DESIGN OF THE FEMORAL CONDYLAR GEOMETRY OF THE ARTIFICIAL KNEE JOINT

Mitsumasa Matsuda(1), Takuzo Iwatsubo(1), Shozo Kawamura(1)
Hirotsugu Muratsu(2), Shinichi Yoshiya(3), Masahiro Kurosaka(3)

Department of Mechanical Engineering
Kobe University
Kobe
Japan

Orthopedics
Kakogawa Hospital

School of Medicine
Kobe University
Kobe
Japan

INTRODUCTION

The location of the knee joint contact point directly affects the lever arm of the quadriceps, which determines the force necessary to be generated for a given external moment(1). Inadequate sliding motion can impair knee function by increasing the likelihood of a flexion contracture, by reducing range of flexion and overtension of the soft tissues(2). The position of the femur on tibia has been determined by equilibrium(3) and minimum energy(4) methods. Primarily their main application was to the normal intact knee where the friction is small.

In this study, a new condylar geometry model of total knee replacement was developed, which can determine the displacement and rotation as a function of muscle force and soft tissue restraints. The validity of this model was determined by comparing the results with the existent design shapes of total knee replacement.

METHODS

We constructed two typical models of the knee joint motion. The first model was aimed to describe the quasi-static behavior of the tibio-femoral joint in standing on bilateral legs for weight bearing condition. Quadriceps force drives the knee extension, on the other hand hamstrings and gastrocnemius work as antagonists. Femur and tibia were bound by ACL, PCL, MCL and LCL. In the second model the femur was vertically fixed to describe the tibial motion relative to the femur in no-weight bearing condition. Hamstrings drives the flexion motion and quadriceps has the role of antagonistic muscle of the knee. The insertion locations of the ligaments on the tibia and femur were based on CT-images.

The objective of this study is to design the femoral condylar geometry of the total knee joint, which moves with low effort. The abilities of flexion and extension motion of the knee were evaluated in order to reduce the tension resistance of the peripheral soft tissue and to diminish the muscle force.

The numerical simulation of the knee flexion and extension motion was performed using the 2-D knee models taken in the sagittal plane. We determined the femoral condylar shapes of the total knee joint that satisfied the above mentioned evaluation factors. Femoral condylar geometries were generated from full extension posture to 130° flexion angle with one degree intervals.

RESULTS

The geometries of the femoral posterior condyle in the sagittal plane are shown in Fig.1. Model (I) is the proposed optimal design determined under weight bearing condition. Model (II) is the proposed design determined under no-weight bearing condition. Model (a), (b) and (c) are femoral condyles existent in production. Model (I) is the largest from all models. Model (II) is almost similar with model (a) as anterior-posterior length, but with smaller superior-posterior radius of the femur. Fig.2 showed the posterior radii variation of the femoral condyles. Our proposed models (I) and (II) have a continuous radii variation, while the existent models (a), (b) and (c) consist only of two

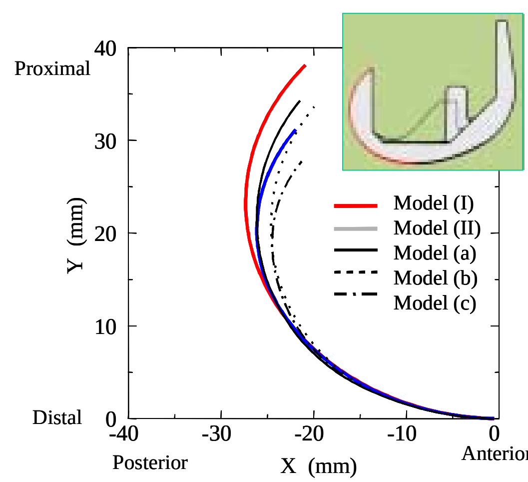


Fig.1 Geometries of the posterior femoral condyles in the sagittal plane. (Model (I): Proposed weight bearing model, Model (II): Proposed no-weight bearing model, Model (a), (b) and (c): Existent design)

or three radii. Radii at the full extension state are the same for all models. In the existent models the radii reduce around 25° flexion angle and then rest constant until full flexion. On the other hand, in our models the radii continuously diminish until 90° flexion. After 90° flexion, the radii of model (I) have a substantial increasing.

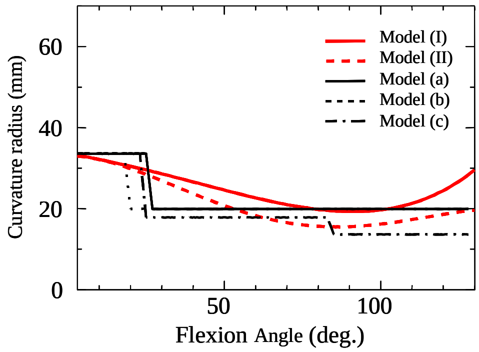
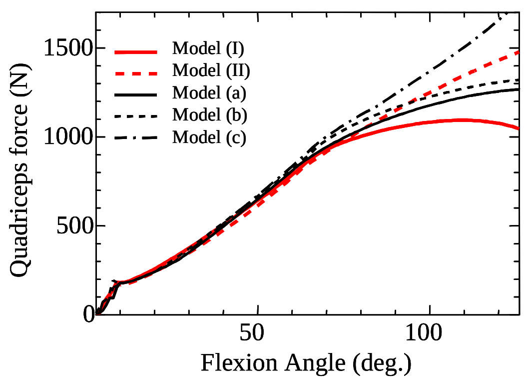
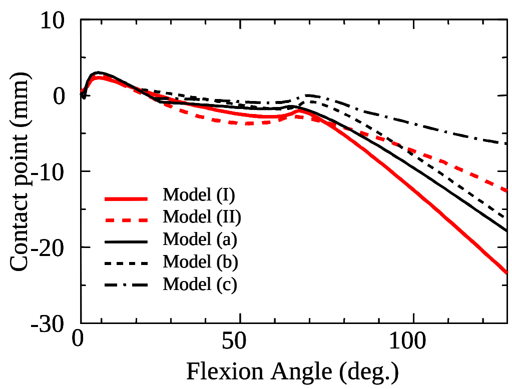


Fig.2 Comparison of femoral surface curvature radii. (Model (I): Proposed weight bearing model, Model (II): Proposed no-weight bearing model, Model (a), (b) and (c): Existent design)



(a) Quadriceps muscle force



(d) Contact point on tibial surface

Fig.3 Comparisons between the proposed models and existent models under weight bearing model condition. (Model (I): Proposed weight bearing model, Model (II): Proposed no-weight bearing model, Model (a), (b) and (c): Existent design)

Fig.3 shows the quadriceps forces and contact paths on the tibial surface, under weight bearing condition, when knee is in extention. There is little difference for quadriceps force from 60° flexion to full extension, in all models (Fig. 3(a)). Model (I) exhibits a strike reduction of the quadriceps force at large flexion angles, this means the high ability for stand up motion from squat state. The anterior–posterior displacements on the tibia were shown in Fig.3 (b). Rolling back phenomena with the flexion angle increasing is notable in model (I). This helps the high ability of squatting motion in standing phase under weight bearing condition. Model (I) exhibites the most suitable behavior followed by the existent design model (b).

CONCLUSIONS

It was proposed a generating method for the optimal femoral condylar shape. The proposed shape of the femur exhibited the reduction of the main active muscle force and the strain decreasing of the peripheral tissues. The proposed model has improved the flexion and extension motion abilities of the total knee joint.

(1) Under Weight Bearing Condition:

The optimal condylar shape of the femur exhibited larger radius at the posterior and the posterior-superior part, in comparison with existent design.

(2) Under Non-Weight Bearing Condition:

The optimal condylar shape of the femur exhibited smaller radius at the posterior and the posterior-superior part, in comparison with the optimal condylar design under weight bearing condition.

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