
Abstract
Posterior cruciate ligament injuries occur much less frequently than anterior cruciate ligament injuries. We review the important physical examination and radiographic findings, as well as provide the indications for nonoperative and operative treatment.

Posterior cruciate ligament (PCL) injuries account for 3% to 23% of knee injuries. In a trauma setting, they are responsible for up to 40% of all knee ligamentous injuries. However, because they are often asymptomatic, PCL injuries are underdiagnosed. In a review of 19,530 athletic injuries occurring over a 10-year period, anterior cruciate ligament (ACL) injuries occurred 31 times more often than PCL injuries. In this population, 20.3% sustained ACL injuries, while only 0.65% had injury to the PCL. Participation in soccer (35%) and skiing (26%) most commonly led to PCL injury.

Anatomy
The PCL has an anterolateral and a posteromedial bundle. It originates approximately 10 mm inferior to the joint line of the posterior tibia and extends in an anteromedial direction to attach to the lateral aspect of the medial femoral condyle. The anterolateral bundle is tight in flexion, while the posteromedial bundle is tight in extension (Fig. 1).

The PCL is the primary restraint to posterior tibial translation and a secondary restraint to external tibial rotation. At both 30° and 90° of flexion, the PCL resists 85% to 100% of posteriorly directed forces. The meniscofemoral ligaments act as secondary stabilizers to posterior translation of the tibia, with the ligament of Humphrey located anterior to the PCL, and the ligament of Wrisberg located posterior to the PCL. These ligaments originate from the posterior horn of the lateral meniscus and insert onto the lateral aspect of the medial femoral condyle. With the knee at 90° of flexion, the meniscofemoral ligaments provide approximately 28% of the total force resisting posterior tibial translation. The posterolateral corner also acts as a restraint to posterior tibial translation, especially when the PCL is deficient.

At its midsubstance, the anterolateral bundle of the PCL is approximately twice the size of the posteromedial bundle in cross-section. The anterolateral bundle is also stiffer and has a higher ultimate load to failure. Therefore, PCL reconstruction has been focused on recreating the anterolateral bundle. However, clinical outcome has been inconsistent. Variables, including graft material, placement of tunnels, number of bundles reconstructed, fixation method, and position of the knee at the time of fixation, all contribute to the results.

Mechanism of Injury
Both high and low velocity mechanisms can result in PCL injuries. A high velocity injury, called the “dashboard” injury, classically occurs in a motor vehicle accident when there is a posteriorly directed force onto the proximal tibia of a flexed knee. Low velocity injuries occur with knee hyperflexion in sports-related injuries that occur when the foot...
is in a plantar flexed position.\textsuperscript{7,8} When PCL ruptures occur, the tears typically occur in its midsubstance.\textsuperscript{9}

**Physical Examination**

There are several tests that can be used to examine for posterior and posterolateral instability (Table 1). The posterior drawer test is the most sensitive diagnostic test for PCL injury. This test is performed with the knee flexed to 90° and a posteriorly directed force is applied to the proximal tibia. It is important to recognize that the medial tibial plateau is normally approximately 1 cm anterior to the medial femoral condyle.\textsuperscript{10} If this relationship is not noted, it is possible to get a false positive of the Lachman or anterior drawer test. The posterior drawer test is graded according to this relationship.\textsuperscript{9} In a grade I injury, the tibia is still located anterior to the medial femoral condyle. The tibia can only be translated 0 to 5 mm posterior to the femoral condyle. In a grade II injury, the tibia is situated flush with the medial femoral condyle. The tibia can be translated 5 to 10 mm posterior to the femoral condyle. In a grade III injury, the tibia is displaced posterior to the medial femoral condyle. The tibia can be translated greater than 10 mm posterior to the femoral condyle.

The posterior sag test is performed with the ipsilateral hip and knee both flexed to 90°.\textsuperscript{11} If the PCL is torn, there may be an abnormal contour or sag evident at the proximal anterior tibia when viewed from a lateral position.

The quadriceps active test is performed with the patient supine and the knee flexed to 90°.\textsuperscript{7} The patient is asked to contract his quadriceps muscle or slide his foot down the table. The tibia will then translate anteriorly from a posteriorly subluxated position. Valgus and varus stability should be examined at 0° and 30° of flexion to determine whether an associated lateral collateral ligament (LCL) or medial collateral ligament (MCL) injury is present.

There are also several tests that can be used to examine for a concurrent posterolateral corner injury. The reverse pivot shift test is performed with the leg externally rotated. A valgus stress is applied to the knee while it is extended from approximately 70° to 80° of flexion.\textsuperscript{12} A positive test is seen with palpable reduction of the displaced tibia. The dial test can also be used to assess posterolateral corner injury.\textsuperscript{11} External rotation of both legs is compared with the knee flexed at 30° and 90°. External rotation is measured using the medial border of the foot or the tibial tubercle as a reference point. A positive test is seen with external rotation increased at least 10° to 15°, compared to the contralateral, uninjured side. Increased external rotation noted to be present only at 30° signifies an isolated posterolateral corner injury. External rotation increased at both 30° and 90° signifies the presence

| Table 1 Physical Examination Tests for Posterior and Posterolateral Instability |
|-----------------------------|--------------------------------------------------|
| **Posterior drawer**        | Knee is flexed to 90°; posteriorly directed force is applied to proximal tibia. |
| **Posterior sag**           | Ipsilateral hip and knee are flexed to 90°; observe the knee from a lateral position for abnormal contour or sag at proximal anterior tibia. |
| **Quadriceps**              | Knee is flexed to 90°; patient either contracts quadriceps muscle or active test slides foot down table. Observe for tibia translating anteriorly from a posteriorly subluxed position. |
| **Reverse pivot shift**     | With leg externally rotated, valgus stress is applied to knee while it is extended from 70° to 80° of flexion. Test is positive when tibia reduces at approximately 20° of flexion. |
| **Dial test**               | External rotation of legs is compared with the knee at 30° and 90° of flexion. |
of concomitant posterolateral corner and PCL injuries. This test may be more easily performed with the patient in the prone position.

Finally, a strict neurovascular exam should be performed. Posterior tibialis and dorsalis pedis pulses should be examined along with distal sensation. Peroneal and tibial nerve motor function should also be evaluated.

**Imaging**

Plain radiographs obtained as part of the routine work-up for any suspected knee injury include the anteroposterior (AP), lateral, sunrise, and tunnel views. Bony avulsion injuries as well as posterior subluxation may be seen on these views. Since avulsion injuries often do well with immediate repair, it is important to make this diagnosis early. Furthermore, a tibial plateau fracture can indicate a more severe injury. Joint space narrowing may be seen with a chronic PCL injury on the weightbearing AP and sunrise views.

Stress radiographs have been advocated to help differentiate between complete and partial PCL tears. Clinical exam is often quite variable. Furthermore, while magnetic resonance imaging (MRI) is extremely sensitive (97%) for identifying PCL tears, it has been shown to be less sensitive in differentiating complete from partial tears (67%). A complete PCL tear is defined as one with no functional fibers resisting posterior tibial translation observed during diagnostic arthroscopy. A partial tear has functional fibers within the ligament that resist posterior tibial translation excluding the ligaments of Humphrey and Wrisberg.

Hewett and colleagues examined 21 patients with PCL tears, of which 10 had complete and 11 had partial tears. A lateral radiograph was taken with the knee flexed to 70° and an 89 N weight suspended from the tibia at the level of the tibial tubercle. The tube-to-cassette distance was set at 1 meter. Translation was measured as movement of the posterior tibial plateau in relation to the posterior aspect of the femoral condyles. Up to 8 mm greater translation of the medial tibial plateau was seen in the presence of a complete tear (12.2 ± 3.7 mm), compared to that seen with a partial tear (5.6 ± 2.1 mm). Complete or partial tear of the PCL was confirmed at diagnostic arthroscopy.

Disadvantages to stress views include the possibility of guarding by the patient, which can activate the quadriceps muscle and reduce the extent of posterior displacement. Furthermore, there is a learning curve for taking and measuring stress radiographs.

MRI has shown a very high sensitivity and specificity, up to 100%, in identifying complete PCL tears. Unlike ACL tears, meniscal tears are seen less often in association with PCL tears. This may be due to decreased load on the posterior horns of the medial and lateral menisci associated with posterior translation of the tibia. Bone bruises also are less commonly seen with PCL tears than with ACL tears.

Bone scans have been recommended in patients with chronic PCL injuries who present with pain and instability. Although rarely used, it may help identify early degenerative changes in the medial and patellofemoral compartments.

**Natural History of PCL Injury**

Determining the natural history of PCL injuries is important for determining whether surgically reducing posterior laxity results in a better outcome in patients with greater laxity. In fact, residual posterior knee laxity after PCL reconstruction has not been unusual. All current reconstructive techniques (tibial inlay, single and double bundle transtibial) are only able to reduce posterior tibial translation to within 0 to 2 mm of the intact PCL in response to an applied posterior tibial load.

The natural history of isolated, partial PCL tears is relatively benign. Two percent of college senior football players in the NFL (National Football League) predraft examinations were found to have chronic PCL-deficient knees. Harner and Hoher hypothesized that this is most likely due to portions of the PCL that remain intact, as well as secondary restraints, such as the ligaments of Humphrey and Wrisberg. However, the long-term result of these injuries is not entirely without consequence. The tibiofemoral contact point moves anteriorly due to the posterior subluxation of the tibia and can lead to increased contact pressures in the medial and patellofemoral compartments, eventually resulting in degenerative changes in these areas. Several studies looking at the natural history of PCL injuries, primarily grade I and II injuries, have allowed us to arrive at these conclusions.

Parolie and Bergfeld examined 25 patients treated nonoperatively for a group of patients that were primarily grade II PCL injuries, 11 of which were acute and 14 were chronic. At a mean follow-up of 6.2 years (range, 2.2 to 16 years), 80% of the patients were satisfied with their knee status and 84% of patients had returned to their previous sports. Of those capable of returning to athletic activity, 68% were able to return to the same level of performance and 16% of patients returned at a diminished level. The investigators found that instability, as determined by the KT-1000 arthrometer, was not related to the patient’s return to sport nor to their level of satisfaction. They also found that if the patient maintained quadriceps strength, he or she was usually able to return to athletic activity. When arthritis developed, it was typically present within the medial compartment.

Fowler and Messieh followed 12 PCL tears prospectively, seven complete midsubstance and five partial, for an average of 2.6 years. Approximately, half of the patients had a trace 1+ posterior drawer and the other half a 1+ posterior drawer. Subjective scores were better than objective. Residual instability was not necessarily correlated with outcome. In fact, absolute stability was not necessarily correlated with functional stability.

Torg and associates reported on 43 patients with chronic PCL injuries (14 isolated and 29 with combined ligamentous injuries) that were followed for an average of 6.3 years (range, 1 to 37 years). They concluded that
while isolated PCL injuries would most likely remain asymptomatic over the long-term, combined injuries tended to result in degenerative changes in both the medial and lateral compartments.

Shelbourne and Gray reported on the follow-up MRI findings of 40 knees with acute PCL injuries. Twenty-three were isolated injuries and 17 were combined injuries. The follow-up MRI was performed at an average of 3.2 years later (± 1.3 years). The investigator found that all partial tears had healed, and 86% of the complete injuries had regained continuity. However, the PCL did not heal back to a normal configuration. Furthermore, these findings were not correlated with a clinical exam.

In 2005, Shelbourne and Muthukaruppan prospectively followed 215 patients with acute, isolated PCL injuries. Patients had either a grade I or grade II injury and were followed for an average of 7.8 years (range, 1 to 18 years). In this cohort, the amount of PCL laxity did not correlate with subjective scores, including a modified Noyes subjective knee survey and the International Knee Documentation Committee (IKDC) Subjective Knee Survey. Moreover, these subjective scores did not decrease from the time of injury. They were unable to identify which characteristics would predict worsening knee function. Although reconstruction was eventually used in nine cases, the investigators concluded that 80% of ruptures can have good or excellent results with effective nonoperative management.

Fontbote and coworkers compared 10 subjects having chronic grade II PCL deficiency with 10 control subjects in gait and one-legged vertical drop from 30 cm. The chronic injuries were examined approximately 4 years after injury. There was no significant difference in strength testing or muscle group activity. They concluded that PCL-deficient patients may not have symptoms of instability that prevent them from being active.

**Treatment Options**

**Acute Injuries**

Isolated grade I and II PCL injuries are usually treated with progressive weightbearing and rehabilitation, and most importantly, strengthening of the quadriceps muscle. These patients are usually able to return to activities within 4 to 16 weeks of the injury.

The treatment of isolated grade III injuries is more controversial. Acutely, the knee is immobilized in full extension for 2 to 4 weeks. This decreases tension on the anterolateral bundle. Furthermore, it accounts for unrecognized posterolateral corner damage that can lead to further subluxation. The patient is then started on progressive weightbearing, with active, assisted range of motion exercises and quadriceps strengthening. Inactive, sedentary patients usually are treated conservatively. However, not all patients do predictably well with nonoperative management, and reconstruction has been advocated by some investigators to prevent the development of medial and patellofemoral arthrosis in high performance athletes. Furthermore, these injuries are often associated with other injuries, such as the posterolateral corner, which may need to be addressed.

Chronic grade I and II injuries usually respond well to physical therapy. If the patient continues to have recurrent swelling and pain, some early degenerative changes may be present. Activity reduction and modification is recommended. Patients with chronic grade III injuries may benefit from PCL and posterolateral corner reconstruction if they also have some degree of posterolateral involvement.

Treatment options include fixation of tibial avulsion injuries, single-bundle transtibial reconstruction, tibial inlay, and double-bundle transtibial reconstruction.

**Avulsion Injuries**

PCL tibial avulsion injuries typically do well with operative fixation. The fragment can be fixed with either a screw or suture, using either an open approach or arthroscopy. A larger fragment can be fixed using a posterior approach and a screw (with or without a washer). However, arthroscopy is helpful for examining other injuries as well. Different methods of suture fixation have been described. One method involves passing five to six sutures through the PCL and then tying them over a bony bridge. A variation on this technique involves wrapping the PCL with sutures and then tying it over a button on the anterior aspect of the tibia. In a study evaluating 29 patients treated with this method, all patients demonstrated a significant improvement on KT-1000 testing, in addition to all but one having a negative posterior drawer test posttreatment.

**Reconstruction**

There are several methods of reconstructing the PCL, including the single-bundle transtibial tunnel technique and the single bundle tibial inlay technique. The tibial inlay technique was developed in response to several concerns about the transtibial technique. First, it was hypothesized that the “killer turn” could lead to increased graft tissue strain, graft elongation after fixation, and graft fraying or failure that could lead to persistent posterior knee laxity. The “killer turn” describes the sharp graft angulation that occurs when the graft winds around the proximal posterior tibia as it heads toward the anteromedial margin of the femur. Additionally, the tibial inlay technique could achieve a more anatomic approximation during graft insertion.

**Transtibial Versus Inlay**

There have been several studies comparing the transtibial and inlay techniques with mixed results. Bergfeld and colleagues examined six matched pairs of cadaveric knees; one PCL was reconstructed with the transtibial technique and one with the inlay method. These investigators found significantly less anterior-posterior laxity with the inlay technique when ranging the knee from 30° to 90° of flexion.
and after repetitive loading at 90° of flexion. Mechanical degradation was found in the transtibial tunnel but not the inlay. They concluded that the inlay allowed less posterior translation with less potential graft degradation than the transtibial tunnel.  

Oakes and associates examined 12 cadaveric knees with transtibial and inlay reconstructions under several different loading conditions. Mean forces in both grafts were significantly higher (up to two to three times) than that seen in the native PCL with the knee flexed beyond 90° for all modes of loading. The only condition in which there was no difference between the forces in the grafts and the native PCL was with a 100 N posterior tibial force. The investigators found that the forces in both grafts were virtually identical with most modes of loading, including 100 N posterior tibial force, 5 N-m of varus/valgus moment, and 5 N-m of internal and external tibial torque. However, with passive knee flexion greater than 95°, mean graft forces in the transtibial tunnel graft were 10 to 20 N higher than that seen with the inlay graft. They concluded that the 10 to 20 N was probably an insignificant difference. However, since both grafts experienced forces much higher than the native PCL, they advised limiting activities that flexed the knee to greater than 90° in the early postoperative period.

Margheritini and coworkers tested 10 cadaveric knees in several stages. First, they examined the intact PCL and then sectioned the PCL to simulate a PCL deficient knee. The PCL was reconstructed using both the single bundle inlay or transtibial tunnel technique, in alternate order. A 134-N posterior tibial load was applied to the knee as it was flexed from 0° to 120°, and measurements of posterior tibial displacement and graft forces were taken at 30° increments. They found no difference between the two reconstruction techniques in reducing posterior tibial translation, but both were significantly different from the intact knee. Furthermore, they found that the single bundle graft carries up to 44 ± 19 N less than intact PCL under the 134-N posterior load. The investigators hypothesized that secondary restraints, such as the LCL and popliteus, may provide additional restraints under posterior loading of the knee, but may also be at increased risk of injury.

MacGillivray and colleagues examined 20 patients who had undergone PCL reconstruction for chronic PCL injuries. Thirteen were reconstructed with the transtibial technique and seven with the inlay method. The investigators found no significant differences in KT-1000 measurements, pre- and postoperative anterior drawer tests, postoperative range of motion, and single-leg hop performance. Overall, the subjective scores were better than the objective measures of laxity.

Seon and Song compared 43 patients who had undergone PCL reconstruction for chronic PCL injuries. They found no significant differences in KT-1000 measurements, objective measures, range of motion, and single-leg hop performance. Overall, the subjective scores were better than the objective measures of laxity.

Double Bundle Reconstruction

The rationale behind the double bundle technique is that it more closely restores normal knee biomechanics. The anterolateral bundle has some residual laxity at full extension, while the posteromedial bundle reduces posterior tibial translation in flexion and extension. The double bundle technique has been described using both tibial inlay and transtibial techniques and a variety of grafts.

There is no consensus yet as to the ideal position for the femoral tunnels. One method involves placing the anterolateral tunnel in a right knee at the 1:00 o’clock position, 6 mm off the articular margin, and the posteromedial tunnel at the 2:30 o’clock position, 4 to 5 mm off the articular margin. Chhabra and coworkers describe the anterolateral tunnel at 1 o’clock, 5 to 6 mm off the articular margin, and the posteromedial tunnel at the 3:00 to 4:00 o’clock position, approximately 4 mm off the articular margin. Garofalo and colleagues describe, for a left knee, placing the anterolateral tunnel at 11:00 o’clock, 8 mm proximal to the articular surface, and the posteromedial tunnel at the 9:00 o’clock position, 8 mm proximal to the articular surface. These investigators recommend tensioning the anterolateral bundle at 70° of flexion and the posteromedial bundle at 30° of flexion. However, the anterolateral bundle can also be tensioned at 90° of flexion, followed by the posteromedial bundle at 30° of flexion.

Single Versus Double Bundle

Fox and associates examined nine cadaveric knees, applying posterior tibial loads from 22 to 110 N, with the knee extended and at 90° of flexion. They found no significant differences between the in situ forces in the two bundles at any knee flexion angle. The maximal in situ forces occurred near maximal knee flexion. Thus, rehabilitation is probably most safely performed at near extension. They also concluded that neither bundle necessarily represents the preferred position to place a graft to totally mimic the PCL. They did recommend choosing the anterolateral bundle at this time because it is nearly double the size of the posteromedial bundle and more stiff.

Harner and coworkers compared single versus double bundle reconstructions using 10 cadaveric knees. A 134-N posterior tibial load was applied to the knee from extension to 120° of flexion. They found that there was up to 3.5 mm more posterior tibial translation in the single bundle reconstruction than the intact knee. However, the double bundle reconstruction restored stability throughout the range of motion. At all flexion angles, the force in the single bundle was significantly lower than in the intact PCL, suggesting that other structures, such as the posterolateral corner, also share the load. The double bundle graft had forces more consistent with in situ force in the intact PCL. They concluded
that the forces generated in the posteromedial bundle may signify that it plays a more important role, especially under a posterior tibial load. Furthermore, because the posteromedial bundle more effectively reduces posterior tibial translation, it may help protect from excess loads on either graft during healing.

Markolf and colleagues studied 13 cadaveric knees that had either single or double bundle reconstructions. They found that the anterolateral bundle restores normal laxity between 45° and 90° of knee flexion and reproduces native PCL forces over a 120° range of motion. However, between extension and 30° of flexion, the anterolateral bundle is approximately 1 to 2 mm lax. The posterolateral bundle reduced laxity in this range, but with higher than normal forces in the graft. The investigators concluded that the 1 to 2 mm reduction in laxity in the 0° to 30° range may not be worth the increased operative time and extra hardware.

Complications
The most common complication of PCL reconstruction is residual laxity. As evidenced by the studies previously discussed, reconstruction can reduce posterior translation, but rarely is found to completely reproduce the function of the native PCL. The most serious complication of PCL reconstruction is neurovascular injury, especially of the popliteal artery. Other potential complications include arthrofibrosis, infection, medial femoral condyle osteonecrosis, anterior knee pain, and painful hardware.

Future Directions
There is still much left to learn about the natural history of PCL injuries as well as PCL reconstruction. Specifically, if isolated grade III PCL injuries go on to medial femorotibial and patellar chondrosis, would PCL reconstruction necessarily alter the course of events? Prospective, randomized level 1 studies on acute grade III PCL injuries are needed to further determine which patients truly need surgery. Surgically, computer navigation may help to improve identification of the insertion sites of the PCL. Finally, more studies on single versus double bundle PCL reconstruction are needed to further elucidate the optimal reconstruction for the individual patient.

Disclosure Statement
None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

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