The influence of the thickness of the cement mantle on the quality of total hip arthroplasty

I. LEVADNYI[1], O. SZYMANOWSKA[2], W. KUNIKOWSKI[3], J. AWREJCEWICZ[4],

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1. Introduction

In the last few decades, endoprostheses have become widely used in treatment of hip joint injuries. The need for this method of therapy has been continuously growing, accompanying the increase in life expectancy and the corresponding increase in the number of elderly people suffering from diseases of the musculoskeletal system.

In the case of using a cement fixation of the stem endoprosthesis of the hip joint, thickness of the cement mantle has a significant influence on the load transfer in a femur. The femoral bone reacts to these changes with a process known as adaptive bone remodelling, which is regulated by Wolff's law. Correctly chosen thickness of the cement mantle is important in a number of cases. First of all, too thin or completely absent cement mantle may contribute to cracking of the cement which, in turn, may lead to aseptic loosening of the mantle or to the increase in the bone density (cortical hypertrophy). Moreover, in the case of thick cement mantle, the load is likely to be poorly transferred to the bone, what can lead to the bone atrophy, lysis and final reduction in the bone density (the process known as stress shielding). In this regard, minimisation of stress shielding is an important factor for the long-term success of implants, as it can cause excessive bone resorption and lead to even distribution of stress in the bone.

2. Materials and methods

In the present study, a 3D model of a single femur was obtained from computed tomography (CT) scans and then studied using the Finite Element Analysis (FEA). The mechanical characteristics of the femur has been found by calculating analytical dependences between the Hounsfield units (HU) obtained from the analysis of tomograms. Hounsfield units determine the dependence between a radiographic density of the femur tissue, presented in arbitrary units [2], and an actual bone density ρ (g/cm3) (see Eq. (1)).

$$\rho = 1 + 7.185 \cdot 10^{-4}\mathrm{HU} \tag{1}$$

The correspondence between elastic modulus, Poisson's ratio and apparent density is given in Eq. (2) [3].

$$E = \begin{cases} 2014\rho^{2.5} & \rho \le 1.2\ \mathrm{g/cm^3} \\ 1763\rho^{3.2} & \rho \ge 1.2\ \mathrm{g/cm^3} \end{cases}, \quad \nu = \begin{cases} 0.2 & \rho \le 1.2\ \mathrm{g/cm^3} \\ 0.32 & \rho \ge 1.2\ \mathrm{g/cm^3} \end{cases} \tag{2}$$

In this work, the size and the shape of ORTAN® (Ukraine) femoral components are used. To investigate the influence of studied issue, five different models were created to represent different sets of cement mantle thickness (1, 2, 3, 4 and 5 mm, respectively) between the femoral bone and the implant, keeping the stem geometry constant. Young's modulus of the cement was set to be equal 2.5 GPa while Poisson's ratio $\nu = 0.29$. In the carried out analysis, the influence of the cement–stem

[1] Ievgen Levadnyi, Department of Automation, Biomechanics and Mechatronics, Lodz University of Technology, 1/15 Stefanowski St., 90-924 Lodz, POLAND, e-mail: evgenabaqus@gmail.com
[2] Olga Szymanowska, Department of Automation, Biomechanics and Mechatronics, Lodz University of Technology, 1/15 Stefanowski St., 90-924 Lodz, POLAND, e-mail: szymanowska.olga@gmail.com
[3] Wojciech Kunikowski, Department of Automation, Biomechanics and Mechatronics, Lodz University of Technology, 1/15 Stefanowski St., 90-924 Lodz, POLAND, e-mail: wojciech.kunikowski@dokt.p.lodz.pl
[4] Jan Awrejcewicz, Department of Automation, Biomechanics and Mechatronics, Lodz University of Technology, 1/15 Stefanowski St., 90-924 Lodz, POLAND and Department of Vehicles, Warsaw University of Technology, 84 Narbutta Str., 02-854 Warsaw, POLAND e-mail: awrejcew@p.lodz.pl

interface debonding process has not been studied. It was assumed that the cement–stem interface and the bone–cement interface are completely bonded. Also, in our study, the hip contact force [1] between the acetabular cup and the implant head during normal walking was set to be equal to: Fx = 520.1 N; Fy = 177.8 N; Fz = 1854.3 N.

Finally, the model of Jacobs [3] has been engaged to study the bone remodelling process and verify the bone tissue adaptation in relation to different thicknesses of the cement mantle.

3. Results and conclusions

Using the bone remodelling theory, changes in the bone density (after two years) were predicted for the cemented stem fixation. The results obtained for five cement thicknesses have been shown in Fig. 2. Looking at the bone density distribution, significant differences can be clearly noticed for different regions. The results show that high reduction in the bone density of the distal and proximal regions (Fig.2) was observed in the first three cases of the cement mantle thickness, i.e. 1 to 3 mm. In turn, no significant changes in the bone density in the abovementioned regions were obtained for the remaining two cases, i.e. for 4 and 5 mm. A further increase in the cement mantle thickness could have detrimental consequences – a thicker cement mantle potentially increases polymerisation temperatures at the bone–cement interface, inducing thermal necrosis of the tissue.

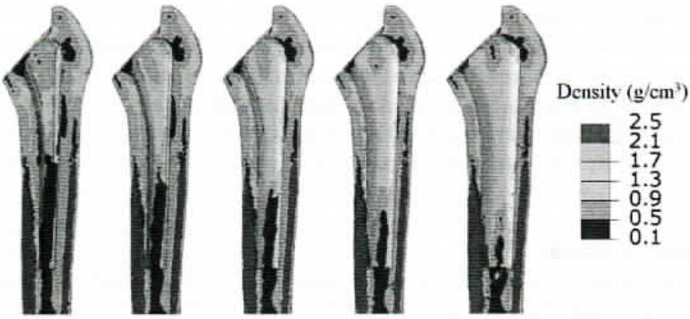

Fig. 1. Final bone density distribution for models with different cement mantle thickness (from 1 to 5 mm) after two years.

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