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FINITE ELEMENT ANALYSIS OF COMPRESSION OF LUMBAR SPINE WITH DYNAMIC IMPLANT

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Abstract: *The degenerative and traumatic injuries of a spine are very frequent. In those cases it is necessary to stabilize the corresponding spine segment using a spine implant. The spinal implants are rigid or flexible, the latter known as dynamic ones in medical practice. In this paper, the problems of the physiological spinal segment and the segment with implant were solved using the computational modelling (finite element method). Computational model consists of 4 lumbar vertebrae L2 – L5, intervertebral discs, joints and spinal implants. The spinal segment was loaded by the force 400N. The displacement of the whole system, contact pressure of cartilages, equivalent strain in cancellous bone and equivalent stress in the implant were analyzed. The deformation of the physiological model and the model with the implant are comparable, but the bone tissue of the model with the implant is dramatically more loaded in vicinity of the screws.*

Keywords: Spine, Implant, Intervertebral disc, Joints, Stress – strain analysis.

1. Introduction

Degenerative diseases and traumatic injuries of a spine afflict a great deal of the population of the Czech Republic. These injuries can lead to the oppression of blood vessels and nerves; besides, injuries of intervertebral discs (ID), joints and vertebrae occur frequently as well. In these cases, it is necessary to stabilize the damaged spinal segment with the implant.

The spinal implants are divided into rigid and flexible. The latter are known as dynamic ones in medical practice. The spinal implant has to stabilize the spinal segment for arbitrary (possible) load. It is clear, that the spinal segment with the flexible implant has to be stiffer than the physiological state of the spine. Moreover, the deformation of the segment in the physiological state is different for arbitrary load. The aim of this paper is stress – strain analysis of the flexible implant.

2. Materials and Methods

We can simulate a function of a spinal segment with the implant using the computational modeling. The computational modeling is suitable, because it allows us to change loads effectively, to simulate different states of the spinal segment and to analyze the results relatively easily. Besides, to perform an experiment in vivo is very demanding.

For a solution of the given problem by means of the finite element method, it is necessary to create a computational model which, in this case, consists of four independent parts: model of geometry, materials, loads and boundary conditions (Manek et al., 2012).

2.1. Geometry model

The geometry was created by using computer tomography (CT) data of a woman. The data were obtained from University of Iova database (Visible Human Project CT Datasets 2012). The geometries of four lumbar vertebrae (L2 - L5) were modelled using the hybrid segmentation in software STL Model Creator (Marcián et al., 2011; Prášilová et al., 2012). Three models were created in this paper in order to compare the results of stress – strain analyses. The first one is a physiological model consisting of 4

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vertebrae, 3 ID, 12 cartilages in joints. The second one is a spine model with a degraded ID. The last one is the model with a dynamic implant and with a degraded ID shown in Fig. 1 (the implant was inserted into vertebrae L2 and L3). The model with the implant consists of 39 parts and the physiological one consists of 19 parts that was modelled in software SolidWorks and ANSYS.

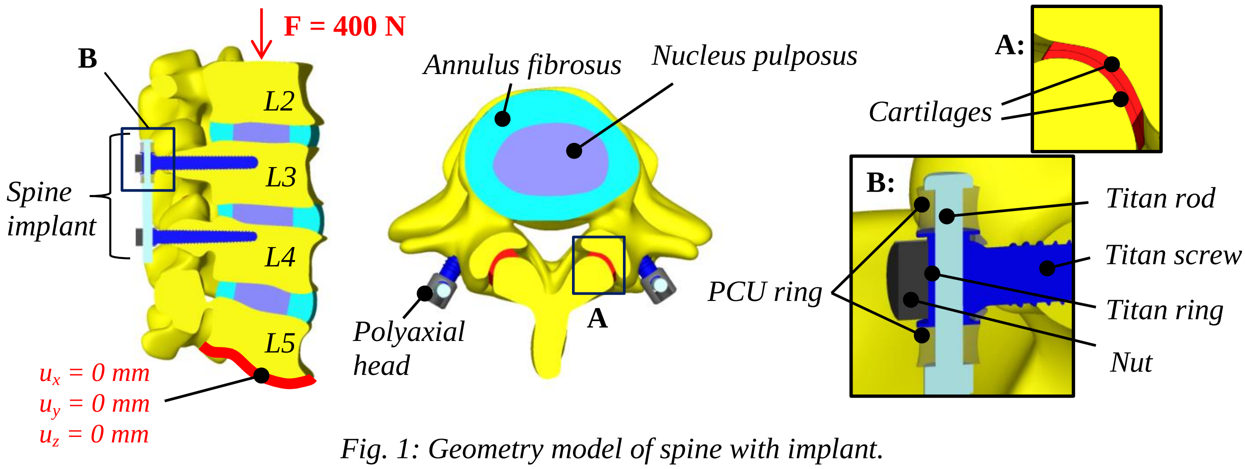

Fig. 1: Geometry model of spine with implant.

2.2. Models of materials

All components of the model was modelled by the linear elastic homogeneous isotropic model of material, which is specified by Young's modulus E and Possion's ratio μ on the basis of literature (Tab. 1), (Martinez et al., 1997; Goel et al., 1997).

Tab. 1: Material properties.

Material	**Young's Modulus [*MPa*]**	**Poisson's ratio [-]**
Cortical bone	***12 000***	***0.3***
Cancellous bone	***100***	***0.2***
Cartilage	***24***	***0.4***
Nucleus pulposus/degraded	***1/0.2***	***0.49***
Annulus fibrosus/degraded	***30/6***	***0.45***
PCU (polycarbonate urethane)	***31.8***	***0.3***
Titanium alloy 100–Ti-6Al-7Nb	***110 000***	***0.3***

2.3. Model of load and boundary conditions

On the bottom surface of vertebrae L5, all nodes were fixed. On the top surface of vertebrae L1, the compressive load F = 400 *N* (Schrazi-Adl et al., 1987) was applied in all analyzed models.

2.4. Computational model

Finite elements SOLID186 and 187 were used for modeling of the vertebrae, cartilages, IDs and implant. SHELL181 was used for the cortical bone (thickness 1 mm). TARGET170 and CONTA174 were used for modeling of contact between cartilages (friction 0.001) and between titan alloys – PCU (friction 0.3). There were created six contact pairs between cartilages (Fig. 1, detail A) and then three contact pairs connected with the implant (titan ring with PCU rings, titan rod with titan ring and PCU rings, see detail B in the Fig. 1).The final number of degree of freedoms (DOF) for model with implant was 2.5 million and the physiological one had 1 million DOF. Due to the character of the problem and of the computational model, the solver was set to the large deflection mode.

3. Results

The total displacement results are shown in Fig. 2. The dominant displacement is in the direction of y axis (anterior – posterior direction). In the physiological model is u_{ymax} = 3.09 *mm*, the displacement of the model with the degraded ID u_{ymax} = 5.12 *mm* and u_{ymax} = 2.92 *mm* when the implant and the degraded ID is used.

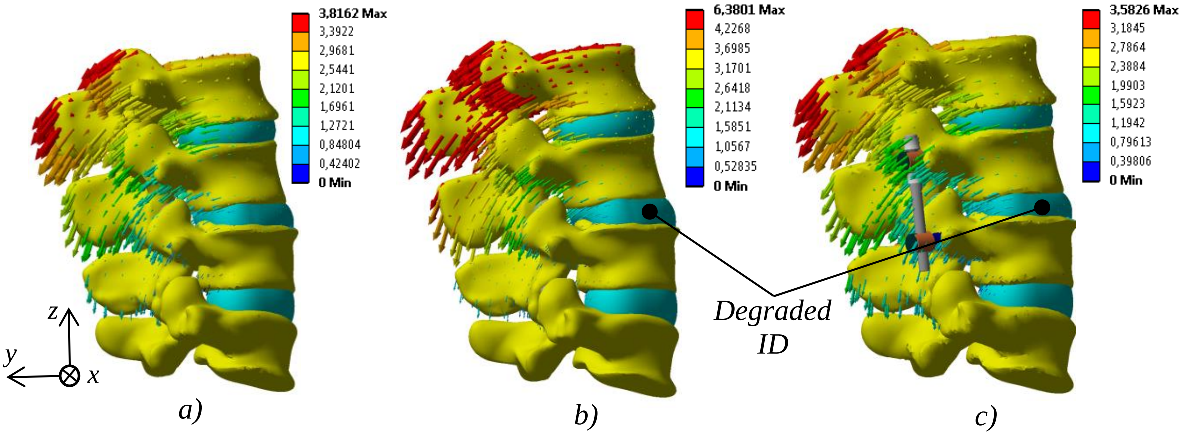

Fig. 2: Total displacement of: a) Physiological model; b) Model with degraded ID; c) Model with implant and degraded ID [mm].

The contact pressures in cartilages were analyzed in all three models. The maximum values of contact pressures are shown in the Fig. 3. The contact pressure distribution in the selected cartilages is shown as well. The greatest contact pressures occur in the model with degraded ID (specifically, in the cartilages of vertebrae L4/L5 (left)). The lowest pressures occur in the model with implant (specifically, in the cartilages of vertebrae L3/L4 (left)).

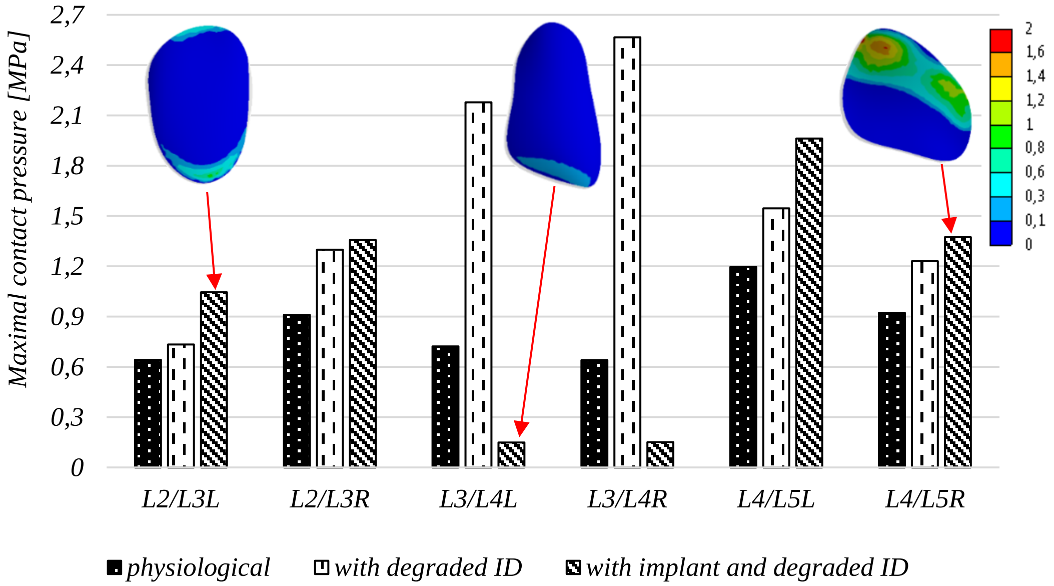

Fig. 3: Graph of contact pressures [MPa] of cartilages (note: Lxx/Lyy – contact between lumbar vertebrae number xx/yy, L – left side, R – right side).

The equivalent strain (strain intensity) was analysed in vertebrae L3 and L4 in the cancellous bone tissue (see Fig. 4a). For better understanding, the colour ranges were changed in order to correspond to intervals of strain intensity suggested by Frost theory (Martin et al., 1989). The Frost's theory says that the bone remodelling is limited by 2000 - 2500 $\mu\varepsilon$ in the physiological statue and the bone overloading lies in the thresholds value 3500 and 4000 $\mu\varepsilon$. From Fig. 4a, it can be seen that the cancellous bone tissue is overloaded in the places in the beginning and at the end of the screws.

To assess the limit state of elasticity, the equivalent stress was determined on the basis of the Von Mises yield criterion. The values of equivalent stress of implant are shown in Fig. 4b. The maximum value (*177 MPa*) is in the titan rod under the titan ring.

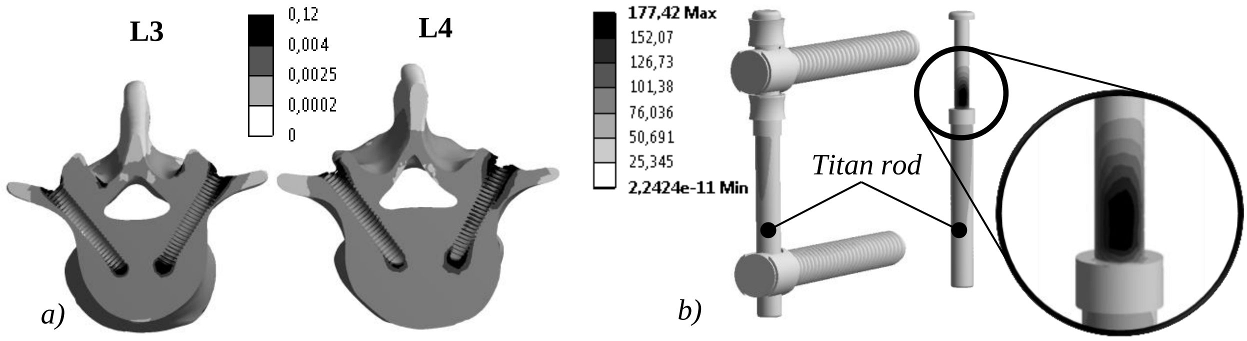

Fig. 4: a) Equivalent strain [-] of vertebrae L3 and L4; b) Equivalent stress [MPa] of implant.

4. Discussion

The results show that the deformations of the physiological model and model with dynamic implant are comparable. The largest u_y displacements occur in the spine model with degraded ID (*40 %* more than in case of the physiological model). As Fig. 2 and the results of u_y displacements show, the dynamic implant significantly decreases the deformations and the spine segment with degraded ID and implant approaches to the physiologic state (the difference is about *5.5 %*).

The range of the calculated contact pressure is from *0.15 MPa* to *2.57 MPa*. The application of the implant decreases the contact pressure between L3/L4 approx. by 94 *%*. On the other hand, the pressure increase by *17%* was occurred between L4/L5. Implant screws cause the stress redistribution in the vertebrae. The most loaded cancellous bone tissue was found in the part enclosing the screws in L3 and L4. Maximum Von Mises stress is *177 MPa* in the titan rod which is subjected to bending. The value of maximum equivalent stress is under the yield stress.

5. Conclusion

This biomechanical study of the spine segment was focused on the stress-strain analysis of the physiological system and the system with the dynamic spine implant and the affected part of the degraded ID. It was shown that the dynamic spine implant has a positive influence on the deformation of the system with the degraded ID. Unfortunately, the bone tissue around screws is overloaded according to Frost theory.

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