FORCES IN ANTERIOR CRUCIATE LIGAMENT DURING SIMULATED WEIGHT-BEARING FLEXION WITH ANTERIOR AND INTERNAL ROTATIONAL TIBIAL LOAD

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INTRODUCTION

Although ACL forces during unloaded knee flexion have been investigated extensively (Xerogeanes, et al., 1995), experimental data on the ACL force during muscle-loaded flexion is scarce. Therefore, the objective of the current study was to experimentally determine the ACL force profile in a weight-bearing knee flexion and investigate the effect of external tibial loads on the ACL force during a weight-bearing flexion. We hypothesized that in a simulated knee flexion movement with muscle loads at a physiological level, (a) there is no significant difference in the ACL force at different flexion angles; (b) the external tibial load (anterior tibial force and internal rotation tibial torque) does not affect the ACL force.

METHODS AND PROCEDURES

An upright knee simulator was developed to simulate dynamic weight-bearing knee motion. The hip and ankle joints in the knee simulator were designed to allow unconstrained tibiofemoral movement in all six degrees of freedom. Linear electrical servo motors (Parker Hannifin, Offenburg, Germany) were incorporated to provide the vertical movement of the hip and to generate the forces in three quadriceps and two hamstrings tendons.

Nine fresh-frozen human cadaveric knee specimens with an age at the time of death of 71 ± 16 years (mean ± standard deviation) were mounted on the dynamic knee simulator.

Knee flexions with a prescribed 100N of body weight were simulated, while a robotic/universal force sensor (UFS) system was used to provide external tibial loads during the movement. Three external tibial loading conditions were simulated, including no external tibial load (termed BW only), a 50 N anterior tibial force (termed ATF), and 5 Nm internal rotational torque (termed ITT). The tibial and femoral kinematics was measured with an ultrasonic motion capture system (ZEBRIS® CMS100, Isny, Germany). These movement paths were then accurately reproduced on a robotic testing system before and after transecting the ACL, and the in-situ force in the anterior cruciate ligament was determined via the principle of superposition (Fujie, et al., 1993).

A two-way repeated-measure analysis of variance was conducted (SAS®, SAS Institute Inc., Cary, NC) to investigate the effect of flexion angle and external loading on the ACL force. A post hoc test using Tukey-Krammer method was also performed.

RESULTS

The first null hypothesis that there is no significant difference in the ACL force at different flexion angles was rejected, because our results of ACL in-situ force show the flexion angle affected the magnitude of the ACL in-situ force (p < 0.001). Meanwhile, the second null hypothesis was also refuted, since the tibial loading significantly changed ACL in-situ force (p < 0.003).
Comparing to the “BW only” condition, the addition of 50N anterior tibial force (ATF) significantly increased ACL force at flexion angles from 15 to 55 degree (p<0.04, Figure 1), while no difference was found in the ACL force between the “ITT” and “BW only” trials for all flexion angles (p>0.05, Figure 2). In each loading conditions, the ACL force remained nearly constant before it gradually decreased beyond 40 degree of knee flexion. The peak ACL forces of the “BW only”, “ATF”, and “ITT” trials was 33 ± 11 N (mean ± standard error), 54 ± 10 N, and 35 ± 5 N, respectively.

**DISCUSSION**

This study shows that, during a simulated weight-bearing flexion (“BW only” trials), the ACL is slightly loaded, and its magnitude decreases with knee flexion. This experimentally corroborates the widely-perceived belief that ACL forces are relatively low during squatting exercise (Shelbourne and Nitz, 1990).

Our results suggest that, in the presence of the muscle loading, ACL provides resistance primarily to an anterior tibial draw but not to a 5 Nm internal rotation torque. It therefore implies that the quadriceps tendons, joint capsule, and collateral ligaments are more likely the structures that restrict the rotational tibial torque.

**SUMMARY**

We experimentally verified that, in weight-bearing knee flexion, the magnitude of the ACL force is relatively low and decreases with increasing flexion angle. The anterior cruciate ligament plays a limited role in restricting axial rotation in a weight-bearing knee flexion exercise.

**REFERENCES**

Fujie, H et al. (1993), J Biomech Eng 115(3), 211-7