Effects of Stem Mal-alignment in The Primary Stability of Total Hip Arthroplasty

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ABSTRACT

Total hip arthroplasty is a surgical procedure to reform the hip joint by replacing the joint with femoral components. Issue of stem malalignment at varus and retroversion degree angles during the procedure had influenced the performance of the arthroplasty especially in revision surgery. Thus, the purposes of the study are to develop the finite element models of total hip arthroplasty and to investigate the effects of stem malalignment in the primary stability of the femur and hip prosthesis. Two cases of malalignment stems at varus +3 degree and varus -3 degree were reconstructed while proper aligned or straight stem was set as reference. The static analysis presenting walking and stair climbing activities is conducted using commercial computational design and analysis software. The effects of stem malalignment in the femur are discussed on the resulting stress distributions and total deformation. Higher stress magnitude was predicted in both malalignment cases as compared to the straight case. The malalignment

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conditions also contribute to larger displacement at the distal end of the prosthesis which can lead to implant loosening.

Keywords: *Total hip arthroplasty, Stem malalignment, Stress distribution, Deformation, Finite element analysis.*

Introduction

Total hip arthroplasty is a surgical procedure to reform the hip joint by replacing the joint with femoral components to represent a ball and socket joint. The procedure is believed to be one of the best alternatives for the later stage of osteoarthritis. However, it also carries its own set of risk and complications that require immediate medical attention or even additional surgeries to treat. The case of implant may also increase the danger of certain complications. Thus, implant malalignment in hip arthroplasty had lead to poor outcomes [1] and increase the risk of revision surgery due to problems such as hip instability, wear, and impact. The problem of malalignment in hip surgery is facing the deformation of the femur which considers the choice of the implant. Deformation can occur in varus and retroversion in different angle.

Finite element modelling of THA femur calls for accurate representation of the femur and the complex loading due to active muscle forces during the various activities including walking and stair-climbing. Walking and stair-climbing have been shown to be important activities for assessing hip implant performance due to the prevalence of the former and the high loading demand of the latter [2]. In-vitro hip joint loading has been investigated and widely used by researchers to estimate muscle and hip joint reaction forces [3-5]. Contact forces and reactions at the hip joint under different daily activities including walking and stair-climbing were measured [6]. Walking being the most frequent daily activity, is dominated by bending forces while stair-climbing exhibited the highest torsion loads or twisting forces [3,6,7]. The implant design and location are important agents in keeping stability and minimizing dislocation of total hip arthroplasty. This purpose of the study is to develop the finite element models of total hip arthroplasty at various malalignment conditions and to analyze the effects of stem malalignment to the primary stability of total hip arthroplasty.

Finite Element Model

Material Properties

Two different materials were considered in the present study to represent femoral stem (titanium alloy) and femoral bone (cortical). The biocompatibility titanium alloy is widely used in the orthopaedic implant as it has good mechanical properties, such alloys have very high tensile strength, high stiffness and toughness. They are light in weight, which have extraordinary corrosion resistance and the ability to withstand extreme temperatures. The materials considered were assumed to be homogeneous, isotropic and linear elastic solids, as lists in Table 1[8].

Table 1: Material properties used in the finite element model

Material	Elastic Modulus (GPa)	Poisson's Ratio	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)
Ti6Al4V	110	0.3	795	860
Cortical Bone	17	0.33	115	121

3D model of femoral Bone and Prosthesis Stem

The full femur model was reconstructed based on the real sized human femur. The prosthesis stem model was designed in accordance to the standard build and size of implant specification using CATIA software, as illustrated in Fig. 1. The specification of the prosthesis stem is 156 mm in length with the classic straight neck angle at 135° degree. The design of the neck length, which are using the long neck modular and the range size of that about (48 mm neck length and offset of 37 mm) [2], as described in Fig. 2.

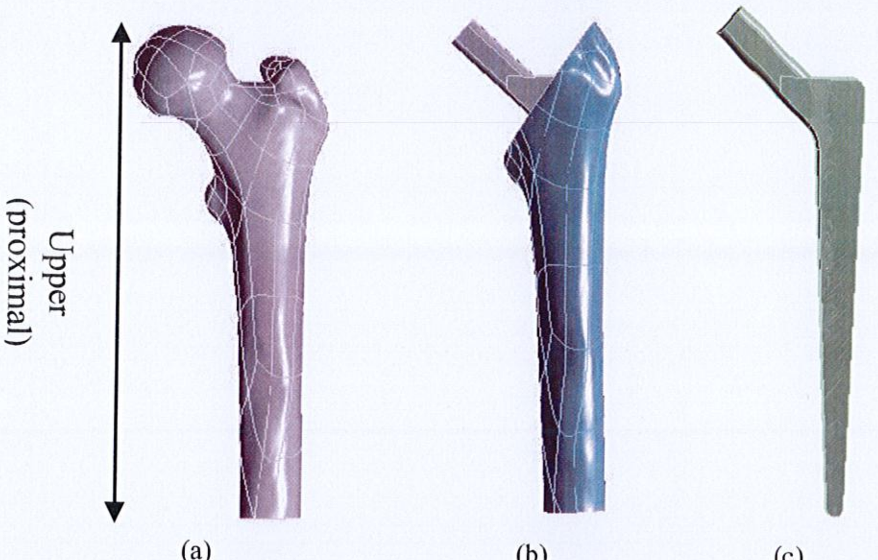


Figure 1: 3D model of (a) intact femur, (b) THA femur and (c) Prosthesis stem

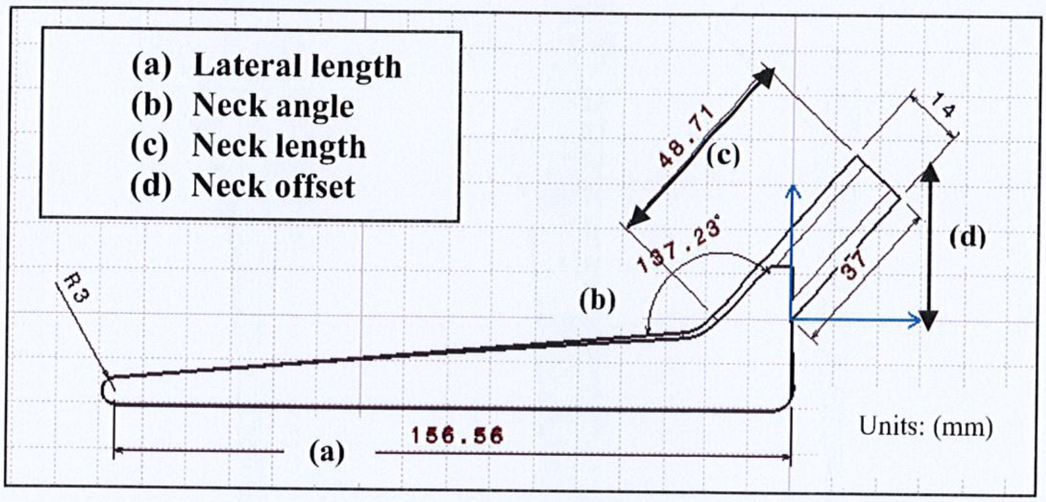


Figure 2: Description & dimensional parameter of stem prosthesis

Different Type of Malalignment Conditions

Different types of varus malalignment were conducted in this study. Fig. 3 shows three models which presenting straight, varus +3° and varus -3 conditions.

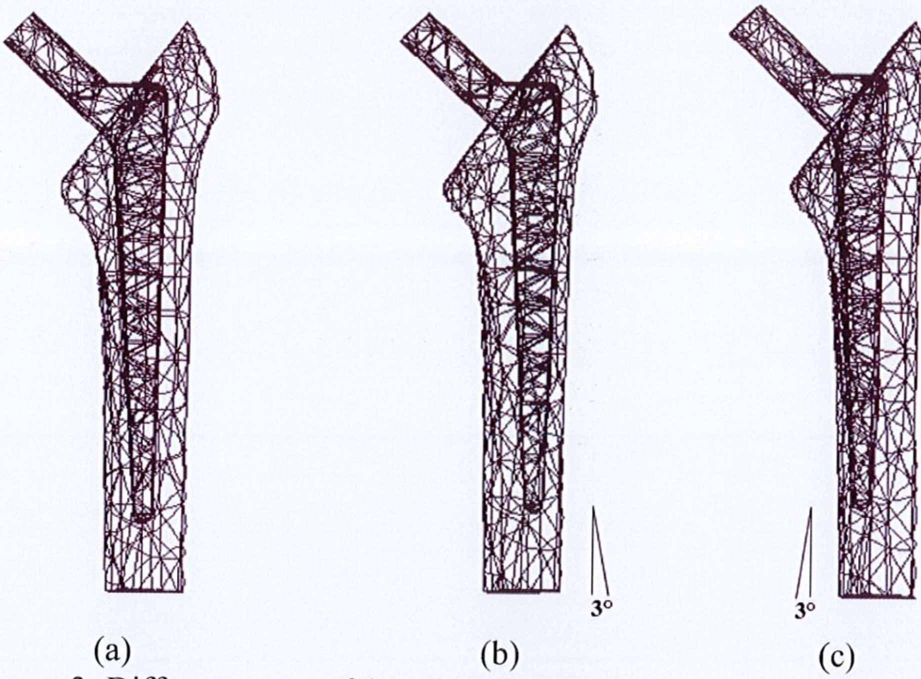
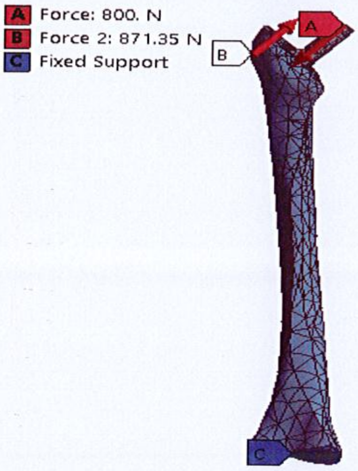


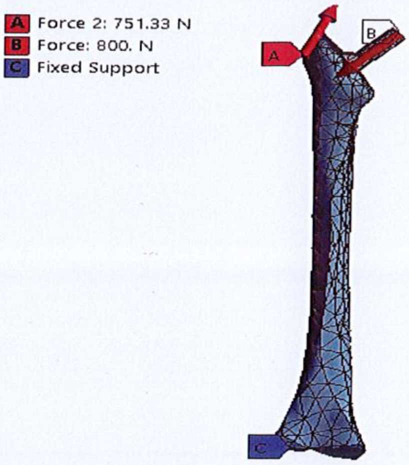
Figure 3: Different cases of (a) aligned/ straight stem and malalignment stems at (b) varus +3° deg., and (c) varus -3° deg.

Loading and Boundary Conditions

Two different loading conditions were considered in this study which representing walking and stair-climbing activities, as illustrated in Fig. 4. The hip load was assigned at the middle top of the femoral stem while the abductor muscle reaction was applied at the trochanteric region. The magnitude of the loadings was described in Table 2(a) and 2(b) for walking and stair climbing activities, respectively, in the direction of three main axis of x, y, and z. These values are derived from previous work involving in-vitro tests of hip joints for a person with a nominal body weight of 800N [3].



(a)



(b)

Figure 4: Loading condition of THA for (a) walking and (b) climbing

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

Direction	Fx	Fy	Fz	Resultant F
Maximum Force(N)	451.4	267.5	1881	1952.81
Abductor muscle (N)	485	-36	723	871.33

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

Direction	Fx	Fy	Fz	Resultant F
Maximum Force (N)	501.6	242.4	1990	2066.36
Abductor muscle (N)	320	-132.2	666.8	801.67

Results and Discussion

Stress Analysis in THA Femur during Walking Load

The result of stress distribution in femoral bones during walking activity is presented in Figure 5 and 6. The result of the stress distribution in the THA femur was compared to intact femur to predict the stress shielding effects after implantation. The effects of stress shielding is believed will contributed to the performance and quality of the bone which further will affects the stability of the implantation [8,9]. The maximum von-Misses stress in intact femur is measured as 10.346 MPa, straight condition is 76.199 MPa, varus +3° deg. is 90.265 MPa, and varus -3° deg. is 99.412 MPa. This higher stress value was indicated as red colour while lower stress in dark blue. Stress concentration of all condition are differs as shown in Fig. 5. Stress are dominant at the middle region of the femur in straight condition but differs in the malalignment cases. In varus +3° case, the stress is concentrated at the medial distal end of the femur while lateral distal region for varus -3° case. This situation had altering the stress distribution along the femur. Fig. 3(a) shows the varus +3° and varus -3° cases will experienced stress shielding problem at the medial distal region. Meanwhile, varus -3° case will lead to stress shielding problem at the lateral distal region. This observation suggested that the malalignment case especially at varus -3° will further affects the bone quality at the distal region and further contribute to the instability of the femoral fixation.

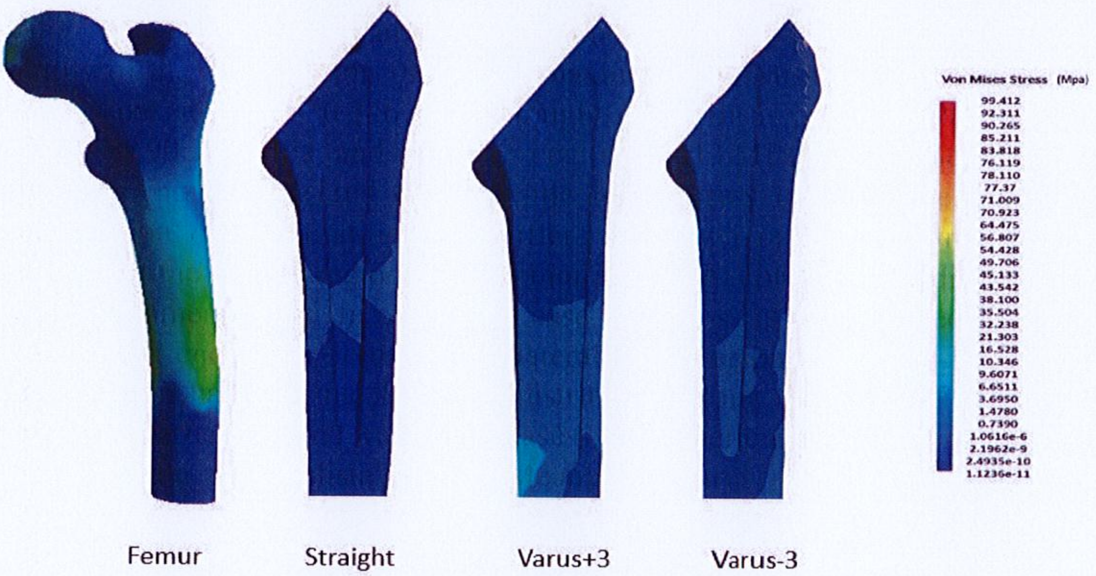
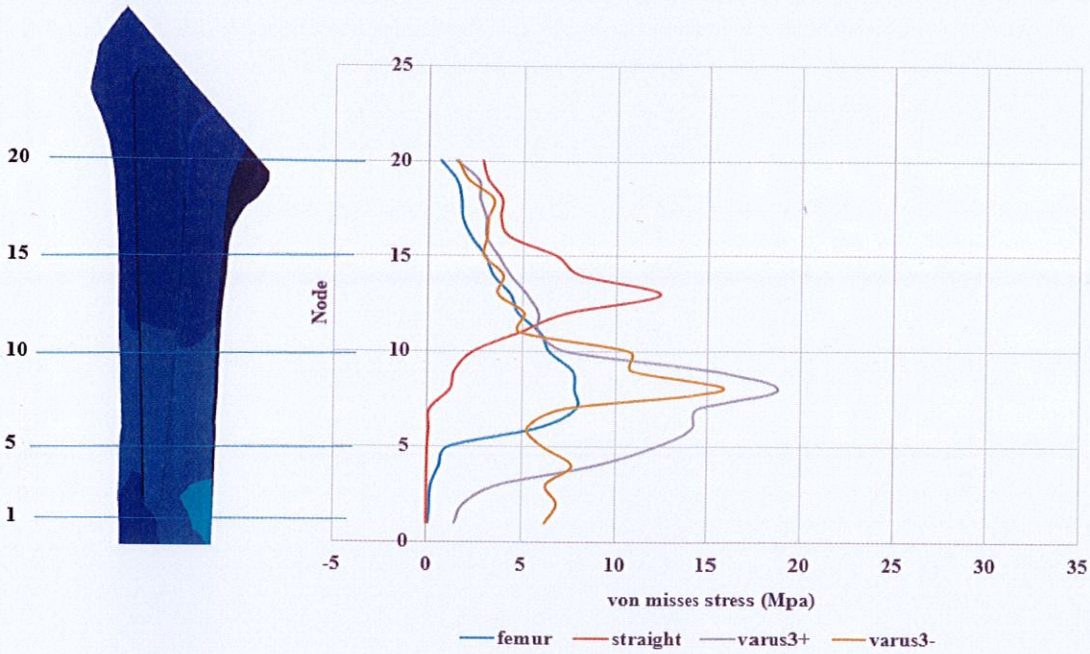
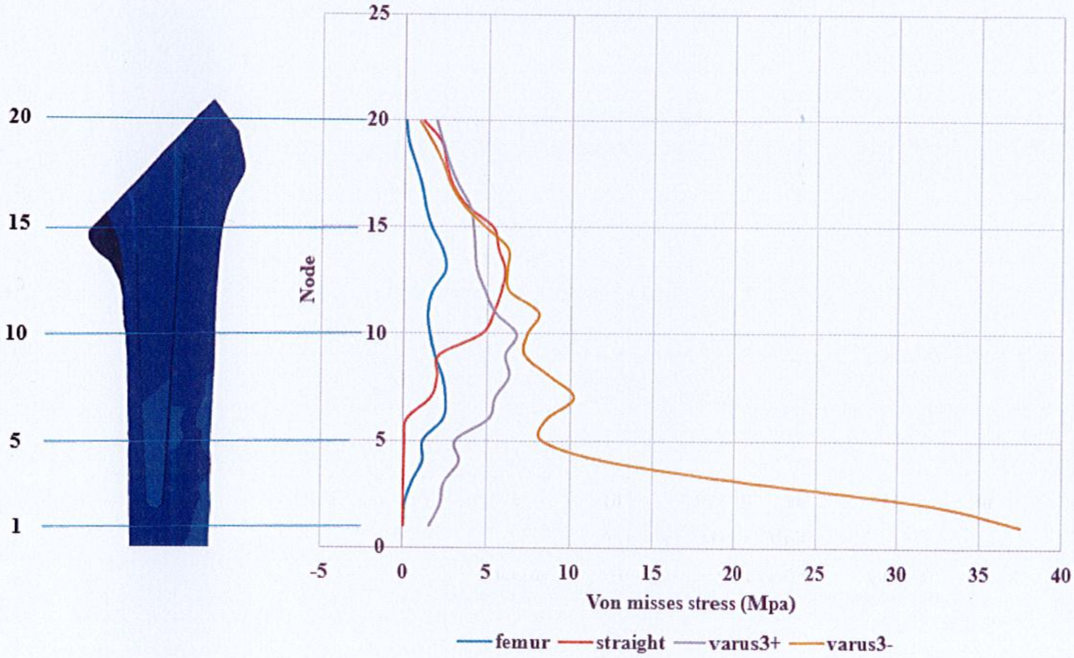


Figure 5: Von-mises stress distribution at walking load condition



(a)



(b)

Figure 6: Pattern of stress distribution at (a) medial and (b) lateral plane during walking load

Stress Analysis during Stair-Climbing Load

The findings of stress distribution of femoral bone at stair climbing activity are presented in Fig. 7 and 8. The result shows that the maximum value of the von-Misses stress at femur is 8.202 MPa, straight malalignment is 77.686 MPa, varus +3° is 112.44 MPa, and varus -3° is 122.28 MPa. The findings of the stair climbing case are almost similar to the walking load activity. However, the alteration of stress at the distal region is highest in varus -3° case at both medial and lateral regions. Stress is concentrated at the distal end of the prosthesis stem for both malalignment cases. Effects of bending moment were more critical in the malignment cases as compared to straignt or proper alignment condition. Thus, the straight alignment will provide better fixation and stability while malalignment will contribute to stress shielding problems.

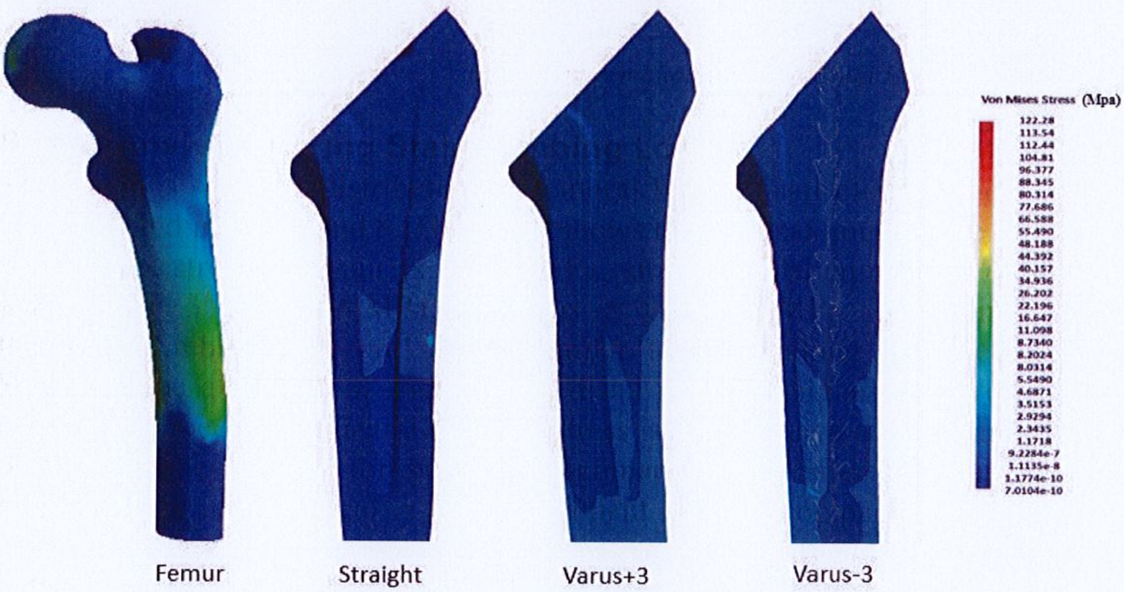
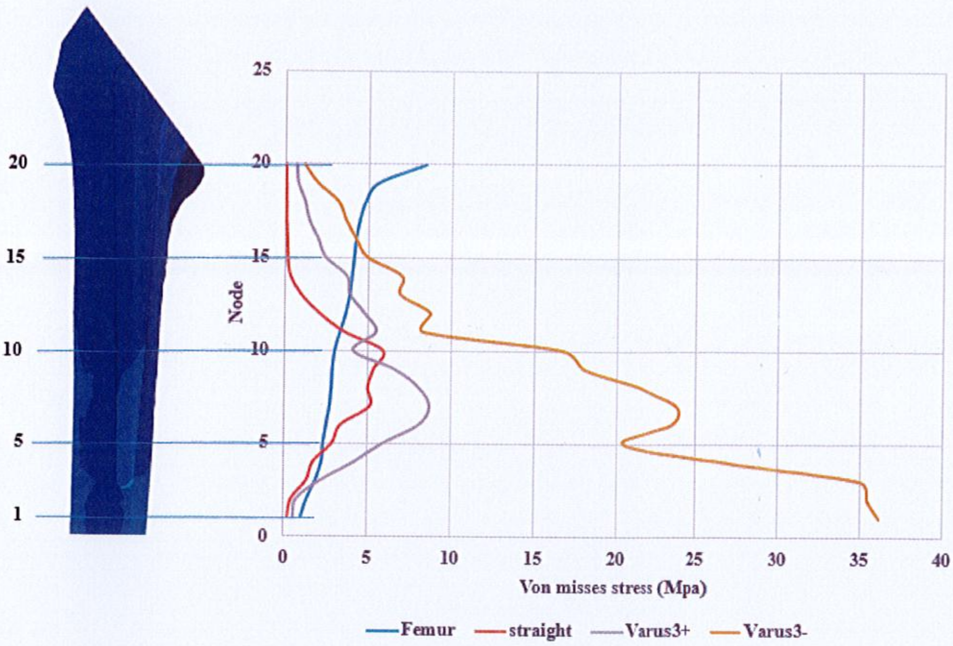
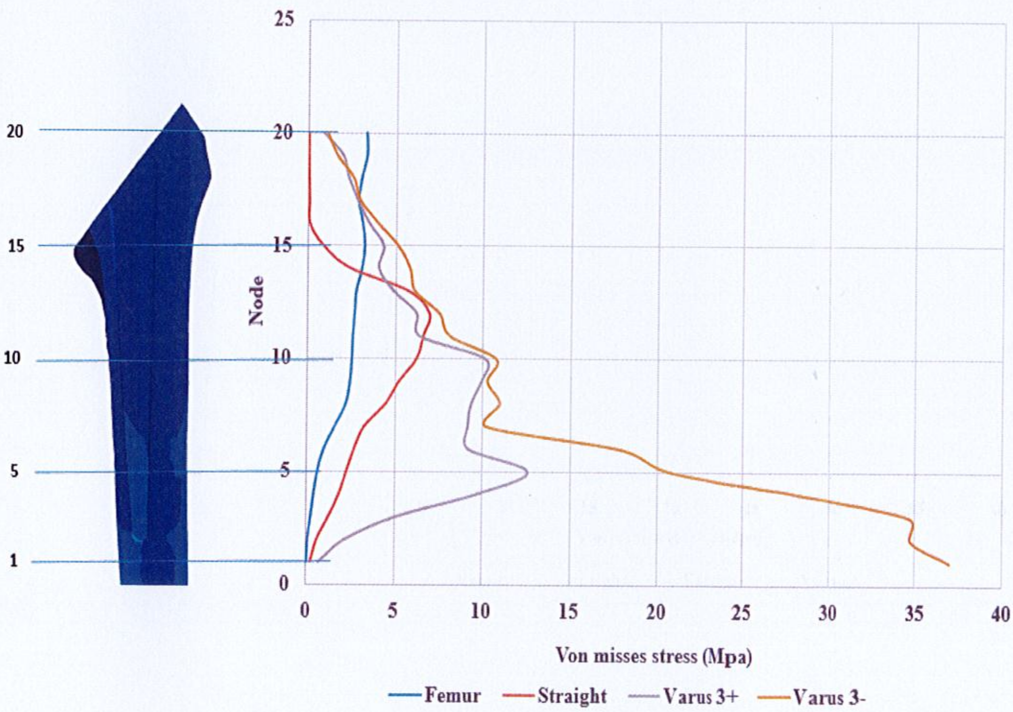


Figure 7: Von Mises stress distribution at climbing load condition



(a)



(b)

Figure 8: Pattern of stress distribution at (a) medial and (b) lateral plane during stair climbing load

Total Deformation of THA Femur

Prediction of total deformation of the femoral bone for all cases was described in Fig. 9 and 10. Results show that malalignment of stems will produce higher deformation to the fixation especially in varus 3-° case. The findings can be clearly observed in Fig. 10 and applicable for both walking and stair climbing activities. The maximum value of deformation at walking and stair climbing condition are 5.1701 mm and 5.2432 mm, respectively in the varus -3° malalignment case. Minimum deformation is predicted at the straight case. The computational findings suggested that the risk of deformation is higher for mal-alignment cases, which may lead to instability of the implantation after period of time.

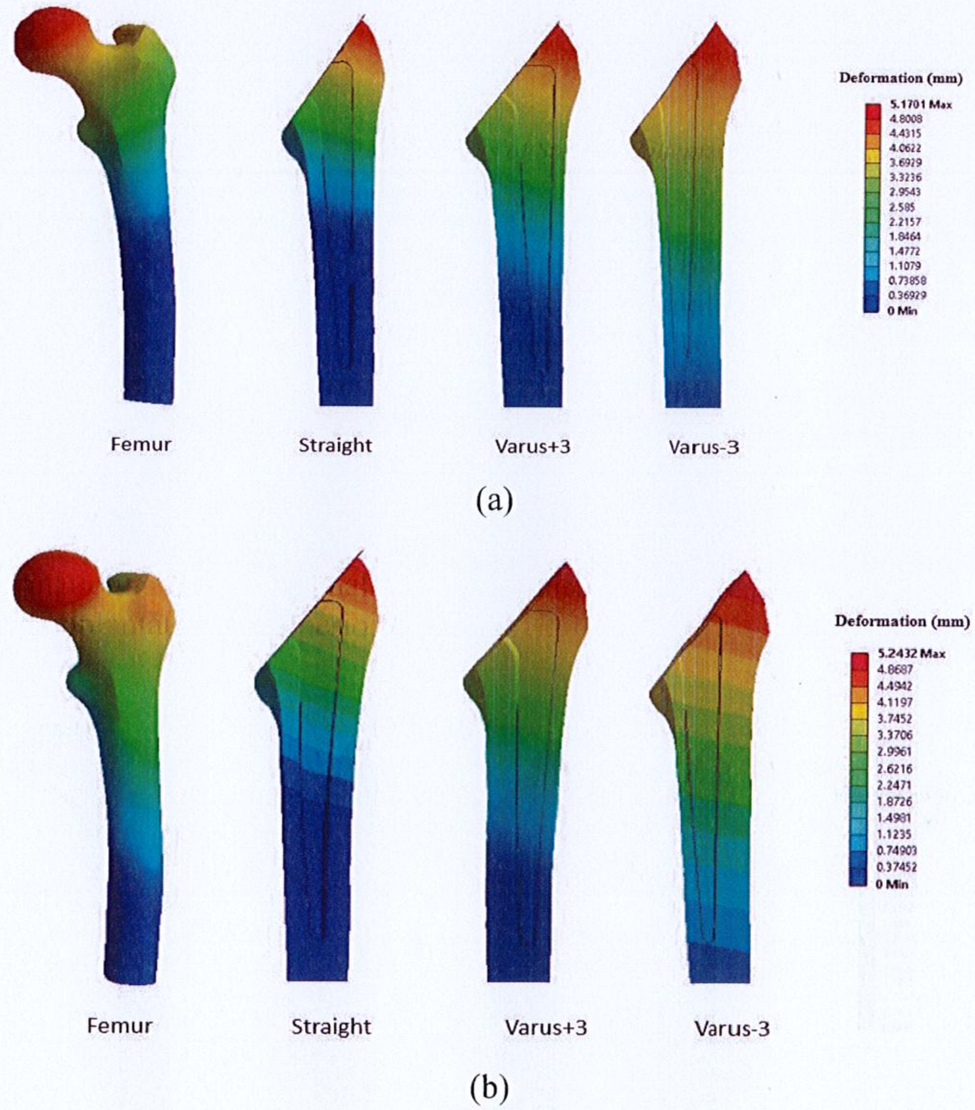


Figure 9: Maximum total deformation of (a) walking and (b) stair-climbing

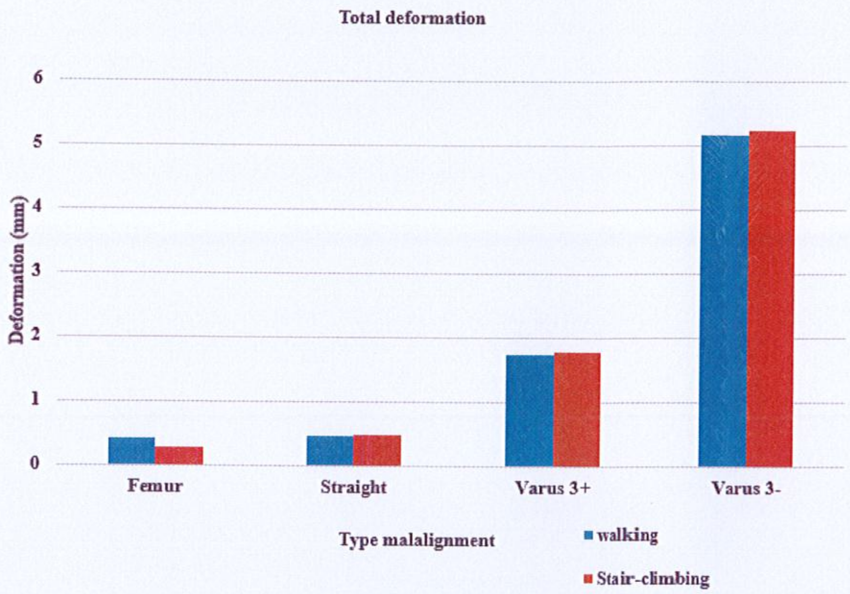


Figure 10: Maximum total deformation between two loading condition

Conclusion

The effect of mal-alignment stem in the primary stability of total hip arthroplasty was presented in the resulting stress distribution and total deformation. It was concluded that the malalignment at varus -3° contribute the highest deformation after loaded. A proper alignment or straight fixation of the implant will minimized the deformation and promote stability. The stress distribution at the distal region of varus -3° femur also indicated higher alteration as compared to straight and varus +3° condition which will contribute to stress shielding problem and further affect the stability of the implantation.

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