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Research paper



Effects of Stem Malalignment in Cementless Hip Arthroplasty: a Computational Study

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Abstract

Implant loosening and deformation issues contribute to the instability of the hip arthroplasty. Prosthesis stem malalignment can occur in varus, anteversion and retroversion in different degrees due to several reasons. In this study, computational analysis of cementless hip arthroplasty with different stem malalignment cases was conducted to investigate the biomechanical effects in hip arthroplasty. Five hip arthroplasty models were developed using finite element analysis which are straight/aligned model, malalignment models at varus +3°, varus -3°, sagittal flexed +3°, and sagittal extended -3°. Results show that different pattern of stress distribution was observed in each malalignment case. The varus -3° malalignment model had demonstrated the greatest risk of failure based on the resulting stress distribution and total deformation.

Keywords: *Total hip arthroplasty; Femoral stem malalignment; Stress distribution; Displacement; Finite element analysis*

1. Introduction

Arthritis is the joint inflammation and it permanently causes pain to the body's joints. The most common type of degenerative arthritis of the hip is osteoarthritis that major happened to elderly people [1]. The femoral and hipbone at the joint rub together causes the pain at hip and will affects the movement of leg [2]. It happened because of cartilage tissue at the joint has damaged. Total hip arthroplasty (THA) is an option treatment for patient who in the late stage of degenerative hip disease. THA is represents the most effective therapeutic modality or surgery and it is now available for the treatment for patient that have problem on arthritic conditions of the hip joint [3]. Although THA is one of the most suggested procedure for later stage of hip osteoarthritis, there is still a caution for surgeons to be alert and understand. The position of stem implant in the femur should be in position as marked to prevent malalignment problem [4]. This precaution is including THA in cemented and uncemented process.

Parker et al. [5] reported that in malalignment issue, there were comprehensions of the proximal femur twisting that occurs as an after effect of failure implant obsession, paying little mind to the intellect for the disappointment of past stem in both established and uncemented stems. The proximal implant and the lever arm of the femoral head constrain the stem in varus and sagittal plane of view. The proximal femoral bone keeps up its singular frame and resist stress after bone load obsession gets to be distinctly powerful. The failure and micromotion happen in the period of an obsession which is the variables degree of dynamic bone distortion takes after resettlement of the prosthesis device [5].

Although many excellent clinical and radiographical outcomes of cementless THA have been reported, periprosthetic bone loss such as wear-related osteolysis and late periprosthetic bone resorption due to stress shielding still remains an issue of concern and may lead to revision surgery or make revision surgery difficult [6].

This purpose of the study is to develop the finite element models of total hip arthroplasty. Different mal-alignment cases study was modeled to represent malalignment condition such as varus +3°, varus -3°, sagittal flexed +3°, and sagittal extended -3°. Effects of the malalignment cases were discussed on the resulting stress and total displacement.

2.0 Materials and Method

2.1 Material Properties

Two different materials were considered in this study to represent prosthesis stem and femoral bone. Prosthesis stem was model as titanium alloy while femoral shaft as cortical or hard bone. The mechanical properties of the material were listed in Table 1. All materials were assumed to be homogeneous, isotropic and linear elastic solids.

Table 1: Material properties used in Finite Element model

Properties	Titanium alloy	Cortical bone
Elastic Modulus (GPa)	110	17
Poisson ratio	0.3	0.29
Yield strength (MPa)	795	115
Ultimate tensile strength (MPa)	860	121

2.2 Femur and Stem Prosthesis Design Model

The design of the prosthesis implant was designed and adapted from available commercial implant model [7]. The implant design was constructed based on the standard of the respective implant specification using commercial CATIA V5 software. The stem length was 156 mm while the classic straight neck angle is about

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135°. In designing the neck length, a long neck modular with the range size of 41 mm neck length and 43 mm offset, was considered. Description of the model is illustrated in Fig. 1 while the 3D model of the intact femur and THA model are presented in Fig. 2.

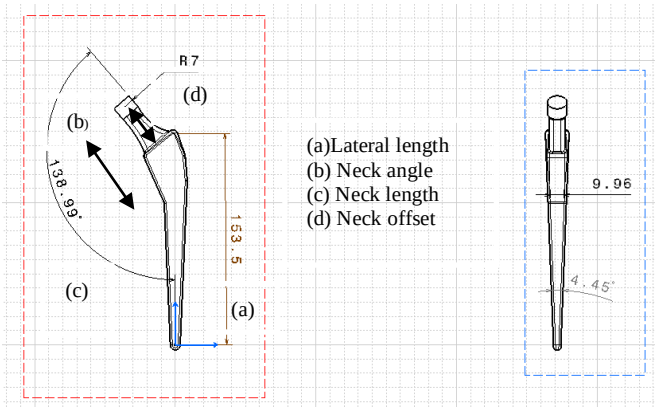
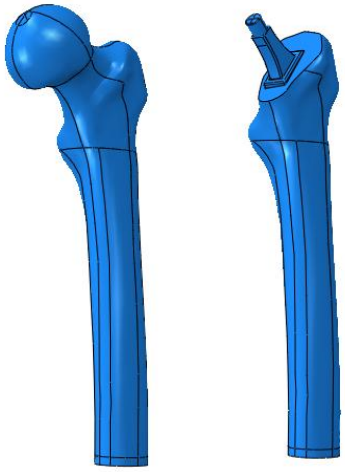


Fig. 1: Description & dimensional parameter of stem prosthesis



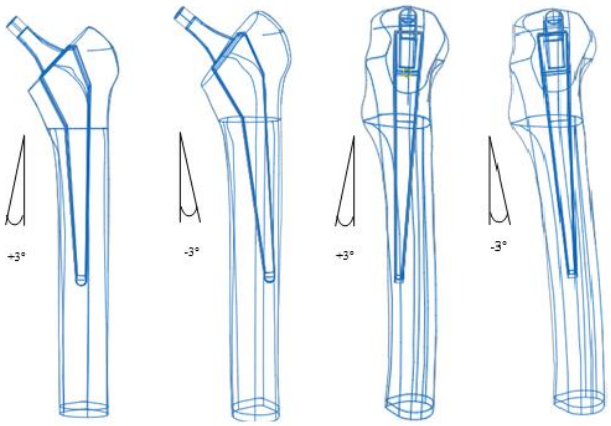
(a) (b)

Fig. 2: 3D model of (a) intact femoral bone and (b) THA model

Five different case study of straight and malalignment cases were conducted in this study to represent malalignment cases. The prosthesis stem was designed in (a) aligned/straight condition, (b) varus +3°, (c) varus -3°, (d) sagittal flexed +3°, and (e) sagittal extended -3°, as presented in Fig. 3. Deformation can occur in varus, anteversion and retroversion in different degrees. For severe varus deformations a straightening osteotomy is generally indispensable and different types of distal fixations of the implant are necessary in milder deformations other solutions are possible. Retroversion can be generally managed with proximally modular stems, stems without metaphyseal component or rarely, with a rotation in opposite direction osteotomy [8,9].

2.3 Different Type Malalignment Conditions

In this research, the different between the von misses stresses and total deformation of model when maximum loading load during walking and stairs climbing have been perform by applying the cases of malalignment. The differences show implant in condition straight, varus +3°, varus -3°, sagittal flexed +3°, and sagittal extended -3°. The results will show the better implant placement due to the maximum stress and deformation of the THA model[9]. The CT scan images were compiled and stacked into biomedical software to develop the three-dimensional(3D) model of femoral bone and were analyzed by using commercial simulation software analysis for THA model for the finite element analysis[10]. The material properties for the bone elements were computed based on previous study [11]. This THA models were automated mesh size of 2mm and was considered with tetrahedron elements for all model.



(a) (b) (c) (d)

Fig. 3: Different malalignment cases at (a) varus +3°, (b) varus -3°, (c) sagittal flexed +3°, and (d) sagittal extended -3°.

2.4 Loading and Boundary Condition

Figure 4 shows the loading and boundary condition of the total hip arthroplasty. The loading analysis was performed based on the common activities by patient which are normal walking and stairs climbing [11]. The division of load applied according to the direction is shows on Table 2 which were extracted from HIP '98 by Bergmann [12] and presenting of 836 N of body weight.

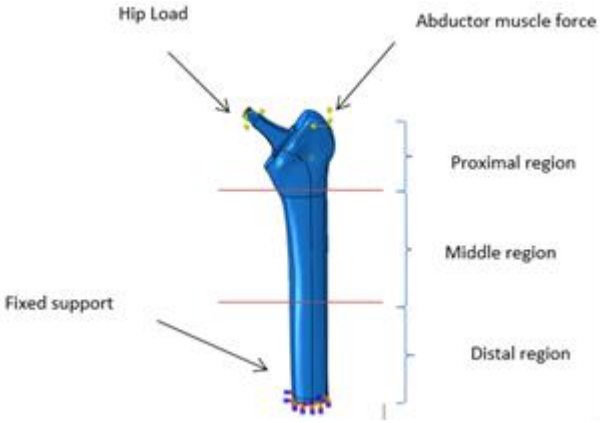


Fig. 4: Loading condition of THA and the coordinate system at left femur [12]

Table 2 (a): Maximum and abductor muscle forces acting during walking.

Direction	Fx	Fy	Fz	Resultant F
Hip Load (N)	707.27	236.33	2085.57	2214.88
Abductor muscle(N)	475.68	19.23	726.48	868.57

Table 2 (b): Maximum and abductor muscle forces acting during stairs climbing.

Direction	Fx	Fy	Fz	Resultant F
Hip Load (N)	855.31	475.77	2089.25	2307.14
Abductor muscle(N)	586.04	240.77	709.76	951.40

3. Results & Discussion

Effects of stem malalignments in cementless hip arthroplasty conducted in this study were discussed in the resulting stress distribution and total displacement.

3.1 Stress Distribution in Total Hip Arthroplasty

Variation of stress distribution within the hip arthroplasty with different stem malalignment cases was presented in Fig. 5. The mismatch of stiffness materials in the femur presenting the implant and cortical bone had demonstrated the stress distribution from proximal to the distal region. Stress was dominant at the stiffer material (implant) in all cases before it was transferred to the bone at the distal region.

In comparison to malalignment cases, the von misses stress in varus -3° (Fig. 5c) show the highest stress with 18.90 MPa for walking load case. The straight or aligned position of stem prosthesis shows the less of stress compared with other cases. Thus, it was suggested that the aligned stem has better stability and will not fail or will experience the longest survivorship of prosthesis implant. Similar findings were also projected in stair climbing load case. The maximum von mises stress experienced by all cases including the intact femur was presented in Fig. 6 for both walking and stair climbing load cases. Pattern of maximum stress values was shown to be similar for both cases but at different magnitude.

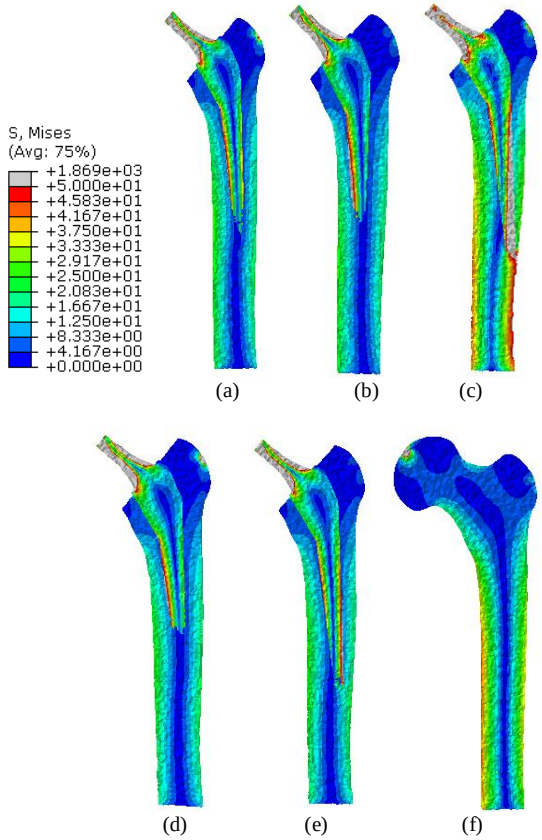


Fig. 5: Von Misses stress of THA on normal walking activity at (a) straight, (b) varus +3°, (c) varus -3°, (d) sagittal flexed +3°, (e) sagittal extended -3° and (f) intact femur

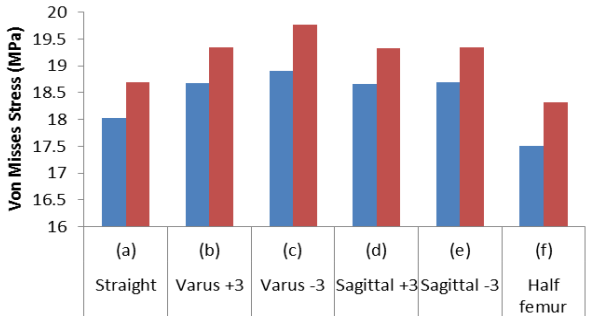


Fig. 6: Comparison of maximum von mises stress in HA femur at different malalignment cases

3.2 Bending Effects of the Prosthesis Stem

The cross-sectional view at middle region of the femur (Fig. 7) suggested the bending effects of the prosthesis stem, as compare to the intact femur. The highest von mises stress also obtained by malalignment case at varus -3°, which is 1.58 MPa and followed by varus +3°. This finding suggested that the bone also experiend the highest bending effects due to the varus malalignment. The pattern of bending effects in other malalignment cases almost similar.

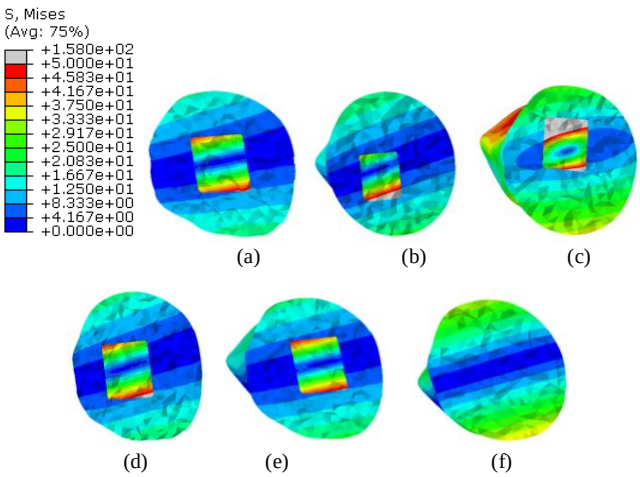
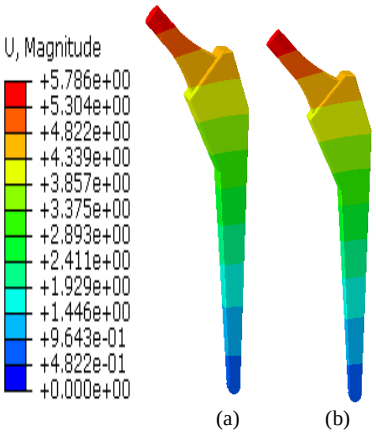


Fig. 7: Von Misses stress on cross-sectional in middle region of THA on normal walking activity at (a) straight, (b) varus +3°, (c) varus -3°, (d) sagittal flexed +3°, (e) sagittal extended -3°and (f) intact femur

3.3 Total Deformation of the Prosthesis Stem

The total deformation parameter is another indication to predict the stability of the hip arthroplasty. Fig. 8 shows the total deformation of the implant at different malalignment cases for walking load case. Similar pattern was observed in all cases which maximize at the proximal part and decreasing through the distal tip. It was expected as the hip loading was applied at the hip joint and the prosthesis stem was inserted and debonded into the femoral canal. However, Fig. 9 shows the detail comparison of the deformation within the malalignment cases. The highest deformation is demonstrated in varus -3° malalignment case (Fig. 9c) followed by varus +3° and sagittal malaligments. Similar configuration was observed in walking and stair climbing load case. The maximum value of deformation on varus -3°in both load cases are 5.786μm and 6.322μm, respectively. The computational findings suggested that the risk of the model that experience the highest value of deformation or total displacement, which may lead to the loosening of the joint [9].



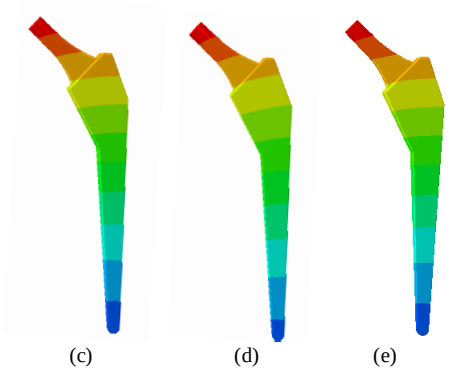


Fig. 8: Deformation of THA on normal walking activity at (a) straight, (b) varus +3°, (c) varus -3°, (d) sagittal flexed +3°, and (e) sagittal extended -3°.

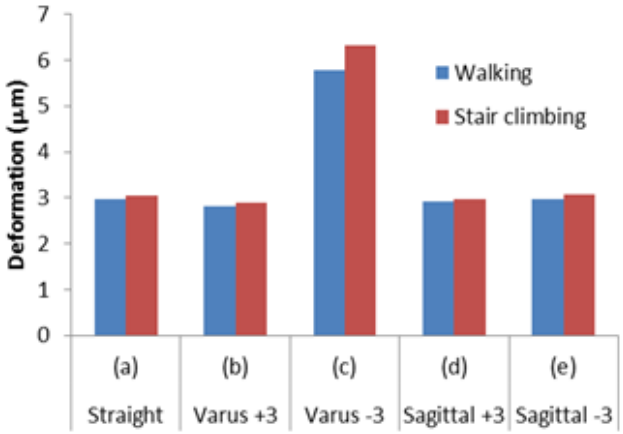


Fig. 9: Comparison of total deformation in THA at different malalignment cases

Thus, the computational findings in this study suggested that the malalignment case will effects the performance of the hip arthroplasty. Issues of implant stability, loosening and stress concentrations in the femoral bone had somehow be related to the current findings. Clinical report also suggested that in the varus rotational movement, some risk might have occurred that is the tip of the stem can cause too much pressure on the lateral cortex, especially when the stem was inserted. The tip of the failed stem formerly rested and the bone is weakened and lead to femoral fracture or a perforation [8,9,10].

4. Conclusion

The computational study had demonstrated the capabilities to investigate the effects of stem malalignment in hip arthroplasty. The presence study on different malalignment cases such as in straight or aligned position, varus +3°, varus -3°, sagittal flexed +3°, and sagittal extended -3° have influenced the hip arthroplasty performance on stress distribution and deformation of these subjects. The varus -3° malalignment model had demonstrated the greatest risk of failure based on the resulting stress distribution and total deformation that can affect the performance of patient in daily life.

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