INTRODUCTION

The medial collateral (MCL) and anterior cruciate ligaments (ACL) are primary and secondary ligamentous restraints against knee abduction during gait, respectively.[1] Knee abduction is an ACL injury risk predictor and component of valgus collapse, which is often observed during ACL rupture.[2] The MCL is a primary ligamentous restraint to knee abduction at knee flexion angles under 30°. Despite this, MCL ruptures only occur concomitantly in 20-40% of ACL injuries.[3] The purpose of this investigation was to understand how athletic tasks load the knee joint in a manner that leads to ACL failure without concomitant MCL failure. The hypothesis tested was that the ACL would provide a greater overall contribution to intact knee forces than the MCL during simulated motion tasks. A second tested hypothesis was that the ACL would demonstrate greater relative peak strain than the MCL during simulated motion tasks.

METHODS

A 6-degree-of-freedom robotic manipulator articulated 18 cadaveric knees from 11 unique donors (age = 47.6 ± 7.3 years; mass = 829 ± 199 N) through simulations of kinematics recorded from in vivo athletic tasks.[4] Four athletic tasks were simulated (male drop vertical jump (DVJ), female DVJ, male sidestep cutting, and female sidestep cutting) while recording forces, torques, and changes in ligament strain simultaneously. Specimens were tested in both intact-knee and isolated-ligament conditions. The isolated ligament condition was also used to identify each ligament’s neutral strain position, allowing the absolute ligament strain throughout each motion to be determined. Following simulation, a uniaxial servohydraulic system tensioned each ACL and MCL to failure along their fiber orientations at a strain rate of 20% per second. Univariate ANOVA was used to evaluate statistical significance (α < 0.05) between the ACL & MCL within each robotically simulated task.

RESULTS AND DISCUSSION

During a DVJ in the intact-knee, the ACL showed greater peak strain than the MCL (6.1% vs. 0.4%; P < 0.01). Greater peak ACL strains were also observed during sidestep cutting tasks (5.4% vs. 0.5%; P = 0.02). In all simulated tasks for the intact-knee, the ACL was continuously under greater strain than the MCL throughout the duration of landing phase (Figure 1). The isolated-ACL condition also showed greater peak anterior force (4.8% bodyweight vs. 0.3% bodyweight; P < 0.01), medial force (1.6% bodyweight vs. 0.4% bodyweight; P < 0.01), flexion torque (8.4 N*m vs. 0.4 N*m; P < 0.01), abduction torque (2.6 N*m vs. 0.3 N*m; P < 0.01), and adduction torque (0.5 N*m vs. 0.0 N*m; P = 0.03) than the isolated-MCL condition. During uniaxial tensioning, ACL specimens preferentially loaded in the AM-bundle exhibited plastic strain of 28.0% and failure strength of 637 N, while MCLs exhibited plastic strain of 15.0% and failure strength of 776 N.

The data confirmed the hypothesis that the ACL would make larger mechanical contributions to knee joint restraint during athletic tasks than the MCL. Irrespective of gender, DVJ and sidestep cutting tasks generated significantly greater peak loads in the ACL than in the MCL. This confirms previously reported bias in ligament loading ratios.[5]
Figure 1: Population average absolute strains for the ACL (red) and MCL (blue) in the intact knee (solid) and isolated-ligament (dashed) condition throughout each simulated motion task. Throughout the majority of simulated tasks, the MCL was unstrained, while the ACL expressed up to 6.3% strain.

ACL:MCL loading ratios were exacerbated as the level of rigor for the simulated task increased. During the DVJ the mean ACL:MCL strain ratio was 15.3 while the sidestep cut ratio was 10.8. The increased ratios in the present study were the result of minimal strain being observed on the MCL throughout each simulation.

The ACL contributed significant torque (> 1.0 N*m) to the flexion and abduction DOFs, but not to internal torque resistance. Significant evidence, has supported valgus collapse as a primary mechanism of noncontact ACL injury.[2] In the present simulation model, the ACL made significant contributions (force > 1.0% bodyweight) to the anterior and medial forces. This corresponds with previous literature that identifies the ACL as a primary resistor to anterior tibial translation and a secondary resistor to medial tibial translation.[1]

CONCLUSIONS

Data from this investigation demonstrated the relative contributions of the ACL and MCL to knee joint restraint during simulated in vivo athletic tasks. In these controlled physiologic athletic tasks, where no ligament damage was inflicted on the specimen, the ACL provided greater contributions to knee restraint than the MCL, which was generally unstrained and minimally loaded. The current findings support that multi-planar loading during athletic tasks preferentially loads the ACL over the MCL, leaving it more susceptible to injury. A greater understanding of joint loading during in vivo tasks may provide insight that improves the efficacy of injury prevention protocols.

REFERENCES


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