Effect of Limited Femoral Internal Rotation and Sex on the Number of Loading Cycles to ACL Failure during Repeated In Vitro Pivot Landings

Melanie Beaulieu, MSc, Youkeun K. Oh, PhD, Asheesh Bedi, MD, Edward M. Wojtys, MD, James A. Ashton-Miller, PhD.
University of Michigan, Ann Arbor, MI, USA.

Disclosures:

Introduction: Until the mechanics of anterior cruciate ligament (ACL) injuries and contributing factors are better elucidated, effective preventive strategies will continue to elude us. Current dogma is that ACL injury results from a single loading cycle, but recent evidence supports tissue fatigue as a possible failure mechanism [1]. In a cadaveric pivot landing model, ACL rupture was found to occur during cyclic loading, hence suggesting cumulative trauma leading to ACL tissue fatigue. Similar failures due to tissue fatigue have been reported in rabbit medial collateral ligament [2].

Limited hip motion in internal rotation, as exhibited by individuals with femoroacetabular impingement (FAI) [3], has been shown to be a contributing factor to ACL injury risk [4]. Could FAI increase ACL loading and thereby reduce ACL fatigue life under repeated loading this also reduce the ACL’s fatigue life. We tested the primary hypothesis that the number of loading cycles required to injury the ACL would be significantly greater in an in vitro model with adequate femoral internal rotation than in a model with limited rotation. Given that women are at a greater risk of sustaining an ACL injury [5], we also tested the secondary hypothesis that the female knee specimens would require a fewer number of cycles to ACL fatigue failure than the male specimens.

Methods: Six pairs of fresh-frozen knee specimens, for a total of 12 specimens, from 3 male (age: 59.3 ± 2.1 years; height: 1.79 ± 0.03 m; mass: 81.0 ± 11.3 kg) and 3 female (age: 59.0 ± 11.5 years; height: 1.69 ± 0.07 m; mass: 56.5 ± 9.8 kg) donors, were dissected. Only the joint capsule, including ligaments, and the tendons of the quadriceps, medial and lateral hamstrings, and medial and lateral gastrocnemii were left intact. The dissected knee specimens were inverted and mounted in a custom-built testing apparatus [6] in 15° of knee flexion. This apparatus simulated a jump landing with a ground reaction force approximating 3 times bodyweight by impacting the distal end of the tibia and producing a compression force, knee flexion moment, and internal tibial torque. Femoral axial rotation was controlled by a device at the proximal end of the femur that consisted of a circular plate able to rotate in the transverse plane and two pre-tensioned springs to resist axial rotation. Muscle forces were present and modeled by means of pretensioned elastic structures connected to the tendons. A differential variable reluctance transducer (MicroStrain, Burlington, VT) was inserted into the anteromedial bundle of the ACL to monitor relative strain at 2 kHz. Tibiofemoral kinematics and kinetics were recorded at 400 Hz via an opto-electric imaging system (Optotrak Certus, NDI, Waterloo, ON) and at 2 kHz via two 6-axis force sensors (AMTI, Boston, MA). From each donor, one knee specimen was randomly assigned to repeated pivot landings with limited femoral internal rotation (3.7 ± 0.7°) and the paired knee specimen to a pivot landing with adequate rotation (16.5 ± 2.3°). Each testing session began with 40 trials at 2xBW (16 non-pivot and 24 pivot trials) from which data were used for a separate study. Then, a non-pivot trial was executed to determine the height from which the weight needed to be dropped to achieve a 3xBW resultant force. Consecutive pivot trials were then executed until ACL injury occurred or until 100 trials were executed. Injury was defined as either a macroscopic failure of the ligament or a 3-mm increase in cumulative anterior tibial translation. The hypotheses were statistically tested by means of a Cox regression model with shared frailty (to account for paired knee specimens). This model predicted the number of loading cycles to ACL failure, with range of femoral internal rotation and sex as the predictor variables. An α < 0.05 indicated statistical significance.

Results: As depicted in Figure 1, ACL failure occurred within fewer loading cycles in the knee specimens with limited range of femoral internal rotation (23.3 ± 12.4 cycles; orange shaded area) in comparison to those with adequate rotation (34.7 ± 26.5 cycles; green shaded area). We were unable to accept the primary hypothesis, however, because this difference was not found to be statistically significant (hazard ratio = 0.93; p = 0.314). The secondary hypothesis was accepted as sex significantly predicted the number of loading cycles required to injure the ACL (Figure 1). Specifically, the number of cycles to failure was significantly lower in the female knee specimens than the male specimens (hazard ratio = 13.28; p = 0.022). All six female knees failed during the repeated pivot landings; failure occurred, on average, within 22.2 ± 16.8 cycles. On the other hand, only one of the six male knees failed during the landings and it did so within 30 trials.
**Discussion:** Results from the present study confirm previous findings that the human ACL is susceptible to a fatigue failure when the knee is loaded repeatedly in in vitro pivot landings [1]. Such results suggest that limiting the frequency of high impact loading cycles as part of an ACL injury prevention program warrants further investigation. This is particularly true for women because we found that a significantly lower number of loading cycles were required to fail the female ACL in comparison with the male ACL, with similar relative load magnitudes (females: 3.3 ± 0.2xBW; males: 3.0 ± 0.3xBW). A shorter fatigue life may explain why the ACL injury rate of women is two to five times greater than that of men [5]. Although range of femoral internal rotation was not found to significantly predict ACL fatigue life, hip range of motion should not be discarded as a contributing factor to ACL injury risk. Differences in the number of cycles to ligament failure were observed between femoral internal rotation conditions, with the lack of significance most likely due to the small sample size. It is noteworthy that only one male ACL failed. Loading magnitude and sample size should be increased in future experiments.

**Significance:** The female knee may be more susceptible to ACL injuries due, in part, to a shorter ACL fatigue life in comparison with the male knee. Limited femoral internal rotation is a potential contributing factor to ACL fatigue life, and thus ACL injury risk.

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**References:**

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