Numerical simulation of artificial hip joint motion based on human age factor

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Abstract. Artificial hip joint is a prosthesis (synthetic body part) which usually consists of two or more components. Replacement of the hip joint due to the occurrence of arthritis, ordinarily patients aged or older. Numerical simulation models are used to observe the range of motion in the artificial hip joint, the range of motion of joints used as the basis of human age. Finite-element analysis (FEA) is used to calculate stress von mises in motion and observes a probability of prosthetic impingement. FEA uses a three-dimensional nonlinear model and considers the position variation of acetabular liner cups. The result of numerical simulation shows that FEA method can be used to analyze the performance calculation of the artificial hip joint at this time more accurate than conventional method.

1. Introduction

Total hip joint replacement is inevitable in orthopedic applications, which aims to improve the quality of life suffering from arthritis. Damage to the hip joint can be due to age and accident factors. Replacing damaged joints with artificial joints becomes the main thing and becomes a necessity in such a case. Replacement of the hip joint is an operating procedure to replace a damaged hip joint with an artificial hip joint [1].

Inadequate range of motion (ROM) after total hip arthroplasty (THA) may cause impingement of the prosthesis in the acetabular cup [2]. Aseptic release of the cup after total hip arthroplasty (THA) or dislocation is due to a breach between the neck of the stem and the edge of the cup [3]. The dislocation itself has two types; Initial dislocations occur due to the femur neck impingement of the acetabular liner cup, while the final dislocations are mostly associated with wear [4]. Total hip arthroplasty with the limited range of motion causes impingement on initial dislocation. The diameter of the femoral head, the diameter of the femoral neck and the position of the acetabular cup liner are the causes of the limitations of ROM [5]. Most of the available data related to the age-changing factor in normal ROM was obtained from studies involving small samples in which subjects were not randomly selected. Some of the existing studies include individuals of all ages, none of which explore the possibility of normal ROM [6]. This is influenced by impaired mobility of joints in the elderly as assumptions about normal ROM in elderly, in determining common hip ROM based on age at the population-based normative values considered important. Finite-element analysis (FEA) is used as a calculation by developing a three-dimensional model for the movement of artificial hip joints, in observing the impingement occurring in some cup liner acetabular position during the simulation motion [7]. This paper presents a 3D motion simulation to study the normal range of motion (ROM) in humans by the
age factor. Finite-element analysis (FEA) to observe impingement occurred and reported Von Mises stress relation, internal rotation and resisting moment.

2. Methodology

2.1 Finite Element method

The artificial hip joints in the finite element model for this study consisted of femoral head, femoral neck and acetabular cup liner. The femoral head and the femoral neck, are assumed to be rigid. In this simulation, the artificial hip joint is modeled using commercial software, ABAQUS [8]. The geometry model of the artificial hip joint follows the model kluess et al [7], as shown in Figure 1 (a). Diameter of the femoral head and the femoral neck are 28 mm and 14 mm respectively, thickness of the acetabular liner cup is 7 mm. Ultrahigh-molecular-weight polyethylene (UHMWPE) is used as a component material of the acetabular liner cup with the assumption of isotropic hardening [9]. The isotropic hardening with UHMWPE materials based on the work of fregly et al [10]. Where the elastic modulus, the poisson ratio and the yield strength of UHMWPE material are set to 945 MPa, 0.45 MPa and 23.56 MPa [11]. The calculation of plastic strain follows the work of Fregly et al [10], see the equations in Eq. (1).

\[
\varepsilon = \frac{1}{2} \varepsilon_0 \sigma + \frac{1}{2} \varepsilon_0 \left( \frac{\sigma}{\sigma_0} \right)^n
\]  

(1)

where the material parameter, \( n \), is equal to 3.

Figure 1 (b) shows a model of the hip joint with meshes the acetabular liner cup. The present model uses element type of hexahedral 8 nodes linear brick (C3D8R) is employed and the number of element 9000 [5]. The model now uses a load value based on the work of Kluess et al [7], but the direction follows results from Bergmann et al [12]. Loads in the x, y, z directions are set at the femoral head's Center Point with values \( F_x = 15 \text{ N}, F_y = 270 \text{ N} \) and \( F_z = -425.5 \text{ N} \), respectively.

(a.)  
(b.)

Figure 1. (a) Model of the hip joint with the femoral head and the acetabular liner cup and (b) Model of the hip joint with meshes the acetabular liner cup [5].

The model simulation process is done in two stages. First, it wears a load on the femoral head by limiting rotation to the femoral head. Second, the load applied to the center of the femoral head is limited by turning the femoral head. The range of internal rotational motion (IR) corresponds to the human age. The variation of the model angle follows Kluess et al [7]. The slope of the acetabular cup angle is 45º and 60º, and the acetabular cup-acetal antversion is 15º and 30º. The femoral neck axis angle and the stem axis line are 135º.
2.2 Range of Motion

The simulation is done based on human age, ROM value is taken based on work Roach et al [6]. Age range is divided into three groups, adult age range 25-39 years old, age range 40-59 years old and age range 60-74 years old. Table 1 shows the ROM by age. Each age range has a certain value at the ROM level. Maximum flexibility, abduction, internal rotation and external rotation are components of the ROM value.

| Age group               | Max. Flexion | Abduction | Internal Rotation | External Rotation |
|-------------------------|--------------|-----------|-------------------|-------------------|
| Adult age (25-39 years old) | 122º         | 44º       | 33º               | 34º               |
| Old age (40-59 years old)  | 120º         | 42º       | 31º               | 32º               |
| Elderly (60-74 years old) | 118º         | 39º       | 30º               | 29º               |

3. Result and Discussion

The hip joint model simulation developed following work of Saputra et al [5], previous model simulation validation comparing the work of Kluess et al (7). The anteversion of acetabular liner cups at 60º and 30º, the mean deviation of the model is 1.32%, respectively. Figures 2 (a) and 2 (b) how the level of impingement based on the human age. In Figure 2 (a) shows the internal rotation in the 25-39 years old, 40-59 years old and 60-74 years old age range taking into account four different position of the acetabular liner cup. The minimum internal rotation demand is 33º, 31º and 30º. Figure 2 (b) shows the highest resisting moments with values of 3.57 Nm, 3.58 Nm and 3.69 Nm. Most artificial hip joints do not caused impingement based on human age ROM.

![Figure 2](image-url)

Figure 2. (a) Comparison of the internal rotation value of the variation in the position of the acetabular cup of liners by age and (b) Plots the rejection moment as a function from an internal angle.

Figure 3 shows the simulation result of stress von mises analysis. In Figure 3 (a) shows the stress analysis age 25-39 years old, Figure 3 (b) shows the stress analysis age 40-59 years old and Figure 3 (c) shows the stress analysis age 60-74 years old. In all three age ranges based on figure analysis, it shows that there is impingement. This dislocation is also expected to occur in the age range 60-74 years old. The position of the acetabular liner cup for inclination and anteversion 45º-30º, 60º-15º, and 60º-30º, was also reported.
Figure 3. Stress von mises: a) acetabular liner age range 25-39 years old, b) acetabular liner age range 40-59 years old and c) acetabular liner age range 60-74 years old with impingement conditions.

The inclination and the anteversion of the acetabular liner cup combinations of 45° -15° are mostly used, proposed by Saputra et al [5]. The artificial hip joints need to be redesigned to accommodate different ROMs based on age.
4. Conclusions
This paper investigates the range of motion based on human age using finite-element analysis. The artificial hip joint of the unipolar model is used in the simulation. Based on simulation result range of motion mostly can be done safely. The impingement and dislocations are estimated to occur in the 60-74 years old age range, with the inclination and anteversion combination of the acetabular liner cup of 45° -15°. Violations between the femoral neck and the acetabular liner cups during contact situations can be predicted by finite-element simulations. The impingement position is higher than the yield strength of the matter it is shown in Von mises stress.

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