A finite element analysis study of the cervical spine implants

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Abstract

Instability and destruction of intervertebral disc structures lead to the formation of degenerative changes also in cervical spine. The aim of this study was finite element analysis influence of the cervical disc implants to changes occurring in the cervical spine under the load transmission (axial compression, flexion and extension).

Keywords: biomechanical analysis; cervical spine, disc implants, finite element methods

1. Introduction

Investigations into the biomechanics of degenerative intervertebral disc disease of the cervical spine are the subject of many clinical trials. Practical limitations in measuring on in vivo conditions shown that evaluation of the damaged cervical spine is a very complicated process. Mostly the evaluation of the mechanical parameters of the cervical section is carried out on the basis of finite element methods. ProDisc-C and DCI disc prostheses are typically used to treat degenerative cervical spine instability. The purpose of our study was to investigate how the implants may be affected by the biomechanics of the cervical spine under the load transmission: axial compression, flexion and extension. By using finite element method, the model was evaluated the distribution of displacements, stress and strain in the cervical spine with implants.

2. Material and methods

Dimensions of the geometrical structure of cervical segments (C3-C7) were obtained from the computed tomography and were prepared using the ANSYS software.

Cancellous bone, cortical bone, endplates, intervertebral discs were described by the isotropic, linear elastic material properties using tetrahedral 10-node elements type Solid187. The intervertebral discs were divided into two parts: 3 layers of annulus fibrosus and nucleus pulposus. Annulus fibrosus contained of fibres at angle of 30° (cross section area 0.02 mm^2) in homogeneous ground substance, which were modelled as non-linear link elements. Ligaments were assigned to 4-node shell elements (Shell181). The different tissues material properties were shown in Tab.1. The articulating facet surfaces were modelled using surface to surface contact elements (with a penalty algorithm and a friction coefficient of 0.1). Numerical simulations have been performed for three cases: an intact model and model with the U-shaped stand-alone DCI implant and with the ProDisc-C artificial discs. The geometrical models and fundamental dimensions width, length, height of all implants were shown in Fig.1. The DCI was made of titanium alloy (Ti6Al4V) and ProDisc-C implant was made of cobalt alloy (CoCrMo) with polyethylene core (UHMWPE) – Tab.1.

A follower load was applied at the superior endplate of C3 vertebra and the inferior endplate of the C7 vertebra was totally fixed. In the first stage, the numerical simulation has been carried out under the influence of an axial compression force equal to 200N. In the second stage, a bending moment of 1.2Nm was applied in flexion and extension.

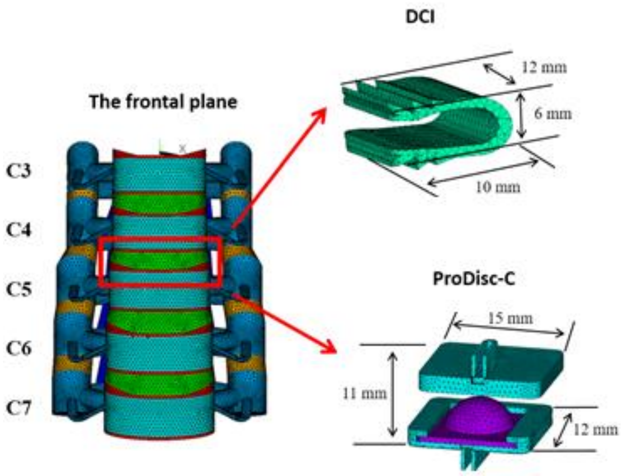

Figure 1: Numerical model of cervical segment spine (C3-C7) with the DCI and the Prodisc-C implants

3. Results

Under axial compression the maximum displacement in an intact segments amounts to 6.4 mm and this is smaller than value in the segments with the DCI and ProDisc-C implants. The highest displacement values in cervical spine models have been demonstrated under flexion. The value is equal to 10.8 mm for both of considered models with implants.

The results also indicate that after the application of the DCI in the cervical spine, there are smaller values of strain, similar to the values obtained in the intact cervical spine (Fig.2). The greatest changes in the strain value were demonstrated in the model with Prodisc-C implant.

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Table 1: Material Properties determined and used for Finite Element Analysis [1,2]

SOLID components			SHELL components		
	Young's modulus [MPa]	Poisson's ratio [-]		Young's modulus [MPa]	Poisson's ratio [-]
Cortical bone	12 000	0,30	Posterior longitudinal ligaments (PLL)	50	0,30
Cancellous bone	100	0,20	Interspinous ligaments (ISL)	12	0,30
Posterior bone	3 500	0,25	Ligamentum flavum (LF)	19	0,30
Cartilaginous endplate	25	0,10			
Nucleus pulposus	1	0,49	LINK components		
Annulus ground substance	4.2	0,45	Annulus fibres	550÷360	0.45
Articular cartilage	33	0,3			
CoCrMo (Prodisc-C)	210 000	0,29			
UHMWPE (Prodisc-C)	800	0,40			

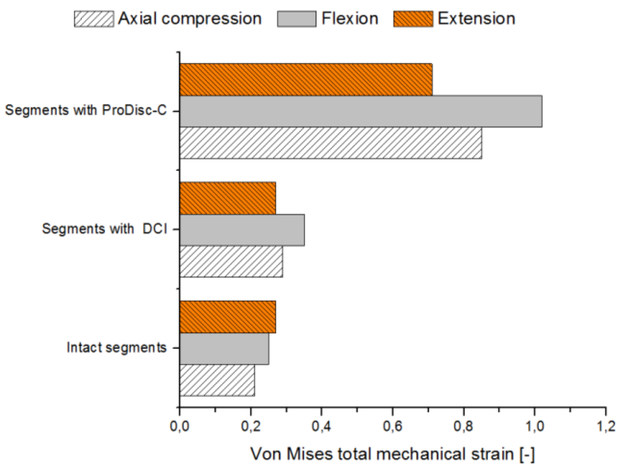

Figure 2: The maximum von Mises strain in the considered implants under compression, flexion and extension

The stress on the implants was measured under axial compresion, flexion, extension was higher for the DCI implant than the values obtained for the ProDisc-C (Fig.3). For both implants the greatest stress occurring under flexion loading (DCI: 476 MPa ProDisc-C: 426 MPa) – Fig.4.

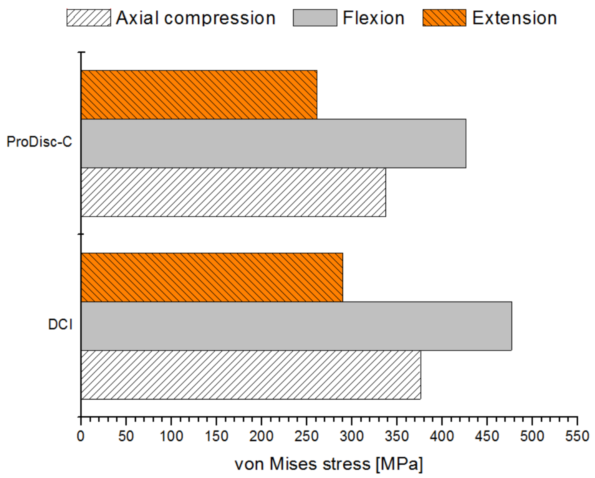

Figure 3: The maximum von Mises stress in the considered implants under compression, flexion and extension

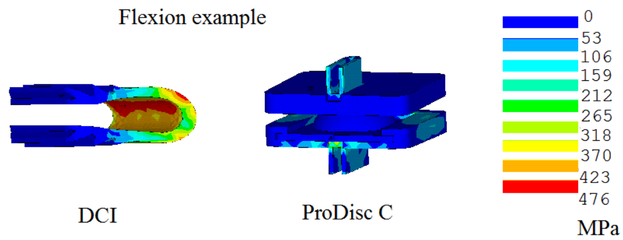

Figure 4: Example stress distribution on the DCI and ProDisc-C implants under flexion loading

Degenerative intervertebral disc disease of the cervical spine is a prevalent condition in our population. The studies have shown that most men (95%) and almost three quarters of women (70%) after age 65 will have some sort of degenerative change [3]. Treatment of the injured cervical spine segment is a very complicated process, because the spine structure has a complex construction. The biomechanical aspect of application the intervertebral disc implants is first of all to maintain continuity of strain of the injured segments of spine.

The analysis showed that the application of the Prodisc-C implant does not given the opportunity to provide to the strain as the strain in a healthy spine (Fig.2). The DCI implant could better maintain the spinal kinematic motion.

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