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Posterior Cruciate Ligament Biomechanics and Options for Surgical Treatment

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Abstract

Treatment algorithms for posterior cruciate ligament (PCL) injury have evolved over the past two decades as the natural history of these injuries has become clearer. Whether they are isolated injuries or occur with other ligament trauma, PCL ruptures substantially alter knee kinematics. Because of the effects of PCL injury and the less than optimal results after nonsurgical treatment, new surgical techniques have been developed.

Several surgical techniques currently are available for reconstruction of the PCL. Most recent reports suggest that the tibial inlay technique is the best choice for restoring posterior tibial stability. Tibial inlay PCL reconstructions can be performed through both open and arthroscopic approaches. Crucial to the outcome of these procedures is detecting all injuries to the secondary restraints, especially the posterolateral corner. Failure to recognize and treat these deficits can compromise the results of PCL reconstruction, emphasizing the need for a detailed, meticulous physical examination when PCL injuries are suspected.

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Posterior cruciate ligament (PCL) injuries can occur in isolation, in combination with other ligament injuries, and in knee dislocations. Combined ligament injuries and knee dislocations usually are treated surgically unless compelling reasons favor nonsurgical treatment. The treatment of isolated PCL injuries is more controversial because earlier reports of short-term outcomes indicated favorable results with nonsurgical treatment.[1,2] Unfortunately, the short-term favorable outcomes appeared to deteriorate with time.[3] In fact, at 15-year follow-up, 90% of patients reported by Dejour and Walch[3] had difficulty walking, suggesting that nonsurgical treatment of even isolated complete PCL injuries with significant laxity was not successful.

Consequently, the evaluation of patients with PCL injuries should include a thorough assessment of their age, activity level, size, limb alignment, and extent of injury to knee structures (including articular cartilage, menisci, ligaments, and capsule). This assessment cannot be completed with MRI alone and requires a meticulous physical examination. Although MRI can detail the areas of injury, it cannot determine the degree of abnormal translation or rotation that is present to accurately determine the extent of injury. Failure to detect the true extent of the PCL injury, a rotational component (posterolateral, posteromedial), or an associated injury (medial or lateral collateral ligament) can lead to faulty decision making and a poor clinical result.

Once the true extent of the knee injury involving the PCL is determined and the risks and benefits of nonsurgical and surgical treatment are discussed with the patient, several options are available if surgical treatment is elected, including transtibial arthroscopic reconstruction along with arthroscopic and open inlay techniques.

Although subjective results of the transtibial technique of single-bundle tibial tunnel PCL reconstruction have been good in general, objective improvement in posterior knee laxity has been unsatisfactory.[4-6] Thus the focus has been on finding a technique that better replicates the anatomy and biomechanics of the intact PCL in an effort to better restore posterior stability. Several different surgical options currently are available at the time of PCL reconstruction: orientation of the tibial side of the graft (tibial tunnel or tibial inlay), number of bundles that are reconstructed (single or double), and the surgical approach (open or arthroscopic).

Open Inlay and Arthroscopic Tunnel Techniques

Bergfeld and associates[7] evaluated cadaver knees reconstructed with single-bundle tibial inlay and tibial tunnel techniques and found a significant increase in graft thinning with tunnel grafts after cyclic loading at the "killer corner" (the angle that the graft must make as it exits the tibial tunnel posteriorly and is directed anteriorly toward the femoral tunnel) compared with inlay grafts. McAllister and associates[8] evaluated posterior laxity and graft pretensions in single-bundle tibial tunnel and tibial inlay techniques in cadaver knees. Minimal differences were observed in knee laxities with tunnel and inlay reconstructions immediately following reconstruction, but the tibial tunnel group had increased laxity after cyclic loading. In addition, the tibial tunnel reconstruction required an average 15.6 N greater graft tension than the tibial inlay reconstruction to restore normal laxity. To better determine the effects of cyclic loading, Markolf and associates[9] evaluated cyclic loading of grafts secured to the tibia with both the inlay and tibial tunnel techniques. They found increases in graft thinning, graft stretch-out, and graft failure after cyclic loading of tunnel grafts at the killer corner when compared with inlay grafts. They found that 10 of 31 tibial tunnel grafts failed at the acute angle created at the killer corner before the study could be completed (after 2,000 cycles), whereas all 31 of the inlay grafts survived testing. Further evaluation of the 21 grafts that survived testing with both fixation techniques revealed that the grafts that had been fixed with the inlay method had significantly less graft thinning than tunnel grafts (12.5% and 40.6%, respectively). Also, the mean lengths of the grafts fixed with the inlay and tunnel methods increased 5.9 mm and 9.8 mm, respectively.

These biomechanical studies showed that there is little difference between the tibial tunnel and tibial inlay techniques of PCL reconstruction with regard to graft forces, knee laxities, and graft pretensions at the time of initial fixation. However, with cyclic loading, significant increases in graft thinning and laxity were observed with the tibial tunnel technique compared with the tibial inlay technique of PCL reconstruction.

Clinical results of PCL reconstruction using a tibial inlay technique with patellar tendon autograft have been good and have yielded predictable outcomes. Additional advantages of this technique include a lower risk of vascular injury and anatomic graft placement on the tibia.

Although underreported in the literature, there is a real risk of injury with transtibial PCL reconstruction. It can be difficult to see the guide pin and drill when the tibial tunnel is created. In addition, the guide pin itself may migrate during drilling.

The tibial inlay technique offers easy, reproducible graft placement posteriorly on the tibia. It can be done through a transverse incision in the popliteal skin crease, which is virtually undetectable. More important, the graft position is easily determined by simply creating the inlay trough between the two palpable bony nodules or mamillary bodies that border the PCL sulcus. This allows anatomic placement of the tibial attachment of the graft.

There are no well-controlled studies comparing single-bundle tibial inlay and tunnel techniques. Retrospective case series comparing tibial tunnel and tibial inlay techniques reported no difference in subjective or objective results;[10,11] however, these studies were underpowered, and some variables were not well controlled.

Open and Arthroscopic Inlay Techniques

The open inlay technique requires the addition of a posterior approach to the knee; this exposure can be difficult in a large patient or in a patient with multiple trauma. In addition, patient positioning can be challenging. This technique requires the patient to be placed in a lateral[12] or modified lateral position or requires an intraoperative position change from prone to supine. Performing an open inlay technique with the patient supine is possible but requires placing the limb in the frog-leg lateral position. Arthroscopic transtibial tunnel techniques, on the other hand, may subject the graft to the killer corner as it passes posteriorly around the tibia.[7,9,13-15]

In conventional transtibial arthroscopically assisted PCL reconstruction, the killer corner, which is approximately 70°,[16] has been implicated as a cause of abrasion and subsequent graft laxity. This has been demonstrated in multiple laboratory and clinical studies.[17-20] In an attempt to improve the open tibial inlay technique of PCL reconstruction, Campbell and associates developed an arthroscopic inlay technique with the potential of combining the benefits of arthroscopic and open techniques: avoiding the open posterior knee approach, preventing the killer corner, and allowing a single-bundle or double-bundle graft to be used.[21,22] Unfortunately, limited clinical experience with this technique and the need for further refinements in instrumentation prevent widespread clinical usage at this time.

Zehms and associates[23] compared the arthroscopic inlay procedure with the standard open double-bundle PCL tibial inlay procedure in cadaver knees with and without posterolateral corner (PLC) deficiency. Ten paired cadaver knees were evaluated with posterior drawer, external rotation (30° and 90°), and stress radiography before surgery and after open inlay and arthroscopic inlay procedures. Both arthroscopic and open inlay techniques restored knee stability to the intact state in all knees, and there was no significant difference in radiographic posterior displacement and external rotation at 30° or 90° of knee flexion or in external rotation. These results suggest that the all-arthroscopic inlay technique may be equivalent to the open inlay technique, with the advantage of avoiding the posterior approach and the challenges associated with patient positioning.

Although the arthroscopic inlay technique has been shown in cadavers to provide results comparable to those of the open inlay technique,[21] it currently requires initial suture fixation, which can be inferior to the screw fixation used with the open inlay technique. Campbell and associates[24] compared suture and screw fixation during cyclic and failure loading in six pairs of human knees (average patient age, 47 years; range, 35 to 55 years) randomized to either an open inlay technique with 4.0-mm cancellous screw fixation or an arthroscopic inlay technique with suture fixation.[25] No significant differences were found between open and arthroscopic inlay techniques in mean load at failure, mean load at 3 mm or 5 mm of displacement, displacement at failure, or stiffness. In addition, no elongation of the constructs was detected in either arthroscopic or open inlay techniques at cycle 1,000 or 5,500, and no differences in structural properties were detected. The relative displacement at 60 N, before and after cycling in four pairs of knees, was not significantly different between the arthroscopic (0.92 ± 36 mm) and open techniques (1.39 ± 0.36 mm; $P = 0.008$). These findings suggest that initial and early fixation of an arthroscopic PCL tibial insertion inlay reconstruction is similar to that of the standard open tibial inlay reconstruction.

Biomechanics of Single-Bundle and Double-Bundle Grafts

Single-bundle grafts usually are used to reconstruct the anterolateral bundle, whereas double-bundle grafts are used to reconstruct both the anterolateral and posteromedial bundles. The double-bundle method of PCL reconstruction appears to be gaining popularity, but the clinical indications are controversial. The enthusiasm for this technique is based largely on biomechanical studies that have shown that the addition of a posteromedial bundle better replicates the normal posterior laxity profile.[26,27]

Recent biomechanical studies have questioned the value of reconstructing the posteromedial bundle. Markolf and associates[28] demonstrated that cutting the posteromedial bundle of the intact PCL produced only small increases in laxity near extension (1 mm), with no change in graft forces. In a separate biomechanical study, Markolf and associates[9] evaluated single- and double-bundle PCL reconstructions using the tibial inlay technique and found that double-bundle PCL reconstructions had small improvements in laxity (1 to 2 mm over 0° to 30° of flexion), but this was at the expense of increased PCL graft forces. This is of concern because high graft forces could lead to elongation of the graft, negating any positive effect this bundle might have on laxity.

Recently, Whiddon and associates[29] compared double- and single-bundle open inlay PCL reconstruction with and without repair of the PLC, using posterior drawer, dial testing at 30° and 90°, and stress radiography in nine paired cadaver knees. The knees were tested intact and after sequential resection of the PCL and the PLC structures. Each knee was reconstructed with a double-bundle, open inlay technique. After testing with and without repair of the PLC structures, the posteromedial bundle was released, and the knee was tested as a single-bundle reconstruction. Stability was increased with the double-bundle reconstruction, which more reliably restored rotational stability than the single-bundle technique, particularly without PLC repair. In spite of the improved performance, the double-bundle reconstruction was unable to replicate the intact state without repair of the PLC injury. The double-bundle technique overconstrained the knee when the PLC was reconstructed. It is currently unknown if this increased stability may be beneficial in severely injured knees in which the posterior capsule is disrupted, or whether it is detrimental and increases the risk of osteochondritis.

Several clinical studies have been conducted to compare single- and double-bundle methods for PCL reconstruction. These studies have shown either no or minimal differences in subjective or objective results between the techniques.[30-32] Thus it appears that a single-bundle reconstruction of the anterolateral bundle is the most important component of PCL reconstruction. Reconstruction of the posteromedial bundle should be viewed as an adjunct to an appropriately reconstructed anterolateral bundle and should not be done at the expense of downsizing or compromising the anterolateral bundle.

Graft Shape

Arthroscopic inlay surgery may be technically easier with a cylindrical bone plug than the standard rectangular-shaped bone plug used by Campbell and associates[24] and Zehms and associates.[23] Sekiya and associates (JK Sekiya, MD, et al, Ann Arbor, MI, unpublished data, 2008) compared the biomechanical strength of an Achilles tendon allograft fixed in an arthroscopic inlay configuration using either a cylindrical bone plug (12-mm diameter) or a more standard rectangular-shaped 12-mm × 18-mm bone plug in nine paired human tibias. Each construct was subjected to 1,000 cycles (at 0.5 Hz) of 20 N to 100 N, followed by load to failure at 1 mm/s; the modes of failure were then documented. The mean loads at 5 mm of displacement, yield point, ultimate load, stiffness values, and total cyclic displacement were not significantly different between the two groups. The mode of failure differed between the two groups, with six of the nine specimens in the cylindrical plug group failing by tendon avulsion from bone and three by bone plug fracture. In the standard plug group, six of the nine specimens failed because of the sutures tearing through the anterior tibial cortex, one failed due to bone lifting out of the socket, one tendon slipped in the tester, and only one failed by tendon avulsion off bone. These results indicate that both bone plug configurations have comparable biomechanical strengths, suggesting that a single cylindrical bone plug may be sufficiently strong.

Graft Choices

The native PCL is a large ligament, so it should be reconstructed with an appropriately sized graft. Several graft options are available, including autografts and allografts. For single-bundle reconstruction, bone–patellar tendon–bone or hamstring grafts can be used. However, many surgeons are using grafts with a larger cross-sectional area, including quadriceps tendon–bone, Achilles tendon–bone, and tibial tendon grafts, all of which are attractive options for double-bundle reconstructions.

The trend toward larger grafts has resulted in an increased use of allografts for PCL procedures, but many potential complications are associated with the use of allograft tissue. The infection risk is very likely underreported because no official reporting system exists to track and monitor these complications. Some proponents of allografts have suggested that athletes can return to play sooner because of a lack of donor site morbidity. Animal studies, however, have shown that allografts have longer incorporation times,[33] and earlier return to play may put the allograft at a higher risk for graft rupture than an autograft. Although the initial results of allografts and autografts are similar, allografts appear to have more potential to "stretch out" with time because of the known slower incorporation time. Clinical results of allograft anterior cruciate ligament (ACL) reconstruction also suggest increased laxity over time.[34-37] Although only a remote risk, allograft viral (human immunodeficiency virus, hepatitis) and bacterial contamination would be devastating and should always be considered and discussed with patients preoperatively. Other factors to consider before using allografts are availability and cost.

Combined PCL and PLC Injuries

Although PCL reconstruction techniques have advanced considerably, clinical outcomes are not uniformly successful, in part because of the failure of many techniques to treat associated injuries, including support structures, particularly those involving the PLC. In recent years, the synergistic relationship between the PCL and the PLC in controlling knee kinematics has been better understood. The risks of continued instability after PCL reconstruction, and, potentially, the development of premature degenerative arthritis in knees with PLC injuries that are not treated have been demonstrated.[4,38-42] Thus, it is imperative that combined injuries to the PCL and the PLC be correctly diagnosed and treated.

Sekiya and associates[43] tested the hypothesis that a grade III posterior drawer sign cannot be present without a PLC injury. Ten paired cadaver knees were tested in the following conditions: intact, with the PCL completely sectioned and with the PLC sectioned. The evaluation included posterior drawer, external rotation (30° and 90°), and stress radi-

Figure 1 Stress radiograph demonstrating posterior tibial subluxation of the injured side.

Figure 2 Stress radiograph of the normal side, demonstrating the absence of posterior tibial subluxation.

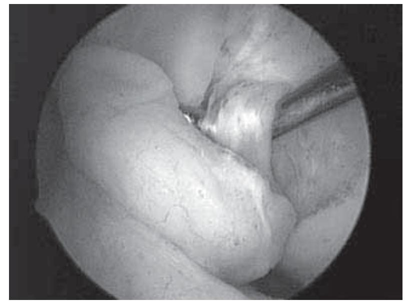

Figure 3 Confirmation of a PCL injury with diagnostic arthroscopy.

ography. The testing showed that a complete isolated PCL injury resulted in a grade II posterior drawer and less than 10 mm of abnormal posterior tibial translation on stress radiography. A grade III posterior drawer and more than 10 mm of posterior tibial translation on stress radiography were indicative of combined PCL and PLC injuries, even with only subtle increases in abnormal external rotation. The results of this study indicate that a PLC injury should be suspected when a PCL injury results in a grade III posterior drawer.

Sekiya and associates[44] also evaluated the importance of the PLC even when a double-bundle PCL reconstruction is done. They hypothesized that adding the posteromedial bundle in a double-bundle PCL reconstruction was sufficient to restore forces and kinematics to the intact state without the need for reconstruction of the PLC in a combined injury model. Robotic testing was used to apply 134 N posterior tibial load and a 5-Nm external torque at multiple flexion angles to 10 cadaver knees that had the PCL and the PLC sequentially cut and reconstructed. The knees were tested under the following conditions: intact, PLC-deficient, PCL- and PLC-deficient, isolated PCL reconstruction, and combined PCL and PLC reconstruction. Combined PCL and PLC reconstruction was found to restore normal kinematics to within 1.2 mm under posterior tibial load and 1.2° when external tibial torque was applied, measures not significantly different than in intact knees. At all angles except full extension, the in situ force in the PCL grafts was found to be significantly less than in the intact PCL. In contrast, the PLC graft forces were significantly higher than in the intact PLC at all angles tested. In addition to abnormal kinematics, the increased forces found in the PLC grafts, as compared to the native structure, may lead to elongation and early failure. Therefore, it is critical to reconstruct the posterolateral corner for PCL reconstruction to be successful, regardless of the technique used.

Surgical Technique

After a review of the history and physical examination findings and imaging studies, examination under anesthesia is done to confirm which knee ligaments are injured and the severity of injury. Many PCL reconstructions are done on patients with combined ligamentous injuries (usually the PCL and PLC). Stress radiographs with more than 10 mm of side-to-side differences likely represent combined injuries (Figures 1 and 2).[43]

Open Inlay–Patellar Tendon Autograft

The patient is placed in the lateral decubitus position, with the injured leg up. The other leg is wrapped in circumferential foam (the "bedroll technique"). A commercially available bracketed leg holder is used, and the hip can be externally rotated to allow access to the front of the knee. Diagnostic arthroscopy is done to confirm the diagnosis (Figure 3). Patients with PCL injuries may have apparent ACL laxity,[13] but if an anterior drawer corrects this laxity, the ACL is intact and it is simply pseudolaxity caused by PCL deficiency. Excessive opening of the lateral compartment of more than 10 mm may be a sign of an associated PLC injury.[45] In acute multiple ligament–injured knees, arthroscopy can be done safely without risk of compartment syndrome if an

Figure 4 PCL patellar tendon graft.

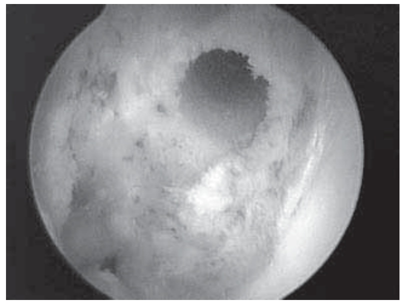

Figure 5 Medial femoral condyle in the right knee, demonstrating the position of a single-bundle femoral tunnel.

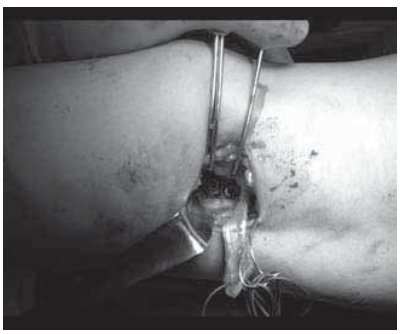

Figure 6 Posterior view of a PCL graft fixed with two cannulated screws.

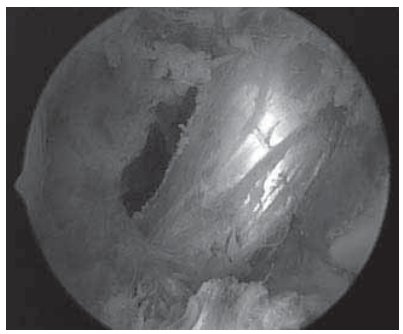

Figure 7 Arthroscopic view of a single-bundle PCL graft.

egress incision is made (the central portion of a planned medial or lateral incision that will be used later for treatment of associated injuries).

A patellar tendon graft is harvested with a rectangular tibial bone plug (for the inlay portion) and a relatively short, trapezoidal patellar bone plug (18 to 20 mm; Figure 4). The posteromedial bundle and meniscofemoral ligaments are preserved if possible, and the femoral tunnel is drilled at approximately the 1:00 to 1:30 position (right knee) and 8 mm from the articular surface of the medial femoral condyle (Figure 5). The back edge of this tunnel is rasped, and a bent 18-gauge looped wire is placed through the tunnel and into the back of the knee for later graft passage.

The leg is placed on a padded Mayo stand, and the posterior inlay approach is made in the popliteal crease. The key to this approach is the medial head of the gastrocnemius, which is mobilized after a hockey-stick incision is made in the investing fascia. This muscle is retracted laterally, past the midline, and Steinmann pins can be drilled from posterior to anterior and bent up to serve as retractors. The posterior bony nodules, or mamillary bodies, are palpated (the medial body is more prominent, and dissection should stay lateral to this), and the popliteus muscle and periosteum are sharply dissected off the back of the tibia. The trough is created with a high-speed burr. A generous posterior arthrotomy is made in the back of the knee (big enough to easily put an index finger through) and the preplaced looped wire is retrieved. The graft, which has been prepared on a back table, now can be secured into the trough. One or two cannulated screws (4.5 mm) are used to fix the graft after it is secured initially with guide pins from the cannulated screws (Figure 6). The patellar end of the graft is pulled up into the femoral tunnel and the knee is cycled. An anterior drawer force is applied, and the femoral bone plug is secured with an interference screw. Additional fixation can be used (with a button or screw-post construct). The final position and fixation of the graft are examined arthroscopically before closure (Figure 7). Radiographs or fluoroscopic images also can be obtained before closure to verify proper placement of the hardware, especially if the surgeon is new to this technique.

Open Inlay—Supine and Prone Positions

Some surgeons prefer a single-bundle tibial inlay technique with an Achilles tendon allograft. The patient is placed supine, and arthroscopic evaluation of the knee is done. Once the arthroscopic examination is complete, the patient is turned prone, and a posteromedial approach to the knee is made similar to that described by Burks and Schaffer.[46] An incision is made in the medial half of the popliteal crease, which turns distal and goes along the medial border of the leg over the medial aspect of the medial head of the gastrocnemius. With careful blunt dissection, the medial head of the gastrocnemius is mobilized and retracted laterally with a blunt retractor to expose the posterior capsule. A longitudinal poste-

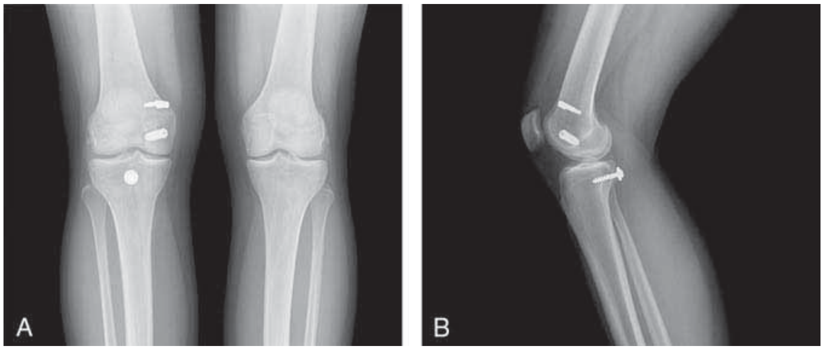

Figure 8 Radiographic AP **(A)** and lateral **(B)** views of a single-bundle inlay PCL reconstruction.

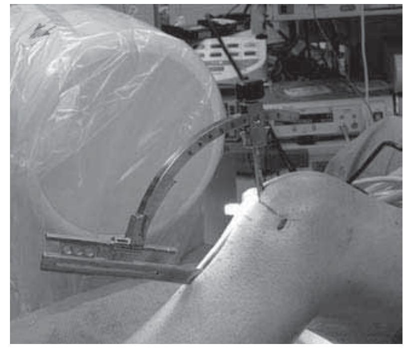

Figure 9 Tibial drill guide positioning for arthroscopic inlay. (Reproduced with permission from Jordan AA, Campbell RB, Sekiya JK: Posterior cruciate ligament reconstruction using a new arthroscopic tibial inlay double-bundle technique. *Sports Med Arthrosc* 2007;15: 176-183.)

rior arthrotomy is made, and the PCL tibial attachment site is identified. In most cases, a portion of the native PCL is still attached to bone. An Achilles tendon allograft is prepared on a back table. A recess with dimensions similar to those of the bone plug of the graft is made with osteotomes and a burr in the posterior tibia at the attachment site of the native PCL. The graft is secured within the recess with a single 6.5-mm × 35-mm partially threaded cancellous screw and washer using standard lag technique. Care is taken to ensure that the superior edge of the bony portion of the graft is flush with the surrounding bone and below the level of the articular cartilage of the medial tibial plateau. The soft-tissue portion of the graft is pulled through the femoral tunnel, and the posterior wound is closed.

The patient is again rotated back to the supine position, and the graft is tensioned with an anterior drawer force applied on the proximal tibia. The graft is fixed with a metallic soft-tissue interference screw placed within the femoral tunnel and reinforced with a staple placed on the side of the medial femoral condyle where the graft exits the tunnel (Figure 8). Arthroscopic evaluation confirms positioning of the graft within the anterolateral portion of the native PCL footprint.

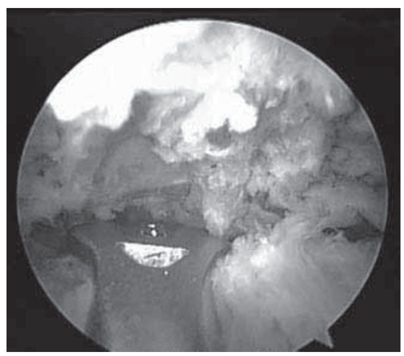

Figure 10 Arthroscopic posterior tibial view of a tibial drill guide for the arthroscopic inlay technique.

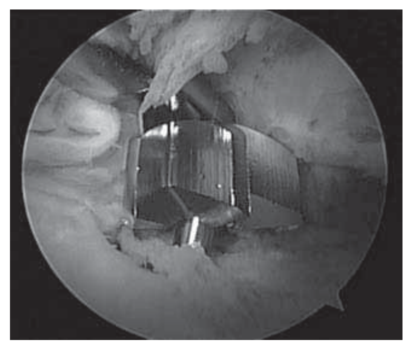

Figure 11 Arthroscopic posterior tibial view of a tibial retro-drill placed from the posteromedial portal.

Arthroscopic Inlay—Supine Position

For complete or combined PCL injuries, a double-bundle arthroscopic inlay technique may have the benefits of the lower morbidity and ease of an arthroscopic transtibial tunnel technique and the biomechanics of an open inlay technique.[21,22] The patient is placed supine on the operating room table. After diagnostic arthroscopy is completed, an arthroscopic PCL guide is used to place a guide pin 6 mm distal to the proximal extent of the PCL footprint on the tibial side (Figures 9 and 10), just distal to the posterior horn attachment of the medial meniscus. A parallel guide is then used to place a second guide pin 6 mm distal to the first one. These guide pins are overdrilled with 4.0-mm cannulated reamers, and the reamer heads are placed onto these guide pins (Figure 11). An 11-mm or 12-mm retrodrill reamer (Arthrex Inc, Naples, FL) is placed through the accessory posteromedial portal and onto each of the threaded pins (Figure 12), and a figure-of-8 socket is created to a

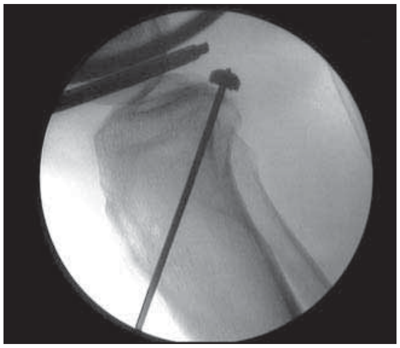

Figure 12 Radiographic lateral view of a tibial drill for the arthroscopic inlay technique.

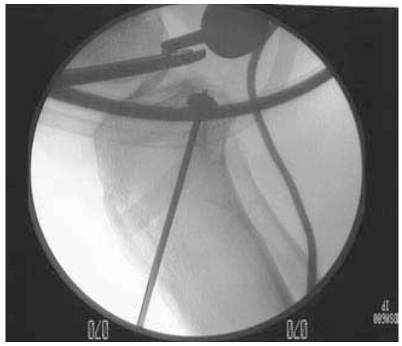

Figure 13 Radiographic lateral view of the 8- to 10-mm posterior tibial inlay socket.

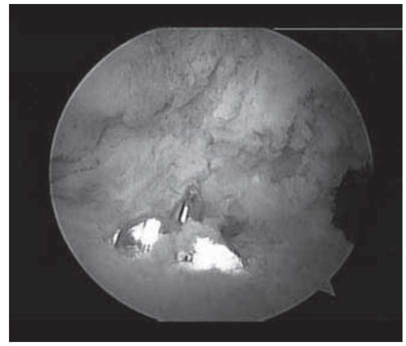

Figure 14 Arthroscopic posterior view of the tibial drill for the tibial inlay technique.

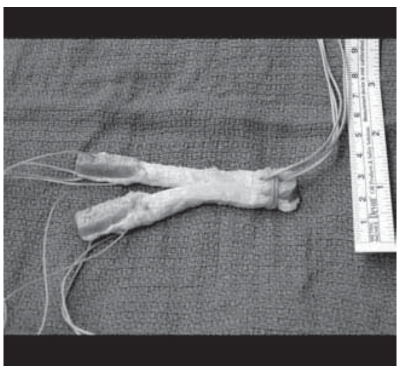

Figure 15 Double-bundle patellar tendon graft.

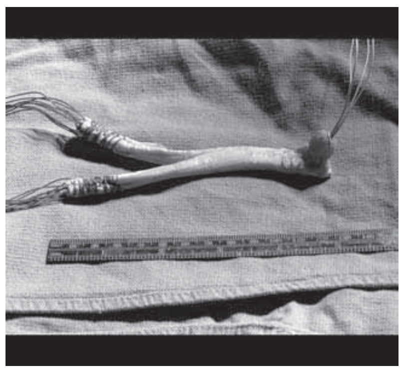

Figure 16 Double-bundle PCL Achilles tendon allograft.

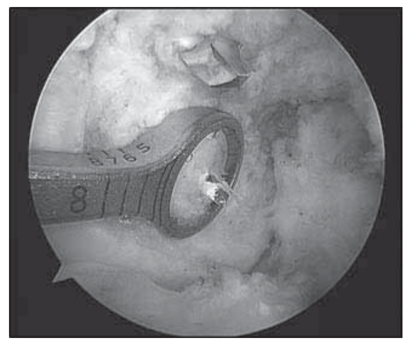

Figure 17 Arthroscopic view of the medial femoral condyle double-bundle technique.

depth of 10 to 12 mm (Figures 13 and 14). A prefashioned bifid quadriceps tendon graft, a patellar tendon allograft (Figure 15), or a split Achilles tendon allograft (Figure 16) can be used. The graft with the single bone-plug side fashioned to fit the figure-of-8 trough is then pulled into the joint and secured into the trough with two No. 5 FiberWires (Arthrex). The rest of the procedure is then done as in an open inlay technique, with the use of standard 11-mm anterolateral and 9-mm posteromedial femoral tunnels (Figures 17 and 18), created from outside-in, and then secured with metal or soft-tissue interference screws (Figure 19).

Recently, two of us (J.K.S. and E.M.W.) have had preliminary success with a single cylindrical plug on the arthroscopy inlay side (Figure 20) and using a bifid soft-tissue graft on the double-bundle femoral side. A contralateral quadriceps tendon autograft was used in patients who preferred autograft. High-demand patients would appear to benefit from the improved healing seen with autograft tissue and may better withstand the intense, aggressive rehabilitation associated with bilateral knee surgery. In lower-demand patients with potential rehabilitation issues who do not want bilateral knee surgery, we use large Achilles tendon allografts.

PCL Augmentation

Because of the healing potential of the PCL, acute injuries can be treated with PCL augmentation. This technique arthroscopically reconstructs the PCL while preserving any remaining PCL fibers. It can be used when there appears to be significant PCL tissue intact despite an unstable PCL examination in the acute setting. This may be particularly appropriate for partial PCL tears in patients with multiple-ligament injuries. PCL augmentation is not appropriate for chronic injuries because the healing potential of chronic PCL tears is lost. However, the appropriate clinical role for this technique has yet to be established.

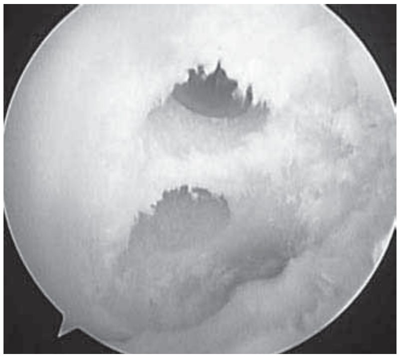

Figure 18 Arthroscopic view of double-bundle femoral tunnels.

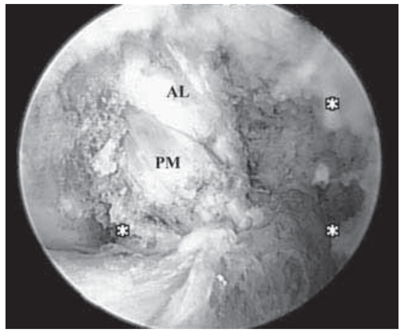

Figure 19 Arthroscopic view of the medial femoral condyle with the double-bundle technique. AL = anterolateral bundle, PM = posteromedial bundle. (Reproduced with permission from Chu BI, Roy R, Martin L, Carcia CR, Cibbs AE, Sekiya J: Surgical techniques and postoperative rehabilitation for isolated cruciate ligament injuries. *Orthop Phys Ther Pract* 2007;19:185-189.)

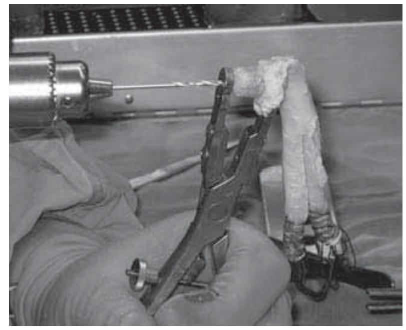

Figure 20 Double femoral bundle with a single tibial plug for arthroscopic inlay.

The augmentation technique can be done with an anterior tibial tendon allograft or a hamstring tendon autograft, as both have been shown to have sufficient ultimate load-to-failure values,[47] and both have a relatively small diameter, allowing for maximal native PCL preservation.

A posteromedial portal is used in addition to standard anteromedial and anterolateral portals. In preparing the femoral tunnel, only a small portion of the anterolateral remnant of the PCL is removed, leaving the residual anterolateral and entire posteromedial tissue, including the meniscofemoral ligaments. A shaver is used to detach the most anterior portion of the anterolateral bundle of the PCL toward the 12:30 clock position in a right knee, leaving most of the remaining anterolateral bundle of the PCL femoral attachment site. The femoral tunnel for the augmentation is placed high (12:30 clock position in a right knee), right off the distal border of the articular cartilage of the medial femoral condyle, and drilled in an inside-out fashion. The tibial tunnel is placed distal to the most distal tibial attachment of the PCL to avoid damaging intact fibers. An EndoButton (Smith & Nephew, Andover, MA) is used to fix the PCL in the femur. After the femoral attachment of the graft is fixed, the posteriorly subluxated tibia is reduced by pulling the proximal tibia anteriorly while flexing the knee 90°. With the knee in a reduced position, the graft is fixed to the tibial tunnel with an Intrafix device (DePuy Mitek, Raynham, MA).

Ahn and associates[48] analyzed the clinical results of 61 patients who had transtibial PCL reconstruction with the preservation of PCL fibers. These patients, at an average age of 30.4 years (range, 20 to 51 years), had isolated PCL injuries (a side-to-side difference in posterior displacement of more than 8 mm) that were treated with transtibial PCL reconstruction with preservation of the PCL fibers. At an average follow-up of 40.8 months (range, 24 to 84 months), the patients showed significant improvements ($P < 0.001$) in Lysholm scores, subjective International Knee Documentation Committee (IKDC) scores, objective IKDC scores, and side-to-side differences. In addition, follow-up MRI studies showed a mean graft thickness of 9.9 ± 1.3 mm in the sagittal plane and 12.3 ± 1.1 mm in the coronal oblique plane, and complete healing of the graft and original PCL fibers as one ligament. There was no evidence of graft loosening or tear at the killer corner. These results support the hypothesis that preserving the PCL fibers in selected patients with acute injuries can provide a good clinical result.

Results

Surgical reconstruction of the PCL using a tibial inlay technique has been generally successful. This technique effectively improves posterior laxity, decreases the quadriceps active test, and improves patellofemoral joint pain, which often is associated with chronic posterior instability.[49,50] Caution must be used to identify and treat combined instability patterns that are common with PCL injuries. Combined ligament instability has been reported to be present in as many as 85% of patients with PCL rupture.[51]

Cooper and Stewart[51] evaluated patients with isolated or combined PCL injuries that were surgically reconstructed over a time period ranging from 2 to 10 years. At an average of 39 months of follow-up, they found an overall posterior drawer improvement of two grades of translation with a solid end point in 40 of 41 patients. Telos stress testing showed an average of 4.11 mm of side-to-side difference, with significantly less difference in those with primary reconstructions compared to revisions.

Noyes and Barber-Westin[52] reported subjective improvement in 18 of 19 patients treated with a two-strand quadriceps tendon autograft with a tibial inlay technique for complete ruptures of the PCL. Eleven of the 19 returned to sports, and 14 of the 19 patients had stress radiographs that demonstrated less than 5 mm of side-to-side difference. Clinical comparisons of transtibial and tibial inlay techniques showed similar results, with a slight trend toward increased joint degenerative changes in the transtibial group and greater improvement in posterior drawer testing in the inlay group.[10,11]

Summary

The tibial inlay technique for PCL reconstruction is a reproducible and reliable method for treating posterior knee instability while avoiding the killer corner and reducing the risk of vascular injury associated with the transtibial technique. Patients must be carefully evaluated for the presence of combined ligament injuries with physical examination and appropriate imaging studies because these must be corrected for the PCL reconstruction to succeed. The tibial inlay technique can be used for both isolated PCL and multiple-ligament injuries. PCL augmentation may be indicated for acute partial PCL ruptures in patients with combined multiple-ligament injuries or with significant PCL tissue remaining despite poor stability. By preserving the acutely injured PCL fibers and providing support for the graft, healing of the native tissue may occur. For chronic injuries or when very little uninjured PCL tissue remains, a PCL tibial inlay technique, either open or arthroscopic, is our preferred method of reconstruction.

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