BIOMECHANICAL ASPECTS OF HUMAN SPINAL INTERVERTEBRAL DISCS WITH APPLICATION OF DIFFERENT DISC IMPLANT SYSTEMS

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Abstract: The main objective of this study was to design three-dimensional geometrical and mechanical finite element model of the intervertebral disc between L2-L3 vertebras in the lumbar spinal segment, to construct different models of the intervertebral disc implants and then to evaluate how far artificial intervertebral discs correspond in their function and mechanical properties to the natural human intervertebral discs. For the purposes of the investigation both numerical and experimental investigation have been considered. For lumbar spinal segment different models with the application of artificial intervertebral disc implants have been created and analysed. All the investigations have their background in everyday medical practice and all the conclusions can be used for proposes of medical applications.

Introduction

The intervertebral discs make up about one fourth of entire length of the vertebral column. The discs absorb the stress and strain transmitted to the vertebral column.

One of the most common problems faced recently in medical practice is the clinical complication of the intervertebral disc degeneration. The degeneration of discs is a complex process that involves variations in the composition and function of the disc. Some of those regressive changes are connected with ageing process making a problem to be nearly universal [2]. This destructive process most frequently is observed as spondylosis, which is an after-effect of disc herniation and bony spurs familiar to osteophytes. Both osteophytes and disk herniations may expanse intervertebral foramina and vertebral canal causing compression acting on nerve roots and spinal cord respectively. This may result in severe pain, dysfunction and disability including weakness and paresis of upper and lower limbs. Compression acting on spinal root results in pain radiating across the back of the shoulder arm and down to forearm and fingers. Spinal cord compression is responsible for progressive weakness of lower and upper limbs that leads to complete disability when untreated. Surgical treatment is employed in those cases when pain does not respond to conservative management and when neurological deficits are developed. Surgical intervention relieves pain and prevents permanent disability caused by neurological deficits. A number of operative procedures have been utilized to relieve compression of the spinal cord and nerve roots caused by a disc disease. However most of them involves stabilisation of the injured spinal segment using different fixation systems. Those procedures relive pain connected with the compression of the spinal cord but at the same time after fusion (artrodesis), fussed vertebras do not perform in the structure of the spine the same role of the motion segment like it is in an intact spine.

From medical and biomechanical point of view it is very important to construct an intervertebral disc implant corresponding in its structure and behaviour to the spinal column to the natural human intervertebral disc.

Materials and Methods

In order to analyse the behaviour of the intervertebral disc implant appropriate FEM model has been constructed. For the purposes of the investigation, former model of and intact spinal segments have been consequently adopted [1]. Geometry and diameters of the artificial intervertebral disc implant has been the same like for a real model constructed by authors. To approximate the structure of the human intervertebral disc the pair of cylinder shaped implants has been utilised. To simplify the numerical solution and to reduce the time of numerical analysis the homogenous material has been used to approximate solid of the artificial intervertebral discs.

Numerical investigation involved the application of hyperelastic material properties. Material is said to hyperelastic if there exist a scalar function of one of the strain or deformation tensors, whose derivative with respect to a strain component determines the corresesopnding strass components [3]. This formula can be expresed by:

$$S_{ij} = \frac{\partial W}{\partial E_{ij}} \equiv 2\frac{\partial W}{\partial C_{ij}}$$

S_{ij} = components of the second Piola-Kirchoff stress tensor
W = strain energy function per unit undeformed volume
E_{ij} = components of the Lagrangian strain tensor
C_{ij} = components of the right Cauchy-Green deformation tensor

For the model Mooney-Rivlin constitutive lows representing stress-strain relationship have been adopted. The Mooney Rivlin strain energy density function has the following form:

$W=a_{10}(I_1-3) + a_{01}(I_2-3) + \beta(I_3^{2}-I_3^{-2})^2$

where:

I_i – reduced strain invariants in the ith direction:

$I_1=I_1I_3^{-1/3}$

$I_2=I_2I_3^{-2/3}$

$I_I=I_3^{1/2}$

a_{10}, a_{01} – Mooney-Rivlin material constants

$$\beta = \frac{(1+\upsilon)}{(1-2\upsilon)}\frac{a_{10}+a_{01}}{24}$$

υ - Poisson's ratio

I_i – invariants of Cauchy-Green's deformation tensors

$I_1=C_{ii}$

$I_2=1/2(I_1^{2}-C_{ij}C_{ij})$

$I_3=det\ C_{ij}$

In order to find a_{10}, a_{01} – Mooney-Rivlin constants, an axial compression test on the biocomatible, hydrophilic, radiolyticaly polymerized and crosslinked vinyl pyrrolidone (VP) has been performed. From the experiment the following strain-stress dependency have been utilised in numerical analysis.

An axial compression load has been applied to the models representing L2 – L3 motion segment before and after the application on artificial intervertebral discs. In a steady state analysis the load has been applied progressively to the value of 6000 N.

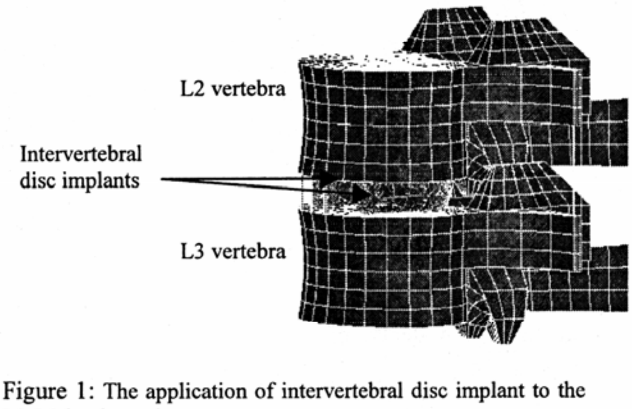

Figure 1: The application of intervertebral disc implant to the L2-L3 lumbar spine segment

Results

Results of the static analysis of the L2-L3 motion segment before and after the application of the disc implants has been compared with the results of the former experimental investigations performed by other scientists and authors [1]. In Figure 2 the results of axial compression test show significant correspondence of the numerical results of the analysis of artificial intervertebral discs with the results (numerical and experimental) accomplished for an intact intervertebral disc.

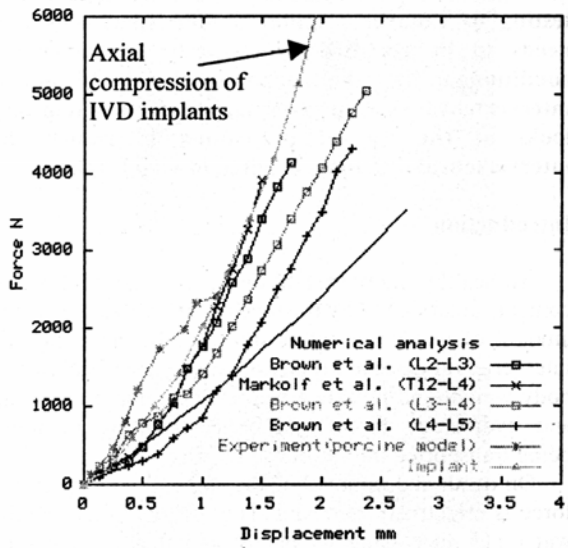

Figure 2: Static test of artificial and intact intervertebral discs

Conclusions

From the above investigation one can conclude that hyperelastic Mooney-Rivlin material constitutive lows seems to be very much applicable to describe the behaviour of materials used to construct artificial intervertebral discs. Additionally axial compression numerical tests performed on artificial disc of presented material constitutive low show significant correspondence to intact intervertebral discs.

REFERENCES

(Books)

[1] Awrejcewicz Jan, Ciach Michał, Kleiber Michał (Eds.), "Proceedings of the Conference on Biomechanics - modelling, computational methods, experiments and biomedical applications", Łódź, December7-8, 1998, pp. 53-64.
[2] Będziński R. „Biomechanika inżynierska, zagadnienia wybrane", Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław, 1997.
[3] Khonke Peter, (Edt.), ANSYS Theory Reference, Release 5.4, Canonsburg, 1994.