The Effect of Malrotation of the Tibial Component of Total Knee Arthroplasty on the Tibial Insert Comparing Different Prosthesis: A Finite Element Analysis

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Introduction: Total knee arthroplasty (TKA) prostheses design and surgical procedure are both very important for knee kinematics and long term survivorship. One of the most common errors in the total knee arthroplasty procedure is malrotation of the tibial component. Ideal alignment of the tibial component is still being discussed. Biomechanical studies have demonstrated that stress on the tibial insert is closely related to polyethylene wear. The objective of this study was to analyze the effect of malrotation of the tibial component on stress on the tibial insert during squatting using a finite element analysis (FEA) comparing two different types of total knee prosthesis.

Methods: Two types of posterior-stabilized total knee prostheses, Scorpio NRG (Stryker Co., Kalamazoo, USA) (NRG) and FINE KNEE (Nakashima medical Co., Okayama, Japan) (FINE), were used for the analysis. The tibial insert of NRG is symmetrical and flat facilitating flexible axial rotation, and the insert of FINE is asymmetrical and congruent with the femoral component. Three dimensional FEA models, consisting of femoral component, tibial insert and tibial component, were constructed from the CAD data. Tetrahedral meshes were generated on these models by FEMAP ver.9.2 (Siemens PLM Software, Plano, USA). The numbers of nodes and elements were 28,254 and 121,536 for NRG, and 32,392 and 138,064 for FINE, respectively. Tibial inserts made from ultra-high molecular weight polyethylene were assumed to be elastic-plastic material and to follow von-Mises yield criterion, while femoral and tibial Co-Cr components were assumed to be rigid. Four nonlinear springs were attached to the tibial component in order to represent soft tissues around the knee. Its nonlinear force-displacement relation was given by,

\[ F = 0.18667d^2 + 1.3313d \]

As Fig. 1 shows, a vertical load was applied for the femoral component which rotated 135 degrees while a horizontal load along the AP axis was applied for the tibial component which internally rotated 15 degrees during knee flexion. Three different initial conditions of tibial components: normal (NRM), internally rotated 10 degrees (IR) and externally rotated 10 degrees (ER), were analyzed. NRM was defined by matching the coronal center of each component. An explicit finite element code LS-DYNA ver.971 and LS-PREPOST ver.4.0 (Livermore Software Technology Co., Livermore, USA) was utilized as a solver and a post-processor. The maximum von Mises stress on the insert surface of the post and condyles was analyzed separately.

Results: Maximum Mises equivalent stresses of tibial inserts are shown in Fig. 2 and Fig. 3. The stresses of post surface rapidly increased after post-cam engagement during roll-back motion. FINE ER had extremely high stress at an early stage of knee flexion because the edge of asymmetrical cam impinged the post. The stress of each FINE model at high flexion was higher than that of NRG. In terms of stresses
on the condyle surface, FINE IR model had high stress at an early stage due to the edge loading at medial posterior border. FINE ER and NRG IR had higher stress on the condyles than each NRM model.

**Discussion:** The axial alignment of components changes the contact area and affects the stress distribution on the contact surface. Wear and fracture of the insert is a common complication of TKA. Moreover, the impingement of components could affect a range of motion and lead to stiff knees. Revision surgeries are related to these complications.

Although many researchers have investigated the polyethylene wear using various analytical methods such as FEA and experimental measurements, most studies assumed the normal position of components. A few studies, to our knowledge, have analyzed the effect of malrotation of tibial components.

The results of this study revealed that NRM model of each prosthesis did not always have lowest stress throughout knee flexion. Though the amount of differences of stress was rather small, the favor of NRG was in ER position and the favor of FINE was in IR position. The increase stress of NRG IR and FINE ER indicated that those malposition should be avoided in TKA.

There are a few limitations about this study. One was boundary conditions. It is very difficult to represent in vivo kinematics of the knee. However, as parameters of this study had been all experimentally examined and roll-back motion of femur was well demonstrated, we consider the results were valid. The other is that this was single cycle analysis. Cyclic analysis is expected in the future study.

**Significance:** This study is the first study which analyzed the effect of malrotation of tibial components for the tibial insert during squatting using different prosthesis.
Fig 2. Stress of the post surface
Fig3. Stress of the condyle surface

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