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STRESS ANALYSIS OF BURCH-SCHNEIDER CAGE

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Abstract: *This article deals with the stress analysis of the Burch-Schneider (BS) cage as applied to a hip joint. Due to the complex geometry of the solved problem, material properties and complex boundary condition, the finite element method was chosen. The solved system consists of the pelvic bone, a part of the os sacrum, a polyethylene cup and ceramic heads. In this work a poor-quality cancellous bone was given by the value of the modulus of elasticity is modelled. Furthermore, two model types are considered in this study – a model with degraded mechanical properties of the cancellous bone, which does not worsen due to stress, whereas the other model shows a case of bone necrosis due to stress. Load was applied to the ceramic head in the direction of the resultant butt force, which had been determined by the resultant forces. The analysis of the results indicates that in the model variant with the necrotic bone tissue of such an extent that was considered, damage may occur due to the cyclical loading. However, in the variant with degraded mechanical properties, which are not deteriorating due to stress anymore, the limit state does not occur.*

Keywords: ***Burch-Schneider cage, hip joint, Finite element method, stress-strain analysis.***

1. Introduction

In the 1960s Charnley and Mc Kee paved the way to the modern hip joint implant. With the increasing quantity of total joint replacements for younger patients it was gradually necessary to perform reimplantations due to loosening or wear of some of their components. The problem with reimplantation occurs in cases where there is a loss of the bone tissue for example because of inappropriate loading leading to the atrophy of the bone tissue, usually near the region of the acetabulum. As the number of patients with this problem has been increasing, a variety of solutions have been proposed. These methods may include the resection arthoplasty (Jasty et al., 1990), reconstruction of the bone defect using a large amount of acrylic cement (Salvati et al., 1975), the use of bipolar prostheses, massive bulk allografts or cementless acetabular components. The anti-protrusio cage belongs into the group of cementless acetabular components can solve the problem of the bone loss in the acetabulum area. It was designed in 1974 to treat a patient with an unhealed acetabular fracture. A year later, this cage was adjusted by Dr. Schneider to use the screw fixation in the distal area (Berry et al., 1992). This adjustment was made to use the cage for bridging defects. The cages are made from titanium alloys because of the biocompatibility and good mechanical properties. The implant is attached to the os illium by screws, the attachment to the os ischium is performed in two ways, either by embedding it into the bone with a subsequent fixation with screws or by fixing it to the bone surface by screws. At every step the hip joint is loaded and subsequently unloaded. In the case of the Burch-Schneider (BS) cage implantation cyclical stress occurs, which may cause damage. The system with the established BS cage can be assessed by using the stress-strain analysis. Determination of the strain and stress of the BS cage is highly problematic as a consequence of the complex system elements geometry, material and load. An effective solution can be computational modelling.

2. Methods

To solve the above-mentioned problems effectively by using computational modelling, numerical methods can be applied, including the finite element method, which is widely used in biomechanics. In

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our case, the ANSYS 12.0 programming environment was used. Solving this problem can be divided into the sub-problems of the geometry model, material, boundary conditions and loads.

2.1. Model of geometry

The BS cage model of geometry was created using the data obtained by the ATOS photometric sensing system, which were subsequently adjusted using the Rhinoceros programme and SolidWorks. The bone tissue model of geometry was created from the input data obtained from CT scans from St.Anna's Hospital in Brno using the STL Model Creator software (Konečný et al., 2010). The model of polyethylene cup was developed with regard to the perfectly corresponding shape with the BS cage using SolidWorks. All the mentioned parts were used in order to create a system to solve the problem. The system created this way was imported into the ANSYS Workbench environment, where the last element of the required system – the ceramic head - was created. The discretization of the cancellous bone tissue in the pelvic area, a part of the polyethylene cup and the ceramic head was performed using SOLID 186 element (hexahedrons). The os sacrum, the BS cage and the second part of the polyethylene cup were discretized using the SOLID 187 element (tetrahedrons). The cortical bone was created using the SHELL 181 element at 1mm of defined thickness. The TARGE 170 and CONTA 174 elements were used to define the mutual contact. Maximum attention was paid to the meshing, so there were 330,000 elements.

2.2. Model of material

It is not difficult to determine the characteristics of technical materials. Living bone tissue changes throughout its life and so do its properties. The quality assessment of the bone tissue can be done based on its CT images, which can further serve for the determination of the material characteristics (Valášek et al., 2010). The BS cage was used in clinical problem where bone quality is quite poor and therefore the cancellous bone tissue has poor mechanical properties too. For this reason lower modulus of elasticity was used. The used values were $E = 100 - 800$ MPa, the Poisson's ratio $\mu = 0.3$ (Fütterling et al., 1998). Cortical bone is defined as an isotropic material of linear elasticity with $E = 14\,000$ MPa and $\mu = 0.3$ (Fütterling et al., 1998). The polyethylene cup model material $E = 800$ MPa, $\mu = 0.4$; BS cage $E = 113\,800$ MPa, $\mu = 0.3$ and ceramic head $E = 380\,000$ MPa, $\mu=0.24$ were all chosen based on the material data.

2.3. Model of loads and constraints

The calculation is realized for the load acting on the joint when standing on one leg, which occurs at some point during slow walking. The calculation was performed using the resultant butt force on a man weighing 80kg. Taking into account the symmetry of a human skeleton, symmetry restraints are defined in the area of the os sacrum and the symphysis pubica. With the implant fixation the variant of embedding into the os ischium was assumed, as well as, subsequently, a trouble-free reception of the implant, which was simulated by the bonded contact. The space between the BS cage and the polyethylene cup is, in clinical practice, filled with cement therefore this relationship is defined as bonded. The movement of the hip joint with the applied total joint replacement with the BS cage occurs between the ceramic head and the polyethylene cup, for this reason it was necessary to define the contact pair with friction.

3. Results

In scientific literature, cases of implant ruptures may be encountered (Gallo et al., 2005; Pieringer et al., 2006). These are fractures in the area of the spinous or flat protrusion, especially around the screw holes. When the hip joint of the operated leg is loaded, the load is transferred from the ceramic head through the polyethylene cup to the BS cage and then to the bone tissue. When the cage works correctly, the polyethylene cup determines the life of the whole total endoprosthesis. It is beneficial to evaluate the contact pressure which is directly proportional to its wear. The value of the contact pressure depends increasingly on the angle of the resultant contact force over the final quality of the cancellous bone, see Fig. 1. The values of the contact pressure are higher in the variant with the necrotic bone tissue.

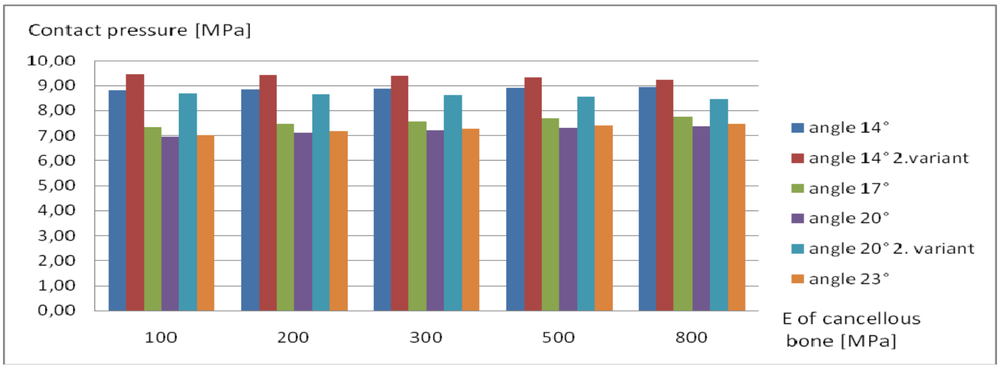

Fig. 1: Contact pressure between polyethylene cup and ceramic head.

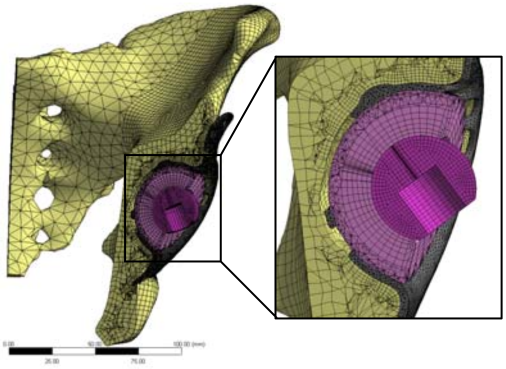

Fig. 2: Variant 1, detail of the acetabulum.

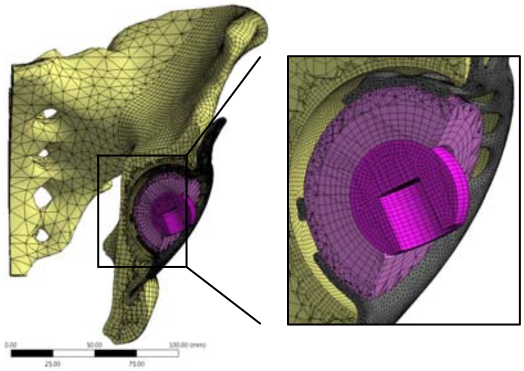

Fig. 3: Variant 2, detail of the necrosis bone.

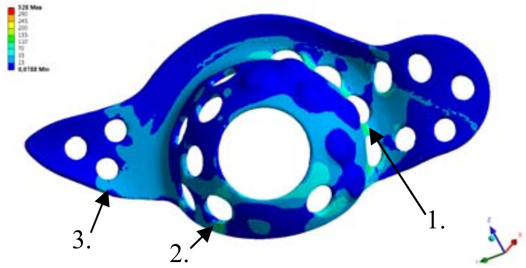

Fig. 4: Critical location for variant 1.

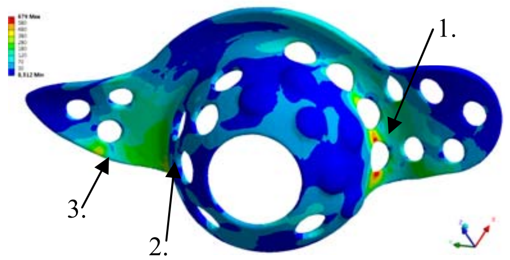

Fig. 5: Critical location for variant 2.

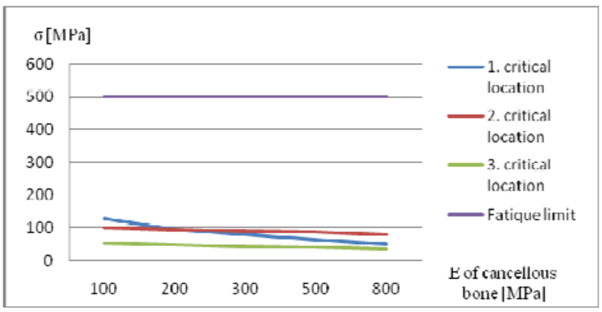

Fig. 6: Equivalent stress in critical location for variant 1.

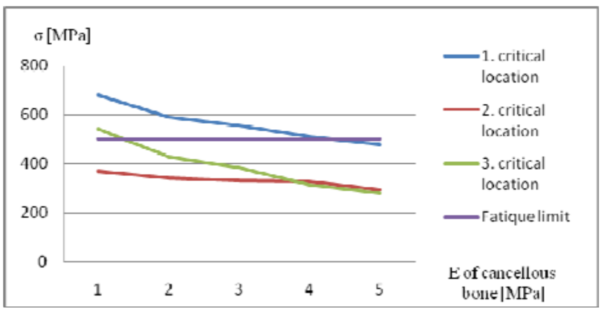

Fig. 7: Equivalent stress in critical location for variant 2.

The analysis of results of the stress distribution in the BS cage is very different for each model. These models can be seen in Fig. 2 and Fig. 3. The corresponding stress values in critical location are shown in Fig. 4 for variant 1and in Fig. 5 for variant 2. These values are reflected in Fig. 6 and Fig. 7. These figures show that the value of stress in critical location goes down with increasing quality of bone tissue. In the case of variant 2 the stresses exceeded the fatigue limit which can cause a damage of the BS cage under which the necrotic bone tissue is located.

4. Conclusion

The presented biomechanical study aims to assess the stress states of the BS cage at the hip joint total endoprosthesis with applied armature. For calculations, two models of geometry were created. Five material models were subsequently added. Implant shifting and maximum stress in critical locations were evaluated and the values transferred to a graph. From the results analysis the following conclusions may be drawn:

In the variant with the worsened bone tissue mechanical properties, which do not deteriorate due to the load in the case where the fixation is embedded into the os ischii, the limit state is not reached. The comparison between the fatigue limit and the maximum stress at critical locations is shown in Fig. 6.

In the case of the necrotic bone tissue under the BS cage, to the extent modelled in this study, the stress reaches unacceptable values. These occur mainly in two critical points – firstly in the transition area between the cup and the rim around the stress concentrators (holes), see Fig. 8, and the second critical point is located on the spinous protrusion in the area of the stress concentrator, see Fig. 8. In Fig. 9 we can see the damaged BS cage in the same critical point as shown in Fig. 8.

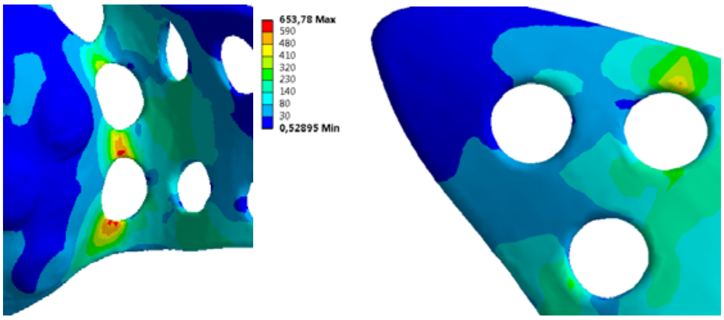

Fig. 8: Critical location for variant 2.

Fig. 9: Damaged BS cage.

These conclusions were based on the biomechanical study. The analysis of the fracture causes of the BS cage is a complex and difficult problem. It is necessary to take the clinical, chemical and biological disciplines into account in way to be able to solve it.

Acknowledgement

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