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Desired Properties of Disc in Numerical Models and Its Influence on Biomechanical Behavior of Lumbar Spine

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ABSTRACT: In this paper, nonlinear finite element modeling has been presented to conduct a parametric study of disc properties on biomechanical behavior of lumbar spine. This model includes vertebrae (cancellous bone and cortical bone), disc (nucleus, annulus fibrosus, and collagen fibers), end plates, and ligaments. 3 dimensions geometry was reconstructed from computed tomography scans of lumber spine. After applying loads (compression, moment and their combinations) and boundary conditions (fixed L5) to the model, finite element analysis was conducted. Experimental tests available in literature indicated that lumbar spine shows a nonlinear mechanical behavior; hence, to consider this nonlinear behavior in this work, ligaments and annulus fibers have been modeled as nonlinear springs. The obtained results of the current study, which include intradiscal pressure and intervertebral rotation, have been compared with previous in-vitro as well as numerical data. The results of this work showed that stiffening the disc leads to decreased intervertebral rotation in different anatomical planes and the intradiscal pressure.

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1- Introduction

A variety of finite element models have been introduced for the lumbar spine model in the field of biomechanical research. The passive lumbar spine is a complex structure composed of vertebrae, discs and ligaments. Many researchers have first assigned properties of materials to spinal structures and then evaluated single-variable material parameters for the purpose of parametric studies conducted using finite element method [1-3].

Given the need for the finite element model to become more realistic, the application of the ideal properties of soft tissue materials, especially the material of the annulus fibrosus and the nucleus pulposus, is a challenge ahead. Therefore, the purpose of this study is to investigate the parametric properties of disc components (annulus fibrosus and the nucleus pulposus) to achieve desired properties.

2- Methods

Three dimensional geometry of the bony structures which consist of the vertebrae *L1* through *L5* (*L1–5*) was reconstructed from Computed Tomography scans (CT-scans) of a 26 year-old male. Briefly, it consisted of five lumbar vertebrae *L1* to *L5* (*L1-5*), intervening discs, and surrounding ligaments (Fig. 1). The behavior of the cortical and cancellous bones was assumed linear elastic while the nucleus and annulus were modeled using hyper-elastic material law. The annular fibers and ligaments were simulated using nonlinear springs that resist tension only. The material properties are summarized in Table 1. The facet joint articulation was also simulated by frictionless surface to surface contact [6].

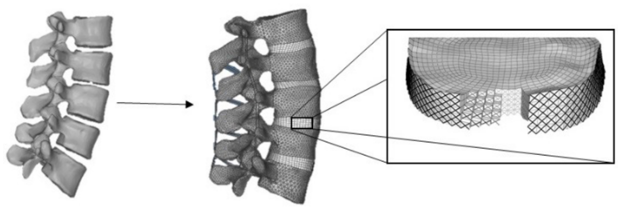

Fig. 1. Three dimensional finite element model of the lumbar spine

Loading was either compression (follower load), moment (in three anatomical planes) or their combination. The load was applied to the superior endplate of *L1* while the inferior endplate of *L5* was completely fixed.

The properties of disc components (annulus and nucleus) were investigated in five different cases, as shown in Table 2. These cases have been extracted from the literature and have been used in previous finite element models [11, 12].

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Table 1. Material properties of the spinal components

Component	Mechanical Properties	References
Endplate	E = 23.8 (MPa) v = 0.40	[8 ,7]
Cancellous	E = 200 (MPa) 25,· = v	[9]
Cortical	E = 12,000 (MPa) v = 0.30	[8]
Ligaments	Nonlinear force-displacement curve	[10]

Table 2. Material properties of the disc components

Disc component	Hyper-elastic (Mooney–Rivlin)		
	Case study	C10	C01
Nucleus pulposus	1	0.06	0.015
	2	0.12	0.03
	3	0.24	0.06
	4	0.36	0.09
	5	0.48	0.12
Annulus fibrosus	1	0.09	0.0225
	2	0.18	0.045
	3	0.36	0.09
	4	0.54	0.135
	5	0.72	0.18

3- Results and Discussion

Spinal responses under 7.5 N.m moment (flexion, extension, lateral bending and axial rotation) for the entire lumbar spine (*L1-L5*) were obtained. In flexion, the fifth case study difference of range of motion was about 55% compared to the first one, whereas this difference was 44% in extension. The amount of change in the range of motion was 18% and 55% in axial rotation and lateral bending, respectively.

The intradiscal pressure is obtained for all four lumbar spine discs at the end of the loading. The intradiscal pressure has decreased for the cases of 1 to 5: the min and max values were, respectively, 60.7% and 76.6% in the flexion mode; 58.1% and 67.8% in the extension mode; 73.6% and 98% in lateral bending mode; and 21.5% and 28.8% in axial rotation mode.

4- Conclusions

Using the nonlinear finite element model developed in this paper, the effect of disc properties on the parameters of desired properties were examined, and the following results were obtained:

• By changing the properties of the disc, the spine's range of motion can be varied greatly in different loading modes.

• By increasing the proportion of hyper-elastic material in the disc, the amount of intervertebral rotation decreases in each loading state.

• Under the combined loading of the *L4-L5* motion segment, the intradiscal pressure has a decreasing trend with increasing hyper-elastic coefficients from the first to fifth case study.

• In combination loading mode for a given case study, the highest intradiscal pressure occurs in flexion mode loading.

• By simultaneously checking the intervertebral rotation results and the intradiscal pressure and comparing them with the in-vitro data, the disc properties of item 1 and 2 show better compatibility.

References

[1] J.R. Meakin, Replacing the nucleus pulposus of the intervertebral disk: prediction of suitable properties of a replacement material using finite element analysis, Journal of Materials Science: Materials in Medicine, 12(3) (2001) 207-213.

[2] A. Rao, G. Dumas, Influence of material properties on the mechanical behaviour of the L5-S1 intervertebral disc in compression: a nonlinear finite element study, Journal of biomedical engineering, 13(2) (1991) 139-151.

[3] N. Yoganandan, S. Kumaresan, L. Voo, F. Pintar, Finite element model of the human lower cervical spine: parametric analysis of the C4-C6 unit, Journal of biomechanical engineering, 119(1) (1997) 87-92.

[4] S. Kumaresan, N. Yoganandan, F.A. Pintar, Finite element analysis of the cervical spine: a material property sensitivity study, Clinical Biomechanics, 14(1) (1999) 41-53.

[5] T.H. Smit, The mechanical significance of the trabecular bone architecture in a human vertebra, PhD thesis, Technical University of Hamburg-Harburg, (1996).

[6] U.M. Ayturk, C.M. Puttlitz, Parametric convergence sensitivity and validation of a finite element model of the human lumbar spine, Computer methods in biomechanics and biomedical engineering, 14(8) (2011) 695-705.

[7] H. Schmidt, A. Kettler, F. Heuer, U. Simon, L. Claes, H.-J. Wilke, Intradiscal pressure, shear strain, and fiber strain in the intervertebral disc under combined loading, Spine, 32(7) (2007) 748-755.

[8] K. Goto, N. Tajima, E. Chosa, K. Totoribe, S. Kubo, H. Kuroki, T. Arai, Effects of lumbar spinal fusion on the other lumbar intervertebral levels (three-dimensional finite element analysis), Journal of Orthopaedic Science, 8(4) (2003) 577-584.

[9] S.-L. Shih, C.-L. Liu, L.-Y. Huang, C.-H. Huang, C.-S. Chen, Effects of cord pretension and stiffness of the Dynesys system spacer on the biomechanics of spinal decompression-a finite element study, BMC musculoskeletal disorders, 14(1) (2013) 191.

[10] A. Rohlmann, L. Bauer, T. Zander, G. Bergmann, H.-J. Wilke, Determination of trunk muscle forces for flexion and extension by using a validated finite element model of the lumbar spine and measured in vivo data, Journal of Biomechanics, 39(6) (2006) 981-989.

[11] H. Schmidt, F. Heuer, J. Drumm, Z. Klezl, L. Claes, H.-J. Wilke, Application of a calibration method provides more realistic results for a finite element model of a lumbar spinal segment, Clinical biomechanics, 22(4) (2007) 377-384.

[12] H. Schmidt, F. Heuer, U. Simon, A. Kettler, A. Rohlmann, L. Claes, H.-J. Wilke, Application of a new calibration method for a three-dimensional finite element model of a human lumbar annulus fibrosus, Clinical Biomechanics, 21(4) (2006) 337-344.