

THE FUNCTION OF THE ANTERIOR AND POSTERIOR CRUCIATE LIGAMENTS IN KNEE EXTENSION EXERCISE

Dumitru I. Caruntu and Mohamed Samir Hefzy

Department of Mechanical, Industrial and Manufacturing Engineering,
The University of Toledo, Toledo, OH, USA

E-mail: mhefzy@eng.utoledo.edu Web: www.mime.eng.utoledo.edu/biomechanics_lab

INTRODUCTION

Most of the anatomical three-dimensional models of the human knee are either static or quasistatic, and therefore they do not predict the effects of dynamic inertial loads, which occur in many locomotor activities. To the best of our knowledge, only two 3-D dynamic models of the human knee are available in the literature. First model, Abdel-Rahman and Hefzy, 1998, is a 3-D tibio-femoral joint model in which two spheres and two planes model the two femoral condyles and the two tibial plateaus, respectively. Yet, it accounts for a rigid contact formulation. Second model, Caruntu and Hefzy, 2001, is a 3-D model which includes both tibio-femoral and patello-femoral joints. It is an anatomically-based model accounting for deformable contact and allowing the wrapping of the quadriceps tendon around the femur, which occurs at large flexion angles.

In this work, we present the 3-D dynamic response of the human knee using the model of Caruntu and Hefzy, 2001. Simulations were conducted to study the response of the anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) in the knee extension exercise. A good agreement has been found between the model predictions and published data.

METHODS

The femur was fixed, and both tibia and patella underwent a general 3-D motion while a forcing function has been applied to the quadriceps tendon. The twelve degrees of freedom describing tibio-femoral and patello-femoral motions were defined using two joint coordinate systems and include 3 rotations and 3 translations for each of the tibia and patella. A simplified contact theory was used to allow for deformable contact at the articular surfaces. The patellar tendon was modeled as a linear spring. Along with the posterior capsule, the lateral and medial collaterals, and the anterior and posterior cruciates were modeled using 12 nonlinear spring elements, Abdel-Rahman and Hefzy, 1998. Coons' bicubic surface patches were employed to allow for piecewise mathematical representation of the femoral, tibial and patellar articular surfaces, Hefzy and Yang, 1993. The dynamic response was obtained by solving a system of nonlinear differential algebraic equations using DASSL, a solver developed

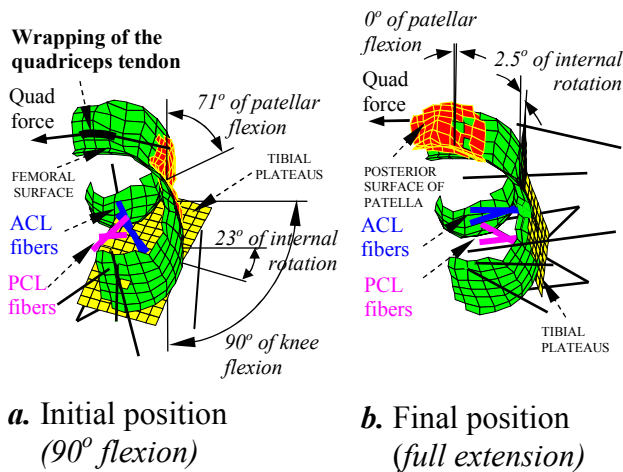


Figure 1: Initial and final positions

by Lawrence Livermore National Laboratory.

Model calculations were conducted to simulate the knee extension exercise and to predict the loads carried by the cruciate ligaments. Three quadriceps forcing functions have been considered. One of them has been specified using Grood *et al.*'s experimental data, 1984, as shown in Fig.2, the case of $F^q=200$ N. The other two forcing functions described a higher level of activation of the quadriceps, as shown in Fig.2, $F^q=400$ N and $F^q=600$ N.

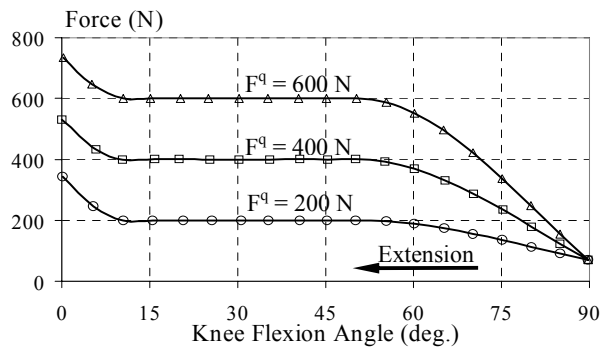


Figure 2: Forcing functions applied to the quadriceps tendon to simulate the knee extension exercise

RESULTS AND DISCUSSION

Model calculations for the knee extension exercise show that at full extension the ACL carries a larger force than the PCL, Fig. 3. Conversely, the force in the PCL is larger than the force in the ACL in the range of 75° to 90° of flexion. These results are in agreement with Wilk *et al.*'s data, 1996, since they reported that maximum posterior and anterior tibio-femoral shear forces occurred around 90° and 0° of flexion, respectively, and it is well known that the posterior and anterior tibio-femoral shear forces are resisted by the PCL and ACL, respectively. Also, our model calculations have shown that the maximum forces carried by the ACL at full extension are larger than

the maximum forces carried by the PCL near 90° of flexion. These findings are consistent with other investigators' data reporting that the greatest amount of tibial displacement occurs within the last 30° of knee extension in the knee extension exercise, Wilk *et al.*, 1996, Grood *et al.*, 1984.

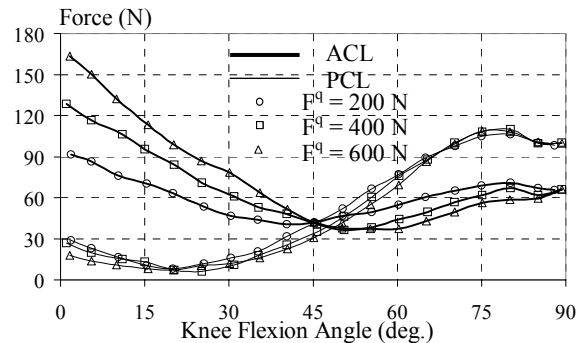


Figure 3: Forces of the ACL and the PCL versus knee flexion angle for different quadriceps forcing functions.

SUMMARY

Knee rehabilitation protocols are used to increase strength and improve range of motion. Different types of exercises are available for patients with ACL and PCL reconstructions. These results suggest that we need to limit initially the range of motion of the knee extension exercise to extensions (a) from 90° to about 45° of flexion for patients with ACL reconstructions and (b) from 45° to full extensions for patients with PCL reconstructions.

REFERENCES

- Abdel-Rahman, E.M., Hefzy, M.S. (1998). *Med. Engr. & Physics*, **20**, 276-290.
- Caruntu, D.I., Hefzy, M.S. (2001). *Proceedings of MEDICON 2001*, 600-603.
- Grood, E.S. *et al.* (1984). *J. Bone Joint Surg.* **66A**, 725-733.
- Hefzy, M.S., Yang, H. (1993), *J. Biomed. Engr.* **15**, 289-301.
- Wilk, K.E. *et al.* (1996). *Am. J. Sports Med.*, **24**(4), 518-527.