CONTACT CHARACTERISTICS OF THE KNEE JOINT IN DEEP KNEE FLEXION

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INTRODUCTION

It appears that the challenge in developing a TKR that allows for deep knee flexion is the understanding of knee mechanics when it is maximally flexed. Only few biomechanical studies have been published to describe the knee response at this position. The objective of the present work is to determine the contact characteristics of the knee joint during a deep squat while the knee is maximally flexed, up to 150° of flexion.

METHODS

An integrated human motion analysis system was employed to measure the relative spatial position of the right lower limb bones (foot, shank and thigh), and the ground reaction forces and moments for a subject performing a deep squat. The net equivalent external loads (forces and moments) at the knee joint for each position undertaken during the deep squat exercise were determined using inverse dynamics. Subsequently, and using a 2-D anatomical mathematical model, the knee joint internal loads including ligamentous forces, tibio-femoral contact force, and quadriceps and hamstrings equilibrating forces were calculated. For this purpose, the knee joint has been modeled as two rigid bodies, the tibia and the femur, undergoing general planar motion in the sagittal plane. The tibia was assumed fixed while the femur slides and rolls along the tibial plateau, without losing contact. Point of contact was enforced in the analysis. The model included ten ligamentous structures to represent the cruciate and collateral ligaments along with the posterior capsule, and two muscle forces: quadriceps and hamstrings. The quadriceps forces were applied through the patellar tendon. X-rays were obtained to determine the mathematical representation of the tibial and femoral articular surfaces. Polynomials of the second and third degrees were used to mathematically describe the different portions of the tibial plateau, the proximal posterior edge of the tibia, the different portions of the condyle, and the posterior and distal edge of the femoral shaft. Nissel’s data, 1985, were used to account for the change of orientation of the patellar tendon force with respect to the tibia. This model also accounts for the wrapping of the patellar tendon around the tibia at flexion angles larger than 90 degrees. For each value of flexion angle the system of equations describing the joint behavior consists of six (6) equations in seven (7) unknowns. The system of equations consists of three equations describing the single point contact and three equilibrium equations. The seven unknowns include the tibial and femoral x-coordinates of the contact point; the X- and Y-coordinates of the origin of the femoral coordinate system with respect to the tibial coordinate system; the tibio-femoral contact force; and the magnitude of the patellar tendon and hamstring forces. To solve this system of equations the patellar tendon force was assumed as a known quantity, and the
system of equations reduced to six (6) equations in six (6) unknowns. This approach simulated an isometric contraction of the quadriceps muscle associated with the co-contraction of the hamstring muscles.

RESULTS AND DISCUSSION

Results were obtained for 12 different positions of the knee joint during deep squat. Model calculations have shown that the path of the femoral contact point as the knee moved toward maximum flexion did not vary as the quadriceps force was changed. At maximum flexion, the contact occurred on the femur at the most proximal point of the femoral condyle. On the other hand, the path of the contact point on the tibia was found to highly depend on the level of quadriceps activation as shown in Fig. 1. In order to go beyond 135° of flexion, a minimum quad force of 3100 N was required, and the contact point on the tibia moved anteriorly as the knee flexion angle increased. When the quad force was kept constant at 900 N, the knee could not go into deep flexion, and the contact point on the tibia moved posteriorly as the knee flexion angle increased. In agreement with Hefzy et al., 1998, the results obtained from this study show that the contact point on the femur occurs on the most proximal point of the posterior condyle when the knee is in deep flexion. However, and while this study predicts that the contact occurs on the tibia anteriorly when the knee is maximally flexed, our previous work reports that it occurs posteriorly. This apparent discrepancy can be easily explained if one looks at the specific activity involving deep flexion. Figure 2.a shows the position assumed by the subject in the present study to achieve deep flexion, and Figure 2.b shows the position that was considered in our previous study. In this study, and to maintain the position shown in Figure 2.a, large quadriceps and hamstring forces were required. These forces have a large posterior component acting on the tibia, causing the tibial contact point to be located anteriorly.

SUMMARY

These results suggest that in order to understand the contact characteristics of the knee joint in deep flexion, more detailed studies need to be undertaken to account for the different activities involving deep knee flexion. By taking this into consideration, future design of TKR capable for deep flexion could be achieved.

REFERENCES