Effect of Tibial Posterior Slope on the Kinematic and Patellofemoral Contact Force After Posterior-stabilized Total Knee Arthroplasty

Hideki Mizu-uchi, Ken Okazaki, Shigetoshi Okamoto, Satoshi Hamai, Umito Kuwashima, Koji Murakami, Yukihide Iwamoto.
Department of Orthopaedic Surgery, Kyushu University, Fukuoka, Japan.


Introduction:
Total knee arthroplasty (TKA) has become one of the most successful orthopedic procedures with reported survival rates of greater than 90% after 15 years. Some problems concerning the surgical techniques has been solved, however, the optimal angle of tibial posterior slope is still controversial for the postoperative knee function. Tibial posterior slope has some effects on the quadriceps force, PF contact force and knee kinematics. Increase of the posterior slope can contribute to improvement of knee flexion and reduce required quadriceps force. On the other hand, anterior tibial translation, posterior articular wear of the insert and anterior impingement of post in the posterior stabilized type (PS) TKA occurred when tibial posterior slope increased. Many clinical studies and cadaveric experimental studies tried to decide the optimal angle of the tibial posterior slope, however, wide range of the cutting error would have a mistaken evaluation.

Recently, some research used computational simulation with a musculo-skeletal model to diminish the limitation of the clinical and cadaveric experimental studies. Therefore, we expected to find the effects of the tibial posterior slope on the knee kinematics and kinetics clearly. The purpose of this study is to investigate effect of the tibial posterior slope on the quadriceps force, PF contact force and knee kinematics using the computer simulation.

Methods:

Computer Simulation
Weight-bearing stair-ascending activity was simulated in this study. The PS components (NexGen Legacy PS design, Zimmer, Warsaw, Indiana) were implanted for a female (162cm, 58kg). Initial coordinate was set up using a computer assisted design software program as our previous studies reported. The implant geometry was imported into a dynamic, musculoskeletal modeling program (LifeMOD/KneeSIM 2010; LifeModeler, Inc, San Clemente, California) (Fig.1). The hip and ankle joints had all three rotational degrees of freedom. The “ankle” section had no translational degrees of freedom. The “hip” section was constrained in the mediolateral and anteroposterior directions but was free to translate vertically under the axial force (in the direction of gravity) that generated a flexion moment at the knee. Quadriceps force, PF contact force and knee kinematics were computed during stair-ascending (from 87° of flexion to 6° of flexion). Sixteen different of the tibial posterior slopes were simulated in this study. Zero degree of posterior slope was defined as the perpendicular to the tibial mechanical axis. We changed the posterior angle at 1 degree intervals ranging from 0 to 15 degrees based on the origin of the coordinate (the center of the tibial insert) in the sagittal alignment.

Validation of the Computer Model
Experimentally (in-vivo) data were used to validate the computational model. Five female patients (mean age: 77, range: 72 to 86 years old, mean follow-up: 23.4 months, range: 9 to 35 months) received the same components with our computer simulation. Continuous sagittal radiological images of stair ascent were obtained for each patient using a flat-panel detector (Hitachi, Clavis, Tokyo, Japan), and analysed using an 2D-3D image-matching technique. Antero-posterior translation and angle of axial rotation of the femoral component relative to the tibial insert were compared between the results of the computer simulation and the in-vivo data.

**Results:**

Simulation of PF contact force and quadriceps force (Fig.2-a)

Quadriceps force and PF contact force were staying between 1500 and 2000 N for all tibial posterior slope from 87° to 65° of knee flexion. Both of the forces increased rapidly on 65° of knee flexion because maximum vertical load were put on the angle. After the peak force, the forces decreased gradually along with knee extension. Maximum quadriceps force were 2598 N (slope: 15°) to 3061 (slope: 0°) and maximum PF contact force were 2989 (slope: 15°) to 3171 N(slope: 0°). Increasing of the posterior slope decreased the maximum force. Fifteen percentage of the maximum quadriceps force and 6 percentage of the maximum PF contact force were decreased by 15° of the posterior slope relative to 0°, respectively.

Simulation of knee kinematic (Fig.2-b)

The femoral components translated anteriorly with the knee extension for all tibial posterior slope. Anterior sliding of the tibial component happened on 65° of knee flexion if the tibial posterior slope were more than 5°. Anterior impingement between the anterior aspect of the tibial post and the femoral component was observed on almost full knee extension if the tibial posterior slope were more than 10°.

Model validation with in-vivo data (Fig.3)

Anteroposterior translation and rotation of the femoral component were simulated closely approximated those measured in in-vivo data. Simulated knees demonstrated femoral rollback and femoral external rotation with knee flexion, although there was some inter-specimen variability in the magnitudes. The predicted rollback and rotation were also within the interspecimen variability of measured.

**Discussion:**

From the present study, quadriceps force and PF contact force decreased by increasing of tibial posterior slope. Increase of the tibial posterior slope induced the position of the femoral component more posteriorly. More posterior position of the contact points between components connect increase of the moment arm which relate to increase of the movement efficiency of the quadriceps to perform some activities. Some papers reported that during rollback contacts of the FT are shifted posteriorly, and the effective lever arm of the force of patellar tendon increases which reduce the loading of the patellofemoral joint.

Anterior sliding of the tibial component and anterior impingement of post in the PS TKA were some adverse effects of the posterior slope. In the present study, anterior sliding of the tibial component happened if the tibial posterior slope were more than 5°. The causes of instability are depended on diminished quadriceps strength, absence of the ACL, design of the implant or tibial posterior slope. Even though many factors can affect the sliding of the tibial component, we were able to evaluate the effect
of the posterior slope with all the same condition of other factors. Anterior impingement between the tibial post and the femoral component was observed on about full extension with more than 10° of tibial posterior slope. Bai et al reported that increased posterior slope cut angle significantly decreased tibial anterior compressive strains and significantly increased tibial posterior compressive strains, and encourage to cut the articular surface of the tibia at a 0° or 3° posterior slope provides the greatest tibial component stability. From their study and our results, surgeons should avoid to cut the proximal tibia with exceed 5 degrees of tibial posterior slope in PS TKA even though the optimal angle of tibial posterior slope is still controversial.

**Significance:**
Our computer simulation showed less than 5 degree of tibial posterior slope was recommended for PS TKA.