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Relationship Between Various Cement Mixture, Cement Fixation and Gait Study for Total Hip Replacement Via Finite Element Analysis (FEA)

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Abstract: To secure the total hip replacement (THR) components, introduced in the 1960s, polymethyl methacrylate (PMMA) bone cement was used as a fixation. The cement polymerizes and becomes firm to hold the implant in place. However, the failure of cement in total hip replacement may lead to hip fractures and dislocations which is detrimental to the patient's well-being whether in the short-term or long-term. Hence, the aim of this study is to find suitable cement mixtures for total hip replacement compromising of Young Modulus of 2.24 GPa, 0.3129 GPa, 0.03394 GPa and 0.07961 GPa, as reported from prior research. Three separate sorts of proximal cemented techniques were used to deposit the PMMA cement: 40 mm cement reduction, 80 mm cement reduction and full cement (datum). The Titanium Ti-6A1-4V (Ti-41) Charnley hip implant stem model with a Young Modulus of 100 GPa and a Poisson's ratio of 0.3 was applied in the ANSYS Workbench 2020 R2 software to be analyzed with the three different proximal cemented approaches for each cement mixtures. Subsequently, the total deformation and von Mises stress were simulated under various loading circumstances, including standing, walking, stair climbing and falling. Nevertheless, as shown in the results obtained, all the hip implants consider safe because their von Mises stress does not exceed the yield strength of Titanium Ti-6A1-4V, which is 0.88 GPa. Finally, it may be concluded that, in comparison to the full cement (datum) and 80 mm cement reduction with Young Modulus of 2.24 GPa, 0.3129 GPa, 0.03394 GPa and 0.07961 GPa, the most improvement in the context of total deformation and von Mises stress is the 40 mm cement reduction with Young Modulus of 2.24 GPa.

Keywords: bone cement, cemented total hip replacement, finite element analysis, total deformation, von Mises stress

1. Introduction

A hip replacement is a surgical procedure of replacing the diseased hip joint with an artificial part called a prosthesis to relieve the pain and improve mobility [1], [2]. The surgery involving hip replacement is one of the most effective joint operations. The improvement significantly increased total hip replacement (THR) effectiveness in joint replacement techniques in the early 1960s. There were above 450,000 total hip replacements performed each year in the United States,

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referring to the Agency for Healthcare Research and Quality [3]. Cristofolini L. stated that the treatment was successful and accepted, with over 800,000 artificial hip joints implanted worldwide annually [4].

There are two types of this replacement: cemented and uncemented total hip replacement, depending on the type of fixation used to hold the implant in place. Total hip replacement is where the damaged bone and cartilage are removed and replaced with prosthetic components. The damaged femoral head is replaced by a metal femoral head attached to the upper part of a metal stem that is placed into the hollow center of the femur bone. The damaged femoral head that was removed is placed in the acetabular cup. Inserted between the metal femoral head and the acetabular cup is a plastic liner or metal spacer to allow a smooth gliding surface [5].

The method used to decide the type of fixation depends on the patient's condition or age, as Zhang et al. collected evidence from five years of annual reports from five worldwide joint arthroplasty registries and randomized clinical trials and meta-analyses [6]. Finally, it concluded that cemented fixation outperformed cementless fixation in terms of long-term survival in primary THAs. Particularly, cementless fixation worked better for younger patients, while cemented fixation worked better for older patients [6]. Throughout the years, many studies have been conducted on cemented and cementless hip arthroplasty to observe the outcome for survivorship and quality of life [5], [6]. Polymethyl methacrylate (PMMA) bone cement was introduced in the 1960s. The purpose was for the total hip replacement component's fixation. The critical factor in the advent of joint replacement as a surgical option was using PMMA bone cement [7]. A cemented replacement aims to immobilize the implant, transfer body weight and service loads from the prosthesis to the bone, and increase the load-carrying capacity of the prosthesis-bone cement bone system.

Hence, the implant inserted inside the bone will carry a portion of the load to reduce stress in some areas of the remaining bone [8]. Stress shielding is the term used to describe this phenomenon, specifically as the bone density decrease occurs when an implant removes the normal stress from the bone. It causes adaptive changes in bone strength and stiffness in the presence of metallic implants, which can lead to implant loosening [9]. Implant loosening is a type of failure that occurs when the implant migrates or moves in the cement or bone. It contributes to 64% of the most frequent cause of revision surgery [10]. The most common cause of implant loosening is the loss of bone mass due to stress shielding [11]. It has caused the load to distribute insufficiently to the femur after the implant replacement. Hence, the stress shielded caused the bone to react by reducing its mass.

Elderly patients usually use this type of implant as cement can help overcome the less active bone growth around the stem. However, cemented implants have disadvantages, which will cause aseptic loosening after long years of usage [12]. The Charnley cemented hip implant model was chosen as the benchmark in this project. Consequently, this project modification on the stem has been conducted and will affect the performance of the implant. Finite element analysis (FEA) performed on the stem and the implant using the ANSYS 2020 R2 software will have resulted in total deformation and von Mises stress. In conclusion, this study aims to observe different cement mixtures with different Young Modulus to discover the strength of cement to prevent stress shielding from occurring and by learning fixation techniques to avoid implant loosening.

2. Literature Review

The literature review offers relevant information about the researcher's works and general facts, including the total hip replacement (THR), stem fixation technique and Polymethyl Methacrylate (PMMA).

2.1 Total Hip Replacement (THR)

Total hip replacement (THR) is a commonly used approach to restore the normal hip joint function disrupted by fractures or diseases [13]. Howell, J. R. (2018) stated that total hip replacement is of successful operation to relieve pain and restore function [14]. Patients with fractured hips will experience difficulties in daily activities such as walking, running, climbing, and many more. This hip fracture could cause total disability, pneumonia, pulmonary embolism and death.

Arthritis is the most prevalent reason for chronic hip pain and disability. The most common types of this disease are osteoarthritis, rheumatoid arthritis and traumatic arthritis. For osteoarthritis, it is commonly known as wear and tear arthritis, which is related to age. It usually occurs in individuals above 50 years of age and often in people with a history of arthritis in the family [15]. Osteoarthritis (OA) is the most common type of arthritis, affecting 9.6% of men and 18.0% of women older than 60 years worldwide [16]. Meanwhile, rheumatoid arthritis is a disease caused by an overactive immune system.

Lieberman et al. stated that hip replacement needs to be done to solve this problem [17]. During total hip replacement, the surgeon will remove the damaged femoral head, and a hole will be drilled in the center of the femur. The head then will be changed with a ball, and a long femoral stem where its size fits with the size of the canal will be inserted into it. A new acetabular cup is securely implanted within the prepared hemispherical socket, as shown in Fig. 1. The cement polymerizes and becomes strong, which fixes the implant [18].

According to the Agency for Healthcare Research and Quality, more than 450,000 total hip replacement operations were done in the United States [19]. Li et al. reported that the replacement operation for broken and damaged femurs was undergone by more than 800,000 patients worldwide, which could be an effective treatment. The surgical procedure will effectively cure patients who suffer from end-stage osteoarthritis of total hip replacement. The percentage of satisfaction among patients who received total hip replacement surgery was high, at 91%, while 77% were satisfied with their total knee arthroplasty (TKA) [20].

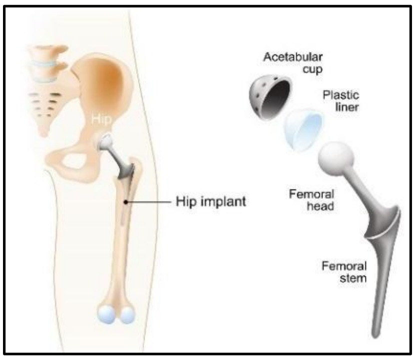


Fig. 1 - Graphic of a total hip replacement [21]

2.2 Stem Fixation Technique

Cement and cementless fixation are the two types of fixation methods in total hip replacement, as shown in Fig. 2. In cement fixation, the mechanism acts as grout by producing an interlocking fit between surfaces. The stem's surface is designed to have a more significant porosity in a cementless design to aid the growth process of the bones on its surface. Longer healing time is required due to the implant being bonded with the femur as the implant depends on the growth of new bone, which is vital for stability. However, polymethyl methacrylate (PMMA) or bone cement used for stem fixation, has been the gold standard for total hip replacement since the early 1960s [22]. Havelin et al. also supported that the fixation of total hip replacements with PMMA bone cement is currently regarded as the gold standard [23].

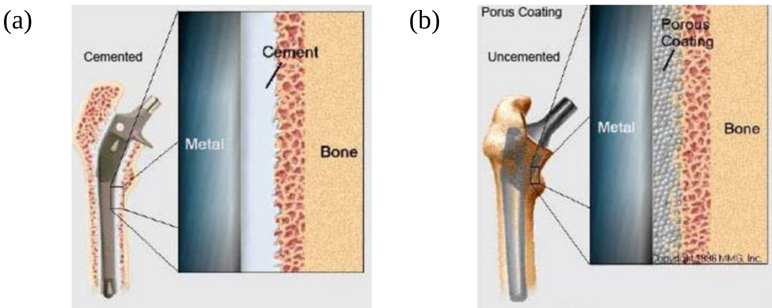


Fig. 2 - Designs of (a) cemented THR; (b) cementless THR [24]

Although bone cement was formerly the gold standard in joint replacement surgery, its usage has dropped due to the introduction of press-fit implants that promote bone development. There is an ongoing discussion on whether cemented or cementless implants in total hip replacement can be used in specific patients based on chronological age. However, converting a surgeon's skill set from cementless implants to installing cemented implants is challenging and may be technically more demanding in specific ways. Some argue that these methods should be introduced to all surgeons. However, it is believed that future surgeons who are successful with cementless implants will learn to adapt to the skillset required for cementing. However, there is no evidence that surgeons with poor outcomes with cementless implants would necessarily have improved outcomes in a subset of patients if they switched to cemented implants.

Moreover, Zhang et al. reviewed that cemented fixation had a more significant long-term survival rate than cementless fixation in primary total hip replacement [6]. Remarkably, older patients recovered better in cemented fixation, whereas younger patients recovered better in cementless fixation. Nevertheless, this method was obtained from big datasets that exclude physiological age and activity profiles and only include chronological age for analysis.

2.3 Polymethyl Methacrylate (PMMA)

Polymethyl methacrylate (PMMA) is one of the most common materials used as bone cement and is frequently used for implant fixation in orthopedic and trauma surgery. The term "cement" is misinterpreted because it refers to a material that joins two objects together. On the other hand, PMMA functions as a space-filler, creating a tight gap that retains the implant against the bone. Bone cement does not have inherent adhesive capabilities, instead relies on a close mechanical interlock between the uneven bone surface and the implant. It works when mixed with two sterile components, a liquid

MMA monomer and a powdered copolymer of MMA-styrene. The liquid monomer polymerizes to produce solid PMMA around the pre-polymerized powder particles. Solid PMMA could be polymerized at ambient temperature because of the structure of the methyl methacrylate monomer. This process is reacted by the polymer's inclination to dissolve in the monomer.

The work of Charnley in 1970, however, was a massive breakthrough in the use of PMMA in total hip replacement since he applied it to ensure the fixation of the acetabular and femoral components and to transmit loads to the bone [25]. Hence, cemented implants can transfer sustained loads over a wider area than uncemented implants. The long-term reliability of cemented hip arthroplasty has two interfaces that provide mechanical stability: the implant-cement junction and the bone-cement interface. Despite the usage and availability of wide varieties of bone cement that have significantly developed over the last century, more research is still being conducted to create new treatment applications and lessen the harmful consequences associated with cement usage.

3. Methodology

In this project, the first step is conducted by selecting the hip implant design. Then, the chosen hip implant will be Charnley hip implant design which will assemble into the femur bone. The space between the implant and femur filled with cement will be constructed in 3D modelling to simulate the total hip replacement (THR) design. Several bone cement models were used to represent different types of proximal bone cement fixation, like proximal cementation, with 40 mm and 80 mm reductions in each gait loading. Moreover, there is also fully proximal cementation in this study. Afterwards, all design models will undergo finite element analysis (FEA) to analyze whether the designs have reduced or increased total deformation and von Mises stress with each gait loading using ANSYS 2020 R2 software.

3.1 Design Domain

The total hip replacement model consists of three main components: the implant, cement and bone. The material properties of the three main components in the cemented prosthesis are shown in Table 1. The Titanium Ti-6A1-4V (Ti-41) was selected and applied for the implant material. The PMMA was used to bond the stem to the femur bone, consisting of cancellous bone and a cortical shell. Moreover, these material properties are isotropic and homogeneous [26]. The values of these material properties were then added to the engineering data in ANSYS 2020 R2 software and applied to the model geometry before the static structural analysis was conducted. Fig. 3 and Table 2 show the labelling of the hip implant parts and their dimensions.

Table 1 - Material properties of stem, cement and bone [26], [27]

Material	Young Modulus	Poisson's Ratio	Yield Strength	Tensile Strength	Compressive Strength	Shear Strength
	GPa		GPa	GPa	GPa	GPa
Titanium Ti-6Al-4V (Ti-41)	100	0.30	0.880	0.830	0.830	0.830
PMMA (Cement)	2.24	0.40	0.029	0.031	0.144	0.041
Femur bone	16.2	0.36	0.115	0.167	0.121	0.084

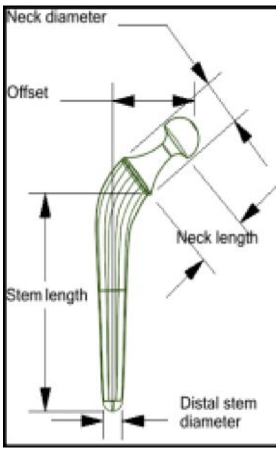


Fig. 3 - Hip implant parts labelling

Table 2 - Dimension of the Charnley hip implant [12]

Offset	Neck length	Neck diameter	Stem length	Distal stem diameter
mm	**mm**	**mm**	**mm**	**mm**
47.77	28.80	25.00	114.53	11.18

3.2 Design Analysis

Design analysis was applied using the static structural module in ANSYS 2020 R2 software. This method simulated the load applied to the implant. In addition, the three different types of proximal bone cement fixation introduced in this study were from a previous study [26] shown in Fig. 4.

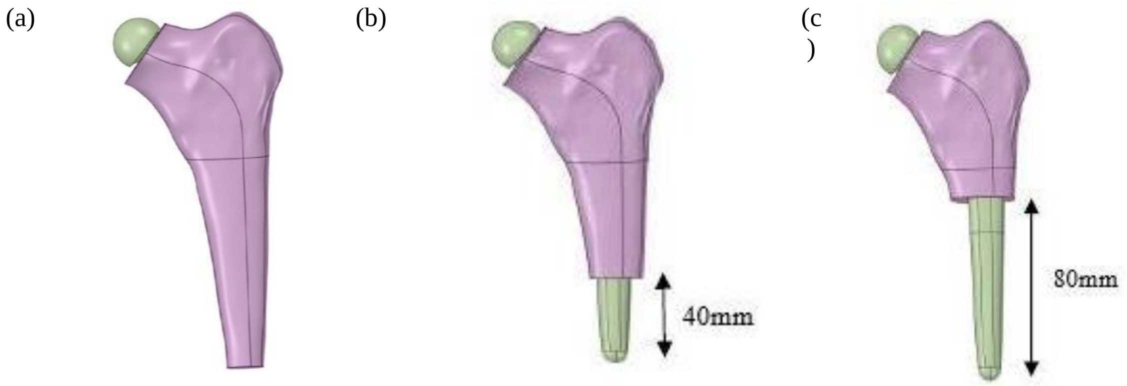


Fig. 4 - The types of proximal cementation used in this study (a) fully cemented; (b) 40 mm cut off; (c) 80 mm cut off [26]

Meshing was applied to calculate the summation numbers of nodes and elements before solving total deformation and von Mises stress. The fine element size took longer to compute a large number of nodes and elements. Hence, the default element size was sufficient to generate the mesh for analysis purposes. So, the number of nodes and elements obtained for this study was 14662 and 7357, respectively. Further meshing was conducted by referring to the published paper [26], which focused on the same femur bone and different materials for a hip implant. Initial values obtained from the finite element analysis for fully cemented were set as the datum for each gait condition and results for comparison.

3.3 Boundary Condition

There are four different types of loading conditions applied to the modified stem. To analyze the performance of the stem under different loading conditions: standing, walking, stair climbing and falling. Two resultant forces were applied to the model. A force was exerted at the stem's femoral head, and another was at the greater trochanter of bone shown in Fig. 5(a). The distal end of the bone was fixed rigidly in X, Y and Z directions, which are $U_X = 0$, $U_Y = 0$ and $U_Z = 0$, as shown in Fig. 5(b). In the analysis, the distal end of the bone was fixed for all conditions. The value of forces exerted on the femoral head, greater trochanter and the loading state for all the conditions are shown in Table 3.

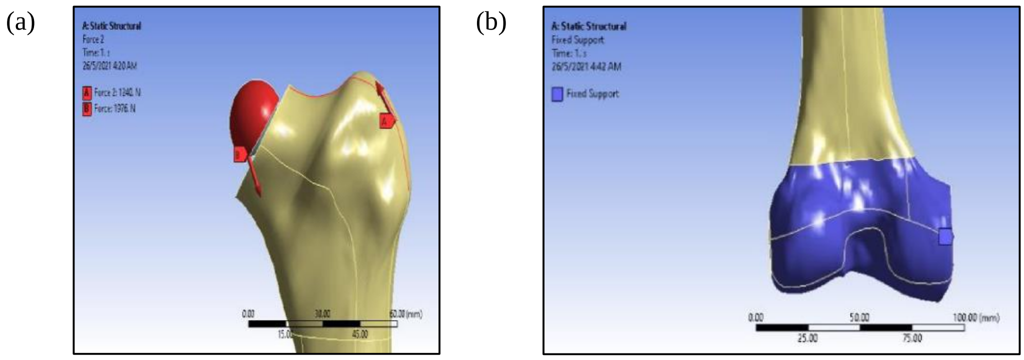
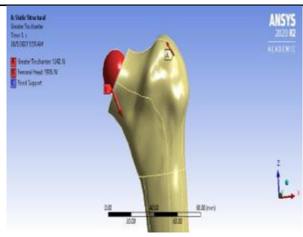
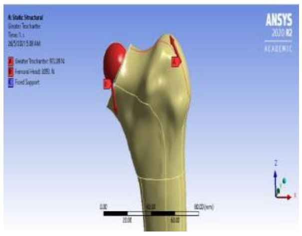
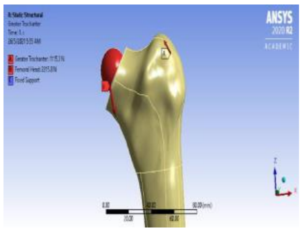
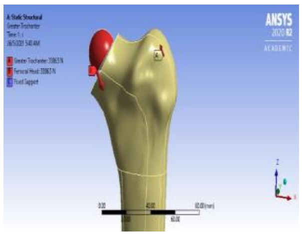


Fig. 5 - The location of (a) the force exerted; (b) fixed support on the distal end of the bone

Table 3 - Force exerted on the model [27] and loading condition for each gait conditions

Type of loading	Femoral head (N)		Greater trochanter (N)		Loading of force
	Resultant	Component	Resultant	Component	
Standing	1976.00	F_x 0.00 F_y 927.68 F_z -1744.70	1240.00	F_x 0.00 F_y -797.06 F_z 949.89	
Walking	2093.00	F_x 382.30 F_y 339.47 F_z -2029.58	972.90	F_x 65.66 F_y -551.62 F_z 798.70	
Stair climbing	2215.80	F_x 639.55 F_y 378.97 F_z -2087.40	1115.30	F_x 282.24 F_y -686.98 F_z 832.02	
Falling	3386.50	F_x 1690.00 F_y -2700.00 F_z 1150.00	3386.50	F_x -1690.00 F_y 2700.00 F_z -2029.58	

4. Result and Discussion

The tabulated results are in two parts for each gait condition, where the first part is total deformation to observe how much deformation occurs on the stem. Next, the second part is von Mises stress, where the maximum value is detected. The results from this study are for benchmarking with the original design of this hip implant fixed as the datum that undergoes a series of gait conditions with specified loads exerted on the model.

4.1 Total Deformation

Referring to Table 4 for cement with a Young Modulus of 2.24 GPa, the implant with 80 mm cement reduction has the highest deformation percentage for all gait conditions except for falling compared with the full cement hip implant design. Therefore, the higher the cement reduction, the higher the value of total deformation obtained. It happened in standing gait conditions where the highest percentage is 11.78% for 80 mm cement reduction. While the lowest is 5.14% as simulated for 40 mm cement reduction compared with the full cement implant.

As for walking and stair climbing, both cases have an identical value for the highest percentage value occurring for the 80 mm cement reduction with a 9.55% increase. While for 40 mm cement reduction, there was only a slight difference in value for the walking and stair climbing which were 5.74% and 5.70%, respectively. For the falling gait condition, both 40 mm and 80 mm cement reduction show improvement in total deformation. In 80 mm cement reduction, the value of total deformation has improved by 3.62%, which is lesser deformation than the full cement (datum). While in 40 mm cement reduction, it has lesser deformation than full cement (datum), and in 80 mm cement reduction, the value of total deformation has improved by 8.15%.

Referring to Table 5, cement with a Young Modulus of 0.3129 GPa has a similar pattern with a Young Modulus of 2.24 GPa, where implant with 80 mm cement reduction has the highest deformation percentage for all gait conditions except for falling compared with the full cement hip implant design. The highest percentage of total deformation increase can be seen at the standing gait condition with 14.13% while 2.91% as simulated for 40 mm cement reduction design compared with the full cement (datum).

As for walking, there were a slight increase for 40 mm and 80 mm cement reduction, where the percentage was 2.12% and 5.08%, respectively. Like walking conditions, stair climbing with a slight increase for total deformation for 40 mm and 80 mm cement reduction where the percentage is 1.97% and 3.76%, respectively. For the falling gait condition, both 40 mm and 80 mm cement reduction show improvement in total deformation. In 40 mm cement reduction, the value of total deformation has improved with the highest percentage of 9.09%, which is lesser deformation than the full cement (datum). While in 80 mm cement reduction, the value of total deformation has improved by 5.25%.

Next, Table 6 and Table 7 show the result of total deformation for cement with Young Modulus of 0.03394 GPa and 0.07961 GPa, respectively. For standing gait conditions, there was an improvement of total deformation in 40 mm cement reduction for both types of cement with Young Modulus of 0.03394 GPa and 0.07961 GPa with 3.10% and 3.40% compared to the full cement (datum). Meanwhile, in 80 mm cement reduction, there were a slight increase in total deformation for both types of cement with Young Modulus of 0.03394 GPa and 0.07961 GPa with 6.02% and 6.04%, respectively.

For walking and stair climbing gait conditions, both types of cement with Young Modulus of 0.03394 GPa and 0.07961 GPa show that the total deformation has a slight increase compared to the full cement (datum) for both 40 mm and 80 mm cement reduction. For falling conditions, 40 mm and 80 mm cement reduction show improvement in total deformation for cement with a Young Modulus of 0.03394 GPa. In 80 mm cement reduction, the value of total deformation has improved by 6.17%, which is lesser deformation than the full cement (datum). In comparison, 40 mm cement reduction improves the highest compared to full cement (datum) and 80 mm cement reduction with the value of total deformation by 8.04%. Meanwhile, for cement with a Young Modulus of 0.07961 GPa, the total deformation improved by 8.14% in 40 mm cement reduction but increased by 4.36% in 80 mm cement reduction from the full cement (datum).

For more observation and comparison, Fig. 6 shows the graph of total deformation for cement with 2.24 GPa, 0.3129 GPa, 0.03394 GPa and 0.07961 GPa, respectively.

Table 4 - Results of total deformation for 2.24 GPa

Gait conditions	Full cement (datum)	40 mm cement reduction		80 mm cement reduction	
	mm	mm	%	mm	%
Standing	3.31	3.48	-5.14	3.70	-11.78
Walking	15.50	16.39	-5.74	16.98	-9.55
Stair climbing	25.44	26.89	-5.70	27.87	-9.55
Falling	5.52	5.07	8.15	5.32	3.62

Table 5 - Results of total deformation for 0.3129 GPa

Gait conditions	Full cement (datum)	40 mm cement reduction		80 mm cement reduction	
	mm	mm	%	mm	%
Standing	4.46	4.59	-2.91	5.09	-14.13
Walking	21.26	21.71	-2.12	22.34	-5.08
Stair climbing	35.11	35.80	-1.97	36.43	-3.76
Falling	7.81	7.10	9.09	7.40	5.25

Table 6 - Results of total deformation for 0.03394 GPa

Gait conditions	Full cement (datum)	40 mm cement reduction		80 mm cement reduction	
	mm	mm	%	mm	%
Standing	5.48	5.31	3.10	5.81	-6.02
Walking	24.58	24.72	-0.57	25.20	-2.52
Stair climbing	40.27	40.71	-1.09	41.06	-1.96
Falling	9.08	8.35	8.04	8.52	6.17

Table 7 - Results of total deformation for 0.07961 GPa

Gait conditions	Full cement (datum)	40 mm cement reduction		80 mm cement reduction	
	mm	mm	%	mm	%
Standing	5.30	5.12	3.40	5.62	-6.04
Walking	23.60	23.95	-1.48	24.46	-3.64
Stair climbing	39.18	39.50	-0.82	40.11	-2.37
Falling	8.72	8.01	8.14	9.10	-4.36

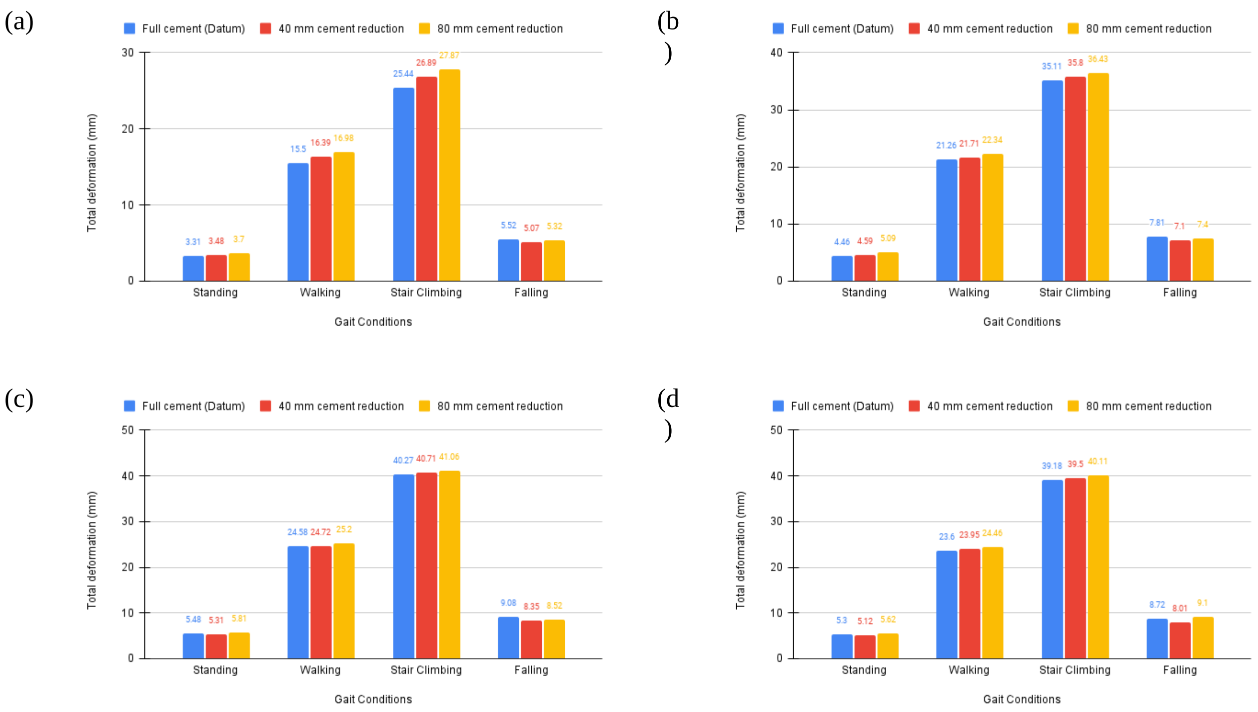


Fig. 6 - Graphs of total deformation for cements with Young Modulus of (a) 2.24 GPa; (b) 0.3129 GPa; (c) 0.03394 GPa; (d) 0.07961 GPa

4.2 Von Mises Stress

From von Mises stress analysis, the three design models consist of full cement (datum), 40 mm cement reduction and 80 mm cement reduction in four different loading conditions, showing the neck region has the highest stress in all the conditions.

Referring Table 8 show the von Mises stress for cement with Young Modulus of 2.24 GPa results. 40 mm cement reduction shows the most improvement in von Mises stress, which is lesser than the full cement (datum) due to the highest percentage of improvement compared to the other cement with Young Modulus of 0.3129 GPa, 0.03394 GPa and 0.07961 GPa. The highest percentage is in stair climbing gait condition with 43.50%, followed by walking with 42.38%, falling with 36.74%, and the least is standing with 7.56% of improvement. Meanwhile, for 80 mm cement reduction, the highest increase in von Mises stress was 28.44% in standing gait conditions, followed by 1.90% and 1.18% for stair climbing and falling, respectively. However, there was an improvement in walking by 4.08%, which is lesser von Mises stress than the full cement (datum).

Next, for cement with a Young Modulus of 0.3129 GPa in Table 9, at 40 mm, cement reduction only at the stair climbing gait condition reduced the stress by 1.81% from the datum. In contrast, the other gait condition showed stress increases from the datum. No improvement in stress is shown at 80 mm cement reduction as all the gait conditions produce higher stress than the datum. The highest stress increase was 12.33% in walking gait, followed by standing with 10.02%, stair climbing at 4.35% and the least 0.51% in falling gait.

Next, Tables 10 and 11 show the result of von Mises stress for cement with Young Modulus of 0.03394 GPa and 0.07961 GPa, respectively. Both show improvement for all gait conditions at 80 mm cement reduction except for falling, as both slightly increased from the datum. The highest percentage of improvement was 4.72% in standing condition for cement with a Young Modulus of 0.03394 GPa. The lowest improvement was 0.44% in walking conditions for cement with a Young Modulus of 0.07961 GPa. For 40 mm cement reduction, there was no improvement for both types of cement with Young Modulus of 0.03394 GPa and 0.07961 GPa as the von Mises stress value was higher than the datum. The highest increase in stress was 6.12% at stair climbing conditions for cement with a Young Modulus of 0.07961 GPa, while the lowest increase in stress was 1.78% at standing conditions for cement with a Young Modulus of 0.03394 GPa.

For more observation and comparison, Fig. 7 shows the graph of von Mises stress for cement with Young Modulus of 2.24 GPa, 0.3129 GPa, 0.03394 GPa and 0.07961 GPa, respectively.

Table 8 - Results of von Mises stress for 2.24 GPa

Gait conditions	Full cement (datum)	40 mm cement reduction		80 mm cement reduction	
	MPa	MPa	%	MPa	%
Standing	81.40	75.25	7.56	104.55	-28.44
Walking	323.23	186.25	42.38	310.05	4.08
Stair climbing	493.38	278.77	43.50	502.74	-1.90
Falling	221.02	139.82	36.74	223.62	-1.18

Table 9 - Results of von Mises stress for 0.3129 GPa

Gait conditions	Full cement (datum)	40 mm cement reduction		80 mm cement reduction	
	MPa	MPa	%	MPa	%
Standing	143.33	157.82	-10.11	157.69	-10.02
Walking	189.57	213.47	-12.51	212.95	-12.33
Stair climbing	219.91	215.93	1.81	229.47	-4.35
Falling	271.62	274.54	-1.08	273.00	-0.51

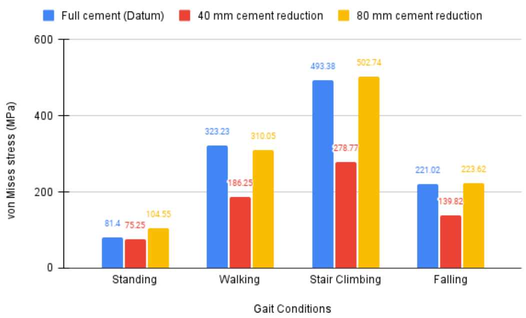
Table 10 - Results of von Mises stress for 0.03394 GPa

Gait conditions	Full cement (datum)	40 mm cement reduction		80 mm cement reduction	
	MPa	MPa	%	MPa	%
Standing	202.62	206.23	-1.78	193.06	4.72
Walking	293.68	301.70	-2.73	280.33	4.55
Stair climbing	291.14	299.58	-2.90	278.60	4.31
Falling	393.02	409.74	-4.25	400.69	-1.95

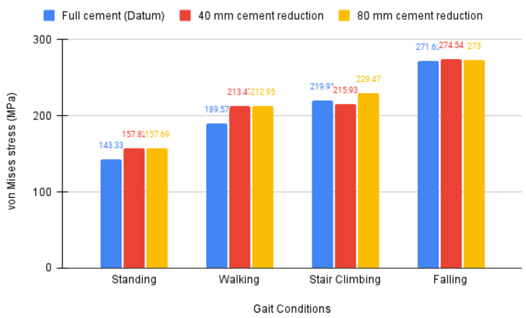
Table 11 - Results of von Mises stress for 0.07961 GPa

Gait conditions	Full cement (datum)	40 mm cement reduction		80 mm cement reduction	
	MPa	MPa	%	MPa	%
Standing	186.58	194.59	-4.29	183.93	1.42
Walking	263.02	278.72	-5.97	261.87	0.44
Stair climbing	262.23	278.27	-6.12	260.21	0.77
Falling	351.92	366.29	-4.08	361.74	-2.79

(a)



(b)



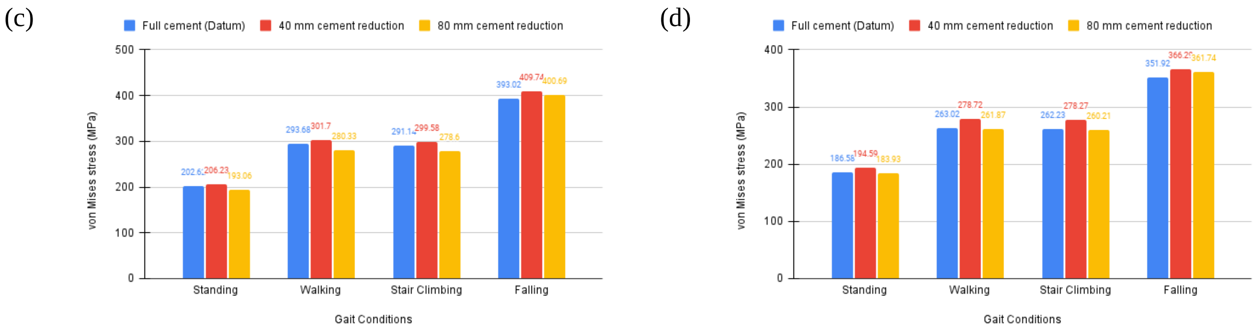


Fig. 7 - Graphs of von Mises stress for cements with Young Modulus of (a) 2.24 GPa; (b) 0.3129 GPa; (c) 0.03394 GPa; (d) 0.07961 GPa

5. Conclusion

Finite element analysis (FEA) was conducted to find the von Mises stress and total deformation of different cement mixtures consisting of Young Modulus of 2.24 GPa, 0.3129 GPa, 0.03394 GPa and 0.07961 GPa. At the end of the study, the von Mises stress and total deformation of different cemented total hip replacements with several gait conditions have been analyzed successfully using FEA. The results showed that all the hip implants consider safe because their von Mises stress does not exceed the yield strength of Titanium Ti-6A1-4V, which is 0.88 GPa. Yield strength is the stress at which a material begins to deform plastically, while the yield point is when non-linear deformation begins. Hence, no models are permanently deformed. The hip implant design with bone cement of Young Modulus of 2.24 GPa with 40 mm cement reduction is chosen as the most improved von Mises stress compared with the full cement (datum) after being simulated under several loading types with the total deformation showed a slight increase. The slight increase in total deformation can still be considered acceptable because of the slight increase from the datum. Besides, the highest stress experienced in stair climbing is 278.77 MPa, while the lowest stress experienced in standing is 75.25 MPa which is still lower than the yield strength of Titanium Ti-6A1-4V 0.88 GPa. To conclude the findings, the hip implant design using the bone cement of Young Modulus of 2.24 GPa with 40 mm cement reduction can be considered safe in terms of mechanical strength.

A few recommendations can be considered to improve for future study. One of it is recommended to use a fine mesh size instead of coarse mesh to increase the number of nodes and elements for higher accuracy during meshing. It might depend on the computer's performance for better meshing. Next, it is also recommended to include the loads exerted on the femur, which might produce more precise simulation results. It is also recommended to perform dynamic analysis in further research.

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