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Comparison of Stress and Deformation Distribution in Steel and Cobalt Chromium Materials for Femoral Bone Implants using Computational Biomechanics Analysis

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ABSTRACT

This study analyzed the mechanical performance of femoral bone implants using two types of materials, namely Alloys and Cobalt Chromium Alloys, and two variations of implant lengths (72 mm and 24 mm, and 80 mm and 20 mm). Simulations were performed using the Finite Element Method (FEM) to evaluate mechanical parameters, such as Directional Deformation, Equivalent Stress, Maximum Principal Stress, and Minimum Principal Elastic Strain. The results of the analysis showed that Cobalt Chromium Alloys material had smaller deformation than Alloys, indicating better stiffness and load-bearing capacity. However, the maximum principal stress value was higher in Cobalt Chromium Alloys, indicating a greater risk of stress concentration. Meanwhile, a larger implant length showed a more even stress distribution than a smaller length. This study provides important insights into the influence of material and implant length on its mechanical performance, and can be a basis for designing optimal implants for specific medical needs.

1. INTRODUCTION

Biomechanics is an interdisciplinary field that combines the principles of mechanics with biology to understand and solve problems in biological systems (Huang et al., 2025; Manna et al., 2024; Wu et al., 2024). One important application of biomechanics is in the design of medical devices, such as bone implants. In this context, biomechanical modeling utilizes numerical approaches and computer simulations to analyze and predict the mechanical behavior of such devices, both under static and dynamic conditions.

Bone implants play a vital role in the medical world, especially to repair or replace the function of bones damaged by injury, disease, or degeneration (Amalraju, 2012; Fauziyah et al., 2025). An effective implant design process requires a deep understanding of stress distribution, deformation, and material behavior under various loading conditions. Therefore, technologies such as Computer-Aided Design (CAD) and the Finite Element Method (FEM) are key tools in the development and analysis of these devices.

In biomechanical analysis, material selection is a critical aspect that affects implant performance. Different types of materials, such as stainless steel and Cobalt Chromium alloys, have different mechanical characteristics, including elastic modulus (Young's Modulus) and Poisson's ratio (Fauziyah et al., 2019). These parameters affect how the implant carries loads and responds to mechanical stress during use (Alemayehu & Jeng, 2021; Gasik et al., 2021; Medina-Galvez et al., 2021; Senthil, 2024). Simulation of stress and deformation distributions in different materials provides important insights for selecting the most suitable material for a particular application.

Based on research conducted by (Amalraju, 2012)investigating the relationship between mechanical factors and structural integrity of stents made of stainless steel and cobalt-chromium alloys. The results show that cobalt-chromium alloys have higher hardness after mechanical expansion, which can affect the distribution of stress and deformation. Meanwhile, in research conducted by (Rizki et al., 2023)which analyzed the distribution of stress, strain, and total deformation on implant plates using the finite element method. Although the focus is on implant plates, the methodology used can be applied to understand the mechanical behavior of materials such as stainless steel and cobalt-chromium alloys in the context of femoral bone implants.

This article aims to simulate and analyze the design of femoral bone implants using a biomechanical modeling approach. The analysis is carried out by considering the distribution of stress, deformation, and performance of the implant material under certain loads. By using CAD/CAM software and finite element methods, this project is expected to produce optimal design and material recommendations for femoral bone implants.

2. METHOD

The method used in this project involves several structured stages to analyze the performance of femoral bone implants. The first stage is the design and creation of an implant model using CAD/CAM software such as SolidWorks, ABACUS, or SketchUp. The model is designed according to predetermined geometric specifications, including the thickness of the long side, the thickness of the implant head, and the total length adjusted to the NPM parameters. The design is then presented in a special template that includes key dimensions and features.

The second stage is the simulation of stress distribution using the finite element method (FEM). In this simulation, the first material used is stainless steel with an elastic modulus of 193,000 MPa and a Poisson's ratio of 0.3. This material is assumed to have linear and isotropic elastic properties. To ensure the accuracy of the simulation, the implant model is divided into small tetrahedron-shaped elements (meshing) with an element size of 0.01 mm for the thickness of the side plate and 0.02 mm for the surface plate. A load of -750 N is applied in the X-axis direction, while six specific surfaces are fixed support to represent the support condition.

The third stage is the analysis of alternative materials. The same model is reanalyzed for Cobalt Chromium alloy material with an elastic modulus of 220,000 MPa and a Poisson's ratio of 0.22. The simulation results of both materials are compared to observe the differences in stress distribution, deformation, and performance of each material.

The final stage is the processing and presentation of the analysis data. The resulting data includes stress and deformation distribution images, meshing results, and maximum and minimum stress and deformation values. All of these results are compiled in a report that includes the performance differences between the two materials and their implications for implant design. This method is designed to provide comprehensive insight into the mechanical behavior of femoral bone implants under various loading conditions.

3. RESULTS AND DISCUSSION

Based on the Tables 1 and 2, which shows the data of deformation and stress analysis results on femoral bone implants using two types of materials, namely Alloys and Cobalt Chromium Alloys, and two different implant lengths (72 mm and 24 mm, and 80 mm and 20 mm). This analysis includes parameters such as Directional Deformation, Equivalent Stress, Maximum Principal Stress, and Minimum Principal Elastic Strain.

Table 1 The data of deformation and stress analysis results on femoral bone implants using Alloys and Cobalt Chromium Alloys (72 mm and 24 mm length)

Material	**Alloys (Length 72 and 24)**	**Cobalt Chromium alloys (Length 72 and 24)**	**Material**	**Alloys (Length 72 and 24)**
Comparison	**Min**	**Max**	**Comparison**	**Min**
Directional Deformation	-10649e+007	6.8743e+007	-8.7692e-007	3.6601e-020
Equivalent Stress	-1.2557e-010	7.6318e+007	1.0772e-011	7.9242e+007
Maximum Principal Stress	-1.0649e+007	6.8743e+007	-9.2333e+0	4.6096e+007
Minimum Principal Elastic Strain	-2.2354e-004	0	4.2744e+006	6.7644e+007

Table 1 The data of deformation and stress analysis results on femoral bone implants using Alloys and Cobalt Chromium Alloys (80 mm and 20 mm length)

Material	**Alloys (Length 80 and 20)**	**Cobalt Chromium alloys (Length 80 and 20)**	**Material**	**Alloys (Length 80 and 20)**
Comparison	**Min**	**Max**	**Comparison**	**Min**
Directional Deformation	-4.5476e+007	4.1448e+006 7	-9.4153e-007	0
Equivalent Stress	1.9388e-011	5.2311e+007	9.4171e-013	6.1858e+007
Maximum Principal Stress	-1.0598e+007	4.1565e+007	-2.2601e+007	4.611e+007
Minimum Principal Elastic Strain	-4.5476e+007	4.1448e+006	-4.6515e+007	1.5699e+006

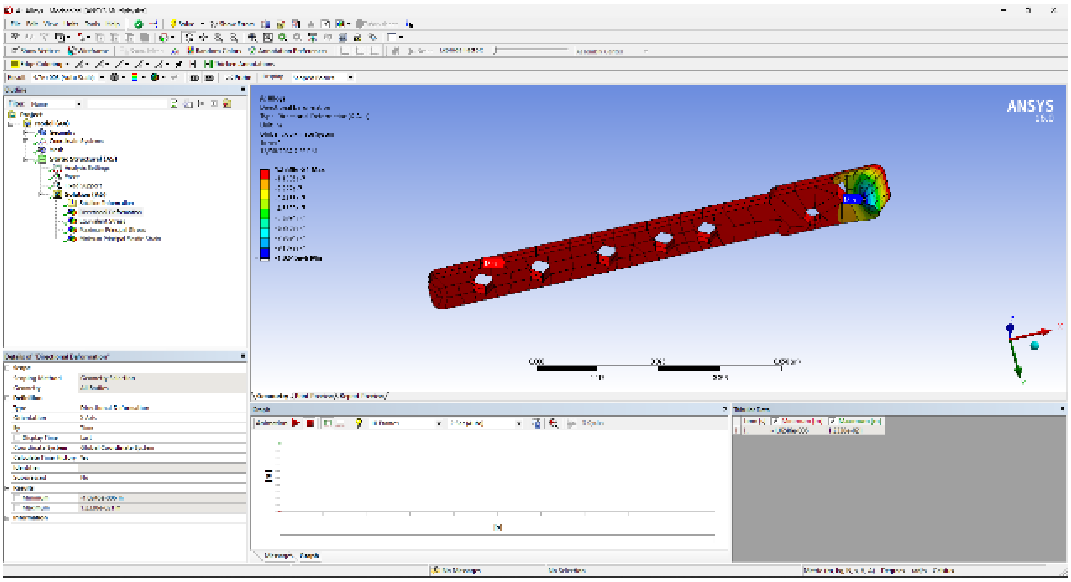

Figure 1 Representative performance of femoral bone implants modeling in metal Length 72 mm and 24 mm.

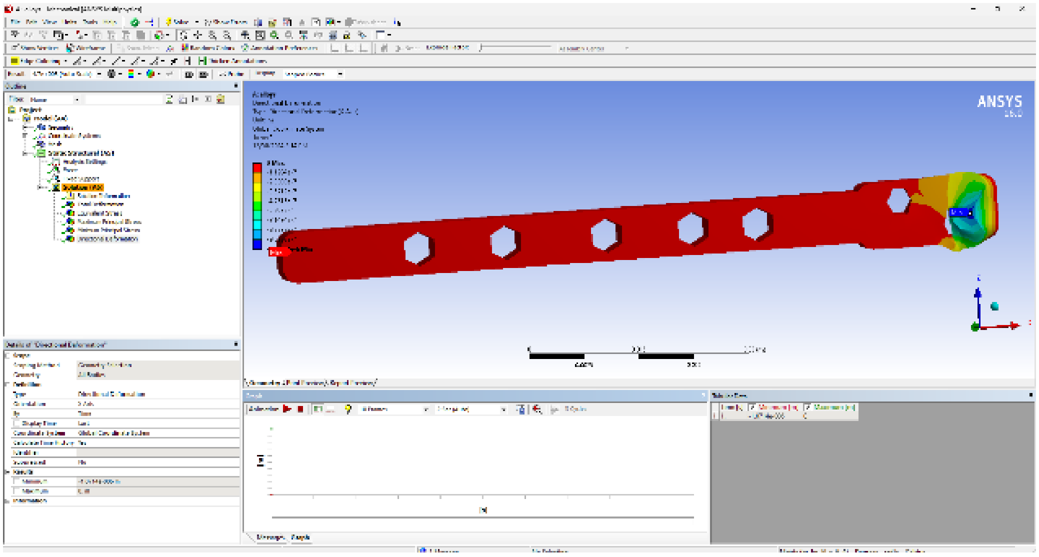

Figure 2 Representative performance of femoral bone implants modeling in metal Length 80 mm and 20 mm

In Figure 1, length 72 mm and 24 mm, Cobalt Chromium Alloys shows a higher Maximum Principal Stress value compared to Alloys. However, the Directional Deformation and Equivalent Stress values in Cobalt Chromium Alloys material are also relatively smaller. This indicates that this material is stiffer and capable of resist deformation better than Alloys.

In Figure 2, 80 mm and 20 mm lengths, a similar pattern occurs, where Cobalt Chromium Alloys tend to have smaller deformation values but larger stresses than Alloys. This difference in performance indicates the influence of material properties on stress distribution and the ability of the implant to withstand deformation under a given load.

From these data, it can be seen that the selection of material and implant length plays an important role in determining its mechanical performance, where Cobalt Chromium Alloys material is superior in resisting deformation but has a greater risk of stress concentration. Interpretation of this data can be the basis for designing optimal implants for specific medical needs.

4. CONCLUSION

Based on the analysis of the mechanical performance of femoral bone implants with two materials (Alloys and Cobalt Chromium Alloys) and different implant lengths, it can be concluded that Cobalt Chromium Alloys are stiffer and better able to withstand deformation, but have a higher risk of stress concentration. In contrast, Alloys are more elastic and more even in stress distribution, even though they experience greater deformation. Implant length also affects stress distribution, where longer implants (72 mm and 80 mm) tend to be more stable and more even in stress distribution, while shorter implants (24 mm and 20 mm) are at risk of experiencing higher stress concentration. Therefore, the selection of the right material and implant length is very important to optimize mechanical performance and minimize the risk of failure in medical applications.

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