PCL INJURY THRESHOLD UNDER DYNAMIC POSTERIOR LOADING

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Introduction: The posterior cruciate ligament (PCL) is the strongest ligament in the knee. It also provides 95% of the force resisting posterior displacement of the tibia. PCL injuries occur in as much as 3% of the general population.[1] The injuries can be isolated tears, resulting for example from hyperflexion in the athletic population[2]. More often, they are combined PCL injuries, resulting from posterior loading of the tibia when the knee impacts the instrument panel during automotive frontal crashes.[3] The long term functional deficits of such injuries include undesirable posterior tibial subluxation, chronic pain, and an increased risk of osteoarthritis.[4] The assessment of the injury risk to the PCL is mostly based on quasi-static studies, with the exception of one study in which five knees were flexed at 90 degrees and tested in dynamic posterior drawer at a speed of 1.8 m/s.[5] Only two PCL ruptures were observed[5], which is insufficient to establish a PCL injury threshold with certainty. The current study aims to determine the injury types, failure loads and failure displacements associated with the dynamic posterior loading of the knee.

Materials and Methods: A total of 14 knee specimens obtained from eight human cadavers (age 66±16 years, average±standard deviation) were tested at 90 degrees of flexion in posterior tibial draw. The knees were excised at mid shaft of the femur and tibia. They were potted in cylindrical pot holders made of aluminum using a room temperature curing polymer resin (Dynacast, Kindt-Collins Company LLC, Cleveland, OH). Three series of tests were conducted. In Series I, eight knees were tested with the patella and all the muscular and ligamentous structures intact. Henceforth, these knees will be referred to as 'intact knees'. In Series II, three PCL-only knees (with patella and all the muscular and ligamentous structures other than the PCL removed) were tested. In series III, three PCL-only knees (similar to Series II) were tested with an additional tibial protection device to prevent tibial bending fracture. A schematic diagram of the test setup is shown in Figure 1.

Testing apparatus and Instrumentation: All tests were conducted using a servo-hydraulic high-speed Instron testing machine (Model 8500, Instron Corp., Canton, MA). A custom made fixture was mounted on the Instron support columns using two aluminum yokes. It included two supporting plates and two guiding rails on which a carriage could translate on linear polymer bearings with a very low coefficient of friction. The femoral pot holder was mounted on top of the supporting plates while the tibial pot holder was clamped to the moving carriage. The actuator of the Instron was connected to the carriage using a steel cable with some slack allowing the actuator to reach the target speed before pulling the carriage. All specimens were tested at a speed of 1.8 m/s and a stroke of 75 mm or more to ensure knee injury. Foam blocks and two aluminum stoppers mounted on the guiding rails were used to slow down and stop the carriage at the end of the test. The posterior motion of the tibia was measured using a linear potentiometer (Model# LWH 225, Novotechnik, Southborough, MA) mounted between the sliding carriage and the yoke. The femoral force was measured using a 8.9 kN (2,000-lb) capacity load cell (Model# 2078-076, R.A. Denton Inc., Rochester Hills, MI) mounted between the femoral pot holder and the load cell mounting block.

Data acquisition and processing: Electronic signals from the load cell and linear potentiometer were sampled at 10,000 Hz using a T-DAS data acquisition system (Diversified Technical Systems Inc., Seal Beach, CA), and the data processing was automated using Scilab (INRIA/ENPC, France), a scientific software package.

Results: All specimens experienced one of the following injuries: simple transverse or oblique fracture of the tibial metaphysis, partial articular fracture of the tibia below the plateau, avulsion at the tibial insertion site with and without a partial articular fracture of the lateral plateau, or PCL mid-substance rupture. Because there were no statistically significant differences found when comparing test results among all three series, all data were grouped in terms of failure modes for further analysis. Partial articular fracture of the tibia below the plateau occurred in only one knee and was excluded from further analysis. The group with tibial metaphysis fractures included a total of seven specimens. The average failure force and displacement were 2.5±0.7 kN and 21.2±5.5 mm, respectively. Four specimens with PCL mid-substance ruptures had an average failure force and displacement of 3.6±0.6 kN and 18.2±2.9 mm, respectively. When comparing these two groups, it appeared that the failure force was significantly higher ($p<0.03$) for the group with ligament rupture compared to the tibial fracture group. Figure 2 shows the average response for the specimens in the tibial metaphyseal fracture and PCL rupture group. Error bars in this figure indicate the average and standard deviation at failure for these two injury groups. When grouping all PCL related injuries (mid-substance rupture and avulsion) together, the average failure force and displacement were 3.3±0.7 kN and 17.2±2.8 mm, respectively.

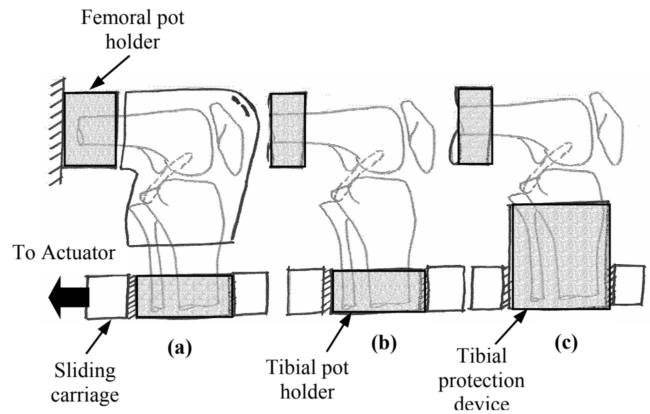

Figure 1: A schematic diagram of (a) Intact knee-Series I (b) PCL only knee-Series II (c) PCL-only knee with tibial protection device-Series III.

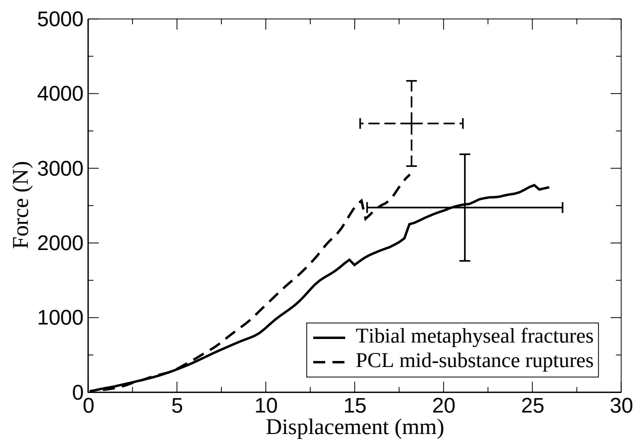

Figure 2: Average force-displacement responses for tibial metaphyseal fractures (n=7) and PCL mid-substance ruptures (n=4).

Discussion and Conclusion: Results from this study indicate that tibial metaphyseal fractures occurred more frequently than isolated PCL ruptures when the load is applied at approximately 100 mm below the joint center. For those injuries, the bending moment generated by the PCL could have fractured the tibia prior to PCL rupture. When aided with a tibial protection device, two mid-substance ruptures and one avulsion occurred. These data can be used to define a PCL injury threshold. Combining the PCL mid-substance ruptures observed in the current and Viano's study (n=6 total), the force and displacement at PCL mid-substance rupture during dynamic posterior loading are 3.3±0.7 kN and 18.2±2.4 mm, respectively.

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References: [1] Miyasaka K.C and Daniel D.M, 1991. [2] Parolie J.M and Bergfeld J.A, 1986 [3] Fanelli G.C, 1999 [4] Covey D.C and Sapega A.A, 1993 [5] Viano D.C et al, 1978.