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BIOMECHANICAL STUDY OF THE CERVICAL SPINE WITH DISC IMPLANTS: A FINITE ELEMENT ANALYSIS

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Abstract: *Overloads of the spine often lead to the formation of degenerative changes. Additionally, the progression of these changes is led to instability and destruction of intervertebral disc structures. Therefore, the cervical disc implants are usually used as technical aids to improve the stability. The aim of the study was to assess changes occurring in the cervical spine, as a result of application of the cervical disc implants.*

Keywords: Cervical spine, Finite element modeling, Disc implants, Mechanical properties.

1. Introduction

Variable loads and overloads of the spine can often lead to injuries and mechanical damage, as well as the formation of degenerative changes. Degenerative intervertebral disc disease of the cervical spine is a prevalent condition in our population, because the studies have shown that 95 % of men and 70 % of women after age 65 will have some sort of degenerative change (Phillips et al., 2005). Treatment of the damaged cervical spine segment is a very complicated process, resulting mainly from a complex construction of spine structure. It is usually based on the use of technical aids in the form of intervertebral disc implants, which must fulfill the basic aspects in term of the biomechanical as well as the clinical ones. The main aim of this study was to assess the impact introduction of the cervical disc implants to changes occurring in the cervical spine under the load transmission (axial compression, flexion and extension). By using finite element model of the cervical spine, the study was conducted to compare the intact segments versus the segments with the DCI implant and the segments with the ProDisc-C implant. This study evaluated the distribution of displacements, stress and strain of considered models.

2. Materials and methods

The numerical model of four-level cervical spine (C3 – C7) was built on the basis of diagnostic computed tomography (CT). The values of each parametric dimensions of the vertebrae included in the numerical model were verified with the dimensions of the vertebrae available in the literature (Panjabi et al., 1990). The final files of the vertebrae models were created in ANSYS. The segments of cervical spine were divided into several structures with different tissues material properties, which are shown in Tab. 1. The vertebrae were modeled of a solid volume (cancellous bone) and a layer of vertebral cortical walls. The models of intervertebral disc were contained 3 layers of annulus fibrosus and the height of the intervertebral discs were between 4.5 mm and 5 mm. The geometry of the implants was constructed with primary dimension available in the literature, which are shown in Fig. 2. Bone and soft tissue and the implants were described by the isotropic, linear elastic material properties using tetrahedral 10-node elements type Solid187. Additionally, three different ligaments were modelled as 4-node shell elements

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type Shell181. Numerical simulations have been performed for three cases: intact segments, segments with the DCI implant and segments with the ProDisc-C implant (Fig. 1).

Tab. 1: Material properties of the cervical spine components.

		Young's modulus [MPa]	Poisson's ratio [-]
SOLID component name	Cortical bone	12 000	0.30
	Cancellous bone	100	0.20
	Posterior bone	3500	0.25
	Cartilaginous endplate	25	0.10
	Nucleus pulposus	1	0.49
	Annulus fibrosus	8.4	0.45
	Articular cartilage	33	0.30
	CoCrMo (Prodisc-C)	210 000	0.29
	UHMWPE (Prodisc-C)	800	0.40
	Ti-6Al-4V (DCI)	110 000	0.36
SHELL component name	Posterior longitudinal ligaments (PLL)	50	0.30
	Interspinous ligaments (ISL)	12	0.30
	Ligamentum flavum (LF)	19	0.30

* Shirazi-Adl et al., 1986; Sharma et al., 1995; Smit et al., 1997; Kumaresan et al., 1999

In first stage, the analysis has been carried out under the influence of an axial compression force equal to 200 N. In each of the considered cases, the axial compression force was applied to the superior endplate of the upper vertebral body (C3), as recommended in the literature (Wilke et al., 1998). In next stage, a pure unconstrained bending moment in flexion and extension (equal to 1.2 N.m) was applied the same as the axial compression. This force is responsible for loading transmission by the cervical spine of an average adult human, resulting from the weight of the head. All configurations of the model were fixed by deducting all the degrees of freedom on the inferior endplate of the lower vertebral body (C7).

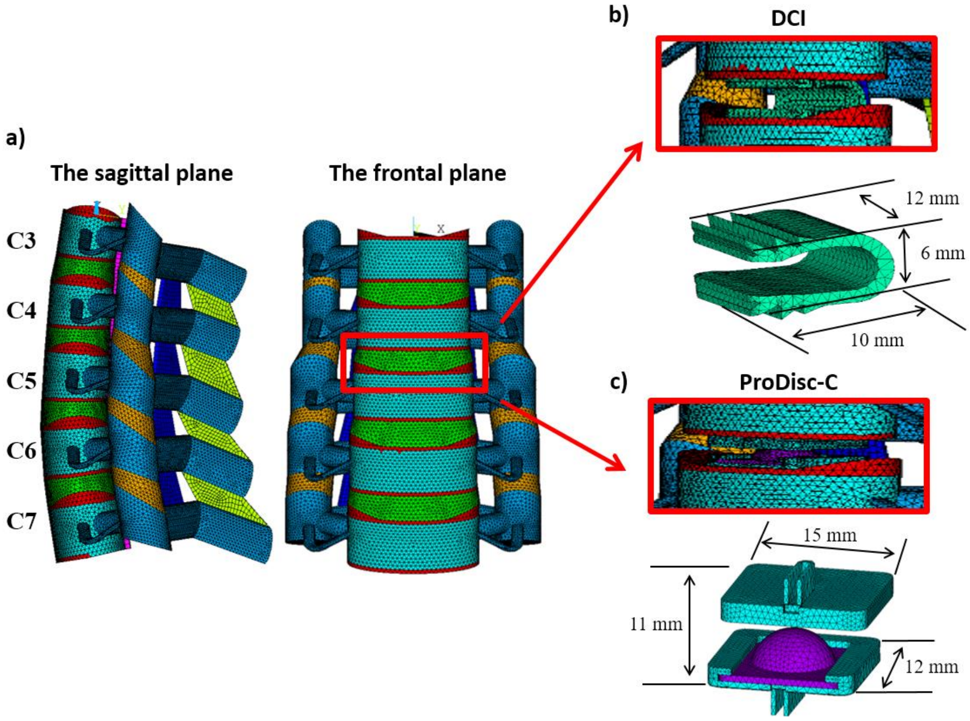

Fig. 1: Finite element model of cervical segment spine (C3 – C7): a) an intact model in the sagittal and the frontal plane, b) model with the DCI implant, c) model with the Prodisc-C implant.

3. Results

The numerical simulations allowed the analysis of the distribution of displacements, stress and strain of considered models, in particular, changes occurring in the intervertebral disc implants. The results of the distribution of global displacement of considered models under axial compression are presented in Fig. 2.

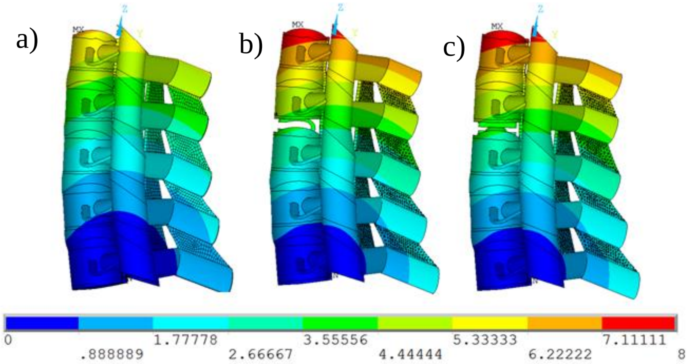

Fig. 2: Distribution of global displacement of three configurations of the model under axial compression: a) an intact model, b) with the DCI implant, c) with the Prodisc-C implant.

It can be concluded that maximum displacement in an intact segments amounts to 6.4 mm. The resulting value is smaller than the maximum displacement of the segments with the DCI and ProDisc-C implants, where the value is equal to 7.8 mm for both of considered models. The maximum global displacement and von Mises total mechanical strain of considered models during axial compression, flexion and extension are presented in Fig. 3.

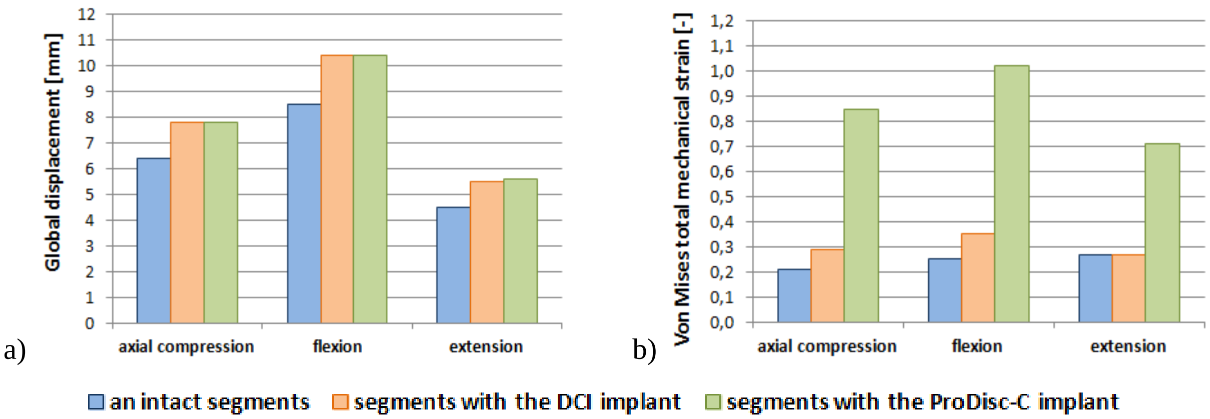

Fig. 3: The mechanical properties of the considered models during compression, flexion and extension: a) the maximum global displacement, b) the maximum von Mises total mechanical strain.

The analysis of the distribution of von Mises stress under axial compression (Fig. 4) showed that the largest value of stress was obtained for the segments with these implants. The maximum values of stress for the segment with the DCI implant amounted to 60 MPa and it is the same as for the segment with the ProDisc-C implant.

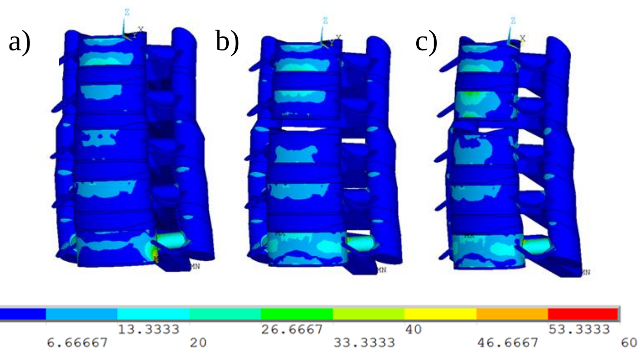

Fig. 4: Distribution of von Mises stress of three configurations of the model under axial compression: a) an intact model, b) with the DCI implant, c) with the Prodisc-C implant.

Considering distribution of the von Mises stress (Fig. 5) for the intervertebral discs implants it can be seen that the maximum values was higher for the DCI implant than the values obtained for the ProDisc-C. In the case of the DCI implant under axial compression, the maximum value was 375 MPa and 337 MPa for ProDisc-C implant. The maximum von Mises stress of considered models during axial compression, flexion and extension are presented in Fig. 6.

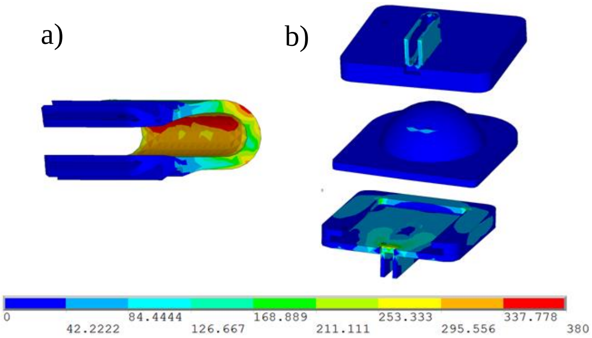

Fig. 5: Von Mises stress distribution in the considered implants under axial compression: a) the DCI implant, b) the Prodisc-C implant.

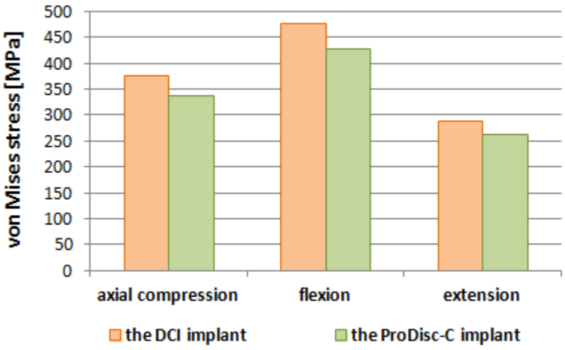

Fig. 6: The maximum von Mises stress in the considered implants under the load transmission.

4. Conclusions

The biomechanical aspect of application the intervertebral disc implants is fundamental to maintain appropriate stiffness and 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 displacement as in a healthy spine and also does not reduce the mobility. The DCI implant could better maintain the spinal kinematic motion, because after the introduction in the cervical spine there are smaller strain.

Acknowledgement

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