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Finite Element Analysis of Trapezoid-Shape Hip Implants with Varying Acetabular Thickness under Static Loading Conditions

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***Abstract* - The hip joint is a joint that connects the thighbone to the pelvis. Over time, these joints can deteriorate and cause problems that can compromise their function. Total hip arthroplasty (THA) is needed so that sufferers of related diseases are able to return to normal activities. This process is carried out by replacing the damaged hip joint with an artificial hip joint (hip implant) consisting of a stem, femoral head, acetabular cup and backing cup. The main focus in this study is to analyze the effect of acetabular cup thickness in different material combination on hip implant design using the finite element analysis (FEA) approach method. Using standard boundary conditions referring to ASTM F2996-13, a 3-dimensional analysis using the finite element method was carried out to determine the influence of acetabular cup thickness on hip implants. MoP and MoM compositions with Co-Cr and UHMWPE materials were used in this analysis. The parameters used are taperBody von-Mises stress, total deformation and von-Mises stress on all implants. This research show that increasing the thickness of the acetabular cup has the same effect as increasing the fermoral head diameter of the implant and that implants with the highest acetabular cup thickness have better performance. However, increasing the thickness of the acetabular cup did not have a significant impact on the overall stress distribution contour of the implant.**

Keywords: Finite element analysis, hip implant, acetabular cup thickness, total hip arthroplasty.

I. INTRODUCTION

The hip joint is one of the most important joints in the human body which connects the thighbone to the pelvis. The hip joint together with the thigh bone supports loads and shocks during activities such as walking, running, climbing stairs and so on. The hip joint is a type of synovial joint which consists of a ball and socket where the joint surface is formed by the head of the femur which articulates with the acetabulum of the hip bone (Iyer *et al.*, 2021). It is known that the hip joint can sup-port four times the load of the human body (Chethan *et al.*, 2019). Over time, these joints can deteriorate and cause problems that can compromise their function. Hip injuries are a very serious and common event that can be very damaging, causing permanent disability and even death (Guo *et al.*, 2022).

Some diseases that can occur in the hip joint are osteoarthritis, atrophic arthritis, avascular necrosis, trochanteric bursitis, and coxa saltans. Osteoarthritis is the most common disease found in the hip joint which causes pain due to stiff joints (Chethan *et al.*, 2021; Taqriban *et al.*, 2021). Meanwhile, other diseases of the hip such as hip fractures that occur worldwide are expected to increase to more than 6.26 million in 2050 (Chethan *et al.*, 2019). Hip joint replacement, also known as total hip arthroplasty (THA), is necessary so that sufferers of related diseases are able to return to normal activities. THA (total hip arthroplasty) is a frequently performed and successful surgical intervention to relieve pain and improve hip joint function in individuals suffering from advanced hip joint arthritis. THA surgery is performed by removing the diseased part of the hip joint and replacing it with a new artificial joint (prosthesis) that functions like a normal joint. THA has been performed since the 19th century as a treatment for patients with fractures and osteoarthritis but has begun to become one of the most sophisticated surgical techniques for human health care since the 21st century (Chethan, *et al.*, 2020). THA is one of the largest orthopedic operations with more than 350,000 and 60,000 operations performed annually in the USA and England (Taqriban, *et al.*, 2021).

The artificial hip joint consists of a neck, femoral head, acetabular cup and backing cup (Chethan *et al.*, 2021). There are many designs and material combinations used in hip implants. The initial hip implant design for the neck and femoral head was designed in one complete piece (monobloc design). Meanwhile, currently various existing designs separate the two components so that this can facilitate the operating process and potentially ease revisions by simply

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replacing the failed component (Gotman, 2021). The stem also has two broad designs, namely modular and non-modular/standard stem (Kiernan *et al.,* 2020). On a modular stem, the neck and stem are arranged separately and there is a thread to join the two. Meanwhile, in non-modular, the neck and stem are arranged singly. Various materials are often used in hip implants such as cobalt-chromium (Co-Cr), ultra-high-molecular-weight polyethylene (UHMWPE), titanium alloys, and cobalt chromium molybdenum (Co-Cr-Mo) (Chethan *et al.*, 2021). The material combination in hip implants can be ceramic on ceramic (CoC), metal on metal (MoM), metal on polyethylene (MoP), and ceramic on polyethylene (CoP/CoPE) (Merola and Afato, 2019).

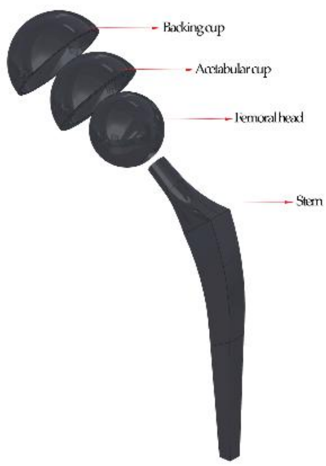
Previously, there were various studies that had been carried out regarding design and performance analysis of hip implants. Sabatini and Goswami (2008), studied the optimization of the cross-section stem shape for hip implants. Wibowo *et al.* (2019), studied fluid-structure interaction analysis in the hip-joint prosthesis during prayer (prayer) activity. Saputra *et al.* (2019), studied a wear formulation of total hip prosthesis for prayer activity. Alkhatib *et al.* (2019), studied the biomechanical performance of porous titanium alloy hip stem during walking and climbing stairs. Tauviqirrahman *et al.* (2023), studied contact pressure in hip joint prosthesis under a gait cycle. Jamari *et al.* (2017), studied the effect of acetabular cup thickness with bipolar and unipolar models which showed that the highest contact stress was produced by the acetabular cup with the lowest thickness. This research only emphasizes the influence of acetabular thickness on the contact stress on the acetabular cup. However, previous studies have focused on the effects of hip implant design and performance under conditions of daily activity. In addition, in previous studies no emphasis was given to standard boundary conditions or the effect of acetabular cup thickness on the overall hip implant. There are many variables in design, such as the shape of the neck profile, trunnion radius, neck length, head diameter, stem cross section shape, etc., which can affect the performance and durability of the hip implant (Chethan *et al.*, 2021). Therefore, the thickness of the acetabular cup must also be considered in hip implant design, because the thickness of the acetabular cup can be optimized if there are large changes in von-Mises stress and deformation. In addition, an analysis of the effect of acetabular cup thickness on hip implants with existing standard boundary conditions also needs to be carried out. Finite element analysis has also played an important role in biomechanical analysis since the late 1970s and has made it easier to design medical devices over the last decade (Chatterjee *et al.*, 2022; Erdemir, *et al.*, 2012; Heller, 2022).

The main focus in this study is to analyze the effect of acetabular cup thickness in different material combination on hip implant design using the finite element analysis (FEA) approach method. A combination of MoM and MoP hip implants was used with Co-Cr and UHMWPE as the materials. The applied boundary conditions refer to ASTM F2996–13 as the finite element analysis standard for non-modular hip implants stem (ASTM, 2013; Bhawe, *et al.,* 2022; Chethan, *et al.,* 2019;).

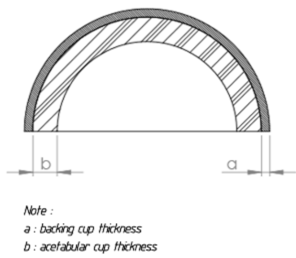
II. MATERIAL & METHOD

2.1 Hip Implant Model

Currently, there are various models of hip implants used in THA surgery. Each of these models has its own advantages and disadvantages. For this study, the hip implant model used refers to the hip implant model that was previously studied by Chethan et al (Chethan, *et al.,* 2021). However, the cross-section shape was modified to be trapezoidal because in previous studies it was known that trapezoid-shaped stems produce lower von-Mises stress values than circular-shaped stems. Therefore, the trapezoid-shaped stem was considered for further analysis, shown in Figure 1 (a). Stem length has been considered 180 mm and taper is kept constant 12/14 mm (Alkhatib *et al.,* 2019). Femoral head size varies between individuals (Lee et al., 2014); however, in this study, it was kept constant at 40 mm. This is adjusted to the average femoral head size for adults in Indonesia, which is around 42 mm for men and 37.6 mm for women (Jamari *et al.*, 2017) the size of the acetabular cup was varied by 2 mm, 4 mm, and 6 mm, shown in Figure 1 (b). This combination was carried out to determine the effect of acetabular cup thickness on the hip implant. Meanwhile, the size of the backing cup is kept constant at 2 mm (Chethan, *et al.*, 2022).



(a)



(b)

Figure 1: (a) Schematic of the hip implant model; (b) Sectional image of the acetabular cup and backing cup on the hip implant

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2.2 Meshing

The meshing process involves dividing components into small elements. The choice of element type depends on the analyst's preference. However, the recommended meshing for FEA simulation of non-modular hip implants stem is a mesh with tetrahedral or hexahedral elements. The application of tetrahedral linear elements (4-node elements) is not recommended for use in this analysis to avoid stress and strain incompatibilities that can occur across elements (ASTIM, 2013). Therefore, in this study the mesh used is linear hexahedral mesh (8-node elements) on the stem and quadratic tetrahedral mesh (10-node elements) used on the remaining part of the hip implant, shown in Figure 2. The application of different elements in the meshing process is used for easier meshing control (Ruggiero *et al.*, 2019).

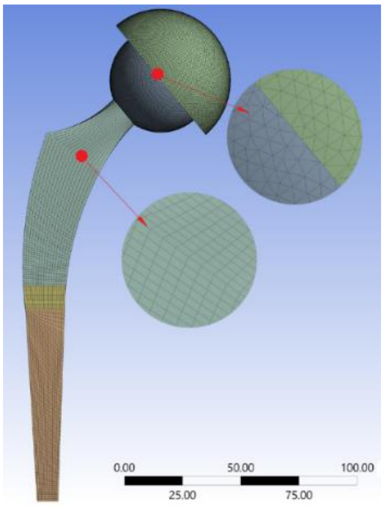

Figure 2: Mesh results in the hip implant model

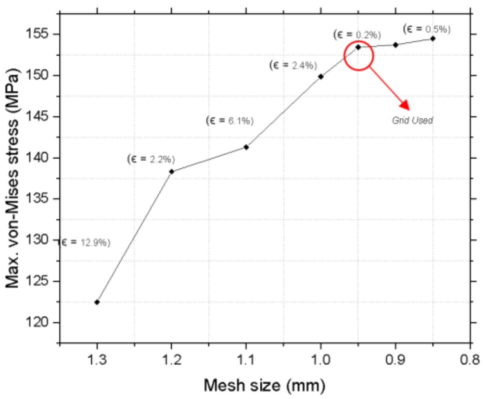

Figure 3: Variation of von-Mises stress values with different mesh sizes

A grid independence study is performed to find the appropriate element density for this analysis thereby optimizing the time and computational load, as shown in Figure 3. This is done by evaluating the number of elements against one of the parameters until the desired stability is achieved. This process is carried out using coarse to fine elements. When the element size is reduced, the skewness value will decrease, which means the meshing quality will increase. Quality meshing can produce simulations that are acceptable or have smaller error values (Lee *et al.*, 2020). The mesh size varies from 1.3 mm to 0.85 mm. It has been observed that there is a decrease in the von-Mises stress value produced when the mesh is reduced from 1.3 mm to 0.95 mm with error variations ranging from 2.2% to 12.9%. Then there is no significant variation in the decrease in von-Mises stress produced by mesh below 0.95 mm. Therefore, for a complete analysis a mesh with a size of 0.95 mm was considered. For a mesh size of 0.95 mm on a hip implant with an acetabular cup thickness of 6 mm, 1120472 nodes and 797295 elements were obtained in the entire implant, given in Table 1. Meanwhile, the different number of elements obtained from each mesh size reduction is presented in Table 2.

Table 1: Mesh criteria obtained throughout the implant body

Mesh Criterion	Explanation
Sizing control	Body sizing
Mesh size	0.95 mm
Number of nodes	1120472
Number of elements	797295
Minimum skewness	6.9745e-007
Maximum skewness	0.86133
Average skewness	0.21744

Table 2: Reduced mesh size, number of elements, von-Mises stress value and error obtained from the previous value

Element Size [mm]	Number of Element	Max. von-Mises stress [MPa]	Error [%]
1.3	312597	122.48	12.9
1.2	390142	138.32	2.2
1.1	505639	141.3	6.1
1	684284	149.86	2.4
0.95	797295	153.43	0.2
0.9	924750	153.73	0.5
0.85	1096251	154.48	-

2.3 Loading and Boundary Conditions

First, the stem must be divided into three sections, requiring two cuts. These cuts represent the locations where stress, strain, and/or deformation will be evaluated. The location of the cut is determined by the CT length of the stem, given in Table 3. CT is the distance from the center of the femoral head on the stem to the farthest distal point (ASTM, 2013). In the analysis to be carried out, the total stem length is 180 mm with a CT length of 175.35 mm. Therefore, the length of the first cut (D) is 80 mm and the second cut (F) is 10 mm from the first cut, shown in Figure 4 (a).

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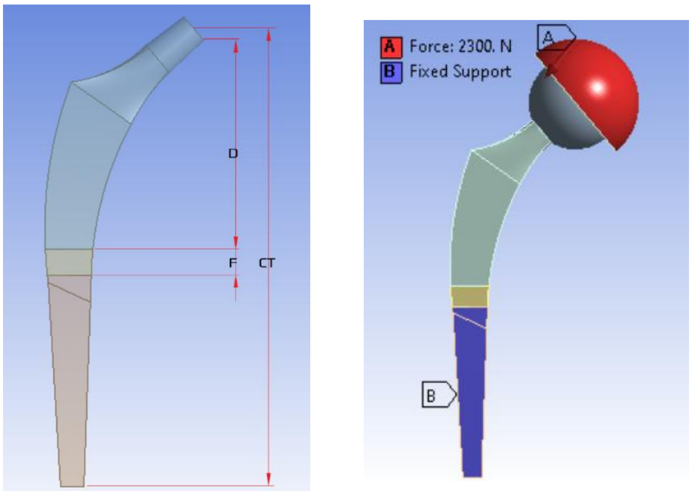
The application of loading and boundary conditions in this analysis is by providing force and fixed support to the hip implant geometry. Both remain constant for all hip implant models. A load of 2300 N is applied to the surface of the backing cup and fixed support is applied to the first cut of the stem downwards as considered per ASTM F2996–13, shown in Figure 4 (b). The purpose of providing boundary conditions with static conditions is to analyze the design strength. Therefore, recommendations for optimizing hip implant design to improve performance can be identified.

Table 3: Cutting parameters on non-modular hip implant stems

Parameter	Symbol	Tolerance [mm]	Stem Length [mm]		
The distance between the center of the head and the most distal point	CT [mm]	± 2	≤120	120<CT<250	>250
First cut (starting from the lower end of the trunion surface)	D [mm]	± 2	0.66 × CT	80	CT - 100
Distance of second cut (after first cut)	F [mm]	-	10	10	10



(a) (b)

Figure 4: (a) Stem that has been cut; (b) Load and fixed support applied to the hip implant

2.4 Material Properties

There are various types of hip implant material composition that can be used (Guo *et al.*, 2022; Merola and Affato, 2019; Soliman *et al.*, 2022). MoP (Metal on Polyethylene) and MoM (Metal on Metal) compositions are two of several available compositions that are often used in THA (Varacallo *et al.*, 2023). In the present study, two different sets of materials MoP and MoM were considered to determine the influence of acetabular cup thickness on hip implants. As mentioned previously shown in Figure 1, the simulated cases are shown in Table 4. In the first set, Cobalt-Chromium (Co-Cr) was chosen as the backing cup material, femoral head, stems and ultra-high-molecular-weight polyethylene (UHMWPE) was used for the acetabular cup. In the second set of materials considered, Co-Cr was selected for the entire hip implant. The material properties used are assumed to be linear isotropic for both Co-Cr and UHMWPE, given in Table 5.

Table 4: Different sizes of acetabular cup and materials applied to trapezoid-shape hip implants

Sl no.	a	b	Hip Implant Materials			
			Backing Cup	Acetabular Cup	Femoral Head	Stem
1	2 mm	2 mm	Co-Cr	UHMWPE	Co-Cr	Co-Cr
2		4 mm				
3		6 mm				
4		2 mm		Co-Cr		
5		4 mm				
6		6 mm				

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Table 5: Mechanical properties of material in hip implants (Aherwar *et al.*, 2015; Bandyopadhyay *et al.*, 2020; Chethan *et al.*, 2021; Bhawe *et al.*, 2022)

Materials	Young Modulus [GPa]	Density [g/cm^3]	Poisson's ratio	Ultimate Tensile strength [MPa]	Yield Strength [MPa]
Co-Cr	200	8.5	0.3	1503	310
UHMWPE	0.963	0.31	0.31	48	17

2.5 Contact Definition

Contact definition is carried out to provide information regarding the type of contact or connection behavior that occurs in the geometry to be analyzed. Because the modeled hip implant geometry has several parts that touch each other or are close to each other, a contact definition is required. In addition, because there are two cuts in the stem, the contact at these parts is also determined. Contact definitions are given in Table 6. The asperity of the contact interface between backing cup- acetabular cup, acetabular cup - femoral head, and femoral head - stem was defined to be the coefficient of friction. However, in both cuts on the stem the contact behavior was defined as bounded so that the stem cut does not change the restrictions on the stem from any direction (ASTM, 2013; Bhawe *et al.*, 2022).

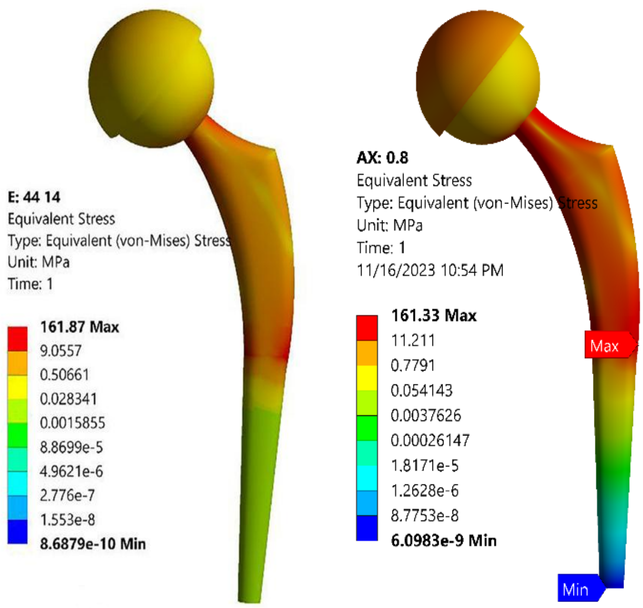
Table 6: Contact definition of hip implant (Bhawe *et al.*, 2022)

Contact Interface	Material Interface	Contact Behavior	Coefficient of Friction
Backing cup – Acetabular cup	Co-Cr - UHMWPE	Frictional	0.23
	Co-Cr – Co-Cr		0.21
Acetabular cup – Femoral head	Co-Cr - UHMWPE		0.23
	Co-Cr – Co-Cr		0.21
Femoral head - Stem	Co-Cr – Co-Cr		0.21
Stem first cut	Co-Cr – Co-Cr	Bounded	-
Stem second cut	Co-Cr – Co-Cr		

III. RESULT AND DISCUSSION

3.1 Validation

The validation process is essential for determining the appropriate method and modeling for the case being analyzed. Verification of the results obtained through the finite element computational approach is necessary to ensure their validity by comparing them with results from published literature under similar conditions (Jamari *et al.,* 2023). For this purpose, the von-Mises stress values for the entire hip implant made of Co-Cr and UHMWPE materials were compared with the results from the previous study by Chethan *et al.* (2021), as shown in Figures 5–6. However, because the model used in this analysis features a stem with a modified trapezoidal shape, validation is performed using a model comparable to those presented in previous literature. Therefore, validation was carried out with circular-shape hip implants with a 44 mm acetabular cup, 2 mm acetabular cup and backing cup, respectively (Chethan *et al.,* 2021). The difference in the von-Mises stress values produced by this study is 0.54 MPa, which is a 0.3% deviation from the results of Chethan *et al.* (2021). Since the error is below 10%, the finite element model is deemed suitable, and the current results have been verified (Jamari *et al.,* 2023).



(a) (b)

Figure 5: Comparison of von-Mises stress contours on the entire hip implant: (a) By Chethan, et al. (2021); (b) Present study

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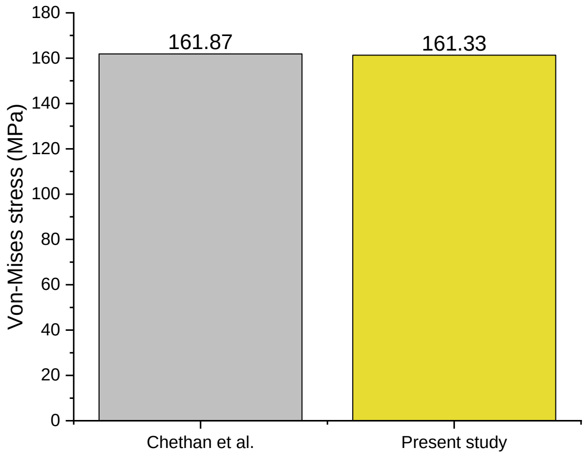

Figure 6: Comparison of von-Mises stress values with Chethan et al. (2021)

3.2 The Effect of Acetabular Cup Thickness

A total of six hip implant models with different acetabular cup thicknesses and material compositions were analyzed. The total deformation, von-Mises stress on the taper body, and von-Mises stress on the entire implant varied with the acetabular cup thickness at different material compositions.

In both combinations of hip implant materials, an increase in the thickness of the acetabular cup results in a higher maximum total deformation value for the implant with an acetabular cup UHMWPE. However, for the implant with an acetabular Co-Cr component, the increase in the thickness of the acetabular cup leads to a tendency for the maximum total deformation value to decrease, as shown in Figure 7. This is influenced by the UHMWPE material, which is softer and has a flexible polymer chain structure, so that when the thickness is increased, the volume of material undergoing deformation increases as well. On the other hand, the reduction in deformation in the hip implant with a Co-Cr acetabular cup is due to the material's greater stiffness. The added thickness does not significantly increase displacement because of the material's orderly crystal structure. As a result, the increase in the stiffer portion of the implant leads to reduced deformation.

An increase in the acetabular cup thickness from 2 mm, 4 mm, to 6 mm resulted in variations in the maximum total deformation of the UHMWPE acetabular implant, with an average increase of 4.95% (5.68% from 2 mm to 4 mm and 4.21% from 4 mm to 6 mm). In contrast, the Co-Cr acetabular implant exhibited an average decrease of 0.51% (0.16% from 2 mm to 4 mm and 0.42% from 4 mm to 6 mm), shown in Figure 8. Notably, the increase in acetabular cup thickness in the UHMWPE-based hip implant led to a noticeable change in deformation values, with an increase of approximately 5%. However, no significant difference was observed in the reduction of total deformation in Co-Cr acetabular cup implants with increasing cup thickness.

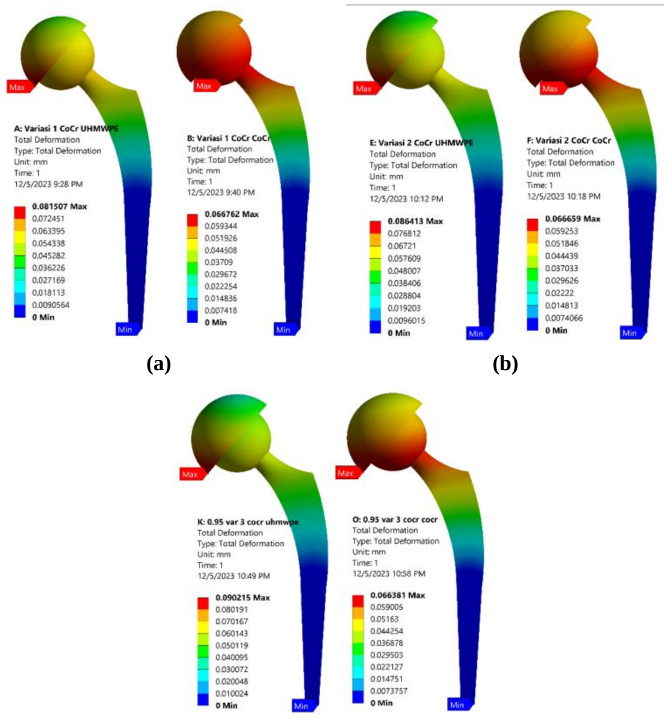

Figure 7: Total deformation contours of the hip implant: (a) 2 mm acetabular cup thickness; (b) 4 mm acetabular cup thickness; (c) 6 mm acetabular cup thickness

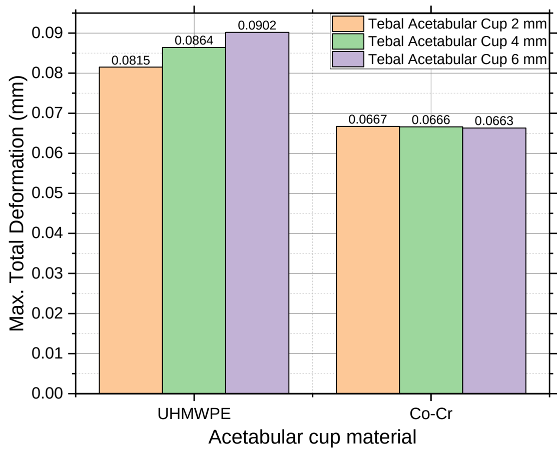

Figure 8: Comparison of total deformation values at different acetabular cup thicknesses and material compositions

The results of the von-Mises stress on the hip implant taperBody are presented consecutively in Figure 9. It can be observed that the von-Mises stress distribution contours on the taperBody are similar for both UHMWPE and Co-Cr acetabular materials. Meanwhile, a change in the von-Mises stress contour occurs only when the acetabular cup thickness is increased from 2 mm to 4 mm, marked by a slight shift in

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the location of the von-Mises stress contour. No change in the von-Mises stress contour is observed when the acetabular cup thickness is increased from 4 mm to 6 mm. This indicates that increasing the acetabular cup thickness does not have a significant effect on the distribution of von-Mises stress contours on the taperBody.

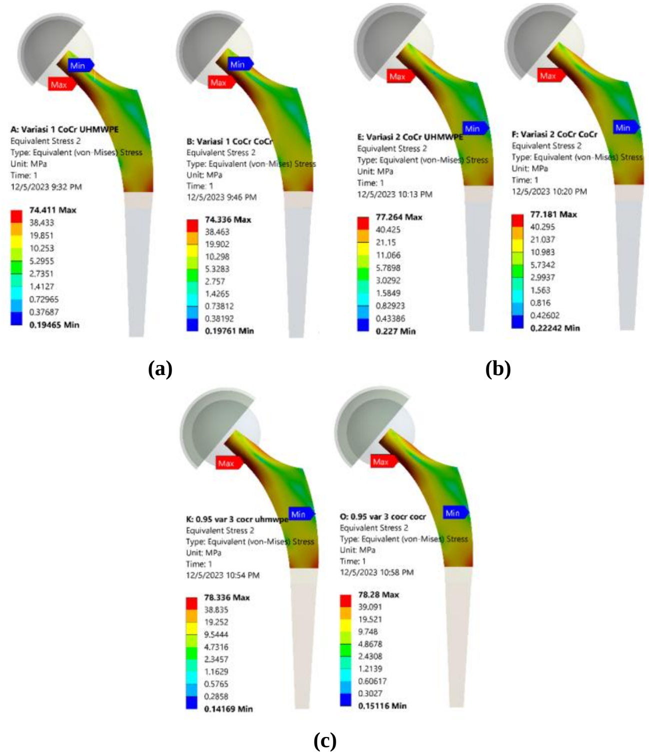

Figure 9: Von-Mises stress contours of taperBody: (a) 2 mm acetabular cup thickness; (b) 4 mm acetabular cup thickness; (c) 6 mm acetabular cup thickness

Increasing the acetabular cup thickness from 2 mm to 4 mm and 6 mm in the hip implant results in a rise in von-Mises stress values at the taperBody for both UHMWPE and Co-Cr acetabular materials, as shown in Figure 10. The maximum von-Mises stress on the taperBody is found at the inferior side of the neck for all acetabular cup thicknesses, regardless of material type. The average increase in von-Mises stress with an UHMWPE acetabular cup material is 2.65% (3.92% for the increase from 2 mm to 4 mm and 1.37% for the increase from 4 mm to 6 mm), whereas the increase for the Co-Cr acetabular cup material is 2.55% (3.69% from 2 mm to 4 mm and 1.40% from 4 mm to 6 mm). The highest von-Mises stress value is found in the hip implant taperBody with a 6 mm thick UHMWPE acetabular cup at 78.336 MPa, while the lowest value is found in the hip implant taperBody with a 2 mm thick Co-Cr acetabular cup at 74.336 MPa. These findings show that increasing the acetabular cup thickness affects von-Mises stress on the taperBody, but the stress remains well below the material yield strength, indicating a low risk of failure.

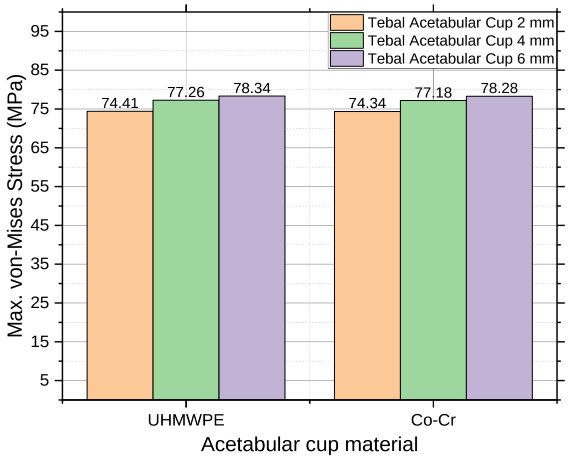

Figure 10: Comparison of taperBody stress values at different acetabular cup thicknesses and material compositions

The simulation results showing the von-Mises stress across the entire stem of the hip implant are presented in Figure 11. Increasing the acetabular cup thickness does not significantly affect the distribution of von-Mises stress contours, regardless of whether the material is UHMWPE or Co-Cr. The maximum von-Mises stress occurs in the stem, specifically around the stem section, for all acetabular cup thickness variations, both for UHMWPE and Co-Cr materials.

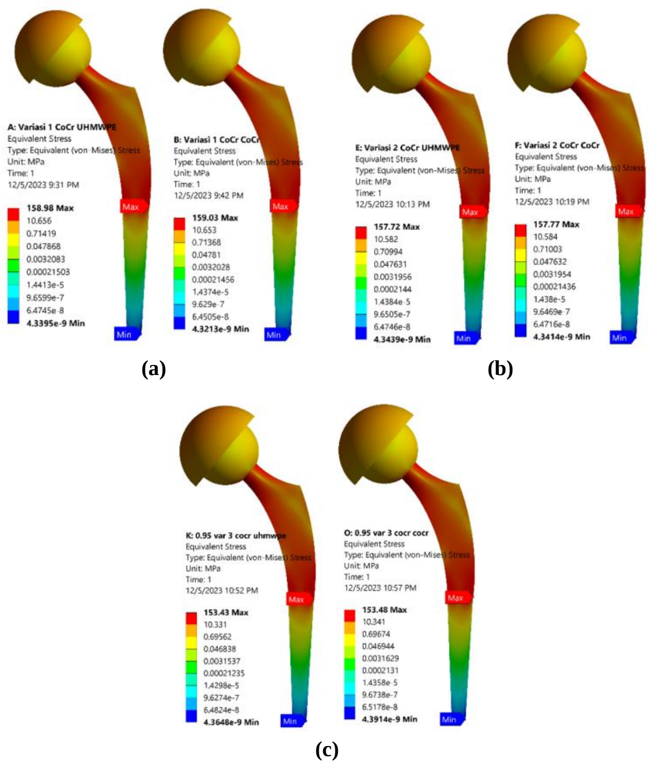

Figure 11: Von-Mises stress contours of taperBody: (a) 2 mm acetabular cup thickness; (b) 4 mm acetabular cup thickness; (c) 6 mm acetabular cup thickness

Increasing the acetabular cup thickness leads to a decrease in the maximum von-Mises stress across the entire

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hip implant, as shown in Figure 12. This effect is similar to the findings of previous studies on the impact of femoral head diameter size on hip implants with a Metal-on-Polymer (MoP) articulation, such as the study by Chethan *et al.* (2021) and Bhawe *et al.* (2022), where an increase in femoral head diameter led to a reduction in the maximum von-Mises stress of the implant. Based on the current study, it can also be concluded that this reduction in von-Mises stress occurs not only in MoP articulations but also in Metal-on-Metal (MoM) articulations. The highest von-Mises stress value was observed in the implant with a 2 mm thick Co-Cr acetabular cup, at 159.03 MPa, while the lowest von-Mises stress was found in the implant with a 6 mm thick UHMWPE acetabular cup, at 153.43 MPa. The average decrease in von-Mises stress for the implant with a UHMWPE acetabular cup was 2.03% (0.86% from 2 mm to 4 mm and 3.4% from 4 mm to 6 mm), while the decrease for the implant with a Co-Cr acetabular cup was 1.8% (0.8% from 2 mm to 4 mm and 2.8% from 4 mm to 6 mm).

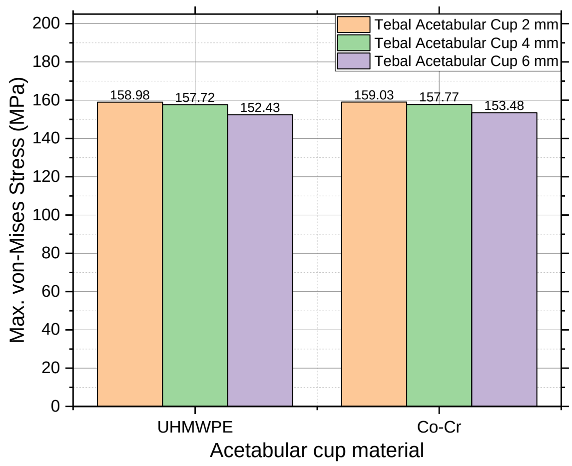

Figure 12: Comparison of acetabular cup thickness and total hip implant stress values for different material compositions

The performance parameters for each hip implant with varying acetabular cup thickness can be evaluated by comparing the von-Mises stress values with the yield strength of the material used. The maximum von-Mises stress occurs entirely in the stem, so the comparison is made between the von-Mises stress and the yield strength of the Co-Cr material used for the stem. The failure ratio for all hip implant models with acetabular cup thicknesses ranging from 2 mm to 6 mm is shown in Figure 13. It can be seen that all models yield failure ratios smaller than one (<1), meaning the von-Mises stress does not exceed the yield strength of the material, and the hip implant remains in a plastic state. This confirms that, in this study, all hip implant models with acetabular cup thicknesses of 2 mm, 4 mm, and 6 mm do not experience failure (*Cunha et al.*, 2024).

A hip implant will perform better with lower von-Mises stress values, leading to an increased lifespan of the implant (Chethan *et al.*, 2021). This is evident in the current study, where a decrease in von-Mises stress corresponds to a lower failure ratio. The hip implant with a 6 mm acetabular cup thickness shows the lowest failure ratio compared to the other models. Although the values are not significantly different from those of models with thinner acetabular cups, increasing the acetabular cup thickness still contributes to a longer implant lifespan. With lower stress values, this implant could be a good option to reduce or minimize the risks of stress shielding in bone, bone loss, and even aseptic loosening (Guo *et al.*, 2022). Furthermore, since this study is limited to using implant models and static boundary conditions, further simulations—such as adding bone or dynamic simulations—are necessary to understand the long-term effects more comprehensively. Additionally, the use of both soft and rigid materials showed similar effects when the acetabular cup thickness was increased. Although increasing the acetabular cup thickness led to some effects, such as increased deformation in the implant with a UHMWPE acetabular cup and a rise in taperBody von-Mises stress accros all implant models, these factors did not significantly impact the overall performance, as shown in this study.

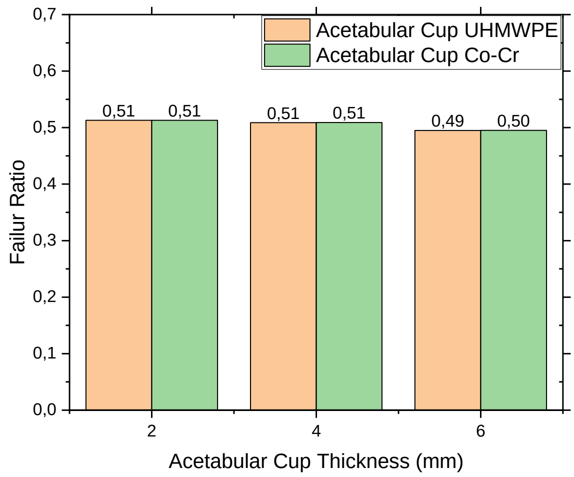

Figure 13: Failure ratio results for the entire hip implant structure

3.3 Limitations of the Study

This study aimed to analyze the effect of increasing acetabular cup thickness on hip implants. A complete analysis was performed under static loading conditions to evaluate how acetabular cup thickness affects the hip implant. However, static loading conditions alone do not fully capture the realistic loading scenarios that occur in the hip implant during daily activities. In this study, moments acting on the hip implant and forces on the joint were not considered, which limits the scope of the analysis. More realistic loading conditions should be

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included in future studies to provide a more comprehensive understanding.

Although this study provides valuable insights into the impact of acetabular cup thickness on the hip implant, only two design parameters were considered, and dimensional variations resulting from the increased acetabular cup thickness were neglected. Wear debris and aseptic loosening, which are leading causes of revision surgeries for total hip arthroplasty (THA) (Chethan *et al.*, 2022), were not factored into the analysis. Additionally, more complex hip implant models, such as those incorporating texture, bone, and ligaments, could further enhance the accuracy of future analyses.

IV. CONCLUSION

An analysis of the effect of acetabular cup thickness on hip implants was carried out. The two sets of material combinations considered in the analysis are Co-Cr and UHMWPE. It was found that increasing the thickness of the acetabular cup has led to a reduction in the von-Mises stress across the entire hip implant. This phenomenon is similar to the effect of increasing the femoral head diameter in implants. The increased thickness also resulted in a decrease in total deformation for implants with a Co-Cr acetabular cup and an increase in total deformation for implants with a UHMWPE acetabular cup. While there was an increase in stress on the taperBody in all models, the values remained well below the yield strength of the material.

Additionally, the increase in thickness did not significantly affect the distribution contours of the stress. Increasing the thickness of the acetabular cup in hip implants has the potential to enhance performance, as evidenced by the reduction in von-Mises stress and failure ratios as the acetabular cup thickness increased. This improvement has the potential to extend the lifespan of the hip implant. Implants with a higher acetabular cup thickness can be a solution to minimize the risk of stress shielding in bones, bone loss, and even aseptic loosening.

REFERENCES

[1] Aherwar, A., Singh, A.K. & Patnaik, A., 2016. Current and future biocompatibility aspects of biomaterials for hip prosthesis. *AIMS Bioengineering*, 3(1), pp. 23–43.

[2] Alkhatib, S.E., Mehboob, H. & Tarlochan, F., 2019. Finite element analysis of porous titanium alloy hip stem to evaluate the biomechanical performance during walking and stair climbing. *Journal of Bionic Engineering*, 16, pp. 1103–1115.

[3] ASTM International, 2013. ASTM F2996-13 Standard Practice for Finite Element Analysis (FEA) of Non-Modular Metallic Orthopaedic Hip Femoral Stems. *ASTM International: West Conshohocken, PA, USA*.

[4] Bandyopadhyay, A., Traxel, K.D., Avila, J.D., Mitra, I. & Bose, S., 2020. CoCr alloys. In: J.D. Bronzino & D.R. Peterson, eds., Biomaterials Science, *3rd ed. Amsterdam: Academic Press*, pp. 257–269.

[5] Bhawe, A.K., Shah, K.M., Somani, S., Shenoy, B.S., Bhat, N.S., Zuber, M. & Chethan, K.N., 2022. Static structural analysis of the effect of change in femoral head sizes used in total hip arthroplasty using finite element method. *Cogent Engineering*, 9, pp. 1–13.

[6] Chethan, K.N., Zuber, M., Bhat, N.S. & Shenoy, B.S., 2021. Finite element analysis of hip implant with varying taper neck lengths under static loading conditions. *Computer Methods and Programs in Biomedicine*, 208, pp. 1–7.

[7] Chethan, K.N., Zuber, M., Bhat, N.S. & Shenoy, B.S., 2022. Optimized trapezoidal-shaped hip implant for total hip arthroplasty using finite element analysis. *Cogent Engineering*, 7, pp. 1–14.

[8] Chethan, K.N., Zuber, M., Shenoy, B.S. & Kini, C.R., 2019. Static structural analysis of different stem designs used in total hip arthroplasty using finite element method. *Heliyon*, 5.

[9] Cunha, A., Yanik, Y., Olivieri, C. & da Silva, S., 2024. Tresca versus Von Mises: Which failure criterion is more conservative in a probabilistic context? *Journal of Applied Mechanics*, 91(11), pp. 111008.

[10] Erdemir, A., Guess, T.M., Halloran, J., Tadepalli, S.C. & Morrison, T.M., 2012. Considerations for reporting finite element analysis studies in biomechanics. *Journal of Biomechanics*, 45, pp. 625–633.

[11] Gotman, I., 2021. Biomechanical and tribological aspects of orthopaedic implants. In: G.P. Ostermeyer, V.L. Popov, E.V. Shilko & O.S. Vasiljeva, eds., Multiscale Biomechanics and Tribology of Inorganic and Organic Systems. *Cham: Springer Nature*, pp. 25–44.

[12] Guo, L., Naghavi, S.A., Wang, Z., Varma, S.N., Han, Z., Yao, Z., Wang, L., Liu, C., 2022. On the design evolution of hip implants: A review. *Materials & Design*, 216, pp. 1–18.

[13] Iyer, K.M., 2021. The hip joint, *2nd ed. Jenny Stanford Publishing Pte. Ltd.: New York*, USA.

[14] Jamari, J., Ammarullah, M.I., Santoso, G., Sugiharto, S., Supriyono, T., Prakoso, A.T., Basri, H. & van der Heide, E., 2023. Computational contact pressure prediction of CoCrMo, SS 316L and Ti6Al4V femoral head against UHMWPE acetabular cup under gait cycle. *Journal of Functional Biomaterials*, 13, pp. 64.

[15] Jamari, J., Saputra, E., Anwar, I.B., Ismail, R., van der Heide, E., 2017. Finite element study of the effect of

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Volume 9, Issue 10, pp 65-74, October-2025
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UHMWPE liner thickness on the contact area and stress distribution in a bipolar hip joint. *Materials Science and Engineering*, 202, pp. 1–8.

[16] Jamari, J., Ismail, R., Bayuseno, A.P., 2021. Finite element analysis of artificial hip joint implant made from stainless steel 316L. *Bali Medical Journal*, 10, pp. 448–452.

[17] Kiernan, S., Geijer, M., Sundberg, M. &Flivik, G., 2020. Effect of symmetrical restoration for the migration of uncemented total hip arthroplasty: A randomized RSA study with 75 patients and 5-year follow-up. *Journal of Orthopaedic Surgery and Research*, 15, pp. 225.

[18] Lee, C.K., Kwan, M.K., Merican, A.M., Ng, W.M., Saw, L.B., Teh, K.K., Krishnan, M., Ramiah, R., 2014. Femoral head diameter in the Malaysian population. *Singapore Medical Journal*, 55, pp. 436–438.

[19] Merola, M., Affatato, S., 2019. Materials for hip prostheses: A review of wear and loading considerations. *Materials*, 12, pp. 495.

[20] Ruggiero, A., D'Amato, R., Affatato, S., 2019. Comparison of meshing strategies in THR finite element modelling. *Mathematics*, 12, pp. 2332.

[21] Sabatini, A.L., Goswami, T., 2008. Hip implants VII: Finite element analysis and optimization of cross-sections. *Materials & Design*, 29, pp. 1438–1446.

[22] Soliman, M.M., Chowdhury, M.E., Islam, M.T., Musharavati, F., Nabil, M., Hafizh, M., Khandakar, A., Mahmud, S., Nezhad, E.Z., Shuzan, M.N.I., Abir, F.F., 2022. A review of biomaterials and associated performance metrics analysis in pre-clinical finite element model and in implementation stages for total hip implant system. *Polymers*, 14, pp. 4308.

[23] Tauviqirrahman, M., Ammarullah, M.I., Jamari, J., Saputra, E., Winarni, T.I., Kurniawan, F.D., Shiddiq, S.A., van der Heide, E., 2023. Analysis of contact pressure in a 3D model of dual-mobility hip joint prosthesis under a gait cycle. *Scientific Reports*, 13, pp. 3564.

[24] Taqriban, R.B., Ismail, R., Jamari, J., Bayuseno, A.P., 2021. Finite element analysis of artificial hip joint implant made from stainless steel 316L. *Bali Medical Journal*, 10, pp. 448–452.

[25] Varacallo, M., Luo, T.D. & Johanson, N.A., 2023. Total Hip Arthroplasty Techniques [online]. Available at: https://www.example.com/article [Accessed 24 June. 2024].

[26] Wibowo, B.S., Wijaya, P.N., Tauviqirrahman, M., Ismail, R., Muchammad, J., 2019. A 3-dimensional computational fluid-structure interaction analysis in the hip-joint prosthesis during solat (prayer) activity. *Jurnal Tribologi*, 20, pp. 125–141.

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