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The Effect of Injury to the Posterolateral Structures of the Knee on Force in a Posterior Cruciate Ligament Graft

A Biomechanical Study*

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ABSTRACT

To determine whether untreated grade 3 posterolateral knee injuries contribute to a significant increase in force on a posterior cruciate ligament reconstruction graft, we measured the force on the graft during joint loading of a posterior cruciate ligament-reconstructed knee with otherwise intact structures and then selectively cut the popliteofibular ligament, popliteus tendon, and the fibular collateral ligament. A posterior cruciate ligament reconstruction was performed in eight fresh-frozen cadaveric knees. One end of the graft was fixed to a tensioning jig with a load cell used to measure force in the graft as loads were applied to the knee. The force on the graft was significantly higher with the posterolateral structures cut during varus loading at 30°, 60°, and 90° of flexion than it was in the same joint under the same loading conditions but with the posterolateral structures intact. Additionally, coupled loading of posterior drawer force and external tibial torque at 30°, 60°, and 90° significantly increased force on the graft with the posterolateral structures cut. There was no significant increase in force on the graft under any condition with a posterior force, valgus force, or internal and external tibial torque applied alone. A significant increase in force occurs in a posterior cruciate ligament graft in knees with deficient posterolateral knee structures. We recommend that in knees with grade 3 posterolateral injuries and evidence of varus or coupled posterior-external rotation instability the posterolateral structures be repaired or reconstructed at the time of posterior cruciate ligament reconstruction to decrease the chance of later graft failure.

Although the anatomy of the posterolateral structures of the knee has recently become more widely understood and better defined,[16,25–28,30] proper diagnosis of injuries to the posterolateral structures with a clinical examination is still difficult. Posterolateral rotatory instability resulting from injury to the posterolateral structures may be unrecognized because of subtle findings that can be overlooked on a physical examination, because these injuries are relatively less common and, in some cases, because they are combined with other ligament injuries.[2,3,10,11,21,22] The posterolateral drawer test, external rotation recurvatum test, adduction stress test at 30° of knee flexion, dial test at 30° and 90°, and reverse pivot shift tests are considered to be the most reliable tests for determining posterolateral injury.[6–8,10,12,13,18]

Patients with isolated PCL tears frequently have few functional limitations.[14,23] However, PCL tears combined with other ligament injuries of the knee cause more residual functional limitations.[11,21,22] It has been reported that undiagnosed, and therefore untreated, posterolateral structure injury is one of the factors associated with cruciate ligament reconstruction failure.[9,17,22] The referral pattern in our clinical practice is such that we receive many consultations for patients with PCL reconstruction failures. We have found most of these patients had untreated or failed reconstructions of posterolateral structure injuries.

Excluding cases in which there have been errors in graft tensioning, femoral or tibial tunnel placement, and fixation methods, we hypothesized that untreated postero-

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lateral structure injury may have adverse effects on PCL reconstructions. Our objective in this study was to determine whether untreated grade 3 posterolateral structure injuries[1] contribute to increased force in a PCL reconstruction graft, thereby contributing to PCL graft failure.

MATERIALS AND METHODS

Eight fresh-frozen cadaveric knees were used in this study. These knees demonstrated no evidence of previous surgeries or instability by clinical examination. The knees had approximately 15 cm of preserved soft tissue and bone on each side of the joint line and were frozen at –20°C. At the time of testing, the skin and subcutaneous tissues were removed from the knees and the following structures were identified: the iliotibial band and its components, fibular collateral ligament, fabellofibular ligament, components of the long and short head of the biceps femoris muscle, midthird lateral capsular ligament, popliteofibular ligament, popliteal aponeurotic attachments to the lateral meniscus, medial and lateral heads of the gastrocnemius muscle, oblique popliteal ligament, and the ligament of Wrisberg.[20,25–27] The femur and tibia and fibula were drilled with metal screws to prevent any rotational slippage during testing and were then potted in polymethyl methacrylate to allow attachment to the knee testing machine.[17] The longitudinal axis of the bones was aligned with the resin molds and the arms of the testing apparatus. The specimens were kept moist at all times by intermittent saline spray.

The central portion of the quadriceps tendon (12 by 80 mm), along with a 12 mm wide by 25 mm long bone block from the patella, was harvested for the PCL graft. An anteromedial parapatellar arthrotomy incision and a posterior arthrotomy incision, at the joint line in the interval between the superior border of the popliteus muscle and the inferior border of the oblique popliteal ligament, provided visualization of the femoral and tibial insertions of the PCL, respectively. The native PCL was then excised sharply, with care taken to protect the ligament of Wrisberg (which was present in all specimens). Arthrex PCL guides (Arthrex, Inc., Naples, Florida) were used to drill the femoral bone tunnel at the center of the anterolateral bundle of the PCL. An osteotome and mallet were used to deepen the trough of the PCL facet on the tibia such that the graft was pulled in line with the normal course of the PCL and so that the graft would be in the same position as the normal PCL attachment on the posterior tibia. The depth of this trough was approximately 4 to 5 mm, with a width of 14 mm. A bone tamp was used to smooth the surface of the trough to minimize friction on the graft.

The femoral bone block was secured in the femoral tunnel with a 9 by 25 mm cannulated interference screw (Arthrex, Inc.). The tibial end of the graft was secured through the tendon end with No. 5 nonabsorbable sutures (Ti-Cron, Ethicon, Inc., Somerville, New Jersey) in a whipstitch fashion. These sutures were then attached to a load cell mounted on a tensioning jig. The tensioning jig had a screw mechanism to apply tension[17] (Fig. 1). The jig was rigidly fixed to the posterior tibia with four K-wires and centered over the posterior tibial trough so that force applied to the graft was parallel to the trough. All surgical incisions were closed before testing. The knee was then mounted in the testing machine.

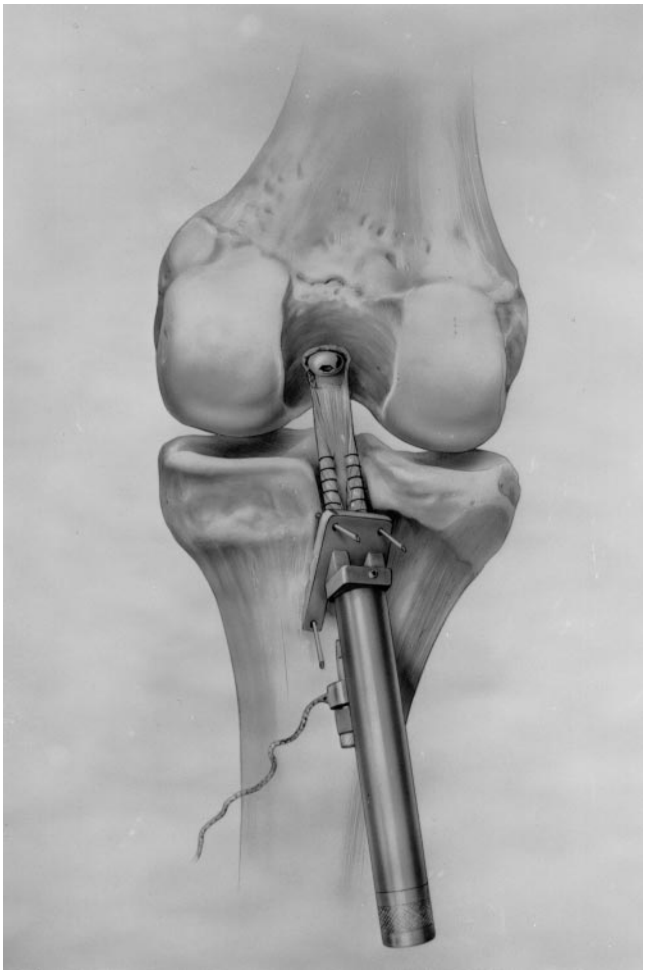

Figure 1. The tensioning jig on the proximal posterior tibia with a load cell secured to the PCL graft.

The PCL graft was tightened and secured in the testing machine while a 100-N anterior drawer force was applied to the knee at 90° of flexion and an 89-N distal traction force was placed on the graft. The 100-N anterior drawer force provided a standardized amount of force to simulate the clinical practice of applying an anteriorly directed force to reduce the posteriorly subluxated tibia during PCL graft fixation with the knee flexed to 90°. The 89-N distal traction force on the graft was used to simulate the clinical practice of pulling the tibial portion of the graft distally during fixation of the graft intraoperatively.[4,5,24] The pretension force on the graft was then measured via its attachment to the load cell. The pretension force on the PCL graft was the force measured when a posterior force of 67 N was applied to the tibia at 90° of knee flexion (simulating a posterior drawer force). The pretension force on the graft was found to average 92 N in our pilot study (see next paragraph) in four knees and was used as the pretension force across this study. The knee was then cycled several times through a full range of motion to minimize stress relaxation and the pretension force was rechecked. Recalibration of the graft pretension force was performed as necessary between testing cycles by adjusting the screw mechanism on the load cell of the tibial tensioning jig during application of the 67-N posterior drawer force at 90° of knee flexion.

A pilot study in four knees was performed before this study was begun so that we could determine the specific joint loads and level of pretension force on the PCL graft. Loads that were tested in the pilot study but not included in this study because no increased graft loading with posterolateral structure sectioning was seen were a posterior drawer force, internal and external tibial torque, and a varus and valgus torque applied at 0°.

The following loads were applied to the knee through the knee testing machine[18]: 67-N posterior drawer force, 10-N·m internal and external tibial torques, 12-N·m varus and valgus moments, and 67-N posterior drawer coupled with 10-N·m external tibial torque at 30°, 60°, and 90°. The pretension force on the PCL graft was recalibrated, if necessary, back to the baseline graft pretension force after each testing sequence for each angle of flexion. The testing sequence included loading the knee three times at each flexion angle (30°, 60°, and 90°) and averaging the results.

Joint loading was performed on the knees after simulated PCL reconstruction with the posterolateral structures intact and then after sequential cutting of the most important posterolateral structures as determined by our pilot and prior published studies.[25–29] In effect, this sectioning created a grade 3 posterolateral knee injury.[1] The popliteofibular ligament (both divisions) was sectioned first at its fibular attachment, followed by sectioning of the popliteus tendon (above the popliteal hiatus), and, finally, by sectioning of the fibular collateral ligament (midsubstance resection). We did not investigate the effect of varying the cutting sequence in this study.

Statistical analysis for the change in force on the PCL graft between the normal and sequential cutting states of the posterolateral structures during motion testing was performed with the Student's *t*-test. Statistical significance was assumed for *P* values less than 0.05.

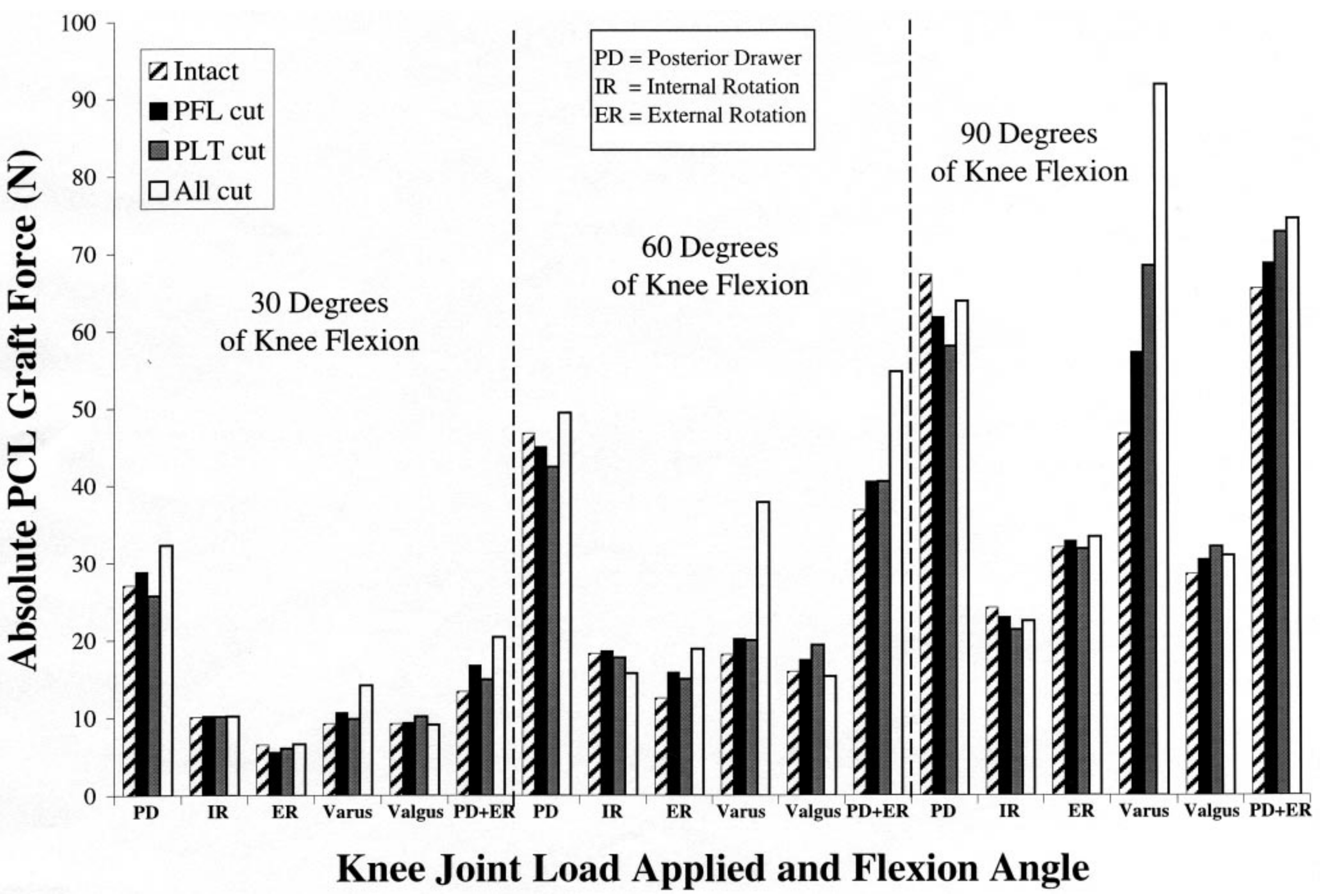

Figure 2. Absolute force on the PCL graft with joint loading conditions after sequential sectioning of the popliteofibular ligament (PFL), popliteus tendon (PLT), and all posterolateral structures (popliteofibular ligament, popliteus tendon, and fibular collateral ligament).

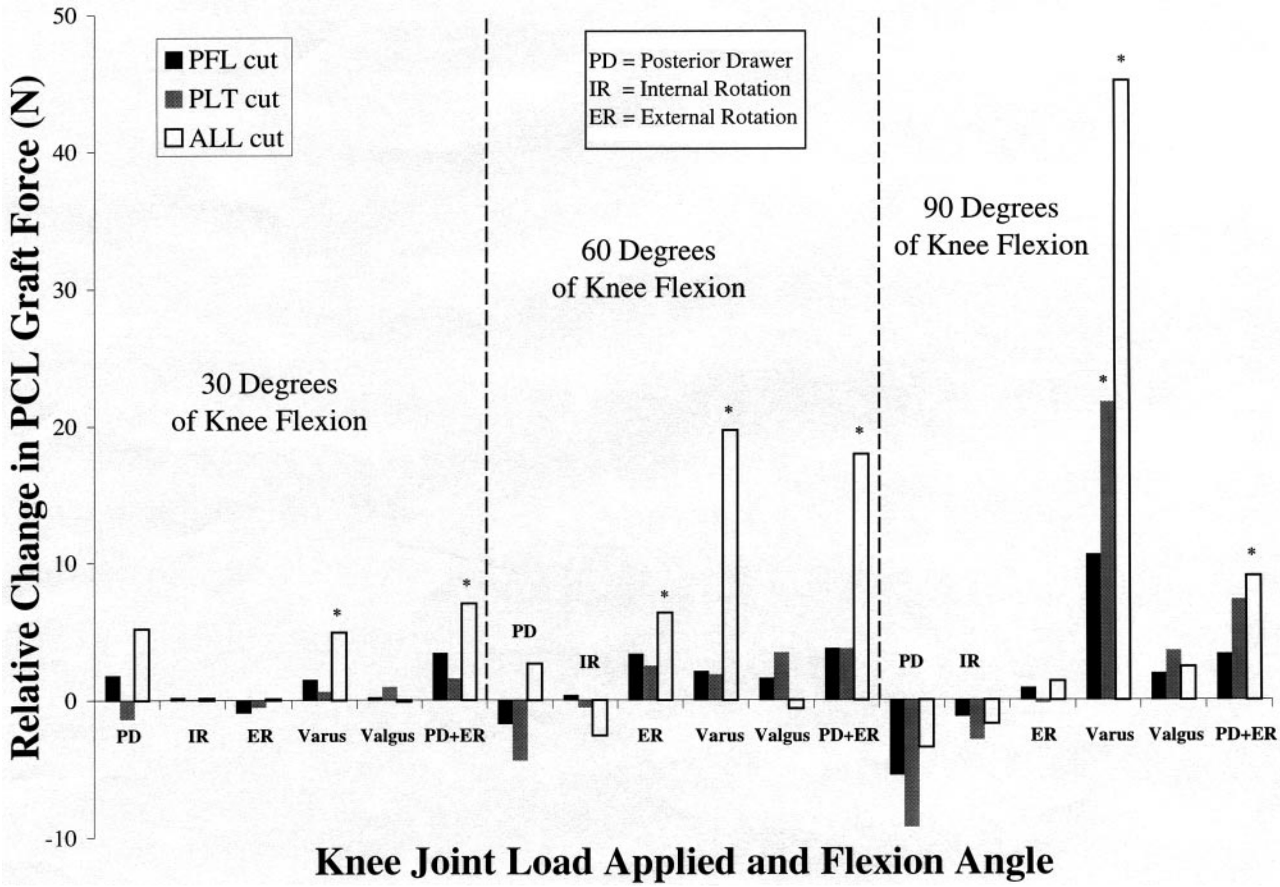

Figure 3. Change in force seen in the PCL graft with sequential sectioning of the popliteofibular ligament (PFL), popliteus tendon (PLT), and fibular collateral ligament (ALL) compared with the intact posterolateral structure state with joint loading. *, statistically significant change ($P < 0.05$).

RESULTS

The absolute forces seen in the PCL graft at each testing condition are reported in Figure 2. Figure 3 summarizes the increase (or decrease) in force seen on the PCL graft during testing after sequential sectioning of the popliteofibular ligament, popliteus tendon, and the fibular collateral ligament relative to the force on the PCL graft with these structures intact. Significant findings are summarized as follows.

The PCL graft force was significantly higher when all three posterolateral structures were transected, compared with loading of the joint with the posterolateral structures intact, with an applied varus moment at 30° ($P < 0.02$), 60° ($P < 0.02$), and 90° ($P < 0.02$) of knee flexion. A significant increase in PCL graft force was also seen after sectioning of the popliteofibular ligament and popliteus tendon when a varus moment was applied at 90° of flexion ($P < 0.02$). In addition, coupled loading of a posterior drawer force and external tibial torque at 30° ($P < 0.05$), 60° ($P < 0.01$), and 90° ($P < 0.002$) of flexion increased the force on the PCL graft for the posterolateral structure-transected state compared with loading of the joint with posterolateral structures intact. A significant increase in force on the PCL graft was also seen when all structures were cut and external rotation torque was applied with the knee at 60° of flexion ($P < 0.04$).

DISCUSSION

We found that there was a significant increase in force on a PCL graft when the main posterolateral structures (popliteofibular ligament, popliteus tendon, and fibular collateral ligament) were transected, compared with the state with the posterolateral structures intact. We believe that this verifies our clinical observation that failure to repair grade 3 posterolateral structural injuries at the time of PCL reconstruction places the PCL graft at risk for failure by increasing the force on the graft. The most important joint-loading conditions that increased the force on the PCL graft were a varus moment and a coupled posterior drawer force and external rotation torque. Both of these loading states independently caused a significant increase in graft forces at 30°, 60°, and 90° of knee flexion with a simulated posterolateral structure injury. Posterolateral structure injury should be made apparent by the presence of motion abnormalities detectable through the varus stress test at 30°,[7,10,18] the posterolateral Lachman test,[18] the reverse pivot shift test,[13] and the posterolateral drawer test.[12,18]

Markolf et al.[19] reported that, with sectioning of the posterolateral structures, varus moments increased the force on the native PCL. In addition to our finding that a varus moment causes an increase in force on a PCL reconstruction graft when the posterolateral structures have been cut, we have also previously reported that a varus moment in patients with a combined ACL and grade 3 posterolateral structure injury significantly increases the force on an ACL graft.[17] This implies that those structures that prevent increased varus joint line opening, primarily the fibular collateral ligament and secondarily the popliteus tendon, popliteofibular ligament, and the midthird lateral capsular ligament,[15] are important structures for preventing a significant increase in force on either an ACL or PCL graft.

Our findings demonstrated that a coupled posterior drawer and external rotation torque increased the force on the PCL graft across all flexion angles tested (30°, 60°, and 90°). The posterolateral structures have been implicated as an important secondary restraint to the PCL in preventing increased posterior translation in the knee.[6,8] Other authors have demonstrated that the role of the posterolateral structures in preventing posterior translation increases as the knee moves from 90° of flexion toward full extension.[6,8] Because we found no significant increase in graft force with a posterior drawer force or an external rotation torque separately (except for external rotation at 60° for all posterolateral structures sectioned), we postulate that it is the coupled increase in posterior translation that occurs with the external rotation torque, as opposed to a straight posterior translation, that caused the significant increase in force on the PCL graft when these forces were applied together.

The limitations of this study are that it is a cadaveric study in which only static loads were tested. The potential influence of dynamic loads, as would be seen clinically, cannot be determined with our testing model. We also speculate that increased applied loads, which are outside the limits of our joint-loading system, could potentially demonstrate a significant increase in force on the PCL graft for either a straight posterior drawer force or an external rotation torque when the posterolateral structures are cut.

In conclusion, we found a significant increase in force occurred in a PCL graft after the posterolateral structures were cut when a varus moment or a coupled posterior drawer force and external tibial rotation torque was applied. We believe that this study verifies the clinical observation that untreated grade 3 posterolateral injuries contribute to PCL graft failures by allowing significantly higher forces on the PCL graft. We recommend that for knees with PCL tears and combined grade 3 posterolateral structure injuries that have evidence of varus or coupled posterior drawer-external rotation instability, the posterolateral structures be repaired or reconstructed at the time of PCL reconstruction to decrease the chance of PCL graft failure after reconstruction.

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