ASPECTS OF CONTACT REGION BETWEEN BONE AND IMPLANT FOR DIFFERENT ENDOPROSTHESIS TYPES

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Lucrarea prezintă un studiu comparativ al implanturilor de şold utilizate în cadrul artroplastiei total, evidenţiind importanţa utilizării unor proteze personalizare în cazul persoanelor cu dizabilităţi. Analiza cu element finit permite studiul diferitelor aspecte ale zonei de contact între os si proteză. Se evidenţiază, comparativ cu protezele clasice existente pe piaţă, avantajele utilizării unei proteze personalizate. Studiul se face pentru opt pacienţi care prezintă aspecte particulare ale articulaţiei de şold. Informaţiile ce se obţin cu ajutorul acestui studiu se pot folosi de medicii ortopezi în momentul alegerii unui anume tip de implant de şold.

The paper presents some interesting aspects of the contact between the bone and the implant in case of different types of endoprosthesis. This comparative study is made for different types of stems. Mechanical adaptation influences the success of many orthopaedic treatments, especially total joint replacements. A good contact between the bone and the stem indicates a long life solution for an endoprosthesis. A personalized stem is very useful for persons with disabilities. The contact results from Ansys illustrate the aspects from the bone – stem interface. With this information the orthopaedist can made a good decision for a proper hip joint endoprosthesis used for a named patient.

Keywords: Total hip arthroplasty, Computational model, Hip prosthesis, Finite element, Modelling, Stem.

1. Introduction

Arthroplasty is the reconstruction or reshaping of a damaged or diseased joint. This elective surgery most often involves joint replacement, the implantation of an artificial joint (*prosthesis*). In addition to osteoarthritis, arthroplasty can be a treatment for conditions including hip fractures, other source of acute trauma and rheumatoid arthritis. Arthroplasty may be used to: replace all or part of a joint with prosthesis, resurface a joint with the patient's own tissue, reshape the bone and cartilage that make up the joint.

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The hip joint supports most of the upper body weight. The hip joints are connecting the torso to the legs and support the upper body weight (Fig. 1 a). The bones of the pelvis, the pubis, the ischium and the illium form a ball-socket joint together with the head of the femur, the log thigh bone (Fig. 1 b). A total hip prosthesis is composed of two components: the femoral (thighbone) component and the cup component (Fig. 2). The joint is fully exposed and the damaged bone and cartilage are cut away or reshaped. A plastic cup is placed in the enlarged hip socket (Fig. 1c). Then, the top of the femur is removed and a metal ball is inserted into the top of the femur (Fig. 1c). Also a metal stem is also inserted into the femur to add stability to the prosthesis (Fig. 1 d). The joint is tested before the incision is closed. The whole stem component is there only to keep the relatively small ball component fixed to the skeleton [1].

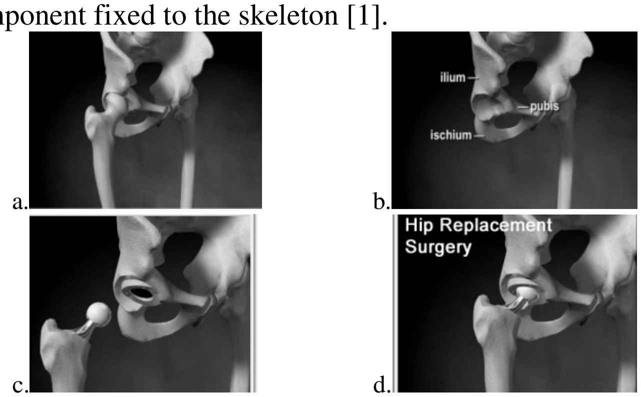


Fig. 1. The hip joint

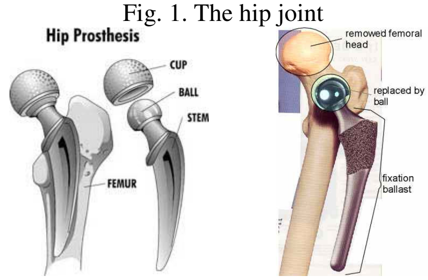


Fig. 2. The hip prosthesis

There are two methods how to secure the fixation of a total hip prosthesis to the skeleton: the cemented total hip - the surgeon uses bone cement for fixation of the prosthesis to the skeleton and the cement less total hip - the surgeon impacts the total hip directly into the bed prepared in the skeleton.

When prostheses are used, they may be made of polyethylene, metal, ceramics or silicone. The most common design is metal-on-polyethylene, although metal-on-metal designs have become more popular in recent years.

The Gruen regions [2], used in radiologic analyses of the pair bone-stem, are (Fig. 3): proximal region 1, 7; middle region 2, 6 and distal region 3, 5.

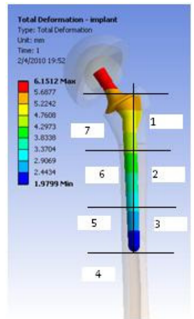


Fig. 3. Gruen regions

2. The 3D model for the femur and the endoposhesis

The 3D model for the femur (Fig. 4) was obtained using computer tomography images. These images were imported in MIMICs and then exported in ProEngineer to obtain the assembly with the endoprosthesis. The assembly was created using cut operations to obtain the shape for the femoral head [4].

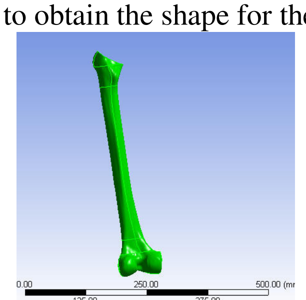
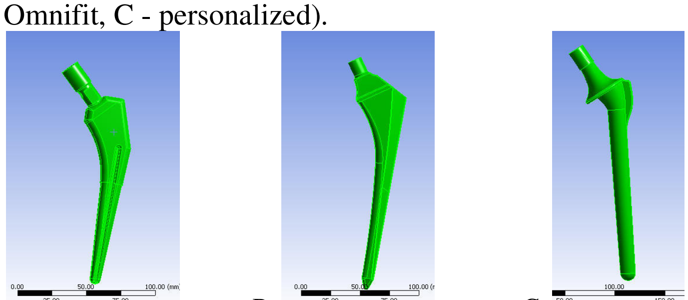


Fig. 4. The 3D model for the femur

The models for the stems were designed in proEngineer – Fig. 5 (A - Taperloc, B - Omnifit, C - personalized).



A. B. C.

Fig. 5. The 3D models for the stems

The model analyzed in Ansys is presented in Fig. 6.

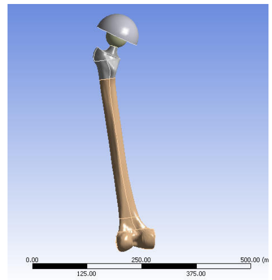


Fig. 6. The femur with the endoprosthesis

3. The finite element model developed in ANSYS

The steps for solving the finite element analysis are:

- import the CAD model from proEngineer;
- assign the materials for the femur and endoprosthesis elements (stainless steel for the stem, ball and exterior cup, polyethylene for interior cup; for the femur - bone properties [3, 5]);
- generate the mesh for the model (Fig. 7) (femur, stem, cup, interior cup)– the model has 14114 nodes and 7175 elements;
- create the environment for the assembly (Fig. 9);
- run analyses - for different stems.

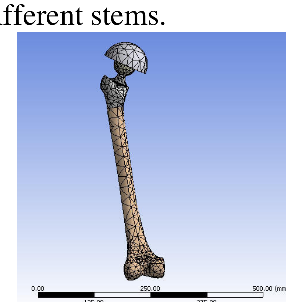


Fig. 7. The meshed model

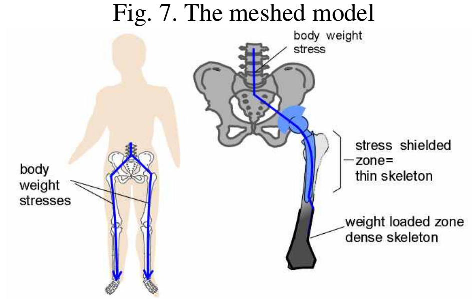


Fig. 8. The scheme for the applied load

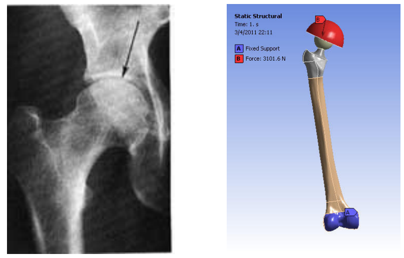


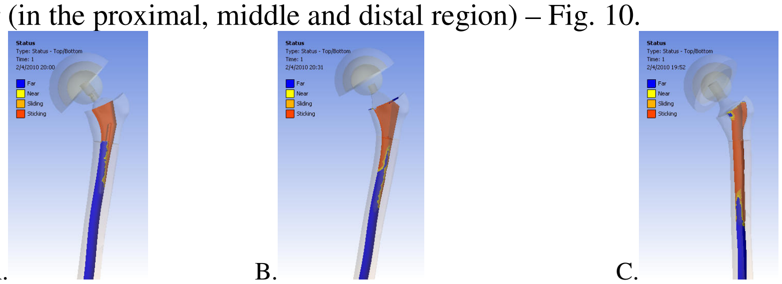
Fig. 9. The load and the fixed support for the model

The load was applied using the scheme from Fig 8, the value is 3100 N [2] – Fig 9.

4. Results

The aspects from the contact region that occurred were studied for eight patients with endoprosthesis. The 3D model of the femur was obtained through CT scan for eight patients. The analyses were run for each patient taking into consideration all three types of implants. Some of the results are presented in figures below.

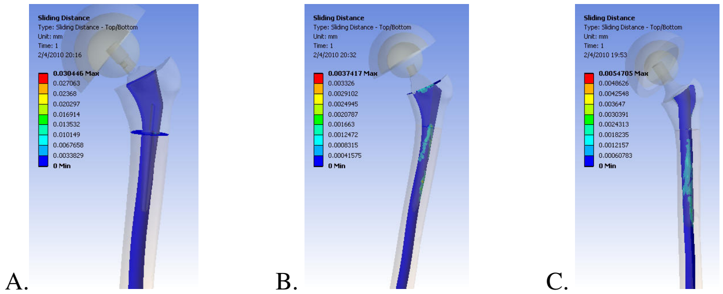
The status of the contact region is shown in Fig. 10. In case of the personalized stem, the contact area is greater, that means a better fixation along the femur (in the proximal, middle and distal region) – Fig. 10.



A. B. C.

Fig. 10. The contact status

The sliding distance has no important values (Fig. 11), but the distribution along the Gruen regions are significant – the worst situation is in the Omnifit stem (B), because the sliding appears in the 1 and 7 Gruen region.



A. B. C.

Fig. 11. The sliding distance

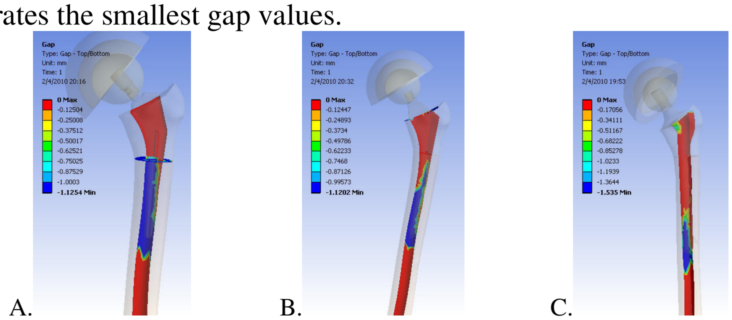
In Table 1 are presented the values obtained for the eight patients.

Table 1.

The sliding distance between the implant and the bone

patients	Sliding distance [mm]		
	Taperloc	Omnifit	Personalized
1	$7.3x10^{-3}$	$3.3x10^{-3}$	$0.6x10^{-3}$
2	$6.3x10^{-3}$	$4.1x10^{-3}$	$1.2\ x10^{-3}$
3	$5.2x10^{-3}$	$6.1x10^{-3}$	$3.4x10^{-3}$
4	$2.9x10^{-3}$	$3.1x10^{-3}$	$1.3x10^{-3}$
5	$6.8x10^{-3}$	$6.3x10^{-3}$	$0.9x10^{-3}$
6	$5.1x10^{-3}$	$5.6x10^{-3}$	$2.6x10^{-3}$
7	$2.1x10^{-3}$	$1.9x10^{-3}$	$1.1x10^{-3}$
8	$4.9x10^{-3}$	$4.8x10^{-3}$	$2.5x10^{-3}$

The gap between the femur and the stem is presented in Fig. 12. The gap shows the regions where no contacts occur between the bone and the implant; if these regions are large, the stem is instable. It can be seen that the personalized stem generates the smallest gap values.



A. B. C.

Fig. 12. The gap

The contact pressure is presented in figure 14 and table 3.

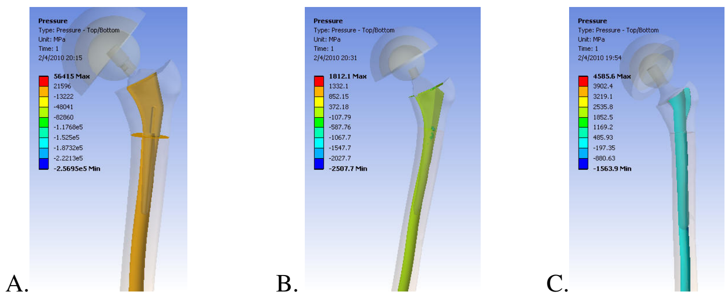


Fig. 13. The contact pressure

Table 3

The contact pressure

patients	Contact pressure [MPa]		
	Taperloc	Omnifit	Personalized
1	0.006	0.0055	10.92
2	0.9	0.07	7.45
3	0.12	0.008	9.58
4	0.019	1.2	6.25
5	0.068	0.003	8.54
6	0.24	0.0045	10.9
7	0.008	0.84	11.6
8	0.009	0.0089	4.3

In Fig. 15 is presented the contact pressure inside the femur for the eight tested patients. The better values are obtained for the personalized stem.

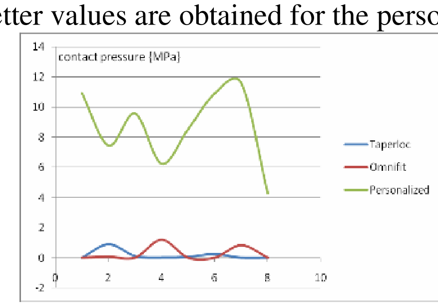


Fig. 15. The diagram for contact pressure

The distribution of the contact pressure is uniform – this means that the stem is working correct.

It is obvious that for the personalized stem, all the studied contact values indicate a good compatibility between the bone and the stem. The orthopaedist can made better decision if he has such analysis before the artroplasty procedure.

6. Conclusions

The presented aspects depicted from FEM analysis for a hip joint endoprosthesis are very useful for the orthopaedist, because better decisions can be made for the patients who need total hip arthroplasty. Using the parameterized capabilities of the proEngineer and the link between ProE and Ansys, many models can be developed easy starting from this one.

This study is useful for obtaining personalized hip joint endoprosthesis for patients that have skeleton deformation. For this kind of patients to realize a total hip arthroplasty is difficult. In these cases after a computer tomography, the model of the bone is imported in proE – the stem and the cup are designed using the bone shape, and finally in Ansys it can be decided if the endoprosthesis is a good one.

An experimental validation of this simulation study is also needed for using personalizes stems.

R E F E R E N C E S

[1]. *R. Bibb*, Medical modelling - The application of advanced design and development techniques in medicine, Woodhead Publishing Limited and CRC Press LLC © 2006, Woodhead Publishing Limited, 2006;

[2]. *A. Davidescu, C. Sticlaru*, Studies by Finite Element Method of some Devices for Treatment of Intertrochanteric Fractures, The 12th IFToMM World Congress, Besançon (France), **vol 1**, pg.112-117, www.iftomm.org, 2007;

[3]. *R.H. Gahr, K.S. Leung, M.P. Rosenwasser, W. Roth*, The Gamma Locking Nail, Einhorn-Press Verlag GmbH Reinbek, ISBN 3- 88756-808-7, 1999;

[4]. *C. Sticlaru, A. Davidescu*, Comparative Study of Fixation Devices for Intertrochanteric Fractures *The 12th IFToMM World Congress*, Besançon (France), **vol 1**, pg.118-123, www.iftomm.org, 2007;

[5]. *J.C. Theis, G. Beadel*, Changes in proximal femoral bone mineral density around a hydroxyapatite-coated hip joint arthroplasty, Journal of Orthopaedic Surgery 2003, **11(1)**: 48–52.