial gap between the cartilage layers was assumed to be 0.5 mm [22]. The cartilage was assumed to be isotropic, linear, and elastic with a Young modulus of 35 MPa and a Poisson ratio of 0.4 [22]. Nonlinear material properties were assigned to spinal ligaments. Naturally changing ligament stiffness (initial low stiffness at low strains, followed by increased stiffness at higher strains) was simulated through a "hypoelastic" material designation (Table). Three-dimensional truss elements were used to simulate ligaments, which were active only during tension.

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