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ORIGINAL ARTICLE

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Biomechanical Analysis of Newly Developed Local Hip Implant from Stainless Steel, Cobalt-Chrome, and Titanium Materials Using the Finite Element Method

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Abstract

Background: Total hip arthroplasty (THA) is one of the most successful health interventions in the last century. However, there have been several reports of dissatisfaction with the hip implant. Most modern implants are manufactured based on Western morphology. This generalized design may not be suitable for all races, particularly Asians, who tend to have a more petite physique and distinct femoral anatomy.

Methods and Results: This study evaluated the biomechanical properties of a newly developed local hip implant using the Finite Element method based on ISO 7206-4, ISO 7206-6, and ASTM F2996-20. The implants were analyzed under static and dynamic load, and three different implant materials were used. The results showed that the titanium (Ti6Al4V) implant had the lowest von Mises stress, the cobalt-chrome (Co28Cr6Mo) implant had the lowest total deformation, and the stainless steel (SS316L) implant had the highest alternating stress and a lower life cycle. All of the materials have more than 1 (>1) safety factor value, which is considered safe for implant manufacturing.

Conclusion: This study offers insights into the performance of various materials under static and dynamic loading conditions, demonstrating that all simulated materials are deemed safe for implant manufacturing.(**International Journal of Biomedicine. 2025;15(4):700-703.**)

Keywords: biomechanical analysis • hip implant • finite element method

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Introduction

Total hip arthroplasty (THA) is a surgical procedure that has a significant impact on restoring the function of damaged hip joints and is one of the most successful health interventions in the last century.[1] Presently, hip joint arthroplasty has a 10-year success rate and 95% survivorship for patients older than 70 years.[2] However, despite the long-term stability and functionality of the Total Hip Replacement system, a 7% rate of dissatisfaction was observed after the THA operation.[3]

The configuration of the prosthesis has been recognized as a crucial determinant of the contact condition between the implant and the bone. Most modern implants are manufactured based on Western morphology and surgical standards.[4] This generalized design template may not be adequate for all races, especially Asians, who are reported to have a more petite physique and possess smaller femoral anatomy compared to Caucasians.[5]

Institut Teknologi Sepuluh Nopember (ITS), in collaboration with the Orthopaedic Department of Dr. Soetomo Hospital, has developed a locally manufactured Indonesian hip implant (ORTHOHITS), whose design is tailored to the Mongoloid race, with a neck offset and neck length shorter than those of European brands. This implant is expected to offer more precise anatomical accuracy and improved biomechanics for Indonesians compared to European brands.

Currently, there are no other locally made Indonesian hip implants available.[6]

Biomechanical testing is a critical component in implant development, as it not only measures durability but also ensures that the implant can function optimally under realistic physiological conditions after several years of use without failure.[7] Numerous studies comparing experimental fatigue data with fatigue life simulation analysis have demonstrated that Finite Element Analysis (FEA) can accurately depict the true stress variations of the hip implant.[8-10] This study aimed to evaluate the biomechanical performance of ORTHOHITS, a newly designed hip implant adjusted for the Mongoloid race by FEA. A total of three implant materials were analyzed using Finite Element models.

Methods

This study compares the biomechanical properties of titanium (Ti6Al4V), cobalt-chrome (Co28Cr6Mo), and stainless steel (SS316L) hip implants created locally. The test was done in accordance with ISO 7206-4, ISO 7206-6, and ASTM F2996-20 standards to provide guidance to implant designers during the FEA process for hip implants.[11-13]

The ORTHOHITS hip joint implant design (Figure 1) was used in this work's geometrical analysis. Materials used in this investigation were stainless steel (SS316L), cobalt-chrome (Co28Cr6Mo), and titanium (Ti-6Al-4V).

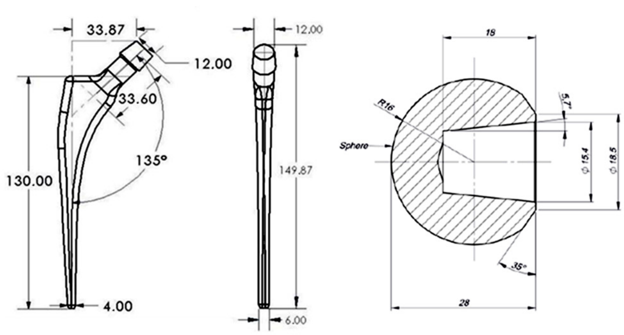

Figure 1. *ORTHOHITS hip implant design.*

The prototype implant presented in this study is a newly designed, collarless, cemented hip implant featuring a trapezoidal shape in the proximal region and a rounded stem region. Its purpose is to transmit the principal stress applied to the bone, which is an important factor for maximum principal stress distribution.

The ORTHOHITS hip joint implant stem length is 130mm with neck offset 35 mm, neck length 33.6 mm, neck-shaft angle 135-degrees, and distal stem diameter 5.4 mm. The design is based on a standard European THA brand but with 3mm shorter neck offset, 2-3 mm shorter neck length and 1.5 mm smaller stem diameter. The femoral head size is 32 mm.

The analysis method employed in this study is FEA using ANSYS Static Structural software. FEA is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems, ranging from complex geometries and numerical solutions to highly complicated stress problems.[14]

The commercial program Ansys Workbench 2021 R1 was used to generate the FEA model. Three-dimensional tetrahedron meshing was used because this method offers flexibility, allowing tetrahedral elements to be used to unite three-dimensional volumes regardless of their shape or topology. The optimal mesh size was estimated, and the highest von Mises stresses remained constant between 3 and 1 mm of mesh size. We used a 2 mm mesh size for rapid, precise, and reliable simulation; the total elements and nodes from the 2 mm mesh size are 15.565 and 27.388.

According to ASTM F2996-20, ORTHOHITS hip joint implant boundary condition is 90 mm from the head's center because the length of the prosthesis ranges between 120-15 0mm. Figure 2 shows the boundary conditions for the ORTHOHITS hip joint implant simulation.[13]

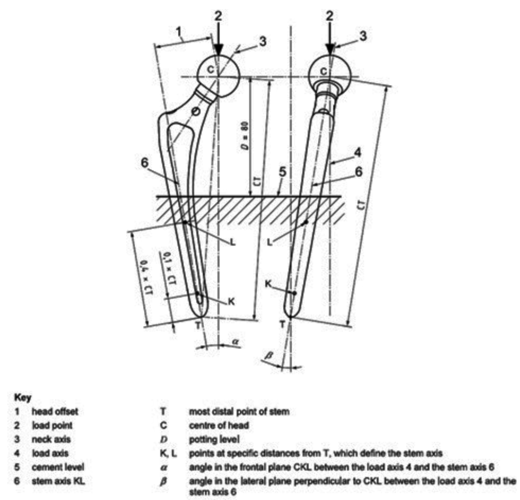

Figure 2. *Positioning of the THA implant during simulation.*

Static, dynamic, and fatigue analysis was performed according to ISO 7206-4, ISO 7206-6, and ASTM F2996-20 standards. The performance and durability of hip implants are thoroughly assessed by following ASTM F2996-20 standards and simulating loading and boundary conditions relevant to real-world situations. The hip implant model was loaded vertically with a maximum of 2300 N and a minimum of 50 N.[11-13]

Results

Static FEA was carried out on ORTHOHITS implants made of three distinct materials. The von Mises stresses induced in the implants and the total deformation obtained from the FEA calculations are shown in Table 1. The location of the maximum stress and the deformation are shown in Figure 3. The following stress distributions were induced in the implants: The maximum stress of all implants is located at the lower stem region, and the maximum deformation of all implants is located at the head.

Von Mises stresses induced in the titanium implant were lower than the stresses induced in stainless steel and cobalt chrome implants. The displacement values in cobalt chrome are lower than those of other materials (Table 1).

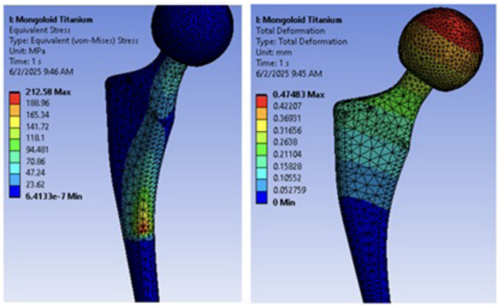

Figure 3. *Location of maximum (a) Von Mises Stress; (b) Total deformation of titanium implant.*

Tabel 1.

Von Mises stress and total deformation for the study implants

Material	Von Misses stress (MPa)	Total deformation (mm)
Stainless Steel	225.09	0.3566
Cobalt-Chrome	236.81	0.2811
Titanium	212.5	0.4748

Considering the stresses induced and the deformation that occurred, the results of the statistical analysis are equivalent based on the material's characteristics. Cobalt chrome has the highest strength, stiffness, and resistance to deformation compared to stainless steel and titanium. It is generally stiffer than other materials, making it better at withstanding deformation under stress. titanium has a relatively low Young's Modulus of elasticity compared to stainless steel and cobalt chrome. This means that it can deform more easily under stress, which means that stress can be distributed more evenly and peak stress value can be reduced.[15-17]

High-cycle fatigue FEA was performed on ORTHOHITS implants made of three distinct materials under ISO 7206-4 standard conditions. The equivalent alternating stress, the minimum life cycle of the implant, and the safety factor are presented in Table 2.

Table 2.

Fatigue Analysis Results.

Material	Alternating stress (MPa)	Life Cycle	Safey Factor
Stainless Steel	374.66	7.8938E+6	1.193
Cobalt-Chrome	119.24	1E+11	1.519
Titanium	115.86	1E+11	2.905

To understand the effects of different materials on fatigue behavior, three different implant materials were assigned to the FEA model, all of the same shape. The fatigue stress distribution and safety factor of all studied materials are shown in Figure 4.

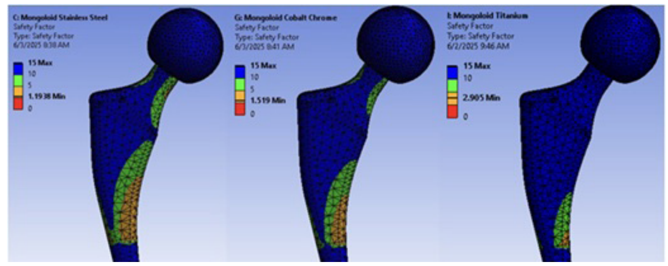

Figure 4. *Stress distribution and safety factor: (a) stainless steel, (b) cobalt-chrome, (c) titanium.*

Discussion

The equivalent alternating stress is one of the most critical parameters because it encompasses all fatigue-related calculations generally, irrespective of any material properties. Altering the characteristics of materials affects not only the fatigue alternating stresses but also the distribution of strain and displacement in the implants.[18,19] The fatigue analysis of the ORTHOHITS implant revealed the highest maximum stress at 374.66 MPa on the neck and stem region of the stainless steel implant. The lowest maximum stress was found at 115.86 MPa on the stem region of the titanium implant.

The safety factor is defined as the factor of safety for a specific design life; any value below 1 indicates that failure has occurred before the intended design life is reached. Based on simulation results, all materials' safety factor values are more than 1 (>1): 1.193 (stainless steel), 1.519 (cobalt-chrome), and 2.905 (titanium). The conclusion is that all of the materials are safe for manufacturing the ORTHOHITS hip joint implant.[20]

In this simulation, the hip implant FEA model was designed to withstand ISO 7206-4 conditions for 5×10^6 cycles without failure. Though the life cycle of the implants is well within the acceptable limit of 5 million, the stainless steel material has a significantly lower life cycle than cobalt chrome and titanium.[11]

The static structural results showed that titanium had the lowest von Mises stress at the stem, and cobalt-chrome had the lowest total deformation at the head of the implant. The material combination for the stem and head of the implant may be further studied to identify the optimal combination that offers higher factors of safety and lower damage values.[21]

The fatigue analysis showed that titanium and cobalt-chrome implants performed much better than stainless steel implants, with lower alternating stress and much higher life cycle (1E+11 vs 7.8938E+6). All of the materials have more than 1 (>1) safety factor value, which is considered safe for implant manufacturing.

The results provide insights into how different materials perform under static and dynamic loading conditions, guiding material selection for the implant productions. The real biomechanical testing process for ORTHOHITS hip implants still needs to be carried out as validation of the Finite Element simulation results.

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Disclosure

The authors report no conflicts of interest in this work.

References

1. Learmonth ID, Young C, Rorabeck C. The operation of the century: total hip replacement. Lancet. 2007 Oct 27;370(9597):1508-19. doi: 10.1016/S0140-6736(07)60457-7. PMID: 17964352.
2. Knight SR, Aujla R, Biswas SP. Total Hip Arthroplasty - over 100 years of operative history. Orthop Rev (Pavia). 2011 Sep 6;3(2):e16. doi: 10.4081/or.2011.e16. Epub 2011 Nov 7. PMID: 22355482; PMCID: PMC3257425.
3. Anakwe RE, Jenkins PJ, Moran M. Predicting dissatisfaction after total hip arthroplasty: a study of 850 patients. J Arthroplasty. 2011 Feb;26(2):209-13. doi: 10.1016/j.arth.2010.03.013. Epub 2010 May 11. PMID: 20462736.
4. Dundon JM, Felberbaum DL, Long WJ. Femoral stem size mismatch in women undergoing total hip arthroplasty. J Orthop. 2018 Feb 15;15(2):293-296. doi: 10.1016/j.jor.2018.02.002. PMID: 29515329; PMCID: PMC5834656.
5. Nakasone CK, Naito KT, Nishioka ST, Andrews SN. A smaller femoral stem is needed for asian females. Arch Orthop Trauma Surg. 2023 Aug;143(8):5353-5359. doi: 10.1007/s00402-022-04723-8. Epub 2022 Dec 6. PMID: 36472638.
6. Edwards K, Leyland KM, Sanchez-Santos MT, Arden CP, Spector TD, Nelson AE, Jordan JM, Nevitt M, Hunter DJ, Arden NK. Differences between race and sex in measures of hip morphology: a population-based comparative study. Osteoarthritis Cartilage. 2020 Feb;28(2):189-200. doi: 10.1016/j.joca.2019.10.014. Epub 2019 Dec 13. PMID: 31843571.
7. Kunčická L, Kocich R, Lowe T. Advances in metals and alloys for joint replacement. Prog Mater Sci. 2017;88:232-280. doi: 10.1016/j.pmatsci.2017.04.002.
8. Kaya F, İnce G. Fatigue analysis on a newly designed hip implants with finite element method. Int J Eng Innov Res. 2015;6:162-78. doi:10.47933/ijeir.1540604.
9. Pekedis M, Yildiz H. Comparison of fatigue behaviour of eight different hip stems: a numerical and experimental study. J Biomed Sci Eng. 2011;4:10. doi:10.4236/jbise.2011.410080.
10. Ploeg HL, Bürgi M, Wyss UP. Hip stem fatigue test prediction. Int J Fatigue. 2009;31:894-905. doi:10.1016/j.ijfatigue.2008.10.005.
11. The International Organization for Standardization. Implants for surgery partial and total hip prosthesis: Determination of endurance properties and performance of stemmed femoral components (ISO 7206-4). 2010. Available from: https://www.iso.org/standard/42769.html [accessed 16 July 2025].
12. The International Organization for Standardization. Implants for surgery partial and total hip prosthesis: Determination of resistance to static load of modular femoral heads (ISO 7206-10). 2018. Available from: https://www.iso.org/standard/71145.html [accessed 16 July 2025].
13. ASTM. F2996-20 Standard practice for finite element analysis (FEA) of non-modular metallic orthopaedic hip femoral stems. ASTM Int Conshohocken. 2020;22:1-11. doi:10.1520/F2996-20.
14. Jagota V, Sethi A, Kumar K. Finite element method: an overview. Walailak J Sci Technol. 2013;10:1-8. doi: 10.2004/wjst.v10i1.499.
15. Kishawy HA, Hosseini A. Titanium and titanium alloys. In: Machining difficult-to-cut materials. Materials Forming, Machining and Tribology. Springer, Cham; 2019. doi:10.1007/978-3-319-95966-5_3.
16. Colic K, Krstić D, Stanić V, Marković M, Kostić I, Radulović M, et al. Finite element modeling of hip implant static loading. Procedia Eng. 2016;149:257-62.
17. Bachtar F, Chen X, Hisada T. Finite element contact analysis of the hip joint. Med Biol Eng Comput. 2006 Aug;44(8):643-51. doi: 10.1007/s11517-006-0074-9. Epub 2006 Jul 6. PMID: 16937206.
18. Browell R. Calculating and displaying fatigue results. Ansys Sol. 2006;7:9-12.
19. Amjad M, Badshah S, Ahmad S, Badshah M, Jan S, Yasir M, Akram W, Alam Shah I, Muhammad R, Khan MI, Yasmeen T. Finite element modeling of stress distribution and safety factors in a Ti-27Nb alloy hip implant under real-world physiological loading scenarios. PLoS One. 2024 Aug 6;19(8):e0300270. doi: 10.1371/journal.pone.0300270. PMID: 39106270; PMCID: PMC11302931.
20. Taqriban R, Ismail R, Jamari J, Bayuseno A. Finite element analysis of artificial hip joint implant made from stainless steel 316L. Bali Med J. 2021;10:448-52. doi:10.15562/bmj.v10i1.2236.
21. Corda J, Chethan KN, Shenoy S, Shetty S, Shaymasunder N, Zuber M. Fatigue life evaluation of different hip implant designs using finite element analysis. J Appl Eng Sci. 2023;21:896-907. doi:10.5937/jaes0-44094.

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