ORIGINAL ARTICLE

2D Computational Tresca Stress Prediction of CoCrMo-on-UHMWPE Bearing of Total Hip Prosthesis Based on Body Mass Index

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ABSTRACT

Introduction: Total hip prosthesis has become one of the important aspects of hip joint replacement surgery. The study about this implant to extent its lifetime is still limited on external factors of the patient that undergo replacement surgery. Besides, evaluating internal aspects also needs to be studied, there is users body weight. **Methods:** Recent paper presented regarding Tresca stress analysis for hip joint implant with 2D finite element study. The vertical load was taken into account with variation based on six categories of body mass index performed in normal walking condition. **Results:** We obtain that the stress magnitude of Tresca is linearly increasing with higher body mass index. Also, Tresca stress distribution will increase equal to body mass index category. Body mass index category III obesity has the highest probability of failure and underweight has the lowest probability of failure from the results of Tresca stress. **Conclusion:** The heavier implant user's body weight is having greater failure probability based on Tresca stress prediction.

Keywords: 2D computational, Tresca stress, Bearing, Total hip prosthesis, Body mass index

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INTRODUCTION

Surgeon doctor has considering total hip replacement procedure for restore functional human hip joints from any diseased suffered by patient (1,2). This medical step is using total hip prosthesis as natural human joint replacement (3). Long-term endurance from total hip implant becomes a strategic aspect that must be focused on reducing failure implant phenomena. Before prosthesis implantation on the patient's hip joint, failure study needs to be done to obtain medical implant performance assessment. Evaluate failure using von Mises has been investigated. Nonetheless, Tresca as alternative preference for failure analysis becomes a better option since safety area of Tresca stress curve is smaller than von Mises stress area. In explain that Tresca failure criteria is safer than von Mises stress.

Some research perspectives to enhance implant ability had been studied, such as dimple addition (2), design (4), medical procedure (5), coating application (6), material investigation (7), and implant geometry

(1). However, all of these studies are implant user's external factors. Medical report has informed that body weight from a patient also contributes to implant's overall ability. Although implant user's internal side is important to study, this area of research is less understood from available papers. Moreover, external aspect from implant user has been examine from medical investigation (8), but the resource that providing mechanical observation was limited. Since user body weight affect implant endurance, it will be interesting to study failure analysis using Tresca with different implant user body weight category.

A numerical problem has been solved using finite element strategy in medical and engineering areas (1,3,9,10). Compared with an experimental investigation, this approach avoids several experimental drawbacks, like high cost, time-consuming, and experimental tool availability (11). 3D model of hip joint implant has been generated on the published study by Ammarullah et al. (12) and Jamari et al. (4) for metal-on-metal hip implant studies. Unfortunately, using its model needs more extended time and capable hardware for obtaining simulation results. Model simplification into 2D can be a solution for the disadvantages of 3D models on solving the numerical problem without significant difference in computational results (1,2).

Ultra-high molecular weight polyethylene (UHMWPE) has become the most choice in hip joint implant for soft material in acetabular cup coupled to other hard material as hard-on-soft bearing (4). A previous study reported To reduce metal ion, the possible solution is choosing soft material for articulating against metallic material. Using metal-on-polyethylene bearing will reduce another negative effect due to metal-on-metal bearing in terms of tissue problems, such as soft tissue necrosis, granuloma, and neoplasia.

The purpose of recent study was to analyse Tresca stress in metal-on-polyethylene bearing of total hip prosthesis. 2D numerical modelling is adopted to reach out this objective with vertical load considering physiological human hip joint under different loading condition based on six categories of body mass index.

MATERIALS AND METHODS

Geometry and material

Referring from previous paper (7), we adopted geometrical parameter with 28 mm for femoral head diameter, 50 μm for radial clearance, and 5 mm for acetabular cup thickness that are commonly used data for hip joint modelling. Implant bearing formed from metallic femoral head that used cobalt chromium molybdenum (CoCrMo) articulating to polymeric acetabular cup that used ultra-high molecular weight polyethylene (UHMWPE). Both of these materials assumed to be homogeneous and isotropic, but for metal, deformation is set to linear elastic and for polymer, deformation is set to non-linear -plastic plastic. UHMWPE stress-stain relationship is presented in Figure 1.

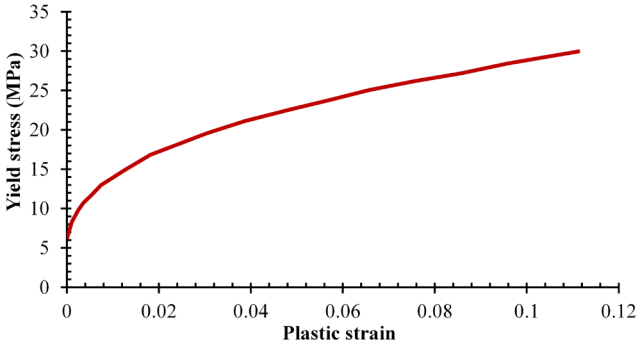

Figure 1 : Stress-strain relationship for UHMWPE.

Finite element model

In order to ease numerical solution, our computational study only examine two main components for contact model as a representative, there are femoral head and acetabular cup with 2D ball-in-socket model. We are not considering micro separation during contact analysis while this condition is under steady-state. 2D FE model of CoCrMo-on-UHMWPE bearing illustrated in Figure 2. The acetabular cup is set to be fixed end without lubrication during for boundary conditions in simulation. Also, this recent study provided surface roughness represented by the coefficient of friction (6).

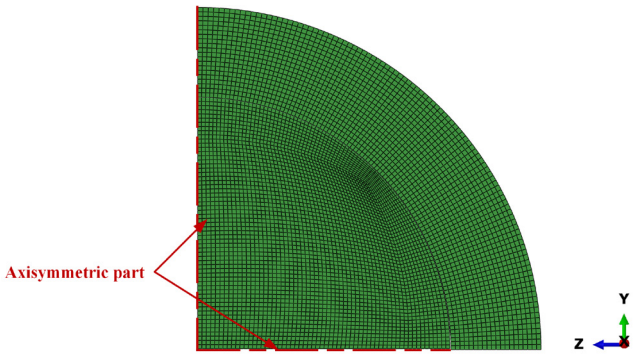

Figure 2 : CoCrMo-on-UHMWPE bearing under 2D model.

Loading condition

We run numerical simulation under normal walking condition based on Jamari et al. gait loading for its condition (4), peak loading was considered for our presented study. Median data for body weight and height of hip joint implant users involved in loading for Jamari et al. research was 85.3 kg and 171 cm. Based on body mass index, its median data classified as overweight category with 2,326 N as peak loading for this category. For other peak loading in another category, approximation method was used to obtain that, and we got 1,396 N, 1,861 N, 2,675 N, 3,024 N, and 3,373 N for smallest to largest body mass index

category in order, except for overweight. Peak loading under normal walking condition based on body mass index used in this research is described in Figure 3.

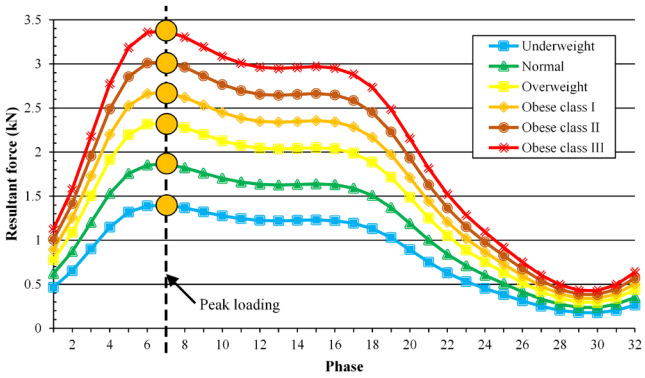

Figure 3 : Peak loading under normal walking condition based on body mass index.

RESULT

Depend on numerical result, Tresca stress magnitude from every body mass index category that we got shows in Figure 4. Under normal walking condition, highest loading is when human hip joint upholds full body weight of implant user. The value of Tresca stress in all body mass index for underweight category is 5.69 MPa, normal is 6.8 MPa, overweight is 7.6 MPa, obese class I is 8.15 MPa, obese class II is 8.67 MPa, and obese class III is 9.09 MPa.

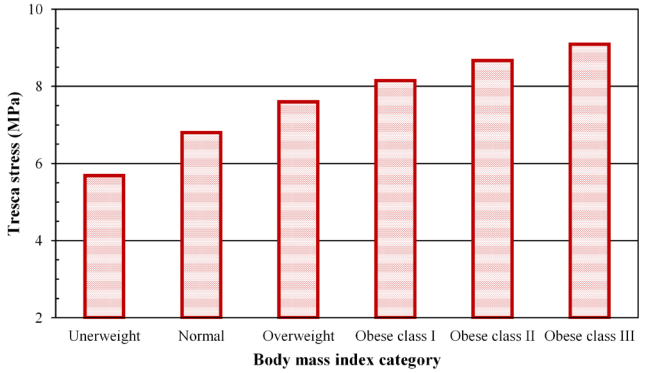

Figure 4 : Tresca stress magnitude of CoCrMo-on-UHMWPE bearing at peak loading under normal walking condition from various categories of body mass index.

Besides, for Tresca stress distribution at peak loading under normal walking conditions from various body mass index categories explained in Figure 5. We can evaluate that Tresca stress distribution will wider and its magnitude will increase equal to heavier implant user's body weight. Tresca stress distribution from the narrowest to the widest was found in body mass index with the categories of underweight, normal, overweight, obese class I, obese class II, and obese class III, respectively.

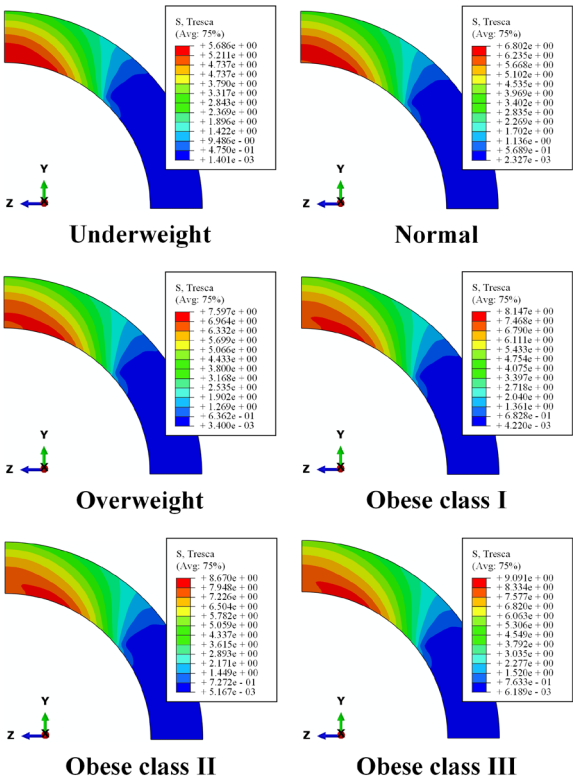

Figure 5 : Tresca stress distribution on UHMWPE acetabular cup at peak loading under normal walking condition from various categories of body mass index.

DISCUSSION

Tresca is one of failure criterion used as alternative of von Mises. The use of Tresca stress in evaluation of implant failure can be seen to be better because safety area on Tresca stress curve is smaller based on Tresca failure theory when compared to von Mises failure theory. Since Tresca stress magnitude increases and its distribution wider, it will reduce safety factor based on the Tresca failure theory.

From various body mass index categories that have been evaluated in this computational simulation, obese category (obese class I, II, and III) seem to have more possibility of failure, especially users with body mass index in obese class III category. This is indicated from Tresca stress result for obese class III category that having the highest magnitude and wider distribution among others body mass index categories. This statement is in line with Sayed-Noor et al. (8) explained higher body mass index will be more likely to need revision surgery in the future.

CONCLUSION

Analysis of Tresca stress under normal walking condition considering implant user's body weight has been established in this paper with 2D FE approaches to evacuate CoCrMo-on-UHMWPE artificial hip joint. It seen that the magnitude of Tresca stress is rising

with widing of its distribution since heavier of implant user. Tresca stress also has corelation with implant endurance on period time. Further exploration in research regarding hip prosthesis in user with obesity will be very promising to started.

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REFERENCES

1. Basri H, Syahrom A, Prakoso AT, Wicaksono D, Amarullah MI, Ramadhoni TS, et al. The Analysis of Dimple Geometry on Artificial Hip Joint to the Performance of Lubrication. J Phys Conf Ser. 2019;1198(4):1–10.
2. Basri H, Syahrom A, Ramadhoni TS, Prakoso AT, Ammarullah MI, Vincent. The analysis of the dimple arrangement of the artificial hip joint to the performance of lubrication. IOP Conf Ser Mater Sci Eng. 2019;620(1):1–10.
3. Ammarullah MI, Basri H, Haryanto I, Jamari. Optimasi Numerik Permukaan Bertekstur pada Total Hip Arthroplasty untuk Mengurangi Tekanan Kontak dengan Variabel Profil dan Kedalaman. ROTASI. 2021;23(1):50–54.
4. Jamari J, Ammarullah MI, Saad APM, Syahrom A, Uddin M, Heide E van der, et al. The Effect of Bottom Profile Dimples on the Femoral Head on Wear in Metal-on-Metal Total Hip Arthroplasty. J Funct Biomater. 2021;12(2):1–14.
5. Cooper HJ, Della Valle CJ. The two-stage standard in revision total hip replacement. Bone Joint J. 2013;95-B(11):84–87.
6. Ammarullah MI, Saad APM, Syahrom A, Basri H. Contact pressure analysis of acetabular cup surface with dimple addition on total hip arthroplasty using finite element method. IOP Conf Ser Mater Sci Eng. 2021;1034(1):1–11.
7. Ammarullah MI. Analisis Pengaruh Variasi Bottom Profile Dimple di Permukaan Femoral Head terhadap Keausan pada Total Hip Arthroplasty. Sriwij Univ. 2019;
8. Sayed-Noor AS, Mukka S, Mohaddes M, Kärrholm J, Rolfson O. Body mass index is associated with risk of reoperation and revision after primary total hip arthroplasty: a study of the Swedish Hip Arthroplasty Register including 83,146 patients. Acta Orthop. 2019;90(3):220–225.
9. Nasution JD, Abidin Z, Ammarullah MI. Desain dan Kalibrasi Sensor Torsi Sumbu Tunggal untuk Aplikasi Pengujian Soft Material Secara Statis. J Rekayasa Mesin. 2018;18(1):39–44.
10. Ammarullah MI, Prakoso AT, Wicaksono D, Fadhlurrahman IG, Yani I, Basri H. Analisis Perpindahan Kalor Konveksi pada Rotary Kiln di PT. Semen Baturaja (Persero) Tbk. J Rekayasa Mesin. 2018;18(2):101–106.
11. Maula MI, Aji AL, Aliyafi MB, Afif IY, Ammarullah MI, Winarni TI, et al. The Subjective Comfort Test of Autism Hug Machine Portable Seat. J Intellect Disabil - Diagnosis Treat. 2021;9:182–188.
12. Ammarullah MI, Saad APM, Syahrom A, Basri H, Jamari. Simulasi Prediksi Tekanan Kontak pada Permukaan Acetabular Cup dengan Aplikasi Permukaan Bertekstur pada Total Hip Arthroplasty. J Rekayasa Mesin. 2020;15(3):237–243.