Current advances in posterior cruciate ligament (PCL) reconstruction have led to excellent clinical and functional outcomes. It is helpful to review anatomy, cadaver sectioning studies, biomechanical studies, clinical outcome data, and novel surgical techniques for posterior cruciate ligament reconstruction, including all-inside reconstructions. Surgeons also should be aware of current controversies regarding transtibial versus inlay, autograft versus allograft, and single-bundle versus double-bundle reconstructions.

**Anatomy**

The anatomy of the PCL has been recently revisited and highlighted by Kennedy et al. The PCL complex is divided into the anterolateral bundle, the posteromedial bundle, and the meniscal femoral ligaments. The meniscal femoral ligaments are divided into the anterior meniscofemoral ligament (otherwise known as the ligament of Humphrey) and the posteromedial femoral ligament (otherwise known as the ligament of Wrisberg). The anterolateral bundle is primarily responsible for restraining posterior tibial translation at 90° of knee flexion, and this bundle has been traditionally reconstructed in single-bundle reconstructions. The posteromedial bundle acts as a restraint to posterior tibial translation at approximately 30° of knee flexion, and this bundle is reconstructed in double-bundle reconstructions. The femoral and tibial insertions are shown in Figures 1 and 2.

A key element in the anatomy of the PCL is the insertion at the base of the tibial PCL facet. Understanding this anatomy is essential to restoring normal PCL function during reconstruction. Whether this insertion site is obtained by using a transtibial approach arthroscopically or an open inlay approach through a posteromedial incision, an...
understanding of the insertion sites of this particular attachment site is critical for a successful PCL reconstruction. More recently, the anatomy of the intercondylar notch and its reference to the PCL bundles were delineated. The top of the notch is referred to as the intercondylar notch apex, and several other points are described. The trochlear point and the medial arch point are the boundaries of the anterolateral bundle and also are used as reference marks for the posteromedial bundle. Also, there is the so-called arch of the cartilage and an area referred to as the straight cartilage, which delineates areas of the anterolateral and posteromedial bundles on the medial femoral condylar wall (Figure 3). As a general rule, the PCL is a much larger ligament than the anterior cruciate ligament (ACL), with an average dimension of 33 × 13 mm. Because it has a crescent-shaped insertion on the femur, it is often difficult to find the so-called isometric point when performing single-bundle PCL reconstructions.

Surgical Technique Options
The two traditional ways of reconstructing the PCL are the open inlay and the arthroscopic transtibial tunnel techniques. Other options include single-bundle (anterolateral bundle) and double-bundle (anterolateral and posteromedial bundle) reconstructions.

The graft choices include a wide variety of autograft and allograft options.

Open Inlay Versus Arthroscopic Transtibial Reconstructions

Biomechanical Evidence
McAllister et al performed a cadaver cyclic loading study and compared transtibial tunnel and tibial inlay PCL graft reconstructions. The reconstructions were brought through cyclic loading to failure. The authors found no important advantage of one technique versus the other.

Clinical Evidence
May et al performed a systematic clinical review of the literature comparing transtibial with inlay PCL reconstruction. Similar to the biomechanical data, the authors reported no important advantage of one technique versus the other.

Single- Versus Double-bundle Reconstructions

Biomechanical Evidence
Markolf et al performed a cadaver study of single-bundle versus double-bundle reconstructions and found that the single-bundle anterolateral PCL reconstruction graft best reproduced normal PCL force profiles, whereas the double-bundle reconstruction slightly reduced laxity at 0° to 30°. Whiddon et al performed a cadaver study comparing single- versus double-bundle reconstructions using an open inlay PCL reconstruction cadaver model. The authors looked at 10 cadaver knees that used bone-patellar tendon-bone allografts and tested these knees in a similar way as the knees would be clinically tested (that is, they used the posterior drawer test, the dial test, and posterior...
stress radiography). The knees were tested intact and then retested after sequential resection of both the PCL and the posterolateral corner structures. The authors found that if they resected the PCL and the posterolateral corner but did not restore the posterolateral corner structures, the double-bundle PCL reconstruction had better rotational stability. However, if they sectioned the PCL and the posterolateral corner and then reconstructed the posterolateral corner, they found no difference between the single- and double-bundle techniques.

**Clinical Evidence**

Single-bundle versus double-bundle reconstructions were compared in a recent systematic clinical review by Kohen and Sekiya. The authors stated the following: “The superiority of single-bundle or double-bundle posterior cruciate ligament reconstruction remains uncertain.” In a comparative study by Wang et al, the authors performed a prospective study of 35 patients, 19 with single-bundle reconstructions and 16 with double-bundle reconstructions. They used hamstring autografts and followed this group of patients for 2 years and found no significant differences in functional scores, ligament laxity, and radiographic changes. Fanelli et al reported on a series of 90 consecutive PCL reconstructions, where the first 45 were performed using a single-bundle technique and the next 45 were performed using a double-bundle technique. Each reconstruction used a transtibial approach and a fresh-frozen allograft. Follow-up was between 24 and 72 months. When comparing stress radiography, KT-1000 arthrometer (MEDmetric) results, the Tegner Lysholm Knee Scoring Scale, and Hospital for Special Surgery functional knee scores, the authors were unable to find any significant differences between the two groups.

**Autograft Versus Allograft**

Hudgens et al also performed a systematic review comparing allograft versus autograft in PCL reconstruction and found satisfactory clinical and functional results from both graft types. Other authors have reported excellent long-term outcomes with the transtibial technique, the open inlay technique, autograft reconstruction, allograft reconstruction, and single-bundle and double-bundle PCL reconstructions.

**Transtibial Tunnel Surgical Technique**

This chapter’s authors prefer an Achilles tendon allograft for single-bundle
Allograft tissue is prepared, and arthroscopic instruments are placed with the inflow in the superior lateral portal, the arthroscope in the inferior lateral patellar portal, and instruments in the inferior medial patellar portal. An accessory extracapsular, extra-articular posteromedial safety incision is used to protect the neurovascular structures and confirm the accuracy of tibial tunnel placement (Figure 4). The incision is made along the posteroomedial tibial crest at 4 to 5 cm distal to the joint line. Dissection is carried down to the fascia, and a plane is created between the medial head of the gastrocnemius and the semimembranosus tendon. Blunt finger dissection is then used to sweep anterior to the gastrocnemius tendon, allowing extra-articular palpation of the mammillary bodies on either side of the PCL facet.

To prepare for a combined PCL-ACL reconstruction, notch preparation is performed first and consists of ACL and PCL stump débridement, bone removal, and contouring of the medial and lateral walls and the roof of the intercondylar notch. Specially designed 90° curets and rasps placed through the notch to the posterior aspect of the tibia are used to elevate the capsule and clearly identify the PCL-tibial footprint. The arm of the PCL-ACL guide is inserted through the inferior medial patellar portal to begin creation of the PCL-tibial tunnel. The tip of the guide is positioned at the inferior lateral aspect of the PCL anatomic insertion site. The bullet portion of the guide contacts the anteromedial surface of the proximal tibia at a point midway between the posteroomedial border of the tibia and the anterior tibial crest, approximately 1 cm below the tibial tubercle. This provides an angle of graft orientation such that the graft will turn two very smooth 45° angles on the posterior aspect of the tibia and will not have an acute 90°-angle turn that may cause pressure necrosis on the graft.

The tip of the guide, in the posterior aspect of the tibia, is confirmed with the surgeon’s finger through the extracapsular, extra-articular posteromedial safety incision. Intraoperative AP and lateral radiographs also may be used. As a double safety check, the surgeon uses his or her finger to confirm the position of the guidewire through the posterior medial safety incision.

An appropriately sized, standard cannulated reamer is used to create the tibial tunnel. The surgeon uses his or her finger placed through the extracapsular, extra-articular posteromedial safety incision to monitor the position of the guidewire. The drill is advanced until it comes to the posterior cortex of the tibia. The chuck is disengaged from the drill, and completion of the tibial tunnel is performed by hand. This provides an additional margin of safety for completion of the tibial tunnel.

The PCL single- or double-bundle femoral tunnels are made from the inside out. Inserting an appropriately sized, double-bundle aimer through a low anterior lateral patellar arthroscopic portal creates the PCL anterolateral bundle femoral tunnel. The double-bundle aimer is positioned directly on the footprint of the femoral anterolateral bundle PCL insertion site. The appropriately sized guidewire is

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**Figure 3** Anterior photograph of a right knee flexed to 90° with a probe (from posterior) separating the anterolateral bundle (ALB) and the posteromedial bundle (PMB) of the posterior cruciate ligament and demonstrating the landmarks surrounding the trochlear point and the medial arch point along the cartilage margin of the femoral intercondylar notch. (Reproduced with permission from Anderson, CJ, Connor G, Ziegler, MD, et al: Arthroscopically pertinent anatomy of the anterolateral and posteromedial bundles of the posterior cruciate ligament. *J Bone Joint Surg Am* 2012;94:1936-1945.)
drilled through the aimer, through the bone, and out a small skin incision. The double-bundle aimer is removed, and an acorn reamer is used to endoscopically drill from inside out the anterolateral PCL femoral tunnel. When performing a double-bundle double femoral tunnel PCL reconstruction, the same process is repeated for the posteromedial bundle of the PCL. There should be at least 5 mm of bone between the two PCL femoral tunnels.

The cyclic dynamic method of graft tensioning is used to tension the PCL and ACL grafts (Figure 5). During this surgical technique, the PCL and/or ACL grafts are secured on the femoral side first with the surgeon’s preferred fixation method. The technique described is a tibial-sided tensioning method. Polyethylene ligament fixation buttons are used for cortical suspensory fixation, and aperture opening interference fixation with bioabsorbable interference screws are used for femoral side PCL and ACL fixation. In combined PCL-ACL reconstructions, the PCL graft is tensioned first, followed by final PCL graft tibial fixation. ACL graft tensioning and fixation follows that of the PCL.

The tensioning boot is applied to the foot and the leg of the surgical limb, and tension is placed on the PCL graft(s) distally using a device such as the Biomet graft-tensioning boot (Biomet). Tension is gradually applied with the knee in 0° of flexion (full extension), thus reducing the tibia on the femur. This restores the anatomic tibial step-off. The knee is cycled through a full range of motion multiple times to allow pretensioning and settling of the graft. The process is repeated until there is no further change on the torque setting of the graft tensioner with the knee at 0° of flexion. When no further changes or adjustments are necessary in the tension applied to the graft, the knee is placed in 70° to 90° of flexion, and fixation is achieved on the tibial side of the PCL graft with a bioabsorbable interference screw for interference fit fixation and backup cortical suspensory fixation with a bicortical screw and a spiked ligament washer or a polyethylene ligament fixation button.

It is very important to use primary and backup fixation. During PCL-ACL reconstruction, primary aperture fixation is achieved with bioabsorbable interference screws, and backup fixation is performed with a screw and a spiked ligament washer and ligament fixation buttons. Secure fixation is critical to the success of this surgical procedure. In the experience of this chapter’s authors, mechanical tensioning of the cruciate ligaments at 0° of knee flexion and restoration of the normal anatomic tibial step-off at 70° to 90° of flexion has provided the most reproducible method of establishing the neutral point of the tibial-femoral relationship. Full range of motion is confirmed on the operating table to ensure the knee is not “captured” by the reconstruction.

**Tibial Inlay Surgical Technique**

Berg\(^1\) first introduced a tibial inlay technique for PCL reconstruction in 1995.\(^1\) This chapter’s authors adapted this technique shortly after its publication and have modified it over the years. The Berg technique has been combined
The advantage of the inlay technique is that it eliminates graft abrasion and attrition associated with the traditional transtibial PCL technique. The PCL graft can be fixed directly into a trough at its tibial origin, and an anatomic PCL reconstruction can be accomplished. The approach is safe because the popliteal artery is retracted by the medial head of the gastrocnemius and is well outside the surgical field. This chapter’s authors also have eliminated the problems associated with repositioning the patient during this procedure by placing the patient in the lateral decubitus position and simply rotating the leg at the hip to access the front of the knee.

**Patient Selection**

In the experience of this chapter’s authors, PCL injuries are rarely isolated. They commonly occur as a result of a motor vehicle crash (the so-called dashboard injury) and usually involve disruption of the posterolateral corner. The posterior drawer test, the preferred test for PCL injuries, can be quantified with stress radiographs. Research has shown that isolated PCL injuries have a side-to-side difference of 10 mm or less on stress radiographs, but a combined PCL- and posterolateral corner–injured knee has a side-to-side difference of 20 mm or more. This chapter’s authors address these injuries within the first 2 weeks and repair and/or reconstruct all the injured structures at that time. The repair and reconstruction of the posterolateral corner yields the best long-term outcomes.

**Patient Positioning**

As indicated earlier, after the completion of an examination under anesthesia, the patient is positioned in the lateral decubitus position with the injured leg up (Figure 6). It is important to pad the contralateral leg and all other extremities and use an axillary roll. A
bean bag is used to hold the patient in position. This chapter’s authors use a tourniquet but do not use a leg holder on the thigh. The surgical foot and leg is placed into a bracketed leg holder, which helps position the leg during the anterior portions of the procedure (Figure 7).

**Surgical Technique**

For patients with an acute combined injury (within 2 weeks), this chapter’s authors usually begin with an egress incision in the center of the planned corner incision to prevent iatrogenic compartment syndrome (Figure 8). A generous (11- to 12-mm) central one-third bone-patellar tendon-bone graft is then harvested and prepared on a back table. A tibial portion of the graft is preferred for the tibial inlay; it is made rectangular and approximately 20 to 25 mm in length. The patellar portion of the graft is “bulleted” and is fashioned to be approximately 18 mm in length (Figure 9). This smaller size facilitates easier graft passage into the femoral tunnel. The graft is placed under tension on a graft board during the next portion of the procedure.

Arthroscopy is then performed, and the injured PCL is débrided with a basket and a shaver. If there are intact fibers (including meniscofemoral ligaments), these should be retained whenever possible. Note that ACL laxity may be normal, which will resolve when an anterior drawer test is applied.26

The femoral tunnel is drilled from the outside in. A subvastus approach is made through an incision in the Langer lines, and a guide is used to place a 0.094-inch (3/32) guide pin high in the notch (at approximately the 1:30 clock position for a right knee) and 6 to 8 mm from the articular surface (Figure 10). The outside-in approach reduces the amount of graft bend in the femoral tunnel (the critical corner).27-29 The tunnel is overdrilled with the appropriate cannulated drill, and bone graft from the drill flutes is collected for later placement in the patellar harvest site. The posterior aspect of the tunnel is rasped to reduce graft abrasion. A looped 18-gauge Luque wire is then positioned arthroscopically through the tunnel and into the posterior aspect of the knee.

The leg is then placed on a Mayo stand and preparation is done for the tibial inlay approach. The surgeon sits on a stool and uses a headlight to directly approach the popliteal fossa. An incision is made in the popliteal crease, and the gastrocnemius fascia is incised. A hockey stick incision is made in the fascia (but not in the skin as originally described by Burks and Shaffer19) (Figure 11). The medial head of the gastrocnemius is identified and bluntly mobilized. Note that the tendinous portion of this large muscle is on the deep surface. The medial head of the gastrocnemius is very mobile and can be retracted laterally, past the midline. This muscle can be held in place with 0.094-inch pins that can be bent and used as retractors. The muscle belly of the popliteus is identified, and a posterior arthrotomy is made at its superior border. This can be enlarged with Mayo scissors, and the preplaced Luque wire is retrieved (Figure 12). The PCL fossa is palpated, and an electrocautery, a rongeur, and a burr are used to create a trough that matches the dimensions...
of the graft. The graft is then brought up to the surgical field and secured to the drapes (as a safety net). The patellar portion of the graft is pulled into the knee (and hopefully directly into the femoral tunnel), and the tibial portion is inlayed into the trough. The graft is secured with 4.5-mm cannulated screws. These screws are serially drilled, measured, and then placed to secure the graft in the trough. It is helpful to clamp the guidewires at the anterior portion of the tibia before drilling to help with screw placement.

The knee is then placed into the bracketed knee holder, and the graft is arthroscopically visualized. If the patellar bone block was not delivered into the femoral tunnel, then it is passed at this point. Sometimes it is necessary to toggle the graft with a right angle clamp to facilitate passage. After it is in the tunnel, the knee is cycled to eliminate any kinking, and the graft is fixed in the femur with a 9 × 20-mm metal interference screw. Note that an anterior drawer force is place on the tibia while the graft is fixed. A Shantz pin with a handle from the external fixation set is useful for this purpose (Figure 13).

The final graft position is examined arthroscopically and also carefully examined on the table, and the remaining ligament repairs and/or reconstructions are completed before standard closure.

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**Figure 10** Intraoperative photograph of arthroscopy being performed with the leg externally rotated and in a bracketed knee holder. Note that the position of the femoral pin is checked arthroscopically.

**Figure 11** Intraoperative photograph of the inlay approach. The medial head of the gastrocnemius is retracted with Steinmann pins and the Luque wire is retrieved from the knee for later graft passage.

**Figure 12** Intraoperative photograph showing the graft inlayed into a trough that was burred into the back of the tibia. Fixation of the graft with posterior to anterior placed screws is accomplished prior to graft passage. PCL = posterior cruciate ligament.
All-Inside PCL Reconstruction

The arthroscopic transtibial, open inlay, and arthroscopic inlay techniques provide reliable clinical and functional outcomes.1-8 Another option is the all-inside technique that uses either autograft or allograft to reconstruct the PCL, using sockets and suspensory fixation in both the tibia and the femur.

The open inlay technique requires a separate posteromedial incision to create a bone trough at the base of the PCL facet. The bone block of an autograft or an allograft is inserted into the tibial trough and secured with cancellous or bicortical screws. The main advantage of this technique is to avoid the “killer turn” that has been described with a transtibial tunnel. The authors argued that this procedure eliminates the killer turn of the transtibial tunnel technique and the large posteromedial incision of the open inlay.

Salata and Sekiya30 published a similar all-arthroscopic PCL reconstruction technique using a fresh-frozen Achilles tendon allograft. Similar to the Campbell et al5 method, the tibial socket is made at the PCL insertion site, using a guide and a retrograde drilling system. A graft with a single bone block is inserted arthroscopically into the tibial socket and secured with suspensory fixation. Arthroscopic passage of the bone block and tibial socket docking can be technically challenging. The short-term outcome data are promising, but complications have been reported, including bone block fracture and nonunion.

A novel all-inside technique uses soft-tissue autograft or allograft with tibial and femoral sockets and suspensory fixation. Although clinical data are not currently available, this method has all the advantages of the inlay and arthroscopic techniques but avoids the posteromedial incision, bone block passage through portals, and the killer turn.

Surgical Technique

Patient Positioning

The patient is positioned supine on the operating table, perioperative antibiotics are administered, and general anesthesia is induced. Both knees are examined to assess the integrity of the cruciate and collateral ligaments. The surgical leg is prepped and draped in standard fashion, and a tourniquet is placed high on the thigh.

Graft Preparation

A tibialis anterior or a peroneus longus allograft with a minimum length of 36 cm is prepared using a graft preparation board. Suspensory fixation is used on both the femoral and the tibial sides of the graft. Two circumferential heavy nonabsorbable sutures incorporating all four tendon strands are placed at 1 cm and 2.5 cm from each end of the graft. These sutures create a coupled, four-stranded construct with a total length of 95 to 100 mm. The graft is the placed on the board under 20 mm of tension (Figure 14).

Arthroscopic All-Inside Reconstruction

Standard superomedial, inferomedial, inferolateral, and accessory inferomedial portals are placed. A diagnostic arthroscopy documents all osseous, chondral, meniscal, and ligamentous
pathology. After a thorough assessment of the knee, an accessory posteromedial portal is created to release the tibial footprint of the native PCL in between the mammillary bodies. The PCL guide is then placed through the anteromedial portal and positioned proximal to the distal edge of the PCL facet. Fluoroscopy or arthroscopic visualization through the posteromedial portal is used to confirm proper guide placement. The drill sleeve is placed flush on the tibia, and the total intraosseous distance is measured. A guidewire is then drilled, and proper placement can be confirmed with fluoroscopy. With the guide in position, the tibial socket is reamed using a retrograde reaming device to a depth of 35 to 40 mm. The PCL guide acts to protect the neurovascular bundle during guidewire placement and reaming.

After clearing out the tibial socket, a passing suture is then placed through the drill sleeve into the joint and retrieved from the inferomedial portal. The femoral suspensory device is brought through the medial cortex while maintaining countertension at the femoral tip of the graft, and the button is deployed. The sutures are sequentially tensioned to insert the graft into the socket to a depth of approximately 20 mm.

Tension is placed on the tibial side of the graft with the knee flexed to 90°. The arthroscope is placed in the posteromedial portal to verify a minimum of 20 mm of tibial graft within the socket (Figure 16). If there is excess graft in the tibial socket, additional graft is pulled into the femoral socket. The 40-mm deep tibial socket ensures that the graft can be tensioned without bottoming out.

Final graft tensioning and fixation are performed with the knee flexed to 80°. A button is attached to the tibial sutures, and the sutures are sequentially tightened to inset the graft into the

Completing the Reconstruction

The sutures from both the femoral and tibial sockets are pulled through the accessory inferolateral portal for graft passage (Figure 15). The tibial end of the graft is inserted first into the joint and deep into the tibial socket. With tension on the graft, the femoral side is inserted into the femoral socket. The femoral suspensory device is brought through the medial cortex while maintaining countertension at the femoral tip of the graft, and the button is deployed. The sutures are sequentially tensioned to insert the graft into the socket to a depth of approximately 20 mm.

Tension is placed on the tibial side of the graft with the knee flexed to 90°. The arthroscope is placed in the posteromedial portal to verify a minimum of 20 mm of tibial graft within the socket (Figure 16). If there is excess graft in the tibial socket, additional graft is pulled into the femoral socket. The 40-mm deep tibial socket ensures that the graft can be tensioned without bottoming out.

Final graft tensioning and fixation are performed with the knee flexed to 80°. A button is attached to the tibial sutures, and the sutures are sequentially tightened to inset the graft into the
tibial socket. Alternate tensioning of both femoral and tibial sutures maximizes graft tension. Backup fixation on the tibial side is achieved by securing the graft sutures with an anchor or a screw-post construct. Final AP and lateral radiographs of this procedure are shown in Figure 17.

Summary

Controversies regarding the ideal PCL reconstruction technique continue to be debated among sports medicine surgeons. Clinical outcome studies have shown satisfactory results regardless of graft choice, surgical technique, fixation strategies, and rehabilitation protocols.

Advances in PCL reconstruction have led to the development of less invasive procedures. The all-inside technique is an arthroscopic method that uses tibial and femoral sockets, extra-cortical fixation, and a high strength graft. The early results are promising, but research is necessary to document the clinical outcomes. Multicenter prospective trials are currently underway that will hopefully guide future treatment decisions.

References


