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Effects of Varus and Valgus Implant Malposition in Resurfacing Hip Arthroplasty

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Abstract: *Resurfacing Hip Arthroplasty is a widely known method despite having complications that lead to implant failure. This study aims to determine the displacement values from several implant malposition hence to identify the maximum principal stress of the femur bone by using finite element analysis. A 3D bone model was generated by using Computed Tomography (CT) image of an osteoarthritis patient. Mechanical Finder v10 software was employed in this study. The bone model generated as an inhomogeneous bone model. A separate RHA implant model with Cobalt Chromium (CoCr) alloy was inserted towards the bone. The implant was placed to the selected angles of varus and valgus position. The patient's body weight is 87.6 kg while the loading and boundary condition simulated the normal walking condition. The highest displacement value was recorded when the implant was placed at the varus position and lowest value on the valgus position.*

Keywords: Resurfacing Hip Arthroplasty: Femoral Bone; Implant Malposition; Maximum Principal Stress; Displacement.

1. INTRODUCTION

Resurfacing Hip Arthroplasty (RHA) is known as the hip replacement method that has high similarities with the condition of the normal person on its outcomes especially on the walking movement. Resurfacing Hip is a hip replacement method that can solve the end-stage of osteoarthritis disease. This method has its priority towards the young and active patient and highly recommended to the patient with age below 50 years old with a good quality of bone [1,2]. Although this method has a good outcome in terms of movement similarities, however, there is a high potential of implant malposition to occur. One of the factors of occurrence on implant malposition in RHA is the limitation during the surgery. The limitation on the difficulty to visualize the acetabular caused by the femoral resection has been giving the technical challenge to the surgeon thus increasing the potential risk of implant malposition [3].

Implant malposition has given an awful impact towards the femur bone and as consequences from that, it affects the patient lifestyles. The bad consequence of implant malposition has been proven by a national review of 50 cases regarding the femoral neck fracture happened to the first 3429 Birmingham Hip Resurfacing. Over the four years period, 50 fractures of the neck of the femur were found and over 45 cases with complete data, 22 occurred in women and 23 in men [4]. Most of the patients with femoral neck fracture can be concluded by the specific errors of operative technique or in other words error in surgical with referring to the implant malposition [5].

The existence of implant malposition might contribute to the incompatibility of stresses and displacement which can be determined through the findings by using finite element analysis. Thus, this study aims to determine the total displacement and maximum principal stress values exerted on the femur bone as the results from the presence of the implant malposition.

2. MATERIALS AND METHODS

As the requirement recommended by the clinical studies for patients suitability to perform Resurfacing Hip Arthroplasty (RHA) [6], a CT image of a patient with age 47 years old has been chosen. The patient bodyweight recorded was 87.6 kg. The patient was having an osteoarthritis disease which was acting on his left femur. Therefore, from the CT Image, a 3D bone model has been developed by using a biomedical software, Mechanical Finder v10.

The CT image was extracted into the biomedical software, Mechanical Finder v10 and the 3D bone model was developed by using its features. Previously, researchers who conducted studies in finite element analysis that related to hip arthroplasties assumed a homogeneous bone model which stated as one of the limitations in their study [7,8,9]. Hence, in this study, the limitation was solved since the inhomogeneous bone model has been developed according to the study made by Keyak et al. [10,11] by assuming a linear relationship between the element 'apparent density' and gray data values which in Hounsfield units (HU). Tetrahedron elements were applied towards the bone model and the implant inserted into the bone was assumed perfectly bonded.

2.1 Prosthesis of the Resurfacing Hip

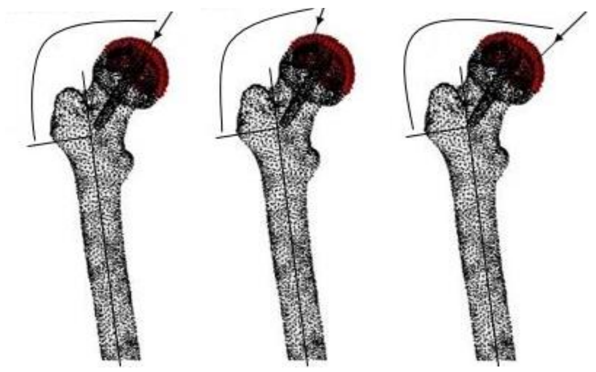
The RHA implant was imported based on previous study by Abdullah et al [12] and assigned as Cobalt Chromium Alloy (CoCr) material. The mechanical properties of the implant are shown in Table 1.

2.2 Implant Malposition

In this study, the implant malposition was categorized into two positions namely, varus position where the implant pin angle is positioned more than 130° and valgus position for the case of implant pin that less than 130° as in Fig.1. Angle 130° was referred to the normal angle which measured from the femoral neck and shaft.

Properties	Unit	Value
Elastic Modulus	GPa	230
Critical Stress	GPa	0.94
Yield Strength	GPa	2.70
Density	(g/cm^3)	8.28
Poisson Ratio	-	0.30

Table 1. Mechanical properties of Cobalt Chromium



(a) (b) (c)

Fig. 1. Implant Malposition of varus and valgus (a) straight implant with 130º(b) valgus zone with <130º (c) varus zone with >130º.

To analyze the displacement and stress on the bone as consequences from implant malposition, there were few angles of varus and valgus have been selected upon this study. The selected orientation of the implant malpositions are as shown in Table 2.

Implant Malposition	Angle
Valgus position (<130°)	122°
	120°
	118°
Varus position (>130°)	138°
	140°
	142°

Table 2: Orientation of implant malposition

2.3 Loading and boundary conditions

The aim of this study is to identify the effects of implant malposition of RHA to the displacement and stress concentration towards the bone, where loading and boundary condition selected in the simulation was based on the physiological loading of a human. Physiological loading of a normal walking condition was selected in this study. The normal walking condition also tends to give a contact force at human joint about 238% of the human body weight [13]. During the normal walking condition, the compressive force will exert on the hip joint and the tensile force will occur at the greater trochanter. As suggested in the study made by Heller et al. [9], the tensile force acted on the greater trochanter during normal walking is around 104% of the human body weight. Thus, these parameters were selected to be performed in this simulation study while the force directions (Fig.2) conducted were as the same as the previous published works [9,14,15].

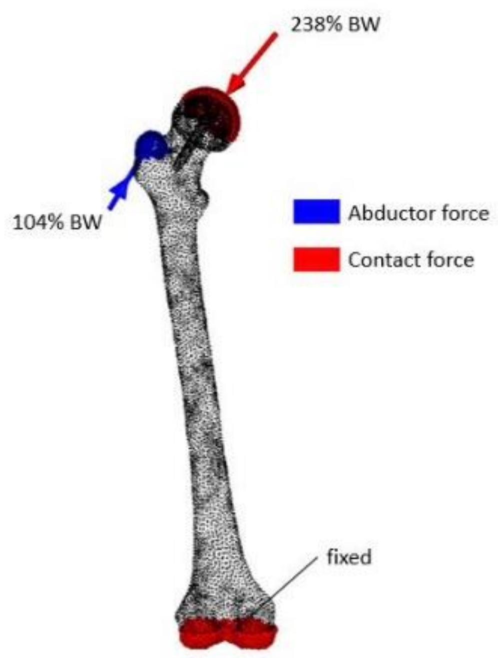


Fig. 2. Loading & Boundary Conditions

3. RESULTS AND DISCUSSION

The findings of the analysis is discussed based on the resulting total displacement and maximum principal stress.

3.1 Total displacement in femoral bone

The highest displacement value was obtained on the angle of varus 140° position where the bone elements displace about 0.11194 mm, while the lowest displacement value in varus group is on the varus 138° position with only 0.06338 mm. The displacement pattern increased significantly after the implant being titled by 2° from 138° to 140° and decreased as the implant moves towards 142°.

In the valgus group, there is a significant difference on the displacement result. The bone elements displaced much lower than the varus group which the highest displacement is around 0.02626 mm acting on the valgus 120° position. The displacement pattern on the valgus group is similar to the varus group where the displacement increased after the addition of 2° and then decreased when the implant moves to another 2°. The lowest displacement among all implant malposition is on the valgus 122° which around 0.01633 mm.

It is suggested that the RHA implant affected the displacement result since the only variable parameter in this study is on the implant angles. However, the displacement values did not increase consistently, hence, it can be assumed that the pin positioning of the RHA implant might contribute to the displacement results based on the applied force direction. Fig. 3 and Fig. 4 show the lowest and highest displacement for valgus and varus malposition groups, respectively.

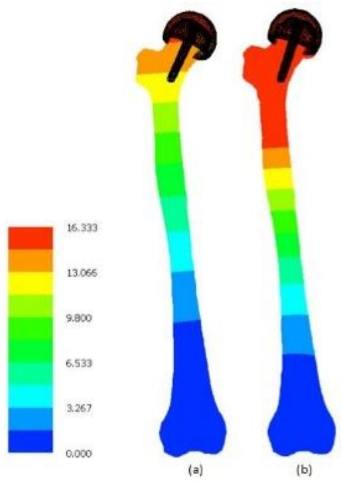


Fig. 3. Comparison contour of the lowest and highest bone displacement value for valgus malposition group (a) valgus 122° (b) valgus 120°

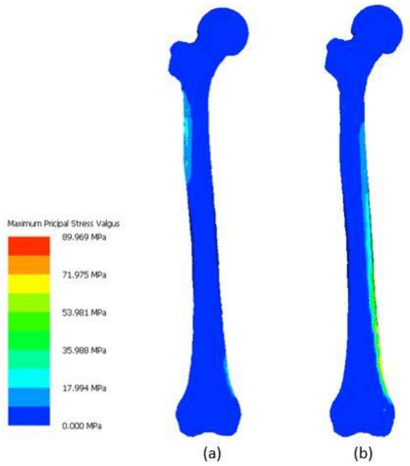


Fig. 5. Comparison contour of the lowest and highest maximum principal stress on valgus malposition group (a) valgus 122° (b) valgus 120°

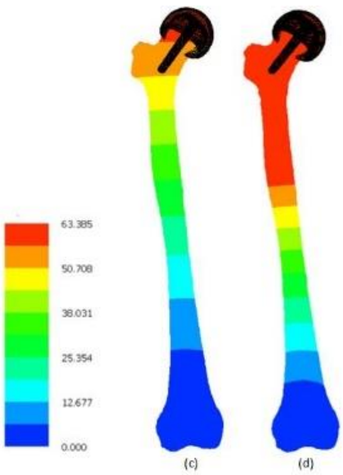


Fig. 4. Comparison contour of the lowest and highest bone displacement value for varus malposition group (c) varus 138° and (d) varus 140°

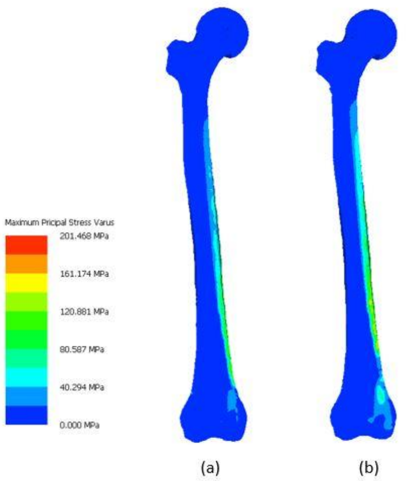


Fig. 6. Comparison contour of the lowest and highest maximum principal stress on varus malposition group (a) varus 138° (b) varus 140°

3.2 Maximum principal stress analysis on the femur bone model

The pattern of maximum principal stress observed in this study was similar to that predicted in the total displacement. The highest maximum stress value among the six implants position occurred at the varus 140° position with 264.622 MPa while the lowest maximum principal stress occurred at valgus 122° position with only 89.968 MPa. The highest and lowest values of maximum principal stress were also acting at the same implant malposition as in the displacement results. Overall, there is a huge difference on the mean value of maximum principal stress on varus position group compared to the valgus position group.

The maximum principal stress result shown on the bone explained that the highest stress value experienced the highest tensile condition by referring to the force direction applied as in Fig. 2.

The variation of the maximum principal stress for valgus and varus malposition groups are shown in Fig. 5 and Fig. 6, respectively.

The presence of implant malpositions has affects the displacement and stress variation. The comparison of the maximum values for both findings is summarized in Fig. 7. Malposition at varus angle indicated higher displacement and principal stress as compared to valgus malposition. Different angles or orientations also contribute to significant changes for the findings.

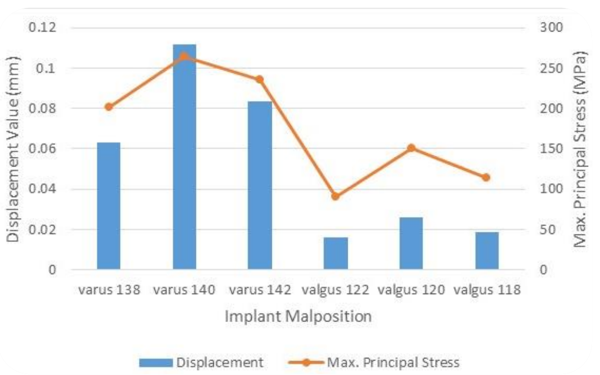


Fig. 7. Bone displacement and Maximum Principal Stress values

Since the RHA implant malposition always occurred on the patient after the post-operative surgery, it might lead to the other factors hence increased the tendency of femoral bone and neck fracture. Nonetheless, the simulation results on displacement value and maximum principal stress value obtained in this study shows a positive impact to reduce any damage formation towards the bone. Also, the results obtained on the valgus position were similar to the conclusion made by the previous works [7,16].

4. CONCLUSION

The analysis suggests that the implant malposition affects the performance of the resurfacing hip arthroplasty. Malposition at varus angle indicated higher displacement and principal stress as compared to valgus malposition with varus 140^{o} indicated the highest principal stress and total displacement.

5. ACKNOWLEDGMENT

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