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Deformation analysis of CoCrMo-on-CoCrMo hip implant based on body mass index using 2D finite element procedure

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Abstract. The paper available of total hip arthroplasty is still concerned with the external factors of implant user, but the internal factor that is the user's body weight has not deeply understood. Our research presents deformation analysis of total hip arthroplasty with different loading conditions based on the patient's body mass index category. 2D model is selected to conducting numerical analysis of CoCrMo-on-CoCrMo that giving vertical load from different category of body mass index, namely underweight, normal, overweight, and obese class I, obese class II, and obese class III using finite element procedures. Peak loading under normal walking conditions from actual condition of human hip joint is adopted. Our result explains that displacement in direction - y is larger in line with greater user's body mass index.

1. Introduction

As long as total hip arthroplasty is used by patient, its medical implant is possible to change shape due to various forces of routine activity [1]. Deformation on bearing surface of hip prosthesis, both femoral and acetabular components has been linked to many factors on its performance [2]. It may influence wear by changing clearance, also bearing sphericity, causing change on lubrication regimes. Furthermore, deformation plays a role in occurrence of instability that one of the most common failure reasons in hip prosthesis. Making deformation less as possible will reduce change shape that crucial strategy for improving implant performance[3].

Research regarding total hip arthroplasty is already underway by previous investigator still focus on external factor of implant user, like surgical procedures of hip prosthesis [4], materials investigation [5], addition of textured surface [6], design of implant [7], and coating as surface layer [8]. Although this effort is essential, the user's internal factor also contributes to progress of research in hip implant. It has been known that higher cases of medical revision surgery needed since patient's body weight rising [9]. Moreover, studying mechanical aspects based on body mass index in total hip arthroplasty needs more detail presentation. This research gap should be filled in further investigation.

Metal-on-metal as bearing option of hip implant has been used in orthopaedic surgery, primarily aimed to younger and active patient compared to conventional metal-on-plastic because of high failure cases caused by wear particle from polyethylene that initiate osteolysis and aseptic loosening [7]. Other bearings option using ceramic have smoother surface for articulation and lower wear rate, but lack of this material with brittle properties is such a concern for patient safety. The main problem of metal-on-metal is its resistance problem and organ response due to metallic wear debris that caused toxicity to become challenging for enhancing overall bearing ability. Besides, studies involving body mass index of different users of hip implants have not been done [2,8]. Further studies related to this bearing need to perform.

An investigation based on finite element estimation has been conducted to avoid consuming time and high price experimental [10,11]. Previous literature presents many researches adopted finite element model for their analysis to study wear [1], contact pressure [2], lubrication [6], and deformation [12] of total hip arthroplasty. Previous literature using 3D finite element model has been done by Ammarullah et al. [13]. However, using 3D model is needing more period and hardware ability. Subsequently, the simplification model from 3D to 2D was selected by Basri et al. [7] and Shankar et al. [2] with reason for speed up computational requiring time without making the results inaccurate. Regrettable until now loading based on body mass index using finite element estimation models have not been presented.

The objective of this investigation was to analysis deformation on metal-on-metal bearing. 2D finite element concept with vertical loads based on body mass index is used to running numerical prediction. According to body mass index categories, six loading variations have been evaluated, and there are of underweight, normal, overweight, obese class I, obese class II, and obese class III.

2. Materials and methods

2.1. Geometry and material

Geometry for hip implant is this research refers to Ammarullah et al. [13] with details are femoral head diameter as 28 mm, radial clearance as 50 μm, and acetabular cup thickness as 5 mm. We choose cobalt chromium molybdenum (CoCrMo) for metallic material in metal-on-metal bearing, assumed homogeneous, isotropic, and linear elastic. Its mechanical properties for cobalt chromium molybdenum are Young's modulus as 210 GPA, Poisson's ratio as 0.3, density as 8300 kg/m^3, and friction coefficient as 0.2 [8].

2.2. Finite element model

In our study, only femoral head and acetabular cup as main representative of hip prosthesis involved in analytical model based on finite element refer to 2D asymmetrical ball-in-socket formation to speed up time [2]. Micro separation is not noticed in the simulation under steady-state contact mechanics for our detail of contact model. An analytical model that has been created explain in Figure 1. For more description in our finite element model, roughness of contact surface is representing on friction coefficient, temperature change is assumed to be constant, acetabular cup outer surface set up to be fixed constraint, then contact is made dry without lubrication [2,8].

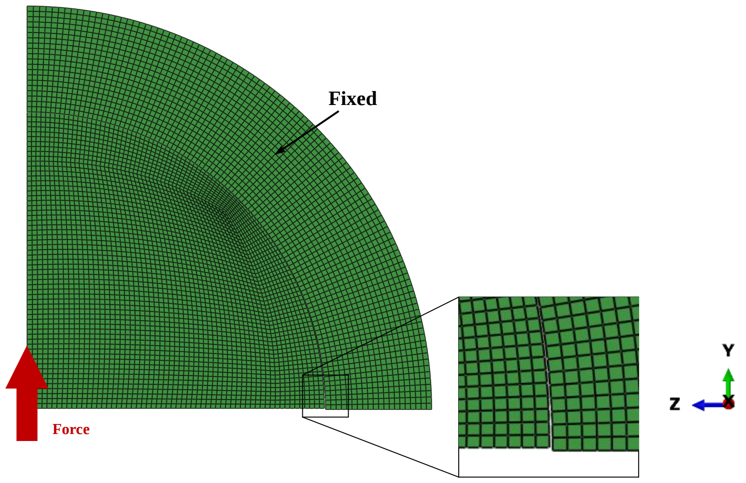

Figure 1. 2D FE model of CoCrMo-on-CoCrMo hip prosthesis

2.3. Loading condition
Using normal walking condition divided its cycle into 32 phases from Ammarullah et al. [5], we only take into account at 7^{th} phase that highest loading. From same literature, user of total hip arthroplasty from four respondent have an average body height of 171 cm and average body weight of 85.3 kg that categorized overweight according to body mass index. We are using an approximation for obtaining other peak loading of body mass index, and there are underweights as 1,442 N, normal as 1,931 N, overweight as 2,326 N, obese class I as 2,721 N, obese class II as 3,117 N, and obese class III as 3,512 N.

3. Results and discussion
Highest displacement in direction – y from each body mass index category in the condition of normal walking is presented in Figure 2. Referring from Ammarullah et al. et al.'s normal walking cycle [5], we divided its cycle into 32 phase and obtained peak loading in 7^{th} phase for every body mass index category. This is rational because this phase is walking condition when full of user's body weight is supported by human hip joint at normal walking. Displacement in direction – y from various body mass index categories are 0.0008814 mm for underweight, 0.001027 mm for normal, 0.001132 mm for overweight, 0.001227 for obese class I, 0.001317 mm for obese class II, and 0.001399 mm for obese class III.

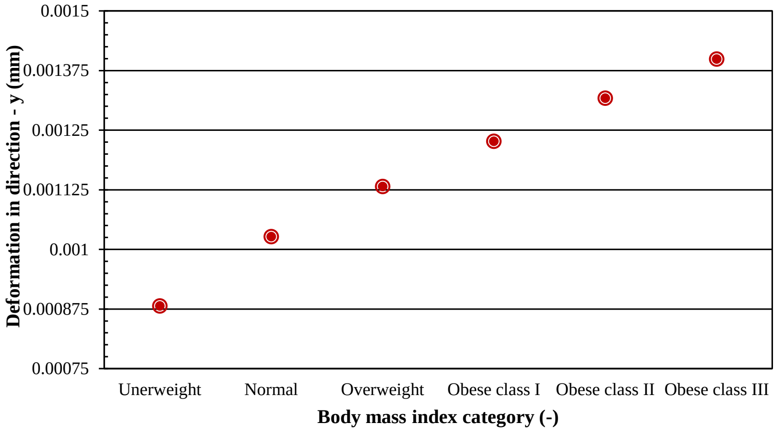

Figure 2. Highest deformation in direction – y of CoCrMo-on-CoCrMo bearing from various categories of body mass index

Moreover, Figure 3 presents displacement distribution in direction - y for different loading according to user's body mass index. In can be observed that the magnitude of displacement in direction – y is rising since heavier user's body weight. Displacement is a crucial aspect of investigation on total hip arthroplasty that impacted instability when large displacement occurs due to the long period from the first surgery [9]. Because of larger displacement and higher body mass index, this causes obese categories from class I until III have more significant failure probability due to instability. The similar explanation also stated by Electricwala et al. [9], obese patient categorized from body mass index is associated with postoperatively from instability correlating with total hip arthroplasty revision. Enhancing implant performance for user's with heavier weight will desire to be initiated.

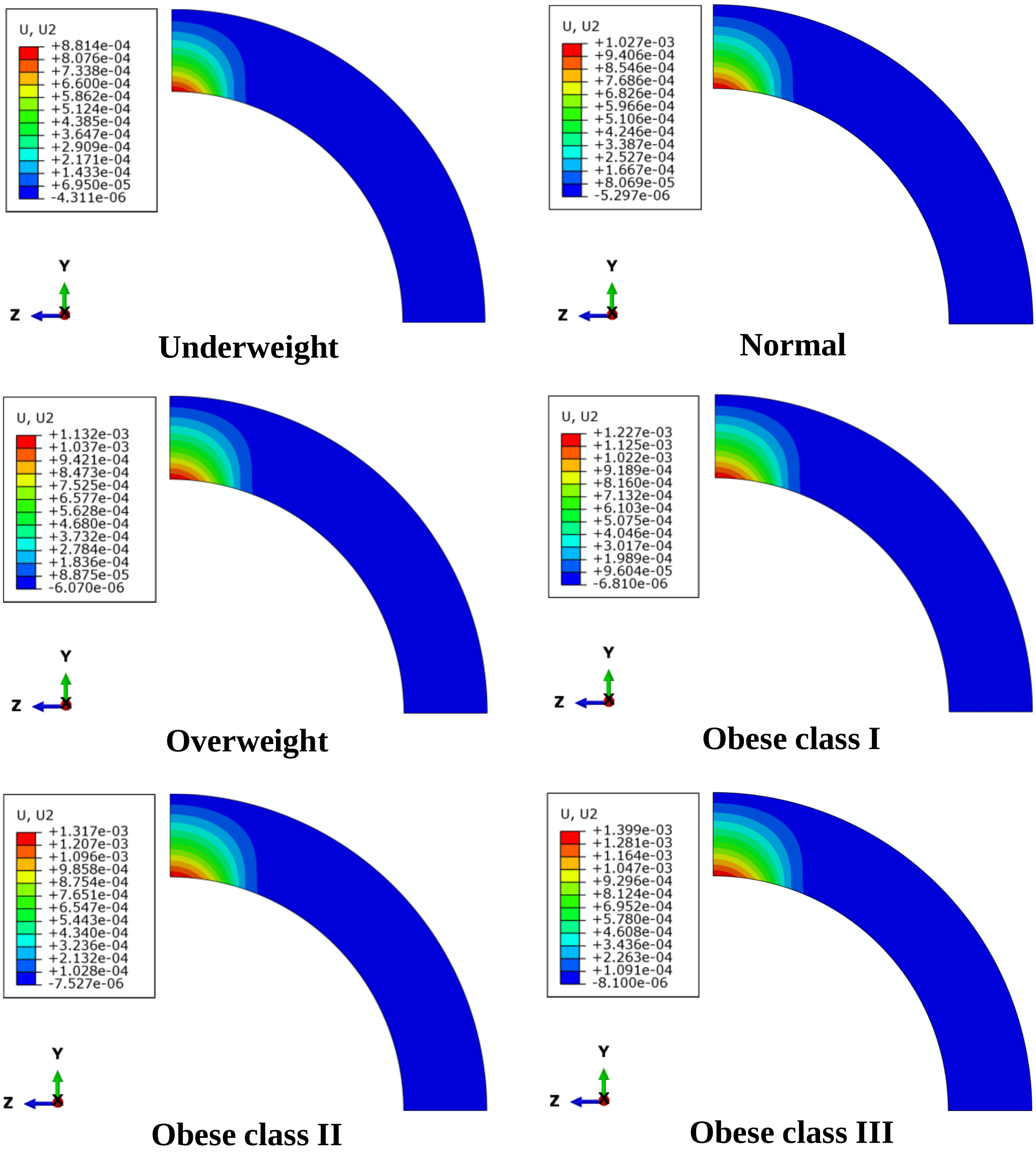

Figure 3. Distribution of highest deformation in direction - y of CoCrMo-on-CoCrMo bearing from various categories of body mass index

4. Conclusions

Computational analysis of deformation on CoCrMo-on-CoCrMo hip prosthesis has been performed under normal walking condition according to user's body mass index category. The result explains that displacement is larger and displacement distribution is wider in direction - y since greater body mass index. Displacement magnitude has a relationship with one of most common failure reasons that is instability in hip prosthesis. Obese categories have higher percentage of failure compared other body mass index categories due to instability. Implant development to making less deformation will be addressed to further research.

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