Topology optimization analysis of implant properties from the thighbone-implant interaction point of view

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Abstract

In this paper the implant mechanical parameters are analysed from the interaction between the implant and the bone point of view. This analysis is based on the previous research concerning the distribution of bone material when an endoprosthesis is introduced into the human body. The topology optimization was used to this analysis and answers the question how the bone material should be distributed to fulfil the condition of optimal distribution. Because in many cases the degradation of the bone in the vicinity of the implant is observed it is needed to find – using the topology optimization – such mechanical properties of the implant material for which the degradation will be no observed.

Keywords: topology optimization, thighbone-implant interaction, implant mechanical properties

1. Introduction

Some patients after some time when the implant was introduced suffer of work loose of the implant. Mainly the cause of this it is the bone degradation in the vicinity of the implant. Such process is widely discussed by surgeons and in the literature e.g. in [2]. To avoid the bone degradation a new type of the implants were introduced in last years. Current achievements in the modelling of new-generation implants are presented in [1]**,** which includes a discussion of ways in which post-implantation degradation can be minimized. Initially, materials such as stainless steel, pure titanium or its alloys, which are characterized by much higher Young moduli than compact bone, were used in implantology. Today new-generation materials begin to be used, materials which mechanical properties are similar to bone properties. They are usually used as a contact layer between the bone and the implant and let to avoid the bone degradation. In this paper it is shown how changes the optimal bone material distribution when the mechanical property of implant material is closer to mechanical property of the bone. This research is based on the previous discussion of optimal distribution of material around the implant [3].

2. Bone-implant modelling

The analysis was made for hip joint endoprosthesis symbolically shown in Fig1a. In Fig. 1b the finite element model of the joint endoprosthesis is presented with two kinds of unit value of loading: force *W* as a representative loading of the bone during the motion and additionally force *P*, a concentrated unit force applied vertically to the thighbone's head.

3. Numerical examples

Minimum compliance approach was adopted to solve considered problem. Authors, earlier tested numerical code was used for numerical analysis.

(a) (b)

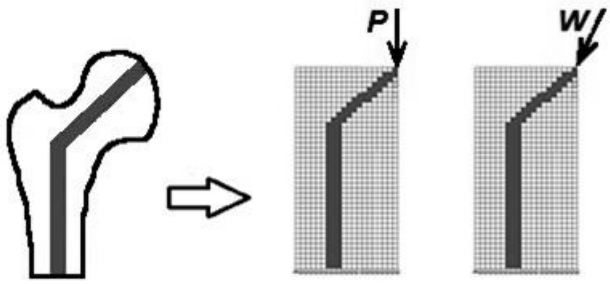

Figure 1: Hip joint endoprosthesis (a) and computational model (b)

When the implant is imposed into the numerical model the optimal distribution of the bone material is changing (Fig. 2). We should realize that in human body the same is going on during the life time. Fig. 2 was obtained for loading with force

a) b)

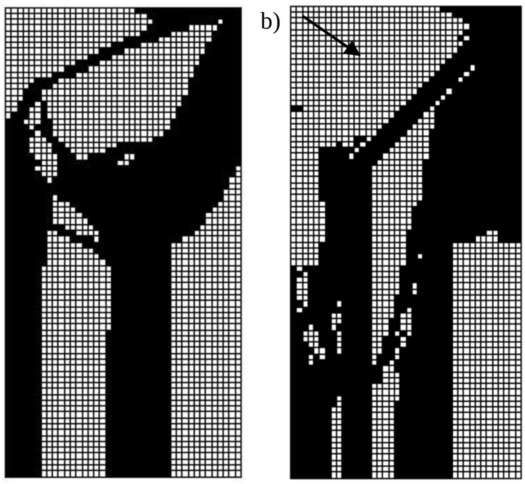

Figure 2: Optimal topology without the implant a) and with the implant b)

P for $\alpha = 0.50$ (α is a mass reduction coefficient specifying what part of mass *m* completely filling volume *V* was used in optimization process). $\alpha = 0.50$ is used for all the examples in this paper. In Fig. 2b there is no material over the implant (see the arrow). This means that optimal distribution of the bone material within the design domain with the implant is different than the distribution of the bone material within the design domain without the implant. Figs 2, 3, 4 are presented in material – void notation. In Fig. 3 the optimal distribution of the bone material is shown for loading *W*. In Fig 3a the same implant as in Fig 2a was used and in Fig. 2b "thinner" implant was adopted. In this case especially upper part of the bone (see arrow in Fig. 3b) is thicken.

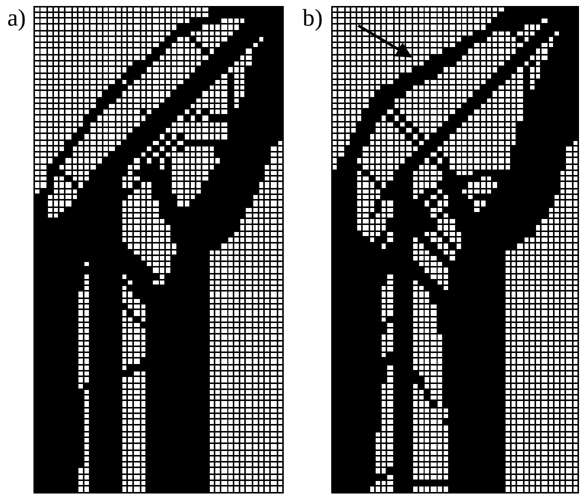

Figure 3: Optimal topology with the "base" implant a) and with "thin" implant b)

The material distributions for different implant densities (since 1.0 to 0.3) instead of the stiff implant's density of 1 were studied for the "thin" implant. The design domain was loaded with force *W*. The aim of the computations was to find out what the bone material distributions would be for a relatively weaker implant. In Fig. 4 as an example the solutions for weaker implant is presented: for 0.9 density (Fig. 4a) and for 0.3 density (Fig. 4b). Comparing with the topology seen in Fig. 3b it can be noticed that the lower the implant density, the wider the thighbone's cortical bone, i.e. the vertical bone elements

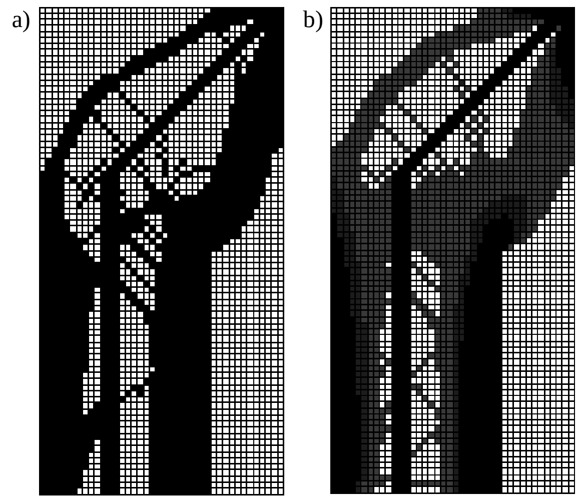

Figure 4: Optimal topology for the implant with 0.9 density a) and for the implant with 0.3 density b)

located in the thighbone's lower part are wider and more interconnected. This is particularly visible if one compares the topology with the 1.0 density implant with the topology with the 0.3 density implant. A comparison of the solutions presented here shows that the solutions at lower implant density are closer to the solution without the implant.

Especially the bone material density distributed for analysed cases can be seen more visible when we analyse the strain energy distribution for optimal solution. As an example in Fig. 5 for considered in Fig. 4 solutions are presented in the scale 0.00 to 0.03. The weaker the implant, the blacker the topologies become, which means that bone material gets concentrated in certain places. The aim of this concentration is to ensure interaction between the implant and the bone.

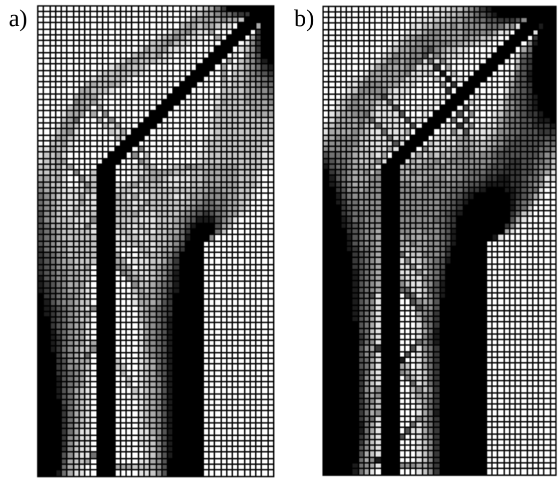

Figure 5: The strain energy distribution of optimal topology in the range of the scale 0.00-0.03 for the implant with 0.9 density a) and for the implant with 0.3 density b)

4. Conclusion

It has been showed, that implant should be made of a material with similar mechanical properties as the bone. In such cases there is no degradation of the human bone in the vicinity of the implant. This means that functionally graded material should be used for implants or special layer between the implant and the bone should be applied.

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