

# ANTERIOR-CRUCIATE LIGAMENT FORCES IN THE INTACT KNEE DURING NORMAL GAIT

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## INTRODUCTION

Few researchers have described knee ligament function in walking despite the many clinical investigations which show that knee ligament injuries, particularly injury to the anterior cruciate ligament (ACL), are the source of persistent neuromuscular adaptations in gait. Furthermore, most rehabilitation protocols following knee ligament injury and repair require normal kinematic and muscle activation patterns during ambulation before the patient may return to full activity. Understanding how the ACL is loaded during normal walking may help to establish more focused and efficient exercise regimens for rehabilitation following ACL injury.

To our knowledge only Morrison (1970) and Collins and O'Connor (1991) have reported ACL forces during gait. The paucity of data on ACL loading is due to the difficulties inherent in the measurement and calculation of muscle and ligament force *in vivo*. In this study, muscle forces obtained from a dynamic optimization solution for normal walking (Anderson and Pandy, 2001) were used as input to a three-dimensional model of the knee (Pandy et al., 1998) to determine knee-ligament forces during gait. The model calculations were analyzed to explain the pattern of ACL loading predicted for gait. Peak ACL force for walking was compared to estimates of ACL force obtained for rehabilitation exercises performed subsequent to ACL injury and repair.

## METHODS

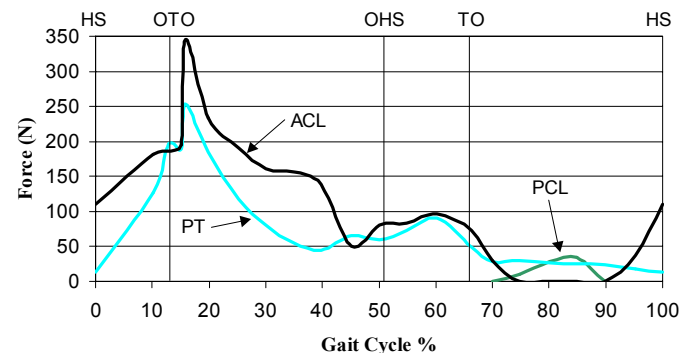
The right leg was modeled using four rigid bodies: thigh, shank, hindfoot, and metatarsals. All joints were represented as described by Anderson and Pandy (2001), except the knee, which was modeled as a six degree-of-freedom joint. The geometry of the distal femur, proximal tibia, and patella was based on cadaver data reported for an average-size knee. The contacting surfaces of the femur and tibia were modeled as deformable, while those of the femur and patella were assumed to be rigid. Thirteen elastic elements were used to describe the geometric and mechanical properties of the knee ligaments and capsule. Details of the knee model are given by Pandy et al. (1998). The model leg was actuated by thirteen musculotendinous units.

A combination of forward and inverse dynamics was used to determine knee-ligament forces in the model. Joint motion, ground-reaction forces, and the corresponding muscle forces obtained from the dynamic optimization solution for gait derived by Anderson and Pandy (2001) were input to the leg model. The dynamical equations of the motion for the three-

dimensional knee model were then used to determine knee-ligament forces at each instant during the gait cycle.

## RESULTS AND DISCUSSION

Figure 1 shows the calculated ligament forces for a complete cycle of gait, beginning at heel strike. The simulation results predict that the ACL is loaded throughout the stance phase of gait. The ACL is loaded throughout stance because the net shear force applied to the tibia is directed anteriorly during this time. Furthermore, the net shear force applied to the tibia is due mainly to the anterior pull supplied by the patellar tendon (not shown). The predicted peak ACL force during gait (344N) is similar to that found for maximum isokinetic knee extension at 300 deg/sec (340N, Serpas et al., in press) and is roughly twice as large as that reported for the leg lift exercise (160N, Shelburne and Pandy, 1997).



**Figure 1:** Force in the ACL and PCL during gait shown with the anterior tibial shear force applied by the patellar tendon.

## SUMMARY

Our calculations show that the ACL is loaded throughout the stance phase of walking, and that the force transmitted to the ligament rivals that predicted for maximum knee-extension exercise performed at high speed.

## REFERENCES

- Anderson, FC, Pandy, MG (2001). J Biomech Eng **123**(5): 381-90.
- Collins, JJ, O'Connor, JJ (1991). Proc Inst Mech Eng [H] **205**(1): 11-8.
- Morrison, JB (1970). J Biomech **3**(1): 51-61.
- Pandy, MG, et al. (1998). Comput Methods Biomech Biomed Engin **1**(2): 87-108.
- Serpas, F, et al. (in press). Comput Methods in Biomech Biomed Engin
- Shelburne, KB, Pandy, MG (1997). J Biomech **30**(2): 163-76.