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INTERACTION BETWEEN PELVIC BONE AND ACETABULAR COMPONENT WITH IMPERFECTIONS IN THE CEMENT LAYER

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Summary: *The article deals with contact stress analysis of pelvic bone after implantation of cemented acetabular component with imperfections of cemented layer. 3D high resolution FE model of pelvic bone was created from the sequence of CT–slices. Imperfections were created both in the cement layer and in the bone tissue by drilling fixation holes. Boolean operations were used for inserting the spherical cemented component. Two contacts were defined in the FE model. The first contact is defined between the cement layer and the pelvic bone and the second one is between the cement layer and the polyethylene cup. The model was loaded by quasi–static joint forces, representing the maximum value of stance phase of gait [Bergmann et al., 2001]. The FE model was used to ascertain the contact stress conditions in the underlying subchondral bone.*

1. Introduction

At the Orthopaedic Clinic of the 1st Faculty of Medicine of the Charles University in Prague, where endoprostheses are applied for more than 30 years, 25–30% reimplantations have been carried out in the last years. It means that one reimplantation comes to every three primoimplantations [Sosna and Pokorný, 2000]. Loosening of the acetabular implant is one of the most serious therapeutic complications of the cemented implants, which is often approved several years after the implantation. The important role in the proces of cup loosening is remodeling of bone tissue as a result of the change of stress field after implantation. Living bone tissue is continuously in the process of growing, strengthening and resorption, a process called ”bone remodeling”. Initial cancellous bone adapts its internal structure by trabecular surface remodeling to accomplish its mechanical function as a load bearing structure. The size and character of the contact stress distribution in subchondral bone depends on the type of imperfections in cement layer. In the case of cemented acetabular implants the remaining cartilage is removed from the acetabulum and the shape is adapted to the original one by means of a spherical milling machine. By this procedure a roughly spherical bed is obtained. To improve the fixation several openings are often drilled into the bone under various directions according to the bone thickness. These openings are drilled in places of sufficiently thick bone where there is no danger

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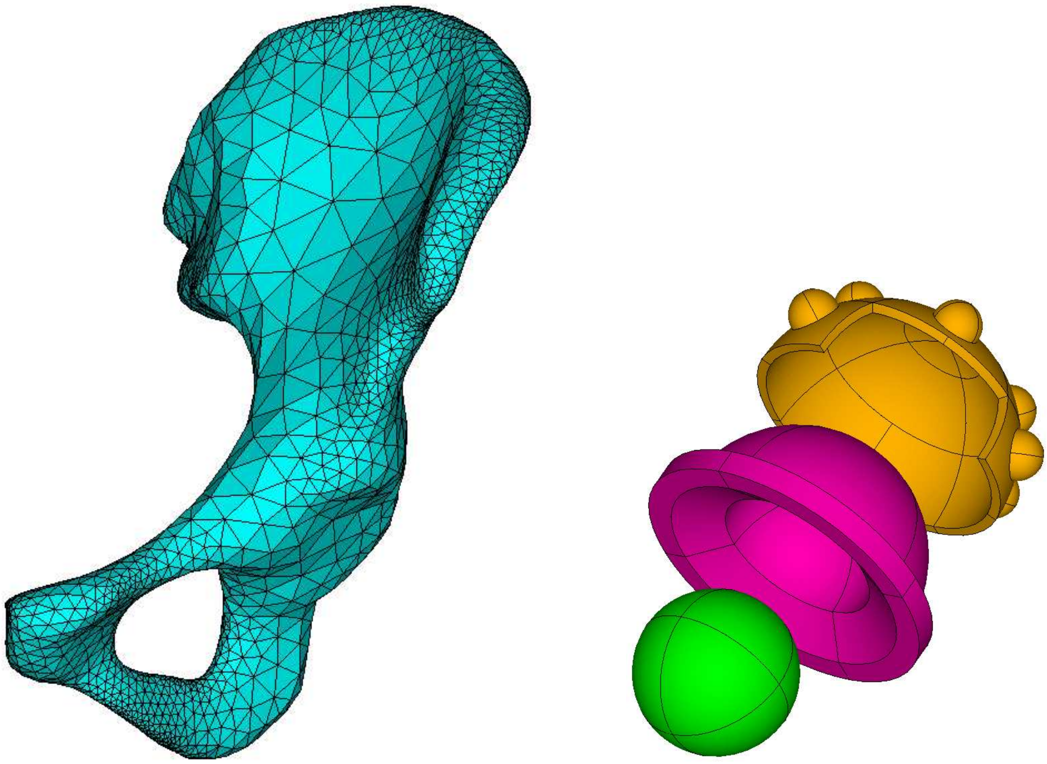


(a) Geometric model of the pelvic bone

(b) Geometric model of the acetabular component

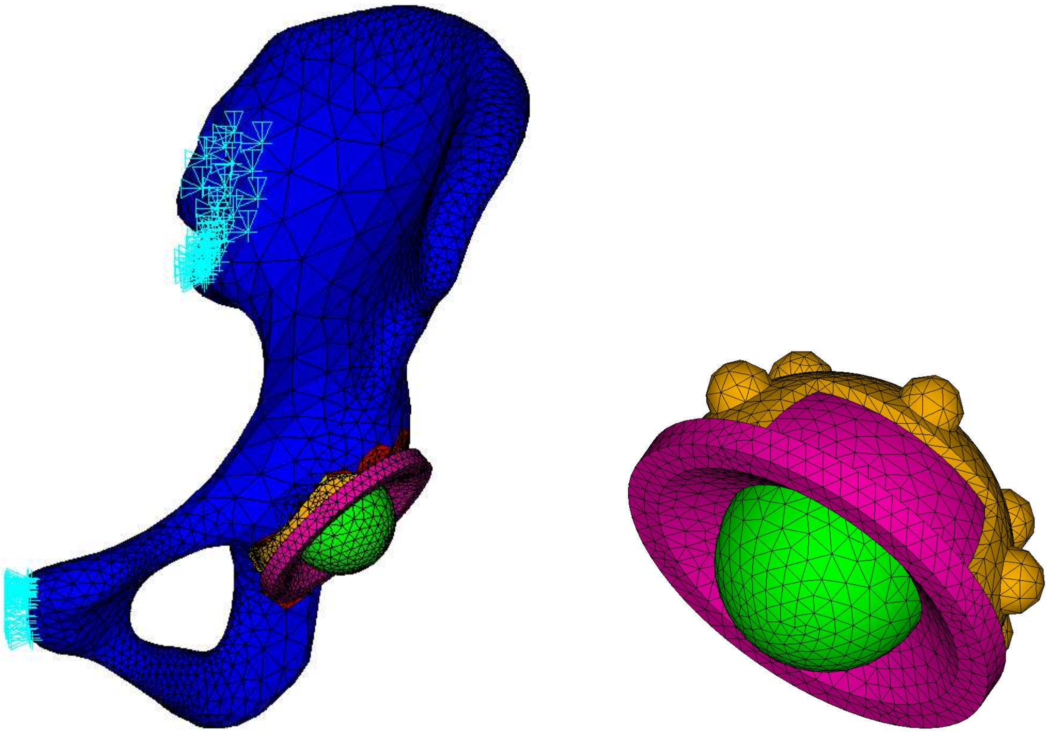
Figure 1: Geometric models

of drilling through the bone and the bone cement (polymetylmetacrylate) would leak into the vascular or other structures in the pelvic. Drill with radius $R = 4\,mm$ or $R = 5\,mm$ or special conical mill is used for the drilling. These openings are meant for the cement to leak through before its solidification. Therefore the cement evelope has irregular shape and the fixation of the polyethylene implant cup is improved. The polyethylene implant cup is pushed into the soft cement and at this moment it should completely fill the bone bed, including the openings in the bone. The fixation is only shape–fixation because the cement does not act as an adhesive.

2. Materials and Methods

Three–dimensional geometrical model of the left pelvic bone (Fig. 1a) is generated from the sequence of 240 CT–slices using segmentation procedures [Vycichl, 2004] followed by surface reconstruction. Geometrical model of polymethylmethacrylate bone cement and polyethylene cup with ceramic head (Fig. 1b) is inserted into the pelvic bone by means of Boolean operations. The prosthesis is inserted with 47.5° inclination and 19.7° anteversion with the ceramic head being positioned at the center of the acetabular cavity.

The whole high resolution finite element model (Fig. 2) is composed of the above mentioned geometrical models. The model consists of 60,402 elements and 75,613 nodes in total. Modeling and all simulations are carried out using ANSYS [ANSYS, 1983] FE package. Elements



(a) FE model of the pelvic bone

(b) FE model of acetabular component

Figure 2: FE models

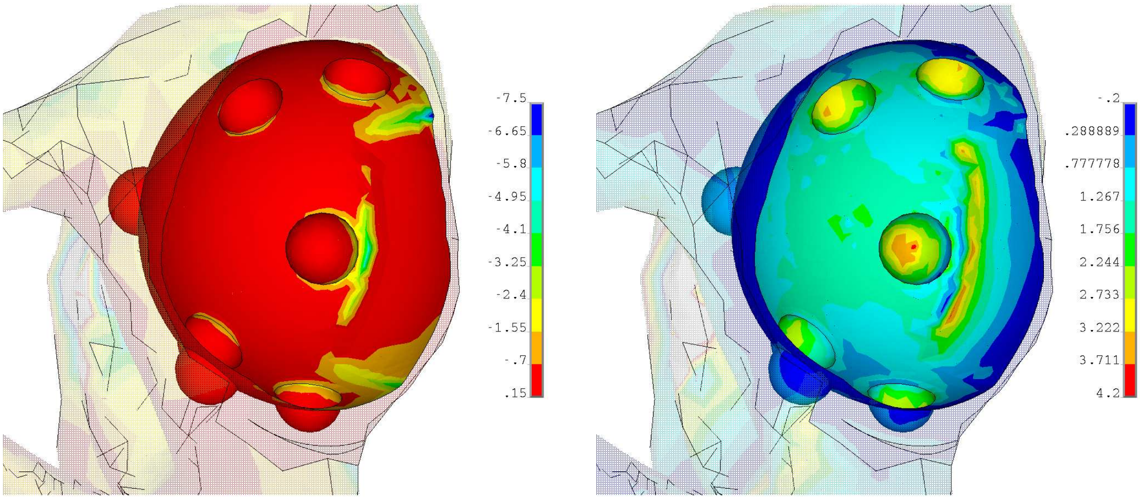
representing trabecular bone are created using quadratic tetrahedral elements SOLID187. The same element type was used for meshing all the other parts of the cemented acetabular component model. The surface of the pelvic bone is covered by the layer of cortical bone modeled with quadratic shell elements SHELL93 of $0.9\,mm$ constant thickness and the surface of acetabulum is covered by the layer of subchondral bone modeled with quadratic shell elements SHELL93 of $0.7\,mm$ constant thickness.

Boundary conditions are specified at the sacro–illiac joint, where the nodes are fixed in all directions and at the contralateral side of the pubic symphysis, where the nodes are fixed in x–, y–directions (Fig. 2a). Two contacts are defined in the FE model. The first contact is defined between the pelvic bone and the external surface of cemented layer. Surface elements TARGE170 cover the surface of subchondral bone and elements CONTA174 cover the opposite surface of the cement layer. The second contact is defined on the internal surface between the cemented layer (TARGE170) and the polyethylene cup (CONTA174). The friction value used $\mu = 0.5$ represents an intermediate value determined for wet femoral bone and titanium implant [Shirazi-Adl et al., 1993], but could vary according to surface roughness of the cement layer and the bone tissue or even the presence of an affective lubricant (e.g. blood). The friction value $\mu = 0.6$ is used for the first contact. The friction value $\mu = 0.8$ is used for the second contact. Material properties assigned to the FE model are shown in Tab. 1.

In 2001 Bergman et al. [Bergmann et al., 2001] conducted unique data based of hip contact forces with instrumented endoprostheses. Synchronous analyses of gait patterns and ground

Table 1: Material properties assigned to the FE model

Material	E (MPa)	ν	Ref.
Pelvis - Trabecular bone	100	0.3	[Dalstra et al., 1993]
Pelvis - Subchondral bone	500	0.3	[Dalstra et al., 1993]
Pelvis - Cortical bone	5,600	0.3	[Choi and Goldstein, 1992]
Bone cement (PMMA)	25,000	0.35	[Helsen and Breme, 1998]
Polyethylene (UHMWPE)	1,200	0.39	[Helsen and Breme, 1998]
Ceramic (AL_2O_3)	380,000	0.22	[Helsen and Breme, 1998]



(a) Max. principal stress distribution σ_3 (b) Max. principal stress distribution σ_1

Figure 3: Principal stress in subchondral bone at the contact with cement

reaction forces were performed in four patients during the most frequent daily activities. In our computational model quasi–static joint contact forces, representative of the stance phase of gait, were applied to the model (body weight $BW = 84\,kg$) during normal walking $4\,km/h$. The loading was applied to the centre of the ceramic head. Interaction of the cemented component with the underlying subchondral bone is studied as contact analysis.

3. Results

Stress distribution in subchondral bone tissue depends on the thickness of the cement layer, imperfections and drilled openings. Maximal values of contact stresses in the subchondral bone occurring during one step (normal walk) are given in Tab. 2 for this specific imperfection in the cement layer. Maximal principal stress distribution is shown in the Fig. 3. The FE model is appropriate for solving contact stress analysis of the interaction between pelvic bone and cemented acetabular component and will be used for spatial optimalization of the holes drilled in the acetabulum.

Table 2: Results of contact stress analysis

Type	Max. (MPa)
Stress σ_3	-7.5
Stress σ_1	4.2

4. Acknowledgment

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