INTRODUCTION

PCL injuries occur at an incidence of 3% in the outpatient sports setting and increase as high as 37% in traumatic settings [1,2]. The majority of the isolated PCL injuries occur from a posterior directed force such as a dashboard injury and during certain sports related activities. However, in the traumatic setting, PCL injuries are less likely to occur in isolation but are more often associated with multiligamentous knee injuries as the vast majority of these are high-energy mechanisms [3]. Recently reviewed their experience in 1,287 operatively treated PCL injuries over a 20 year period. They found that 67% of patients were male. Additionally, their results showed that a fourth to a third of these reconstructions were performed for isolated PCL injuries. 35% of isolated PCL injuries occurred more commonly following sports related injuries, with a predilection for soccer.

Anatomy

The primary function of the PCL is to provide resistance to posterior translation of the proximal tibia on the distal femur. It also serves as a secondary restraint to external rotation and varus stress of the tibia. The anatomy mirrors these functions (Figure 1). The PCL is approximately 38 mm in length and 13 mm in diameter. It has two distinct bundles named the anterolateral bundle (ALB) and the posteromedial bundle (PMB). The larger ALB is tight with knee flexion. The smaller PMB is tight with progressive knee extension. The PCL is surrounded by the meniscofemoral ligaments, which are present 70% of the time. The ligament of Humphrey is anterior to the PCL, whereas the ligament of Wrisberg is posterior to the PCL. These ligaments support the PCL, providing secondary restraint to posterior tibial translation.

The femoral attachment of the PCL is a broadly shaped crescent on the anterolateral aspect of the medial femoral condyle. The bifurcate prominence is a lateral ridge which separates the ALB and PMB in the anterior-posterior plane, and also serves as the proximal border of the ALB and PMB. A horizontal bony ridge on the tibia, named the bundle ridge, separates the ALB from the PMB. The femoral origin of the ALB has been described to range from 112-118 mm in area [4]. Anderson and colleagues have described the femoral center origin of the ALB as 7.4 mm from the trochlear point, 11.0 mm from the medial arch point, and 7.9 mm from the distal articular cartilage [5]. The center of the ALB tibial attachment site is located 6.1 mm from the fibers of the posterior medial meniscus root, 4.9 mm from the bundle ridge, and 10.7 mm from the champagne glass drop-off. The tibial insertion of the PCL is in a central sulcus on the posterior aspect of the tibia approximately 10-15 mm below the articular surface [6]. This insertion is in direct line with the posterior attachment of the medial meniscus.

The posteromedial bundle (PMB) is smaller in origin on the
femur at approximately 60-90 mm² area[4]. It is bordered by the medial intercondylar ridge proximally, the ALB anteriorly, and the anterior meniscofemoral ligament distally. Anderson and colleagues described the femoral origin as 11.1 mm from the medial arch point and 10.8 mm from the posterior point of the articular cartilage margin. The tibial attachment of the PMB has been described as 105 mm² area and is located 3.1 mm lateral to the medial groove of the medial tibial plateau articular surface and 4.4 mm anterior to the champagne glass drop off [5].

Several studies have addressed the roles of the ALB and PMB in differing degrees of flexion and extension [7-10]. The ALB acts as the primary restraint to posterior translation and is under the greatest tension when the knee is at 90° of flexion. The PMB is the main structure ensuring posterior translation stability near full extension and functions as a secondary restraint to knee rotation. Kennedy and colleagues used differing graft fixation angles of ALB and PMB bundles in a series of DB reconstructions to assess these functions[9]. Those authors reported that ALB graft force peaked during mid flexion and that the PMB graft force peaked at both full extension and deep flexion during a posterior tibial load from 0° to 120° of knee flexion.Ahmad and colleagues found that the ALB becomes longer and more vertical as the knee flexes [7]. Conversely, the PMB becomes shorter and more horizontal with progressive flexion. This orientation change places the restraining force vector of the PMB bundle in line to counteract posterior tibial translation at increasing flexion angles and vice versa with the ALB. These studies suggest that the two bundles act as a synergistic and co-dominant restraint to posterior tibial motion throughout knee flexion and extension.

Mechanism of injury

In contrast to most anterior cruciate ligament (ACL) injuries, the most common mechanism of injury to the PCL comes from a contact mechanism resulting in a posteriorly directed force to a flexed knee, although hyperextension mechanisms do occur. Two of the classic stories one hears is the dashboard injury in an MVA or a fall directly on the field with the knee flexed. Often, a fall onto a flexed knee with the plantarflexed foot places a posterior force on the tibia and results in PCL rupture. In higher energy trauma events, this injury mechanism often occurs with injuries to other capsuloligamentous structures, which is often the case.

Additionally, a third proposed mechanism of PCL injuries can occur from hyperextension, which leads to an avulsion injury of the PCL from its femoral origin. This injury mechanism is often associated with disruptions of the proximal posterior capsule.

DIAGNOSIS

History

In contrast to ACL injuries, patients with isolated PCL tears often times will not come to clinic directly after the event[11]. Instead, they may present to the physician’s office after an indolent course with non-specific complaints of instability. The physician should attempt to elicit as much information as possible, including when the patient first noticed their symptoms, the mechanism of injury, and activities that alleviate/worsen their symptoms. Patients may report instability or discomfort with kneeling, squatting, or decelerating while running, as these movements stress the native PCL[11,12]. Most PCL injuries however are not isolated and occur in conjunction with a multi-ligamentous injury, sometimes presenting with a knee dislocation, a medical emergency. These cases often are high-energy trauma such as MVAs.

Physical exam

The physical exam should incorporate all of the standard components of an orthopedic evaluation, including inspection for edema, palpation for swelling and point tenderness, range of motion testing, gait analysis, assessment of neurovascular status, and exam maneuvers specific to the knee such as varus-valgus stability and McMurray’s test. In the acute setting, a thorough neurovascular examination needs to be performed. One needs to take into account that the injury may have occurred as part of a knee dislocation. A missed neurovascular injury is catastrophic and can be limb-threatening.

The posterior drawer, shown to be the clinical test with the greatest sensitivity and specificity, is the traditional maneuver used to assess PCL integrity (Figure 2) [13]. The patient is placed in a supine position with their affected knee at 90 degrees of flexion, and the physician applies a posterior force to the proximal tibia. The amount of tibial translation is then correlated...
with the degree of injury, with 0-5 mm, 5-10 mm, and 10-15 mm corresponding with Grade I, II, and III injuries, respectively. The physician should compare the degree of translation to the contralateral leg, as the baseline laxity of the knee will vary between patients.

As it is difficult to precisely quantify the degree of tibial translation, [14] proposed an alternative scoring system for the posterior drawer exam. They rated Grade A, B, and C PCL injuries based on the relative location of the tibia in relation to the femoral condyles. The normal resting position of the tibia is about a finger breadth anterior to the femoral condyles; Grade A injuries have slight loss of offset, Grade B have the tibia even with the femur, and Grade C have the tibia posterior to femur. Furthermore, a KT arthrometer can be used to help obtain more objective measurements of knee laxity; however the diagnostic accuracy has not been shown to be significantly different than a standard posterior drawer test and are not commonly used in practice[15,16].

The Quadriceps Active Test (also called the Muller test) starts with the patient in the same supine position with 90 degrees of knee flexion[17]. The patient is then instructed to raise their heel off of the table, while the physician holds the ankle in place to prevent the knee from extending. As the quadriceps contracts, it exerts an anterior force on the tibia, moving the tibia from a subluxated to reduced orientation. A positive test is noted with this anterior shift of the proximal tibia.

Numerous additional clinical tests have been described that may also assist in the diagnostic process, including the dynamic posterior shift, Godfrey's test, and reverse Lachman[18]. One needs to perform a thorough ligamentous examination for the remaining ligaments as well as PCL injuries generally do not occur in isolation as previously discussed. One needs to pay particular attention to the posterolateral corner.

Imaging

Imaging is always warranted following suspected PCL injury. In the acute high energy trauma, a thorough trauma series is mandatory as concomitant injuries are quite common. In the office setting, a standard knee series is often sufficient with standing AP, flexed PA, lateral and patellofemoral view (merchant or sunrise). One needs to evaluate for any bony avulsions, joint space asymmetry, and more subtle joint incongruencies to suggest mild subluxation. While standard, radiographs are often times negative.

The diagnostic accuracy of knee x-rays may be enhanced by stress imaging to allow a dynamic test in the setting of a PCL tear, not to diagnose the injury, but rather to give a thorough evaluation of concomitant injuries about the knee, including the other ligamentous structures, menisci, and cartilaginous injuries. In a study of 48 patients with acute isolated PCL injuries, MRI demonstrated that 25%, 23%, and 12.5% of the knees also had meniscal injuries, focal cartilage lesions, and fractures, respectively [21]. In regards to PCL injuries, the diagnostic accuracy of MRI has been reported near 100% specificity and sensitivity[22,23]. However, [24] reported a diagnostic accuracy of 57% (range 40-80%) amongst seven experienced musculoskeletal radiologists when assessing chronic PCL injuries on MRI. The authors speculated that healing of the PCL in continuity may occur in chronic injuries, making them more difficult to detect than acute PCL injuries.

Non-operative management

While there is no official consensus on a treatment algorithm for isolated PCL injuries, the vast majority of surgeons agree that non-operative management is appropriate for isolated Grade I and II PCL injuries [12,25,26]. Numerous studies have evaluated the non-operative treatment of isolated PCL injuries, although the vast majorities are very poor quality studies which have been retrospective in nature. The other limiting factor depends on the type of non-operative management employed. Most recommend using a brace that places a posterior bolster on the tibia or an anterior drawer for a period of around 4 weeks to allow the knee to heal in as correct a position as possible, followed by physical therapy with particular emphasis on the quadriceps which helps support the PCL [14,27-30]. Several studies have prospectively assessed the outcomes of non-operative management [11,31-34]. Shelbourne et al., has followed a large cohort of isolated PCL injuries, most recently reporting the results of 68 patients with a minimum of 10 years follow up [11,32,33].

OUTCOMES

In an earlier study with an average of 5.4 years follow-up, [11] examined the radiographic findings in 68 patients with Grade 1 (25 patients) and Grade 2 (43 patients) injuries. They did not demonstrate a statistically significant increase in radiographic knee arthrosis in the affected knee (10 patients) compared to the contralateral knee (3 patients), though their results were reported as one group rather than categorizing the results by grade of injury. In a subsequent study of the same cohort at an average of 14.3 years follow up, Shelbourne et al., reported that only 5 patients (11.4%) had joint space narrowing greater than 2.0 mm in the medial compartment secondary to the PCL injury [32]. This lack of radiographic arthrosis contradicts the findings of other studies, which have suggested that the medial and patellofemoral compartments undergo the greatest degeneration following a PCL tear [14,27,35].

Interestingly, knee laxity has not been shown to consistently predict radiographic or functional outcomes following PCL injury [30] reported that increased laxity was associated with lower subjective and objective scores. However, these findings have been repudiated by several studies demonstrating no significant correlation between laxity and return to activity, patient satisfaction, radiographic arthrosis, and functional scores[14,28,29,32,33,35].
At an average of 17 years of follow up, [32] reported mean CKRS and IKDC scores of 81 and 73 points, respectively, in 44 patients treated non-operatively. They concluded that, while their patients did exhibit some limitations, the functional scores were generally good; therefore, any surgery to repair isolated PCL tears should produce significantly better results than those reported in their study.

Non-operative rehabilitation

As there are no studies comparing various methods non-operative rehabilitation, a clear consensus has not been established on the proper therapy regimen [36,37] reported on cylinder cast immobilization for non-operative management of acute Grade I and II PCL tears, noting improved anteroposterior stability and good/excellent clinical results in 100% of their patients at 2+ years of follow up. [31] evaluated a novel dynamic brace (“PCL-jack”) in 21 isolated Grade II PCL injuries, resulting in improved posterior tibial sag scores and a mean Lyshom score of 94.0 at 2 years. Furthermore, several studies have associated better functional results with improvements in quadriceps strength [35,38].

[36] proposed rehabilitation guidelines for non-operative PCL injuries. In their protocol, they suggest that the knee be immobilized in extension for the first 2-4 weeks following injury, allowing only 0-90 degrees of prone passive ROM for the first 2 weeks. They also recommend that, for the first 12 weeks, the “PCL-jack” brace should always be worn and advised against isolated hamstring strengthening. After 12 weeks, the patient may stop wearing the brace and begin isolated hamstring exercise, along with a progressive lower extremity strengthening. At 19+ weeks, the patient can begin sport-specific agility drills and may return to play once clearing functional criteria evaluated by the physician.

Our current recommendation is to use a PCL type brace or a hinged-knee brace with a posterior bolster that gives the knee a relative anterior drawer. The brace can be removed with PT early on to begin range of motion. The brace is discontinued around 4 weeks with continued range of motion along with strengthening exercises focused on the quadriceps with avoidance of isolated hamstring strengthening for 3 months. We generally allow patients to return to sport beginning at 3 months. We tend to support the use of non-operative management for all Grade I and II injuries and the vast majority of isolated Grade III tears.

Operative management

Operative management of PCL injuries has generally been reserved for Grade III injuries refractory to conservative management or Grade II and III injuries in combination with concomitant knee injuries [12,25,26]. As alluded to earlier, the vast majority of PCL tears occurs with other ligamentous injuries and therefore require surgical intervention. Several areas of controversy are debated in regards to the surgical technique of PCL reconstruction, including SB vs. DB, type of graft material, transtibial vs. tibial inlay, femoral and tibial tunnel placement, and preservation of the PCL remnant. Comparison of these techniques is quite difficult; as most of these procedures are being done as part of a myriad of other operations with differing severity that encompass high energy multiligamentous knee injuries with concomitant meniscal and cartilaginous injuries. However, a selected number of these topics will be subsequently discussed in greater detail.

Single-bundle vs. Double-bundle

Earlier attempts at PCL reconstruction focused on the ALB due its larger size and greater strength than the PMB. However, interest in the biomechanical advantages of the PMB has lead to the recent advent of DB reconstructions.

Several biomechanical studies have attempted to discern if there is any additional benefit in DB techniques, compared to that of the traditional SB method. These studies focused mostly on the AP tibial translation with some studies showing no significant difference between constructs [39,40], while other results suggested improved stability with the DB reconstruction [8,41-43]. Furthermore, [43] reported increased rotational stability of the knee with the addition of the second bundle, which has been the consensus with biomechanical studies but has not necessarily borne out in clinical studies.

In vivo studies have produced conflicting results regarding SB vs. DB reconstructions. Several studies have demonstrated no significant benefit in the DB technique, reporting similar functional scores, radiographic changes, and knee laxity [44-49] demonstrated differences in laxity between the constructs; however, both groups still reported similar Lysholm scores in each of the studies. In a prospective study of 53 patients, [50] showed no differences between the SB and DB groups in range of motion, Tegner activity score, Lysholm scores, and the IKDC subjective form at 2 years of follow up, despite decreased anterior laxity and higher IKDC objective scores in the DB group. [51] concluded that the DB reconstruction produced significantly better results in their prospective study of 50 patients. At 2+ years of follow up, the DB group reported better posterior stability and IKDC scores (both objective and subjective), though there was no significant difference from the SB group in Lysholm scores and Tegner activity scores.

As noted by several systematic reviews [52,53], the heterogeneity of surgical techniques and conflicting results of these biomechanical and clinical studies make it difficult to definitively conclude that the DB technique produces better outcomes than the SB reconstruction. The general consensus at this point is that the DB technique produces better objective stability with equivalent subjective outcomes. Additionally, the DB technique has greater risk of complications.

Graft selection

Various types of grafts have been described, including autografts (bone-patellar tendon-bone, hamstring, quadriceps) and allografts (Achilles, tibialis anterior and posterior, bone-patellar tendon-bone, hamstring, quadriceps) [54]. However, few studies have directly compared the different grafts in isolation. In a retrospective study, [55] assessed 37 patients who underwent a SB reconstruction with either a 4-strand hamstring tendon autograft or a 2-strand tibialis anterior allograft, reporting that both groups demonstrated clinical improvement at a 2 year follow up. The authors concluded that both constructs were equally viable options in PCL reconstruction, as there were no significant differences between the different grafts in regards to knee laxity, Lysholm score, Tegner activity level, or IKDC ratings.

[56] performed a biomechanical study to compare quadriceps allograft vs. Achilles allograft, reporting similar creep deformation, stiffness, and modes of failure between the
two constructs. The only significant difference was a greater maximum force exhibited by the quadriceps allograft during failure testing. They argued that the quadriceps tendon allograft offers several theoretical advantages, compared to that of an Achilles or hamstring graft, in PCL reconstruction: (1) the PCL’s cross-sectional area and footprint are larger than that of the ACL, which could be better replicated with larger sized graft such as the quadriceps tendon; (2) a bone block would allow for earlier bone-to-bone healing; (3) the bifid anatomy of the quadriceps tendon could be utilized in a DB reconstruction. Despite these potential benefits of the quadriceps tendon, no specific graft has been proven to be consistently superior to the others in PCL reconstruction.

**Tibial Inlay vs. Transtibial**

Berg was the first to describe tibial inlay technique as an alternative to the standard transtibial reconstruction, citing several theoretical advantages such as the elimination of the “killer turn,” facilitation of graft tensioning, and preservation of the Sharpey fiber–bone transition zone (Figure 3) [57]. However, this novel inlay technique has inherent drawbacks as it requires the patient to be placed in a prone position and is traditionally performed through an open approach, though an arthroscopic method has recently been described which has shown comparable biomechanical stability in vitro [58].

[59] performed the first cadaveric study to compare the transtibial and inlay techniques. They demonstrated decreased knee laxity with the inlay technique, which conflicted with subsequent studies that did not report any significant difference [60,61]. In an effort to assess the effects of the “killer turn,” [62] compared the transtibial and inlay approaches in 62 cadaveric knees, noting that the inlay reconstruction produced better results in regards to graft thinning and failure. [61] also saw increased graft failure in the transtibial group, though other studies [60,63] have demonstrated comparable results between the 2 techniques with respect to mean graft forces.

Few clinical studies have directly compared the outcomes of the transtibial and inlay reconstructions. In a study of 41 patients, [64] failed to show any significant difference between the 2 techniques in Lysholm knee scores, Tegner scores, and posterior laxity at short term follow up. A subsequent study with extended follow up (mean = 12.3 years) reaffirmed the similar functional outcomes and laxity seen in their previous findings, as well as a comparable incidence of radiographic changes between the 2 groups[65]. In a retrospective analysis of 20 patients who underwent transtibial or inlay reconstructions, [66] reported no significant differences in knee stability, Lysholm scores, Tegner scores, or AAOS knee scores.

Similar to the comparison of SB vs. DB techniques, several systematic reviews have been unable to draw definitive conclusions regarding the superiority of the transtibial vs. tibial inlay methods [67,68]. These authors cite a lack of high quality studies, conflicting results, short-term follow up, and confounding surgical techniques as limitations in their overall assessment.

Our current technique[69,70] for PCL reconstruction involves an arthroscopic inlay technique using an Achilles allograft. Typically these are multiligamentous knee injuries with a high propensity to stiffness. Thus taking an autograft adds another insult to the knee worsening pain and swelling, increasing the likelihood of stiffness. Given the lack of evidence to demonstrate that autograft demonstrates improved outcome, allografts decrease the likelihood of arthrosis without the increased risk of failure of the graft. We drill from anterior tibia using a flipcutter, one size larger than the circular plug of the graft. We tie the tibial side over a button and use a soft tissue screw for the femoral side.

**Anteromedial vs. Anteriolateral Transtibial Tunnel Placement**

In an effort to minimize the stress forces at the killer turn in the transtibial technique, [71] proposed drilling the tibial tunnel anterolaterally, rather than the traditional anteromedial placement. The authors noted that the lateralization of the tibial tunnel produced a more collinear alignment in the coronal plane between the tunnel and the graft. In a retrospective cohort study of 60 patients, Kim et al. reported that the anterolateral tunnel was associated with decreased posterior tibial translation, though there was no significant clinical difference in Lysholm and IKDC scores between the two techniques[72]. However, the study was limited by a lack of randomization and the incorporation of 3 different types of grafts.

A rare but significant complication of PCL reconstruction is damage to the neurovascular structures in the posterior knee. Franciozi et al., proposed another benefit of the anterolateral technique in regards to the safety of the popliteal artery[73]. In a cadaveric study of 22 knees, the distance between the tibial guidewire and popliteal artery was found to be significantly closer in the anteromedial tunnels versus that of the anterolateral technique. Furthermore, the trajectory of the medial approach intersected the popliteal artery in all of the knees while the lateral approach did not converge with the artery in any of the specimens. The authors noted that their results supported the MRI findings reported by [74] where the popliteal artery was...
lateral to the central axis in 94.3% of knees and medial to the central axis in none of the knees. Therefore, the anterolateral approach may provide several biomechanical and safety benefits when compared to anteromedial tunnel placement.

**LONG-TERM OUTCOMES**

A limited number of studies have assessed long-term outcomes following PCL reconstruction. [76] reported a case series of 25 patients who underwent a SB PCL reconstruction with an average follow up of 9.1 years. No patients underwent a concurrent ligamentous reconstruction, though a partial medial meniscectomy was performed in 7 patients and one patient underwent a microfracture surgery at the time of the PCL reconstruction. While there were significant post-operative improvements in IKDC scores, they noted that these values were only nearly normal or normal in 41% of their patients. They attributed this finding to the increased residual laxity in the reconstructed PCLs. The authors further noted that these patients with residual laxity often have to reduce their sports activities, though they did not report on return to play percentages. Additionally, they found that 60% of their patients had cartilage damage at the time of surgery, which was associated with significantly worse functional outcomes at the latest follow up. One of the major limitations of this study was the usage of 3 different types of grafts (15 semitendinosus gracilis, 9 bone - patellar tendon - bone, and 1 Achilles).

In a prospective study of 30 patients, [76] reported 10 year outcomes after undergoing PCL reconstruction with a hamstring tendon autograft. Seven patients underwent a concurrent procedure at the time of the PCL reconstruction, including 4 partial lateral meniscectomies, 2 MCL repairs, and 1 subtotal medial meniscectomy. IKDC subjective and Lysholm scores were found to be 87 and 90, respectively. Radiographic analysis demonstrated Kellgren-Lawrence grade 2 or 3 changes in 8 out of 22 patients, though the authors noted that 4 of these patients underwent a meniscectomy. Of note, little to no difficulty in running was reported by the 26 patients who were available for 10-year follow up. The authors concluded that the reconstruction provided good results for symptomatic PCL injuries.

**PCL Avulsion**

Avulsion of the PCL at the tibial eminence is a rare injury that is managed differently than an intrasubstance tear. [77] reported on 5 minimally displaced PCL avulsions that were treated conservatively, noting non-union and poor functional outcomes in 4 of these patients. Traditionally these injuries were managed with an open approach given the technical difficulty of accessing the tibial eminence. More recently, [78] described an arthroscopic approach on 13 patients, demonstrating osseous union with little to no posterior instability in all 11 of the patients who were treated in the acute phase. The authors recommended fixation of small, medium, and large osseous fragments with suture anchors, pins, and screws, respectively. When treating 36 PCL avulsions with suture fixation, [79] reported a 100% radiographic union rate with a significant improvement in mean Lysholm scores from 35 preoperatively to 95 postoperatively. Given the favorable outcomes seen with operative intervention, most surgeons would opt for surgical fixation of PCL avulsions rather than non-operative management.

**SUMMARY**

As PCL injuries are increasingly becoming more recognized, it is important for the clinician to have a working knowledge of the function and presentation of injuries to this important knee stabilizer. Keeping this in mind, the exact mechanism of injury, physical examination and further advanced imaging can help further define the extent of injury to either an isolated PCL tear versus a combined injury in concert with posterolateral or posteromedial structures. For isolated PCL grade I and II tears, a course of non-operative management with PCL bracing and physical therapy produces good outcomes. Isolated grade III injuries can often times be treated non-operatively at first, but operative management may be required if the patient continues to be symptomatic despite conservative treatment. Multi-ligamentous knee injuries and symptomatic isolated Type III tears necessitate operative intervention in the form of reconstruction. Several operative options exist for reconstruction including SB, DB, tibial inlay, and anterolateral or anteromedial transtibial techniques. While no clear cut technique has been shown as superior, future studies and advancements in diagnosis and management may yield a more defined treatment algorithm that will likely help improve outcomes for PCL injuries.

**REFERENCES**


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