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The Influence of Facet Joint Load Transmission in the Spine Column on the Mechanical Properties of the Intervertebral Disc in Finite Element Modeling

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Abstract: This study is aimed to determine the impact support of the spine motion segments on mechanical properties of the intervertebral disc (IVD). In the simulations, the combinations of flexion-extension movements in spine motion segments were modeled. The analysis of the mechanics of the intervertebral disc clearly indicates a wide differentiation between anterior/posterior anatomical locations in the annulus fibrosus.

Introduction

The intervertebral disc is a highly-specialized element of the spine then provides flexibility and adsorbing capacities. Additionally, the disc separates adjacent vertebra and acts as a shock absorber, dissipating energy between them under loading. When mechanical loads are transmitted along the spine, the IVD mainly supports compression and flexion stresses. This results in excessive hydrostatic pressure in the nucleus pulposus and generates circumferential tensile stresses in the surrounding annulus fibrosus [1,2]. The aims of the present study are to develop a finite element model of a thoracic motion segment which allows the simulation of different movements in segment and their influence on the layer structure of the annulus fibrosus of IVD.

Material and methods

Simplified numerical model of the thoracic spine segment was built on the basis of diagnostic CT. The motion segment (Th11-Th12) is divided into several structures with different tissues material properties, which are shown in Table 1. Model contained 6 layers of fibers inclined alternatively at an angle of 30º to the horizontal plane embedded in a homogeneous ground substance. Annulus fibers and 3 different ligaments were modeled as non-linear links elements. Two cases of spine motion segment are examined: intact segments and acutely injured segments with anterior column only. Both cases are modeled using tetrahedral 10-node elements for the endplates and rigid elements to simulate the bone behavior. These segments models were used to predict load transmission in axial compression (using force 650 N), flexion and extension (gradient force 650 N causing bending moment) on the behavior of the IVD.

Table 1: Material properties of the motion segment components [3,4]

Link component name	E [MPa]	υ [-]	Θ [mm^2]	Solid component name	E [MPa]	υ [-]
Annulus fiber 6 layer	550÷360	0,45	0,2	Cortical bone	12 000	0,3
Anterior longitudial ligaments	20	0,3	64	Cancellous bone	100	0,2
				Endplata	25	0,1
Posterior longitudial ligaments	50	0,3	20	Nucleus pulposus	1	0,49
				Annulus ground substance	4.2	0,45
Interspinous ligaments	12	0,3	40	Articular cartilage	33	0,3

Results

The changes of the height in individual layers of the structure of the annulus fibrosus in anterior and posterior location of the IVD of both models are shown in Fig. 1. The loads acting on the annulus fibers layer change the IVD height and thus are causing the bulge in accordance with the generally known mechanism. This is caused by the fact that the collagen fibers of the annulus fibrosus under the influence of the load decrease the angle of inclination relative to the surface of vertebral bodies.

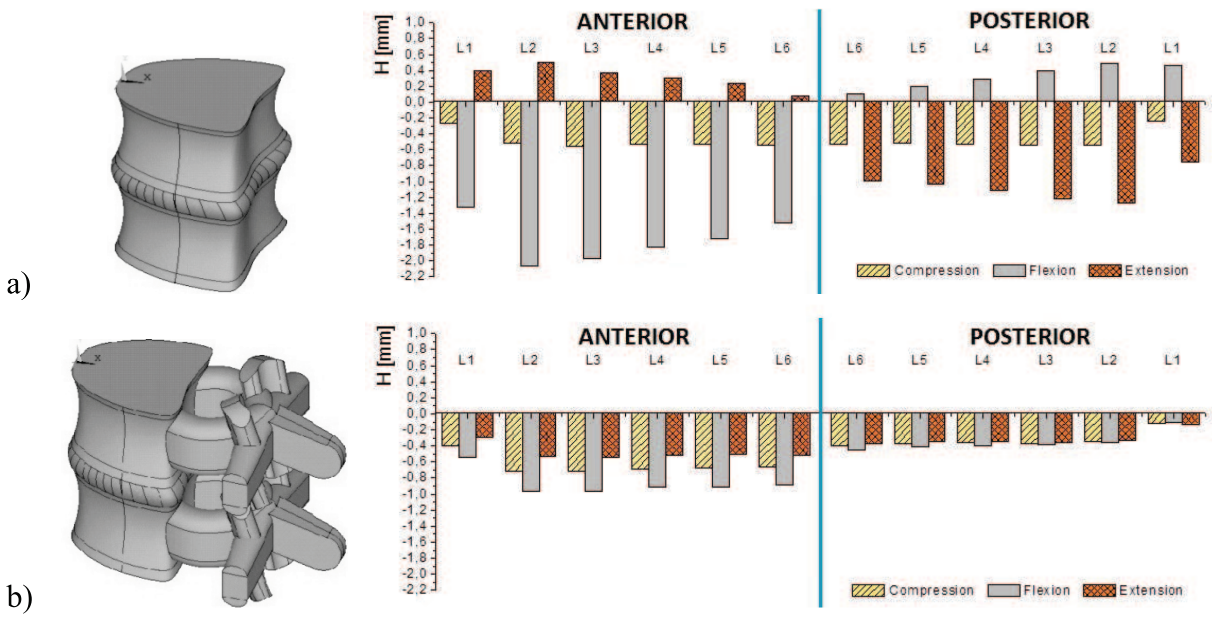

Fig. 1: The value of the height difference (H) layers in anterior and posterior location of the IVD for the three load incidents in the model: a) intact segments; b) acutely injured segments

Analyzing these results for both models it can be noted that posterior column undertakes a significant role in the transfer of loads through the spine. The posterior column constitutes an additional support for the spinal column, especially during flexion and extension. This effect significantly levels tension of the annulus fibrosus in the anterior or posterior region, depending on the acting load.

Summary

The facet joints included in the three-point support of the spin motion segment allow to compensate a large loads acting on the IVD as indicated by the results of the above research.

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