# Stress Evaluation of Lower Limbs with Hip Osteoarthritis and Hip Arthroplasty

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***Abstract*—Stress shielding and bone remodeling effects are critical issues in promoting long term stability of Total Hip Arthroplasty (THA). Stress shielding occurs when the femur experiences less stress after the presence of the prosthesis stem. In this study, biomechanical evaluations of lower limbs are established using the finite element method in corresponding to stress distributions. Lower limbs CT images of 64 years old female with hip osteoarthritis (OA) are used in developing three dimensional inhomogenous models. To represent THA limb, the left femur with hip OA problem was cut off and a prosthesis stem was implanted. The results show different stress distribution of lower limbs with OA and THA. Stress is defined to be concentrated at stiffer prosthesis stem while femur experienced less stress. The proximal region of femur is leading to stress shielding effects. Furthermore, gait instability is projected to occur based on the stress variation adaptation between operated and non-operated femur.**

***Index Terms*—lower limbs, hip osteoarthritis, hip arthroplasty, stress shielding, stress adaptation**

## I. Introduction

Hip osteoarthritis (OA) is one of the most prevalence diseases affecting the joints of the body, especially in elderly population. Several studies have reported that several demographic risk factors such as female gender, body mass index and age contribute to the disease. While symptom of hip dysplasia is considered as predisposing risk factor [1], [2].

In later stage of osteoarthritis, hip replacement is the most suggested option for treatment. Insertion of prosthesis stem and acetabular cup will reform as ‘ball and socket’ function for the disease hip joint. Although the prosthesis has achieved long term fixation, some complications are still predicted which can promote bone resorption and aseptic loosening [3]. Stress shielding effects is one of the common factors that associate to the aseptic loosening and failure of implant [3], [4]. Reducing of stress-strain stimuli in bone will increase bone resorption levels and altering bone remodeling [5]. Presence of a hip stem has created a mismatch in the elastic modulus of two materials which are bone and stem. A simple mechanical rule mentions that the stiffer component will sustain greater part of the body loads. Consequently, the stem shaft component is overloaded, whereas the bone around the shaft is unloaded [6].

Patients with hip osteoarthritis and total hip arthroplasty will experience gait pattern adaptation. Several studies have reported that the adaptation occurred not only at OA limb or operated limb, but also to non-affected limb [7]-[9]. In hip OA cases, Kiss (2010) [8] has identified that the functional abilities are substantially influenced by the severity of osteoarthritis and the motion of the affected hip is significantly restricted. While, the non-affected joints demonstrate an important role in the compensation mechanism and the relative assurance of gait stability [8], [10]. Analysis of the variability gait parameters are very important and may serve as relevant parameter in evaluation of mobility, fall risk and the response to therapeutic interventions [11], [12]. As body-mass index (BMI) and muscles strength factors are necessarily linked to gait stability and performance [1], [13], evaluation of stress-strain stimuli in lower limbs should be considered for further biomechanical explanation.

The objectives of this research were to (i) develop non-homogeneous model of lower limbs with hip OA and hip arthroplasty and (ii) to evaluate the stress variation and adaptation of lower limbs on both cases. A physiological load of quiet standing is considered in the analysis on using the finite element method.

## II. Finite Element Model

### *A. Lower Limbs & THA Model*

Computed tomography (CT) based images of a 64-year old female patient were used in developing a 3D lower limbs model using commercial biomedical software, Mechanical Finder v6.1. The model was designed to be inhomogeneous material with distributed Young’s moduli

Manuscript received January 30th, 2014; revised May 12th, 2014.



doi: 10.12720/jomb.4.2.100-104

predicted using the Hounsfield unit of the CT images. The FE model of lower limbs was consisted of sacrum, left and right ilium and both femur shaft. Bond between cartilage, acetabulum and femoral head, sacrum and ilium were assumed to be rigidly connected. The bone-cartilage-bone complex being a viscoelastic material and will be deformed at a high strain rate and stiffness will increase considerably during impact loading [14], [15]. Therefore, the difference of response between the rigid and actual hip joint will be minimized [15]. Three dimensional models of lower limbs with hip OA is illustrated in Fig. 1(a) while model of limb with THA in Fig. 1(b).

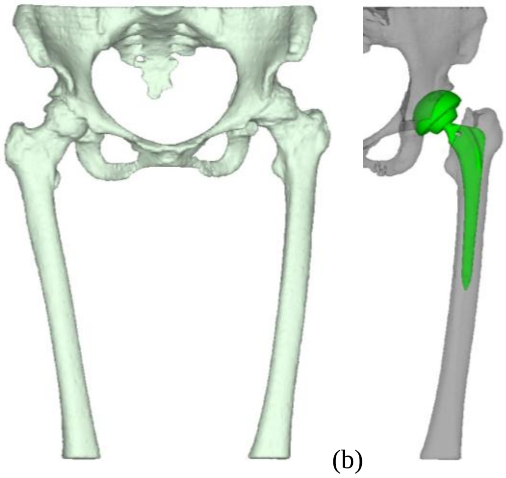

(a) (b)

Figure 1. 3D model of (a) lower limbs with hip OA and (b) left femur with THA

To demonstrate hip arthroplasty of the lower limbs, a CAD data set of hip replacement was imported and aligned to the left hip joint which suffered for hip OA. The hip replacement was modeled as titanium alloy (Ti-6Al-4V) material with 113.8 GPa and 0.34 of elastic modulus and Poisson's ratio, respectively. Interfacial connection between implant and bone was considered as perfectly bonded. Distribution of young modulus of inhomogeneous lower limbs model is presented in Fig. 2. Higher values of young modulus at the outer part indicate hard or cortical bone.

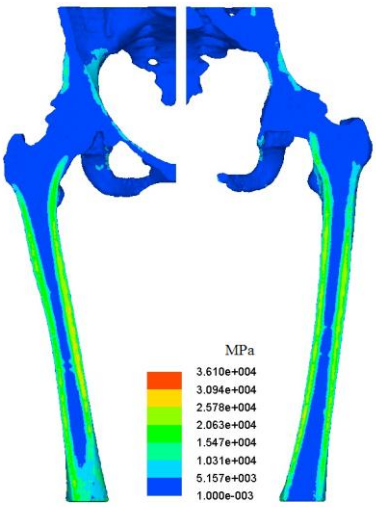



Figure 2. Distribution of young modulus of inhomogeneous model in cross-sectional view

### B. *Loading & Boundary Conditions*

A load case of quiet standing was considered to investigate the weight distribution through both limbs. Posture of quiet standing in the foot side-by-side position contributes to structurally and functionally equivalent of the lower limbs [16], [17]. A distributed load of 60kg which represents the body weight of patient was applied at the cross sectional pelvic and fixed at the distal cut of femoral shaft, as illustrated in Fig. 3.

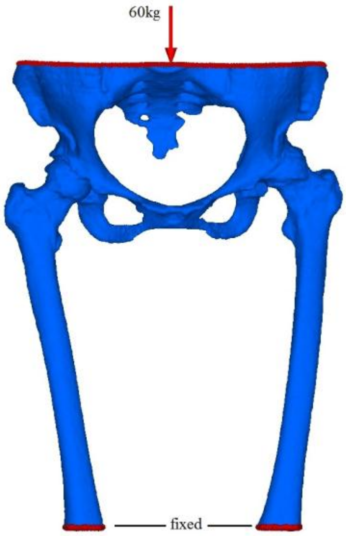


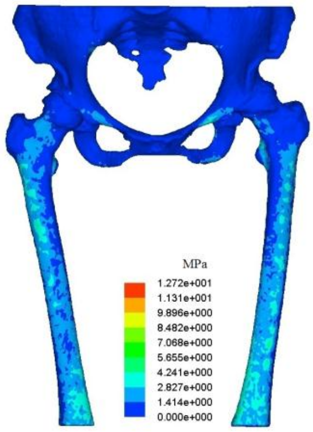

Figure 3. Loading and boundary conditions of lower limbs model

## III. Results & Discussion

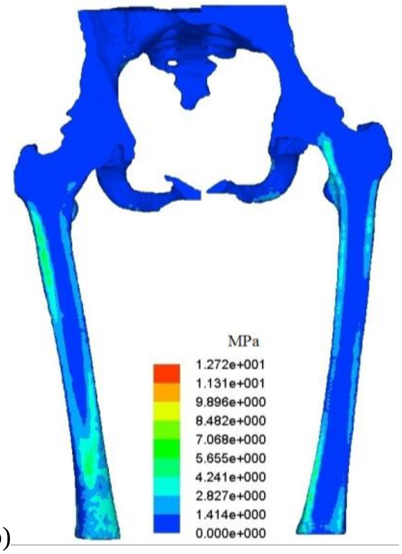
Results of the analysis are presented and discussed in terms of the equivalent von Mises stress. Investigation between OA and THA lower limbs was conducted to evaluate the stress variation and their influences to stress shielding and stress adaptation at non-operated limb.

### A. *Stress Evaluation of Lower Limbs with Hip OA*

The body weight of a patient is transferred to lower limbs and should be distributed to left and right limbs, symmetrically [17]. Unfortunately, the stress variation was found to be different between right and left side as hip OA occurred at the left joint. Overall observation of stress distribution is illustrated in Fig. 4(a).



(a)




(b)

Figure 4. Equivalent stress variation of lower limbs (a) frontal view and (b) cross-sectional view

The different stress is clearly identified at the neck region of femur. In the healthy joint, the stress is distributed to the femoral shaft through the tronchanter region while the OA joint shows concentrated stress at the medial region of the neck and lesser tronchanter.

The variational difference between the healthy and OA lower limbs will contribute to bone remodeling adaptation even without artificial material implanted. Thus, the geometry of hip femoral may potentially be deformed after certain period due to the OA problem. Distributed stress transferring to lower limbs is described more detail in cross-sectional view as illustrated in Fig. 4(b).

### *B. Stress Shielding Effects in THA Lower Limbs*

Presence of prosthesis stem in lower limbs has created mechanical instability into the skeleton system. Load will be transferred more to stiffer metal stem and initiated to stress shielding problem to the surrounding bone. Such situation is clearly observed computationally in Fig. 5 where the stress is dominant at the prosthesis stem. Less stress is predicted at the proximal femoral shaft and thus may promote bone resorption and become weak [18].

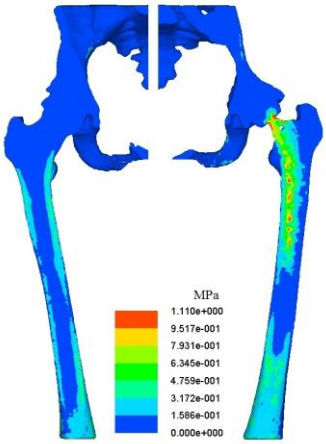



Figure 5. Equivalent stress variation of THA lower limbs at cross-sectional anterior-posterior (A-P) view

Development of human bones is very unique and believed to be a very economical system. As the human skeleton is loaded, the bones of the lower limbs will sustain the load due to the body weight. If the load is large, the skeleton will grow more bone tissue in the loaded area. The mineralized tissues are more closely packed and become stronger to sustain the increased load. While in the areas of diminished load, the skeleton preserve as much bone tissue as is necessary to sustain the low load level [19]. Normally, the skeleton in the unloaded areas is weaker and has high risk fracturing in unexpected high force.

Selections of several nodes are made to indicate different lines at the medial and lateral regions, as described in Fig. 6. The similar points are selected for both the THA limbs and OA limbs for comparison. Patterns of stress distribution along the medial and lateral regions are observed. For indication purpose, symbol 'O' indicates the selection node at proximal region while node 'A' at the distal end of femoral shaft.

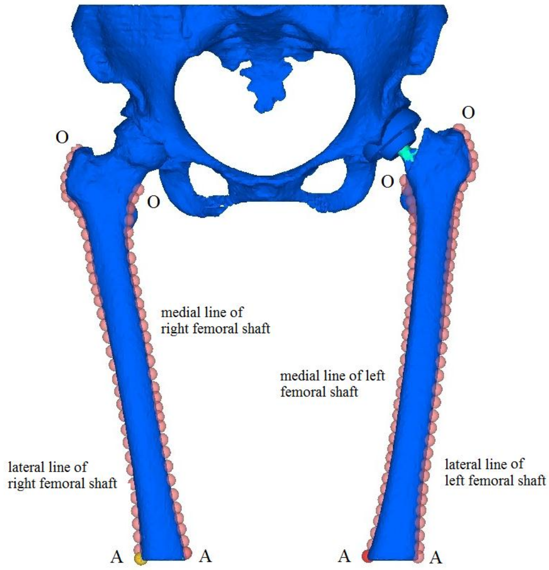



Figure 6. Selection of nodes to represent different lines of each region

Fig. 7 and Fig. 8 show the pattern of stress distributions of the left femoral shaft with THA and hip OA at the medial and lateral regions, respectively. In the medial region, the femur with THA experienced low stress at the proximal and bottom part of shaft. The stress is high at the distal end of prosthesis stem. Differ to OA femur, stress shows higher value at the proximal part as the absence of hip implant. Stress shielding is projected in this proximal region for the current study. Clinical findings by previous researchers also reported that the bone mineral densities were found decreased at the proximal part of operated limbs [3], [20], [21].

In the lateral region, both femurs show similar pattern of stress distribution. However, the stress magnitude in the THA femur is defined to be higher than the OA femur especially at the bottom part. The stress was transferred to the bone totally at the distal end of prosthesis stem. The higher stress may contribute to bone thickening and expected to imitate patients' gait adaptation.

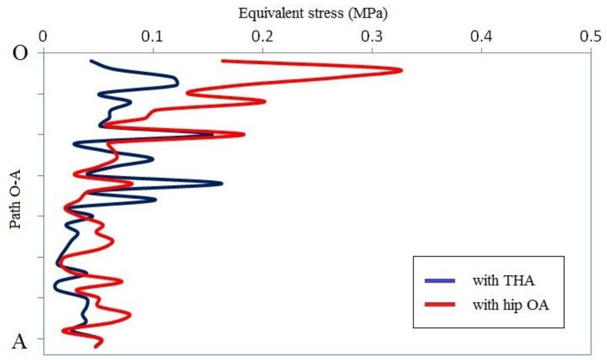



Figure 7. Pattern of stress distribution at medial region of left femoral shaft (operated and non-operated)

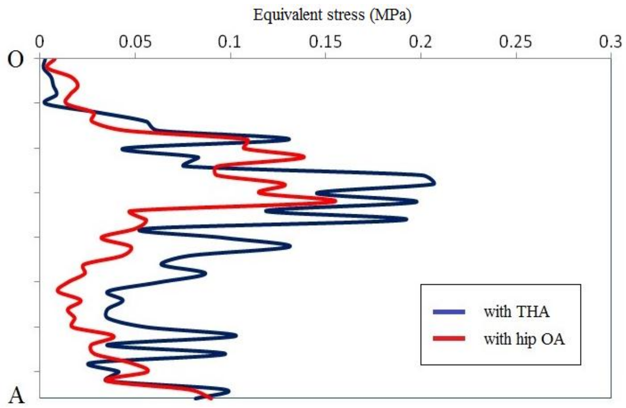


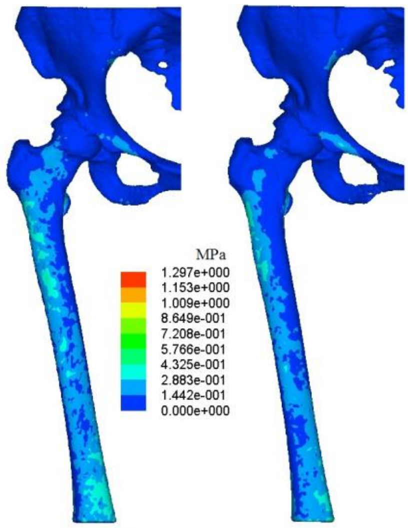

Figure 8. Pattern of stress distribution at lateral region of left femoral shaft (operated and non-operated)

## C. Stress Adaptationn in Non-Operated Limb

Observation from rehabilitation researchers has notified about gait adaptation in hip OA and THA patients. The difference occurred in both affected/non-affected and operated/non-operated limbs. Beaulieu et al [22] have reported that the biomechanical function of lower limb of THA patients do not return to normal and risk of developing other joint diseases may be increased. The current computational findings contribute to the crinical situation. From biomechanical point of view, the stress adaptation could influence the gait performance. Fig. 9 shows the difference of equivalent stress variation in the non-affected and non-operated limbs.

View of anterior-posterior plane shows the stress alterations are dominant at the proximal region of femoral shaft. Average stress around 0.3MPa at non-affected limb is decreased to 0.1MPa at the trochanteric region. However, the pattern of stress distribution of both femurs shows similar trends at the medial and lateral regions as described in Fig. 10 and Fig. 11.

The limitation of this study is that the variability of physiological load was not studied. Additional studies will be required to determine the effects of rehabilitation techniques and approaches to kinetic parameters and muscles activity. Different types of loading can be considered for analysis. Advanced studies are also required to demonstrate the correlations between the computational findings and gait performance.




(a) at OA limbs (b) at THA limbs

Figure 9. Stress Adaptation of right femoral shaft for non-affected and non-operated limb

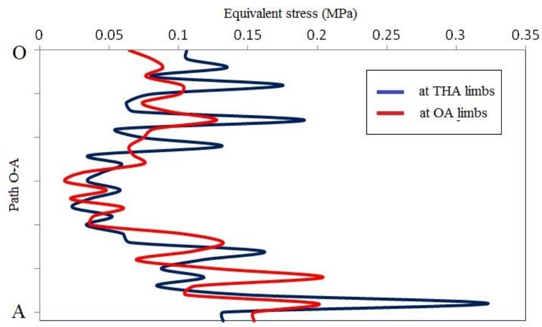



Figure 10. Pattern of stress distribution at medial region of right femoral shaft (THA limb and OA limb)

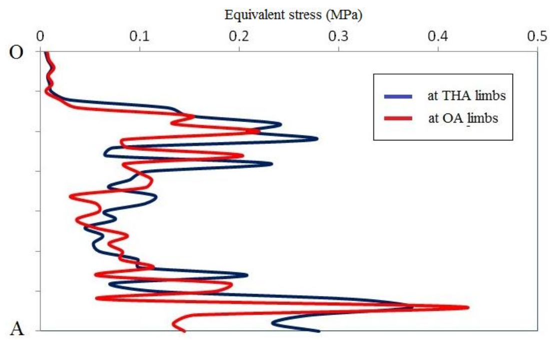



Figure 11. Pattern of stress distribution at lateral region of right femoral shaft (THA limb and OA limb)

# IV. Conclusion

Proper stress variation along lower limbs will develop bone growth appropriately. Adaptation of stress due to hip osteoarthritis or hip arthroplasty may initiate to bone remodeling alteration. Stress variation of lower limbs with hip osteoarthritis indicates higher value at the medial region of femoral neck. For the THA limb, the proximal of femoral shaft indicate lower stress as the load is dominant in the prosthesis stem. The phenomenon described as stress shielding will enhance bone resorption, while higher stress value in bottom part leads to bone thickening. Furthermore, non-affected and non-operated limb also affected indirectly. Stress adaptation that indicated in on non-operated limb could contribute to poor gait stability.

## ACKNOWLEDGMENT

The authors wish to thank Prof. Yukihide Iwamoto and Assoc. Prof Yasuharu Nakashima from Department of Orthopaedic Surgery, Kyushu University for the clinical data support and encouragement.

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