Analysis of Stress and load Distribution on Hip and Knee Joint after Unilateral Total Hip Arthroplasty

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Abstract. Total hip arthroplasty (THA) is a highly successful operation for treatment of osteoarthritis (OA) that can improve mechanical function and condition in the hip joint. Clinical studies have reported that hip and knee OA often occurs on contralateral (non-implanted) side after unilateral THA. Purpose of this study was to analyze and verify the clinical test data result by utilizing 3-dimensional (3D) static finite element method (FEM). Various material properties of THR implants were used to perform the analysis to show difference in force reaction and stress distribution in lower extremities. Results from this study suggest that both local and systemic stress-shielding occur on lower extremities. It demonstrates that the force reaction with unilateral THA surgery is carried more in ipsilateral side (implanted side) than contralateral side, while the maximum stress value was higher on contralateral side of femoral condyles than ipsilateral side.

Keywords: Total Hip Arthroplasty (THA), Finite Element Method (FEM), Osteoarthritis (OA)

1 Introduction

Total hip arthroplasty is a common surgical procedure for the treatment of hip osteoarthritis[1]. THA is highly successful operation performed hundreds of thousands of times worldwide each year and it provides patients with complete pain relief and improved hip functions[2]. However, recent studies have reported progression of hip OA might be related to the progression of knee OA[3]. Study done by Shakoor et al. reported that among patients whose initial THA was followed by total knee arthroplasty (TKA), 71% underwent TKA on the contralateral side[4]. Study also demonstrated that using gait analysis, medial compartment load of the knee was significantly higher in the contralateral knee compared to the treated side at 1-2 years after successful unilateral THA[5]. Another study done by Umeda et al. performed radiographic evaluation of the knee OA after THA. They reported that 33% of test subject showed progression of medial tibiofemoral OA on the contralateral side, while only 10% showed progression on the THA side[3]. The resistance to OA progression on the ipsilateral side may be caused by the lower offset and resultant lateral shift in mechanical axes[3].

Purpose of this study is to analyze and verify the clinical test result by utilizing 3-dimensional (3D) static finite element method. 3D model of lower extremity
including iliac crest, sacrum, femur, and tibia is created. Static loading is placed on the top of sacrum to determine the resultant stress and load distribution at the knee joint.

2 Material and Methods

Subject specific 3-dimensional finite element model of lower extremities of a man 47 years old and 176 cm tall was generated from computed tomography (CT) scans provided by Korea Institute of Science and Technology Information (KISTI). Left femur was chosen to be implanted with cobalt chrome alloy (Co-Cr) stem and head, UHMWPE acetabular cup as shown in Figure 1. The stem and acetabular cup models were created with commercial software Pro Engineer using the specifications from previous studies [6,7]. Final model consisting bone, implant and acetabular cup consisted of 79,965 nodes and 42,575 elements. ANSYS 13.0 was used for this study.

Boundary conditions were set to assume the static and stand still position. Proximal part of tibia was set as the fixed support and some surfaces where are anatomically attached by muscles such as adductor brevis, adductor longus, and cracilis were set to have zero rotation in all axes, permitting translation to all 3 axes. Nachemson performed in-vivo measurement on lumbar 3 of 70kg male and reported that the approximate axial load on the L3 is 500N in standing at ease case[8]. Therefore, the loading force of 500 N is applied on sacrum as shown in Fig 1. Two material constants (elastic modulus and poisson’s ratio) for typical implant materials were obtained from other literatures and some material properties (as denoted by N###) are arbitrarily created to see the effect of modulus on stress distribution as shown in Fig. 1[9-11].

3 Results

Simulation result showed that when Co-Cr implant was used, force reaction in ipsilateral(implanted) side was 269N and contrateral(nonimplanted) side was 233N as
shown in Fig. 2. Total force reaction was 15% higher in ipsilateral side compared to the contralateral side. As elastic modulus increased, force reaction increased on the ipsilateral side and decreased on the contralateral side.

Interestingly, the result showed that higher stress concentration occurred on the contralateral femoral head and condyles. Maximum equivalent stress value (von Mises) was higher for the model with Co-Cr implant when compared to the intact model (w/o implant). As elastic modulus increased, maximum stress on the contralateral head also increased whereas stress on contralateral femoral condyles decreased as shown in Fig. 3.
4 Discussions

Shakoor et al. demonstrated that the OA evolves nonrandomly; after the joint is unilaterally replaced, the contralateral limb was significantly more likely to show progression of OA than is the ipsilateral limb[4]. Natural load distribution on the femur is altered after the THA and the implant will carry a higher portion of the load, which is termed as stress shielding[12]. Finite element analysis result showed that load distribution on the ipsilateral side of Co-Cr hip implant was higher than contralateral side by 15%. Also, the contralateral side of Co-Cr hip implant had 8% lower force reaction compared to intact model.

However, maximum stress of contralateral femoral head showed increase of 9% and contralateral femoral condyles showed increase of 20% with Co-Cr. This is due to the fact that flexibility tends to be higher on the contralateral side since the elastic modulus of cortical bone is much lower than that of cobalt chrome alloy. This stress distribution rather than load shielding may be related to OA on hip and knee joint. Yoshida et al. reported that anomalous mechanical stress was main cause of progressing OA[13]. Max stress also occurred on the medial part of contralateral side (Fig 4), which showed a strong tendency to clinical OA occurrence[4].

Simulation result showed that as elastic modulus increased, maximum stress on contralateral femoral condyles decreased. Force reaction on knee joint showed similar pattern by decreasing as the elastic modulus decreased on contralateral side. This is caused by the rigidity material and difference in force flow. Since the femoral condyle is further away from the implant position, force reaction seems to be the main cause of this phenomenon.

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References

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238