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Influence Of The Material Type, Flexion Degree And Axial Compressive Loads On Contact Stress Generation On The Tibial Insert Of The Total Knee Endoprosthesis

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Total knee joint endoprosthesis implantation is one of the most common surgery today performed in humans. Replacement of the damaged articular surface, restoration of basic knee joint functions, and pain elimination are the basic objectives of these surgery. The aim of this study is to analyze stress distribution on the tibial insert made of polyethilen UHMWPE depending on metal components' material types, knee joint flexion, and axial compressive loads. In this study we have used reconstructed models of the femur and tibia. Knee joint prostheses model, as well as the analysis of stress distribution is created using Catia V5. The results show approximately uniform stress distribution for a given knee prosthesis design, corresponding pressure, flexion degree, and material of the tibial and femoral components. Maximal stress values are located on the lateral and medial part of the tibial insert, and thus are not of the crucial importance for the tibial insert wearing.

Keywords: Biomaterials, stress distribution, knee joint prosthesis

0 INTRODUCTION

Biocompatible materials usage in medicine are aimed at returning form and function of replaced biological structures. In orthopedics, materials used in implantology ensure adequate ductility, corrosion resistance, wear resistance, biocompatibility, and integration with bones [1,2].

Stainless steel, cobalt superalloys, titanium and its alloys, ceramics, and, very rarely, composite materials are generally used in orthopedic surgery today. Polymer UHMWPE has found wide application. This material has remarkable properties of the abrasion resistance, friction resistance, excellent ductility, low density, biocompatibility, and biostability. Listed properties make UHMWPE very attractive material for bearing surfaces in the total knee replacement [3, 4].

With polyethylene tibial inserts advent, great attention is focused on reducing this material wear, because it primarily affects endoprosthesis loosening in total knee replacement. Contact bearing surface stresses are the main reason for material fatigue and tibial insert wear, which further affects the implant lifetime [3, 4].

1 RELATED WORK

Static and kinematic analysis of the contact stress distribution using finite element method (FEM) presented in current studies define tibial insert thickness and sliding ratio influence on the wear occurrence

Cho et al. show elastoplastic contact between metal femoral component and polyethilene tibial insert. Stress maximal values are noticed in anterior part of the tibial insert, and greater wear is noticed in the implant medial part [5].

S. O'Brien et al. have examined and analyzed surface contact pressure between femoral component and tibial insert and sliding length using FEM [4]. The results suggest that maximal values of the contact stress are approximatily at 26,2MPa, and as such are not crucial on the wear appearance.

D.J. Van den Heever et al. exercised FEM analysis on the custom made partial knee prosthesis and prosthesis selected from a catalog. It is concluded that custom made prostheses create smaller contact stresses compared to those prostheses selected from catalog [6].

Oonishi et al. compare knee joint endoprosthesis made of cobalt alloy with aluminum and ceramic coating. Wear between

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femoral component with ceramic coating and UHMWPE tibial insert is considerably less than wear between femoral component without coating and tibial insert. Wear between tibial insert made of UHMWPE and femoral component with aluminum coating have shown stable low wear level [7].

2 MATERIALS AND METHODS

For the load influence on the tibial insert analysis 3D finite element model was used. We analyzed material, body weight and flexion degree influence on the tibial insert stress distribution. Same endoprosthesis knee model was used in each applied analysis. We only changed values of the body weight and flexion degree angles.

We investigated fixed bearing of the tibial component. Polyethylene UHMWPE is common tibial insert material, and tibial and femoral components materials are listed in Table 1 [1, 8].

Stress/strain analysis is conducted in Catia V5. Finite element grid includes material characteristics (defined in Table 1), and structural properties that define the structural reaction under load. Parabolic tetrahedrons demonstrated an optimal solution for the elements of the model (side 2.5mm).

3D models of femur and tibia are reconstructed from MRI images, and knee joint endoprosthesis 3D model created in Catia V5 (Fig.1).

Three different positions of the knee joint were simulated with these models, i.e. flexion of 15°,45°, and 60° [8]. In every position, tibia and its components were fixed, and femur and femoral component were loaded with axial load. Loads depend from human weight, i.e. 50kg, 75kg, 100kg, 125kg.

FE analysis simulation consider following assumptions:

- Tibial insert is deformable body with Poisson coefficient of 0.4;
- Tibial insert from underside is fixed to stationary tibial component surface;
- Femur and femoral component are rigid bodies; and
- Tibia and tibial component are rigid bodies.

Fig. 1. *Total knee Endoprosthesis Model*

Table 1. *Metalic materials properties applied in FE analysis [1]*

Matrial type	**Rm**	**Reh**	**Rds**	**E**	**OH**	**R**
Stainless steel						
Austenitic steel AISI 316	550	205	270	198	8	7,87
Austenitic steel AISI 317	570	250	290	193	8,5	7,97
Austenitic steel AISI 321	600	230	265	197	8	7,95
Precipitation-hardening steel AISI630 (17-4PH)	1300	1500	450	202	9	7,82
Co Alloy						
Co-Cr-Mo	700	900	350	225	10	8,6
Ti Alloy						
Ti-6Al-4V	1020	1050	625	114	7,5	4,42
Fe Superalloy						
SAE A-286	110	600	370	201	9	7,92

Legend: **Rm**, **MPa** - Tensile Strength; **Reh**, **MPa** - Yield Strength; **Rds**,**MPa** - Dynamic Durability; **E**,**GPa** - Young's Module; **OH**, / - Wear Resistance; **R**, **g/cm^3** - Density

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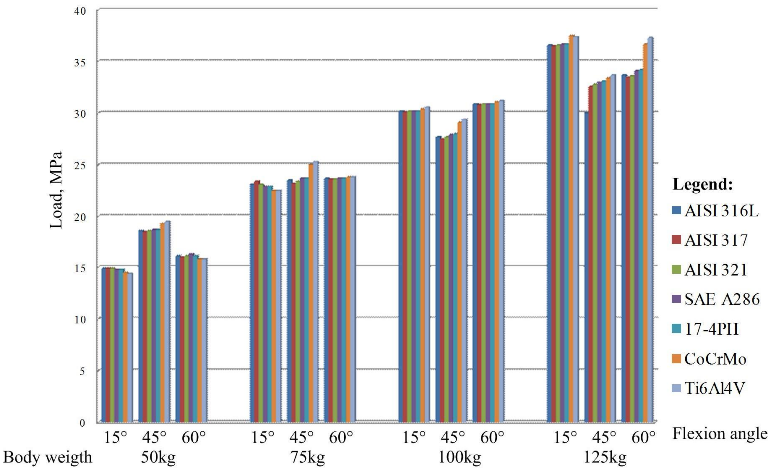

Fig. 2. *Histogram of the tibial insert contact stress depending on flexion angle degree, body weight, and femoral component material type*

Contact between femoral component and tibial insert was simulated in such way that rigid body (femoral component) deforms soft body (tibial insert).

Tested models correspond to purely numerical modeles, having key factors, such as muscles and ligaments are not taken in consideration and are not included during modeling process. Simulation refers to compressive axial loads since the effects of torsion and bending forces are not observed [9].

3 RESULTS AND DISCUSSION

Distribution of tibial insert stresses for different body weights, obtained by FEM analysis, is shown by histogram in Figure 2.

In the first extreme case, when the body weight is 50kg, the smallest stress values occur for the flexion of 15° and 60°. These values are around 15MPa for all metal material types. Slightly higher values are for flexion of 45° and do not exceed 20MPa (Fig.2).

For men, optimal body weight is from 75kg to 100kg. In the first optimal case, it could be noticed that values of the contact stresses are approximately the same regardless material type or flexion degree. These values do not exceed 25 MPa which correspond to S. O'Brien results [4]. The only exception is a slight stress decrease flexion of 45° when the femoral component is made of cobalt and titanium alloys (Fig.2).

In the second optimal case, stress values are approximately the same. Stress decrease is observed for the flexion of 45°. For the same angle slight stress increase is noted when the femoral component is made of cobalt and titanium alloys, like in the first optimal case (Fig.2) [4, 6,8].

In the second extreme case, the greatest stress values occur. These values are slightly higher than 35MPa. Tibial insert is the most loaded for the flexion of 15°. When the femoral component is made of cobalt and titanium alloys, for the flexion of 60°, there is a stress values increase of 10MPa compared to the other metal materials (Fig. 2).

Results of this study shown in Figure 3, coincides with results presented in [5]. Maximal values of contact stresses are observed on the lateral and medial part of the tibial insert. In the case of the flexion of 15°, maximal values of contact stresses are located in the dent of the tibial insert. In the case of flexion of 45° and 60°, maximal values of contact stresses are displaced anterior (Fig.3) [8]. Anterior displacement can be related to tibia AP sliding occurrence.

4 CONCLUSION

Tibial insert of the total knee endoprosthesis is the most imposed and loaded elements of the artificial knee joint. Its overall mechanical characteristics affect wearing effects and durability. It also has the strong infuence on the range and the intensity of a patient’s everyday activities. Deeper understanding of the knee joint, as well as the total knee prosthesis kinematics, requires precise geometrical, mechanical and kinematic models.

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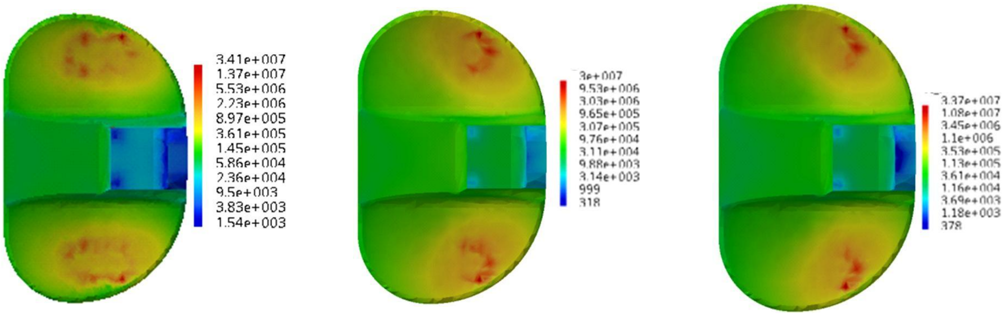

a) b) c)

Fig. 3. *Von Misses Stress for flexion of:: a) 15°, b) 45°, and c) 60°*

In our study we used reconstructed 3D models of human femur and tibia, 3D model of endoprosthesis, and corresponding kinematic (digital mock-up) models. Varying different prostheses parameters and gait parameters related to the knee joint we analysed the range and distribution of static loads on tibial insert of the total knee endoprosthesis. The results show approximately uniform stress distribution for a given knee prosthesis design. Maximal stress values are located on the lateral and medial part of the tibial insert, and therefore without significant importance for the tibial insert wearing. Our study is aimed at development of the integral gait analysis system for the clinical purposes that will noninvasively assist orthopedic surgeons to select the optimal prosthesis design for each individual patient.

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6 REFERENCES

[1] B. Ristić, Z. Popović, D. Adamović, and G. Devedžić, “Izbor materijala u ortopedskoj hirurgiji,”, Vojnosanitetski pregled, Vol. 67, pp: 847-855, 2010.

[2] M. Bahraminasab and A. Jahan, “Material selection for femoral component of total knee replacement using comprehasive VIKOR” Materials and Design, Vol. 32, pp: 4471-4477, 2011.

[3] S. Utzschneider, N. Harrasser, C. Schreder, F. Mazoochian, V. Jansson, “Wear of contemporary total knee replacements – A knee simulator study of six current designs” Clinical Biomechanics, Vol. 24, pp: 583-588, 2009.

[4] S. O’Brien, Y. Luo, C. Wu, M. Petrak, E. Bohm, J.-M. Brandt, “Computational development of polyethylene wear model for the articular and backside surfaces in modular total knee replacement“, Tribology International, Article in press, pp: -, 2012

[5] C.H.Cho, T.Murakami, Y. Sakai, T. Kawano, Y. Iwamoto, “Elasto-plastic contact analzsis of an ultra-high molecural wigth polyethylene tibial component based on geometrical measurement from a retrieved knee prosthesis“, Journal of Engineering in Medicine, Vol. 213, pp: 251 - 259, 2004.

[6] D.J. van den Heever, C. Scheffer, P. Erasmus, E. Dillon, “Contact stresses in patient-specific unicompartmental knee replacement“, Clinical Biomechanics, Vol. 26, pp: 159 - 166, 2011.

[7] H. Oonishi, M. Ueno, S.C Kim, H. oonishi, M. Iwamoto, M. Kyomoto, “Ceramic Versus Cobalt – Chrome Femoral Components; Wear of Polyethylene Insert in Total Knee Prosthesis“, The Journal of Arthoplasty, Vol. 24, pp: 374 - 391, 2009.

[8] J. Shi, “Finite element analysis of total knee replacement considering gait cycle load and malaligment“, PhD Thesis, University of Wolverhampton,2007.

[9] Ž. Stepanović, M. Živković, S. Vulović, Lj. Aćimović, B. Ristić, Z. Grujović, “Visoka, otvorena, klinasta osteotomija tibije: analiza pet modaliteta unutrašnje fiksacije metodom konačnih elemenata“, Vojnosanitetski pregled, Vol. 68, pp: 867-871, 2011.