

# Numerical analysis of hip implant surfaces

Aleksandra Vulović<sup>\*,\*\*</sup>, Nenad Filipović<sup>\*,\*\*</sup>

<sup>\*</sup> Faculty of Engineering, University of Kragujevac, Serbia

<sup>\*\*</sup> Bioengineering Research and Development Center (BioIRC), Kragujevac, Serbia

aleksandra.vulovic@kg.ac.rs, fica@kg.ac.rs

**Abstract**— Total hip arthroplasty is considered as one of the most successful surgeries. Cementless hip implant surface structure has been identified as a significant factor when choosing the implant that will be inserted in a body. Our aim was to numerically analyze how three different Ti-6Al-4V hip implant surface topographies affect the shear stress distribution under the static load corresponding to single leg stance. Finite Element Analysis was performed for three developed hip implant and bone models, using material properties and boundary conditions adapted from literature. Based on the criteria that shear stress at the implant-bone interface should be minimized to promote bone ingrowth, we were able to conclude which model would be the best choice for the hip implant surface topography as well as to determine if location of surface topography influences the shear stress results.

**Keywords**— Hip Implant, Finite Element Method, Surface Modification, Shear Stress

## I. INTRODUCTION

Total hip arthroplasty (THA) is considered as one of the most successful surgeries, with more than million hip replacement procedures performed annually worldwide [1]. During this procedure, cemented or cementless stem is inserted into the hollow femoral bone. The main advantage of cemented stems is that they achieve stability from the cement which connects bone and implant. With cementless hip implants, their stability depends on the connection formed between the bone and the inserted implant. The bone-implant connection can be improved by choosing an appropriate surface structure. Implant surface structure has been identified as an important factor when choosing the implant that will be inserted in a body. The first approach to analyze surface structure of an implant was using *in vivo* experiments, which indicated that increased surface roughness leads to better bone-implant integration [2]. Recently, surface modifications of oral implants [3] have been analyzed using numerical methods, however, not many studies have been performed for the hip implants.

In our previous studies [4-6], we have analyzed implant surfaces that included cylindrical topographies. As a result of the application of the finite element method, we were able to obtain shear stress distribution on the surface of the hip implant topographies and perform an assessment to determine which surface topography could potentially be used for hip implant. In this work we were wanted to determine if the location of topography has an effect on the shear stress values. Therefore, the aim of this study was to numerically investigate how three different surface topographies, located in the middle of the model, affect the shear stress distribution under static load

corresponding to single leg stance. As in our previous study, the analysis was performed using the Finite Element Method, using the same boundary conditions.

The rest of the paper is arranged as follows. Created models, applied material properties and boundary conditions are described in Section 2. Section 3 covers the results of the finite element analysis as well as the discussion, while the conclusion is provided in Section 4.

## II. MATERIALS AND METHODS

### A. Geometries

To carry out computational simulations, three model of modified hip implant surface and femoral cortical bone were created. Created hip implant models can be seen in Fig. 1. The difference between these three models was in the distance between half cylinder structures. Compared to our previous studies, in this one we positioned half cylinder topographies in the middle of model and left both ends smooth.

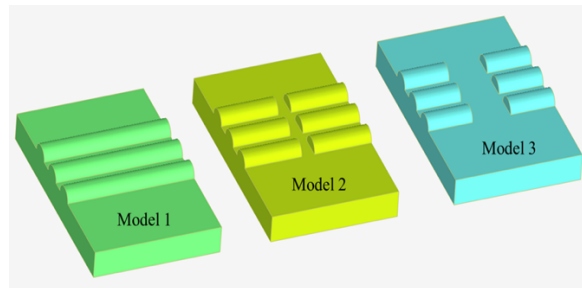


Figure 1. Hip Implant Models

The overview of the complete model that was analyzed (hip implant model and femoral cortical bone model) is presented in Fig. 2. The focus was on the hip implant – femoral bone interaction in the femoral shaft, which is the reason why we did not create cancellous femoral bone model.



Figure 2. Overview of the analyzed model

The total numbers of nodes and elements for each model (including femoral cortical bone and hip implant) are given in Table 1.

TABLE I. NUMBER OF NODES AND ELEMENTS FOR EACH MODEL

	Models		
	Model 1	Model 2	Model 3
Number of nodes	55902	54942	54642
Number of elements	48400	47394	47142

### B. Material Properties

Two materials were used in order to describe the behavior of hip implant material (Ti6Al4V) and femoral cortical bone. Both materials were considered to be linear elastic, isotropic and homogeneous. Two parameters, Young's modulus and Poisson ratio, were needed for numerical simulations and values for both materials were adapted from the literature (Table 2).

TABLE II. NUMBER OF NODES AND ELEMENTS FOR EACH MODEL

Materials	Material Properties		
	Young's Modulus [GPa]	Poisson ration	Reference
Hip Implant (Ti6Al4V)	109	0.34	[7]
Femoral cortical bone	16.7	0.3	[8]

### C. Geometries

In order to compare with previous results, the applied boundary conditions were the same as in our previous studies [4-6]. The force was applied on one side of the model and was distributed on the whole surface (Fig. 3).

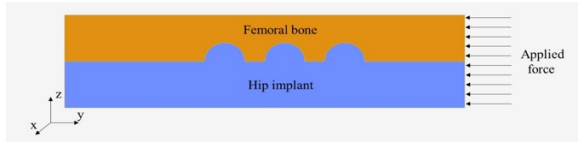


Figure 3. Loading Conditions

The applied constraints were:

- The upper surface of the femoral cortical bone was fixed,
- The bottom surface of the implant was locked in the z direction,
- The sideways of the implant were allowed to move in the y and z direction,
- Everything else allowed to move in all three directions,
- Friction between cortical bone and hip implant was considered with a friction coefficient of 0.39 [7].

## III. RESULTS AND DISCUSSION

### A. Model 1

The shear stress distribution for the first implant is presented in Fig. 4. As it can be seen, shear stress values

were in the range from 0.00104 MPa to 6.859 MPa. The peak values were located in the corners where the force was applied, and these high values were the result of the applied boundary conditions. As it can be seen in the figure below, other segments of this model had values up to 2.75 MPa.

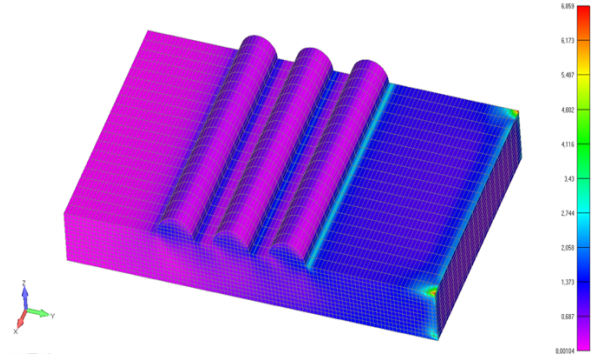


Figure 4. Model 1 – Shear stress [MPa]

The higher shear stress values were closer to the side of the model where the force was applied. Moving from location where the force was defined, it can be observed that the shear stress values on the smooth implant surface reduced, and on the other end of the model were almost 0 MPa.

### B. Model 2

The shear stress distribution for the second implant model is shown in Fig. 5. The shear stress values were in the range from 0.0025 MPa to 6.899 MPa.

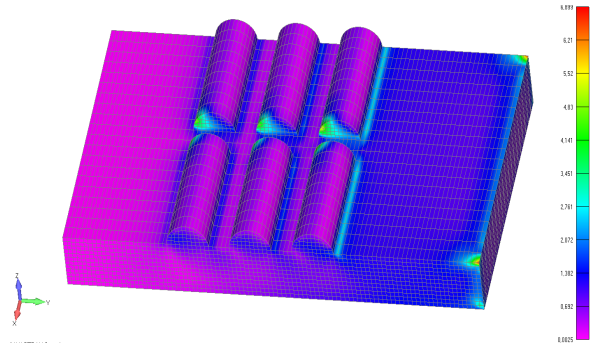


Figure 5. Model 2 – Shear stress [MPa]

As in the previous case, the peak values were located in the corners where the force was applied. Although the rest of the model had lower values, they were not as low as in the previous case (up to 6.1 MPa). It can be noticed that each of the half-cylinder topography had an area where the values were between 4 and 6 MPa. The shear stress values on the smooth implant surface reduced moving from side where the force was applied.

### C. Model 3

The shear stress distribution for the third implant model is shown in Fig. 6. The shear stress values were in the range from 0.0121 MPa to 9.435 MPa.

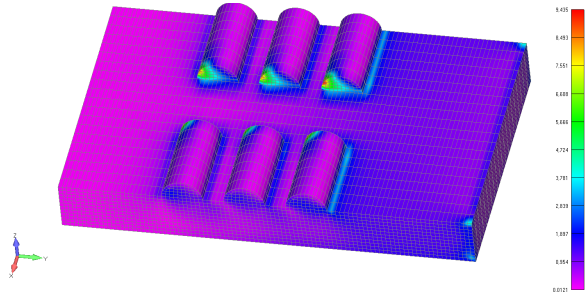


Figure 6. Model 3 – Shear stress [MPa]

Compared with two previous cases, the highest shear stress values were not in the corners where the force was applied. Instead, the peak values were located on the half-cylinder topographies. As it can be seen in the figure above, the highest values were located in the half-cylinder closest to the side of the model where the force was defined. The shear stress values on the smooth implant surfaces significantly reduced when moving towards the end of the model, and in this case the values were lower compared with two previous models.

#### D. Comparison of the results

Comparing the previous results for models 1, 2 and 3, it can be noticed that the shear stress values were in a similar range for models 1 and 2. However, if we analyze the values without corner peaks, models 1 and 2 were not in the similar range. Overview of the results, including values with and without corner nodes are presented in Table 3.

TABLE III. OVERVIEW OF THE OBTAINED RESULTS

Values	Models		
	Model 1	Model 2	Model 3
Including corner nodes	6.859 MPa	6.899 MPa	9.435 MPa
Not including corner nodes	2.75 MPa	6.1 MPa	9.435 MPa

In order to promote bone ingrowth, the shear stress values at the implant-bone interface should be minimized. Considering this criteria, we can say that, model 1 would represent the best choice. If we look at the shear stress distribution, we can also conclude that model 1 would be the better option as it showed the distribution without peak values outside of the corner nodes.

Comparison with the best options from our previous studies is presented in Table 4.

TABLE IV. COMPARISON WITH PREVIOUSLY PUBLISHED RESULTS

Models	Values
Model 1	2.75 MPa
Model [4]	4.145 MPa
Model [5]	3.209 MPa
Model [6]	3.036 MPa

Based on this comparison, we can say that the model 1 presented in this paper would could potentially be the best choice for topography. However, additional simulations using dynamic load should be performed.

#### IV. CONCLUSION

The shear stress should be minimized in order to improve bone-implant connection. Based on the shear stress parameter, the model 1 presented here would be a suitable option for hip implant surface topography. These preliminary results indicate that having a surface topography in the middle of the model could be a good option. Our previous studies indicated that increased distance between half cylinder topographies leads to increased shear stress values, and that it is optimal to have only one half cylinder width-wise. These models confirmed our findings, and also have shown that the location of half cylinder topographies did not affect the increase of shear stress.

#### ACKNOWLEDGMENT

This research is supported by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 952603 - SGABU. This article reflects only the author's view. The Commission is not responsible for any use that may be made of the information it contains. This research is funded by Serbian Ministry of Education, Science, and Technological Development [451-03-9/2021-14/200107 (Faculty of Engineering, University of Kragujevac)]. This research is funded by Serbian Ministry of Education, Science, and Technological.

#### REFERENCES

- [1] L. Shan, B. Shan, D. Graham, A. Saxena, "Total hip replacement: a systematic review and meta-analysis on mid-term quality of life," *Osteoarthritis and Cartilage*, vol. 22, no. 3, pp. 389 – 406, 2014.
- [2] L. F. Cooper, "A role for surface topography in creating and maintaining bone at titanium endosseous implants," *The Journal of prosthetic dentistry*, vol. 84, no. 5, pp. 522-534, 2000.
- [3] J. F. Santiago Junior, F. R. Verri, D. A. de Faria Almeida, V. E. de Souza Batista, C. A. A. Lemos, E. P. Pellizzer, "Finite element analysis on influence of implant surface treatments, connection and bone types," *Materials Science and Engineering: C*, vol. 63, pp.292-300, 2016.
- [4] A. Vulović, N. Filipović, "Computational analysis of hip implant surfaces," *Journal of the Serbian Society for Computational Mechanics*, vol. 13, no. 1, pp. 109-119, 2019.
- [5] A. Vulović, N. Filipović, "Effect of Hip Implant Surface Modification on Shear Stress Distribution," In *International Conference on Computational Bioengineering*, pp. 151-159, Springer, Cham, 2020.
- [6] A. Vulović, F. G. Warchomicka, N. Filipović. "Finite Element Analysis of Surface Modification of Titanium Alloy Used for Hip Implant." In *Materials Science Forum*, vol. 1016, pp. 1544-1548. Trans Tech Publications Ltd, 2021.
- [7] S. Das, S. K. Sarangi, "Finite Element Analysis of Femur Fracture Fixation Plates," *International Journal of Basic and Applied Biology*, vol. 1, no. 1, pp. 1-5, 2014.
- [8] K. S. S. Aradhya, M. R. Doddamani, "Characterization of Mechanical Properties of SiC/Ti- 6Al-4V Metal Matrix Composite (MMC) Using Finite Element Method," *American Journal of Materials Science*, vol. 5, no. 3C, pp. 7-11, 2015.