Chapter 41

Posterior Cruciate Ligament Reconstruction

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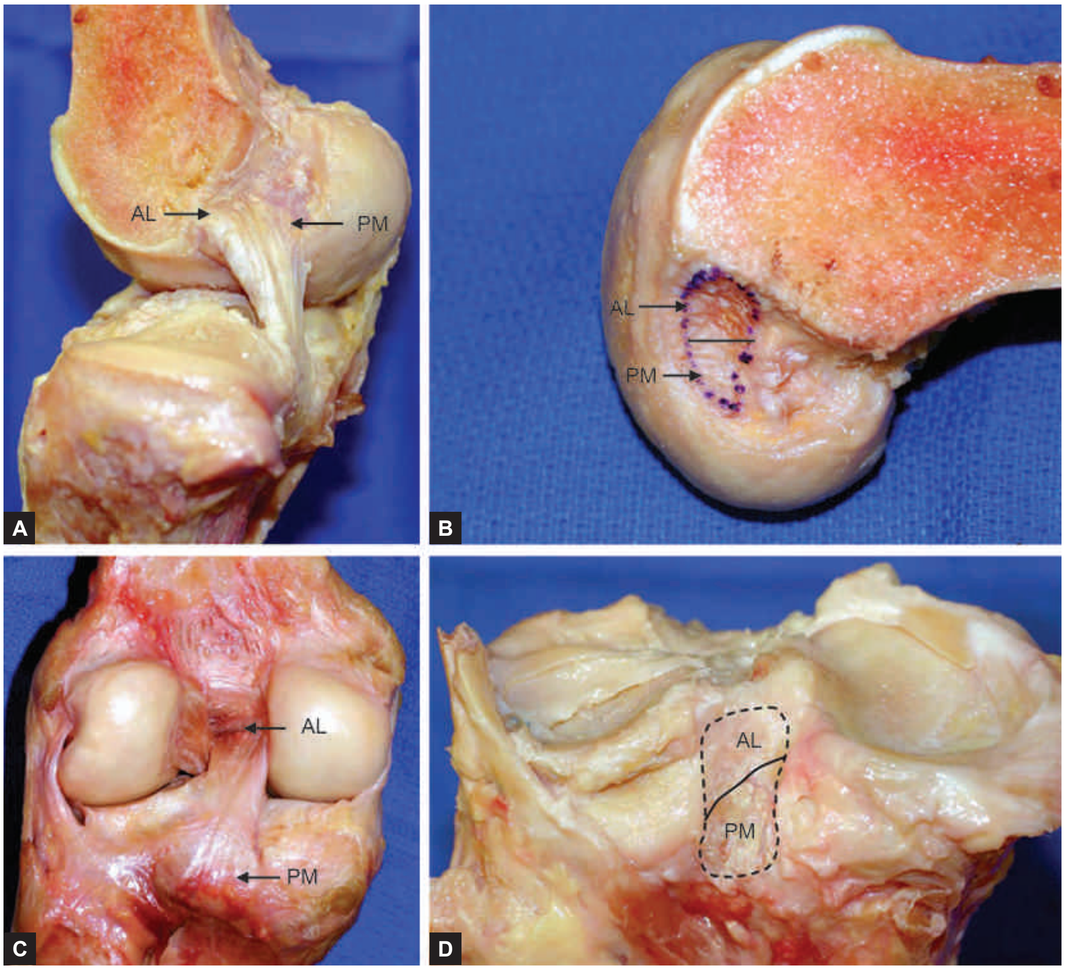
Ideal and successful treatment of posterior cruciate ligament (PCL) injuries remains elusive due to its complex anatomy and biomechanics. Historically, the outcome of PCL reconstruction has been inferior as compared with anterior cruciate ligament (ACL) reconstruction. The results of reconstruction by various surgical techniques continue to vary in different studies. However, in the last two decades, continuous research on PCL anatomy, biomechanics, and function has provided newer insights into the treatment options and techniques including inlay or tunnel technique, graft and fixation options, single or double bundle, and rehabilitation methods. With the help of recent literature review, this chapter would focus on the basics of anatomy and biomechanics of PCL, their influence on the treatment option; natural history of tear and alteration in biomechanics; diagnostic modalities and their usefulness in various scenarios; various treatment options (single and double bundle), fixation methods, and rehabilitation.

ANATOMY

Posterior cruciate ligament (PCL) is the primary restraint to the posterior drawer contributing approximately 90% of the resistance along the flexion arc.[1] It is a very strong ligament with tensile loads reported in the range of 739–1627 N.[2,3] Its strength is derived from a broad cross-sectional area and broad footprint over femur and tibia. It is a 32–38 mm long ligament whose diameter is 1.5 times more than the ACL and footprint three times larger than that of diameter.[4-6] To recreate this dumbbell, shape of ligament is difficult and this makes the PCL reconstruction difficult. PCL is functionally divided into the anterolateral (AL) and PM bundles based on femoral and tibial insertion.[4] The AL bundle tightens in flexion whereas the PM bundle tightens in extension. Harner et al. demonstrated that the AL bundle possesses superior structural properties than the PM bundle. The AL bundle is 2.1 times stiffer than the PM bundle and possesses 2.7 times ultimate strength as compared with the PM bundle.[6] Hence, the current surgical recommendation for single bundle PCL reconstruction is to reconstruct the AL bundle. Also, the AL bundle tightens in knee flexion that is more important for the PCL function. But this bundle description of PCL is oversimplification. Makris et al. dissected 24 pairs of knee and proposed that the PCL region is divided into four anatomic and functional fiber regions (anterior, central, posterior-longitudinal and posterior-oblique) whose tensioning and relaxing patterns are different in varying positions of the knee.[7] In a study on 12 cadaveric knees, Hatshushika et al. found an interesting topographical correlation between tibial and femoral attachments.[8] Femoral fibers followed high and low configuration but tibial footprint followed a parabolic or transverse type of attachment. This complex anatomy of the PCL renders PCL reconstruction difficult with current techniques by merely placing tubular/flat graft within circular tunnels.

The tibial footprint of the PCL is located between the posterior horns of two menisci about 1–1.5 cm below the posterior tibial margin in the 'PCL facet.' The anterolateral bundle (ALB) arises from superior part of the facet above the shelf and posteromedial bundle (PMB) arises below the shelf. Lowermost fibers of PLB merge with tibial periosteum and posterior tibial capsule. ALB and PLB fibers further extend upward and medially to be attached onto the medial femoral condyle (MFC). ALB is attached mostly to the roof of the intercondylar notch and PLB to the medial side of the wall (**Figures 41.1A to D**). This division of fibers is based upon the tensioning pattern in flexion-extension and is based upon dissection rather than true anatomic division.[4,9] ALB has a larger cross-sectional area and is much stronger than PLB. Recently,



Figures 41.1A to D Images of cadaveric dissected 'right knee' shows attachment of posterior cruciate ligament (PCL) fibers; the AL bundle and PM bundle over tibia and femur. Image (A) shows both the AL bundle and PM bundle attachment over MFC with knee in extension. Image (B) reveals the area occupied by both bundles over the MFC when seen in knee flexed where in the AL bundle occupies near the roof or high position and the PM bundle occupies low position near articular cartilage. Image (C) shows the attachment and orientation of PCL fibers from the back of the knee. Image (D) shows the origin of PCL fibers over the back of the tibia. *Abbreviations:* AL, anterolateral; PM, posteromedial; MFC, medial femoral condyle

another interesting observation was made by Hoof et al. on embalmed nine cadaveric knees using CTscan.[10] They replaced the PCL by a best fitting cylinder on a CT model and suggested that average tibial and femoral footprint of the PCL was 189.1 mm^2 and 293.3 mm^2. The mean diameter of the best-fit cylinder was 10.5 mm and mean coverage on tibial and femoral footprint was 76.5% and 46.5%, respectively. The central axis of this cylinder was central on the tibial footprint and AL on the femoral footprint of the PCL. The practical implication of this study is profound indicating that with the existing techniques of PCL reconstruction; it is difficult to restore the anatomical footprint of the PCL over tibia and femur. Double-bundle PCL (DB PCL) reconstruction could be more logical as it covers more footprints. The experimental evidence is encouraging.[9,11,12] However, clinical evidence is not supportive.[13]

The PCL is also flanked by the meniscofemoral ligament (MFL), anteriorly (ligament of Humphrey) and posteriorly (ligament of Wrisberg).[14] Both anterior and posterior MFL arise from the posterior horn of lateral meniscus and are attached onto the MFC anterior and posterior to PCL, respectively. Their presence is quite variable. A review of 16 anatomic studies (1022 cadaveric knees) done by Gupte et al. revealed that 91.1% knee have at least one MFL.[15] Posterior MFL was more frequent than anterior (70.4% versus 48.2%). The MFL offers a significant biomechanical advantage to the knee due to its size, stiffness and strength.[14] Recent biomechanical analysis revealed that aMFL and pMFL stiffness is almost equal to the PM bundle of PCL.[16] The MFL also guides the movement of lateral meniscus rendering it less vulnerable for injuries due to more mobility. Unpublished study of Demeo and Bergfeld (2004) proved that they offer 30–60% resistance for posterior drawer in 90° knee flexion. Due to their varied functional role in the knee, they should be preserved during PCL reconstruction.

Function of PCL Complex

The primary function is to restrain posterior tibial translation as the knee moves from extension to flexion especially from 30°–90° flexion.[1,9] Posteromedial and posterolateral capsule, collaterals provide posterior restraint between 0° and 30° flexion. It is also secondary restraint to varus, valgus and external rotation at high flexion angles. Covey et al. demonstrated that posterior translation of tibia increases by two fold (7.23 ± 0.65 mm) at 90° flexion as compared with 20° flexion (3.41 ± 0.77 mm) at 74 N posteriorly directed force over tibia after selective sectioning of the PCL.[17] Greater than 12 mm posterior drawer is not PCL injury alone indicating damage to posterior capsule.[18]

Epidemiology and Mechanism of Injury

PCL injuries are not as common as ACL injuries. Overall incidence of PCL injury is 1% to 44%.[19] But the incidence can be as high as 95% in combined high velocity ligament injuries due to road traffic accidents. The PCL is injured in contact sports or during road traffic accidents.[20]

1. Hyperflexion of the knee with plantar flexed foot is most commonly observed mechanism in sports injuries.[21]
2. Hyperextension is the other mechanism of injury which can rupture posterior capsule too.
3. Isolated PCL tears are also observed during fall from two wheelers over the road with the knee flexed and posteriorly directed force (pretibial trauma).
4. Dashboard injury to the knee where passenger sustains posteriorly directed force over tibia also results in PCL tear with associated fractures and PCL injury. PCL injuries are quite frequent with periarticular fractures, in which it is missed over 60% of time.[22]

Altered Biomechanics of Knee after PCL Tear

Martin et al. demonstrated that chronic isolated tear of the PCL alters the medial compartment kinematics during weight bearing.[23] PCL tear causes persistent subluxation of medial tibia posteriorly so that MFC rides anteriorly over tibial upslope. This deranges the kinematics of medial compartment. The lateral compartment is not affected. Also, posteriorly subluxated tibia brings the patella closer to femoral trochlea causing increased contact pressure in the patellofemoral compartment. In 10 patients with grade 2 PCL tear, Cristian et al. demonstrated that their knees had decreased maximum valgus moment during stance phase and increased vertical ground reaction force during midstance phase of gait.[24] Skyhar et al. concluded after a cadaveric study that isolated sectioning of the PCL leads to increased pressure in the medial compartment of the knee and the patellofemoral joint.[25] This may explain the increased rates of osteoarthritis in the medial and patellofemoral compartment of the knee. For long, it was thought that an isolated PCL tear can be managed conservatively and is a more benign injury. However, Strobel et al. in 2003 concluded after knee arthroscopy of 181 patients with isolated PCL tear and revealed that 80% had MFC articular cartilage damage and 50% had patellar cartilage damage after 5 years.[26]

Effect of Posterolateral Corner (PLC) Injury, Hamstring and Gravity Over PCL

Injury to PLC causes increase in stress over the PCL and PCL replacement graft by 30%.[27] This effect is quantitatively maximum at low flexion angles.[28] Hamstring activity too increases forces over the PCL especially at 90° flexion of the knee. Gravity too increases the force over the PCL and graft especially in supine position by causing posterior sag.

Clinical Evaluation

Detailed history is helpful in eliciting the mechanism of injury and possible ligaments involved. Clinical features vary in acute and chronic setting of the PCL tear.

In acute PCL tear, there might be an abrasion over the knee or tibia indicating direct injury over the tibia. There might be effusion in the knee and tenderness in the popliteal fossa. If PLC is injured, there might be ecchymosis over the lateral aspect of the knee and upper end of the leg indicating posterolateral capsular tear. Assessment of neurovascular structures cannot be underestimated. Posteriorly directed force can disrupt popliteal artery resulting in vascular deficit. Involvement of common peroneal nerve is not uncommon especially in multiligament injury. Serial examination of pulse is of extreme importance in acute injuries. Absent/feeble pulse or if ankle brachial index is less than 0.9 as compared with uninvolved knee, arteriogram is indicated in such situation which can be performed while doing CT or MR scan of the knee.

Chronic tears of the PCL result in instability and pain both. The patient may complain of instability while climbing stairs, walking up or down inclines (ramps) or while lifting heavy loads with the knee flexed. They might complain of knee pain suggesting involvement of the medial compartment of knee and patellofemoral joint causing arthrosis. On examination, the tibia sags posteriorly with knee flexion. The most accurate test is posterior drawer at 90° flexion with sensitivity of 90% and specificity of 99%.[29,30] The posterior drawer is graded from 1 to 3. Normally, the tibial plateau is 1 cm ahead of femoral condyle in 90° flexion. Grade 1 posterior drawer means that tibia can be pushed 3–5 mm posteriorly but step-off is still present. In grade 2, the tibial plateau is flush with femoral condyle where posterior drawer is between 5–10 mm. In grade 3, the tibial plateau is no more flush but is felt behind the femoral condyle where posterior drawer is more than 10 mm. Associated injuries of posterolateral corner (PLC), posteromedial corner or ACL should be confirmed by appropriate tests. Test for meniscus should be performed to rule out meniscal tears. Medial joint line tenderness may indicate developing arthrosis in medial compartment. Patellofemoral crepitus and facet tenderness indicate involvement of the patellofemoral joint.

Radiological Evaluation

Plain X-ray of the knee comprising A-P, lateral and Merchant's view is done to evaluate the knee. Narrowing of the medial compartment, avulsion fracture of PCL, involvement of the patellofemoral compartment, posterior sag, tibial slope and medial Segond fracture can be easily recognized. Medial Segond fracture indicates medial meniscus tear. The lower limb alignment is assessed by hip to ankle scanogram while standing. Varus malalignment are quite frequent with chronic PCL injuries.

Stress radiographs (Telos, Marburg, Germany) are the most essential part of radiographic evaluation. It is a simple method of objective evaluation of sagittal translation of the tibia over femur. It helps in differentiating partial from complete tears of PCL and the amount of sagittal translation posteriorly. It also objectively informs about

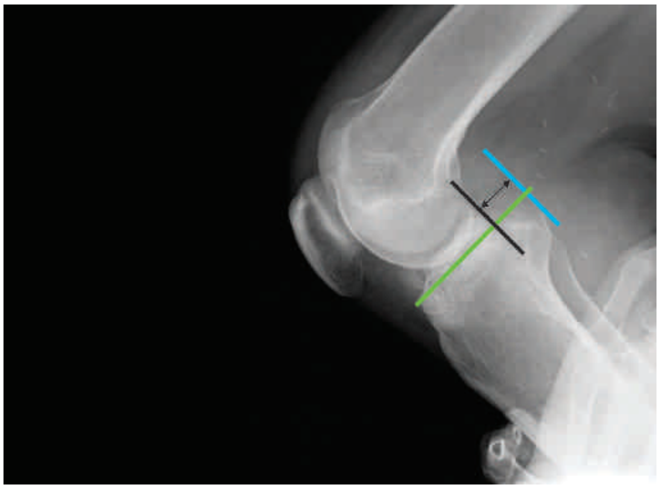


Figure 41.2 Plain radiograph of the left knee showing manual posterior drawer stress X-ray to assess insufficiency of the posterior cruciate ligament. The green line represents the tibial plateau. Black line represents the back of femoral condyle and blue line represents the end of tibial plateau. The arrow between blue and black represents the measure of posterior translation

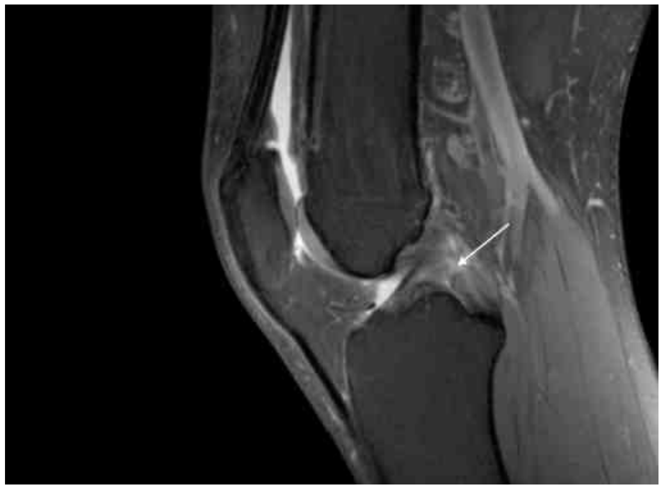


Figure 41.3 Proton density fat saturated sagittal T2 MR image reveals complete posterior cruciate ligament tear (white arrow)

the functional status of the PCL that appears healed on MRI but may remain functionally defunct. However, the availability of such instruments is a rarity in most centers of developing nations. In such scenario, a simple forced posterior drawer in 90° can help in approximate grading of posterior drawer (**Figure 41.2**).

Further evaluation is performed by MRI. MRI has accuracy of 96–100% in predicting PCL tears.[31] MRI is more sensitive (100%) in an acute tear setting rather than chronic.[29] MRI determines the location of the PCL injury, meniscal and cartilage pathologies and associated collateral ligament status. Grade 1 and 2 tears of the PCL on MRI may look normal. In such situation, clinical examination and stress radiographs are helpful to differentiate between functional or nonfunctional PCL (**Figure 41.3**).

Bone scan may be performed in chronic PCL tear to diagnose early medial compartment arthritis which may not be detected by X-ray or MRI.

Natural History of PCL Tear

Natural history of ligament tear comprises of 'what its absence does to the joint and what happens to itself.' In the absence of functional PCL, the biomechanics of knee joint is altered leading to arthritic changes in the medial compartment and the patellofemoral joint. The rate of articular cartilage involvement varies from 12% to 52% and rates of meniscal tear vary from 16% to 28%.[32-34] Radial tears in the middle and posterior part and longitudinal tear in the anterior horn of the lateral meniscus have been reported.[34] As far as the functional outcome is concerned, conservatively managed PCL tear may have a benign outcome in short term but gradually the joint function deteriorates. Parolie et al. concluded that 80% (20 out of 25) athletes report satisfactory outcome after a mean of 6.2 years.[35] Torg et al. followed 43 patients out of which 14 patients had isolated PCL tear and others had combined instability.[36] At a mean of 6.3 years (1–37 years), 5 (36%) patients with isolated PCL tear reported excellent outcome, 7 (50%) reported good outcome, whereas patients with combined instability fared poorly. One-hundred thirty-three patients of grade 1 and 2 isolated PCL tear followed by Shelbourne et al. for a mean period of 5.4 years with 68 were followed up on long-term.[19] There was no change between initial and final laxity. Radiographic changes in the knee and the subjective outcome of the patient had no correlation with grade of laxity. Regardless of laxity, 50% of the patients could return to same sport at same or higher level and 30% of them could return to the same sport at lower level. There are many reports about spontaneous healing of PCL after tear. The PCL has better chance of healing as compared with the ACL due to robust blood supply. After studying 18 patients over 1 year with stress radiographs and MRI, Mariani et al. reported that partial PCL tears heal well and complete PCL tears greater than 12 mm or PCL tear associated with other ligament injuries are less likely to heal.[37] Jung et al. too demonstrated that out of 46 cases of complete PCL tear, more than 72% heal (on MRI) after 2 months.[38] Tears associated with combined instability are less likely to heal. Shelbourne et al. followed 40 patients with isolated PCL tear and combined injuries for 3.2 ± 1.3 years and classified them into high (22), mid (14) and low grade (4) PCL injuries.[39] All low- and mid-grade injuries healed whereas 19 out of 22 high grade too healed. Even patients with combined instability showed signs of PCL healing. So, this concludes that isolated partial or complete tears of PCL stand a chance of healing and should be managed conservatively. The question arises at the end that whether PCL reconstruction would prevent arthritis of the knee or not? The answer remains elusive as no study has proven the theory that PCL reconstruction would prevent knee arthritis.[40]

Figures 41.4A to D Image showing various graft options: (A) Quadrupled hamstring graft; (B) Bone-PT-bone graft; (C) Quadriceps tendon-bone graft; (D) Tendoachilles-bone graft

Nonoperative Treatment

Indications

1. Grade 1 and 2 isolated tears of PCL with secondary restrains (PLC and posteromedial corner) normal.
2. Undisplaced avulsion fracture of PCL. The decision is supported by appropriate clinical and radiological evaluation.

Principles of Conservative Management of PCL Tear

Phase 1: 0–6 Weeks

1. Rest, ice, compression and elevation for a few days and nonweight bearing gait training.
2. Knee immobilization in extension preferably in posterior tibial support PCL brace (**Figures 41.4A to D**) or cylindrical cast 3–4 weeks. It is important to eliminate posterior sag of the proximal tibia with the use of appropriate padding in the brace/cast. In the modified PCL brace, the femoral side straps of brace are tied firmly to push femur posteriorly whereas the tibial side straps are tied loosely to prevent further push to tibia posteriorly.
3. Quadriceps strengthening is the mainstay of rehabilitation which counteracts force of gravity and hamstrings which displace the tibia posteriorly.
4. Active straight leg-raising in knee brace, hamstring and gastrocnemius stretching.

Phase 2: 6–12 Weeks

Patient is permitted to mobilize the knee through the full range. Quads are continued to be strengthened further as they are PCL synergists. Proprioception training can be started. PCL braces can be given for 3–4 months especially while walking.

Phase 3: 13–18 Weeks

Initiation of running and sports specific training is started. Return to sports is by 4–5 months after clinical and radiological assessment of healing of the ligament and complete return of strength of the knee.

Role of PCL Braces in Rehabilitation

Varieties of commercial braces (PCL-Jack brace, Ossur CTi brace, DonJoy PCL brace) are available in the market. The purpose of a PCL brace is to prevent tibia from subluxating posteriorly under the influence of gravity and simultaneously push the femur down. This action can help healing of PCL in optimal length without getting elongated and prevents PCL graft from abrasive forces acting at killer turn of tibia.

An ideal PCL brace would be the one that can continue exerting such static effect during the complete range of knee movement and also let the length tension relation of PCL be maintained during the movement of the knee. Recently, Jansson et al. concluded that the currently available braces do not provide adequate support to PCL 'in motion' as they exert same forces throughout the range of movement whereas in the normal PCL, the tension varies throughout the flexion.[41] However, a static PCL brace which can support tibia from subluxation posteriorly, especially during healing phase, could be useful in early days of immobilization.

OPERATIVE TREATMENT

Indications

1. Grade 3 symptomatic PCL tear.
2. Combined instabilities.
3. Posterior drawer more than 10–12 mm on Telos stress radiography.
4. Displaced PCL bony avulsion (PCL appears buckled on MRI with displaced fragment).

Factors for PCL Reconstruction

1. Timing.
2. PCL remnant preservation or excision.
3. Graft selection.
4. Single or double bundle.
5. Tibial tunnel or inlay technique.
6. Fixation.

Timing

Acute Grade 3 PCL Tear

PCL reconstruction is usually done as an elective procedure after 3–6 weeks of initial injury. In the waiting period, other extra-articular instability, if significant, is dealt with. Also, the posterior capsule tends to heal which is not only important for posterior stability but also for all arthroscopic PCL reconstruction to prevent fluid extravasation. Delaying PCL reconstruction for long can lead to capsular scarring and persistent posterior subluxation especially in multiligament injuries. In such a situation even if PCL is reconstructed, the outcome is usually poor in the wake of persistent subluxation.

Chronic PCL Tear

If the knee is clinically unstable, stress X-rays reveal grade 3 posterior drawer or bone scan shows early arthritic changes in medial compartment, it would be prudent to go ahead with the PCL reconstruction. Further delay can lead to arthritic changes in the knee. If PCL reconstruction is performed in arthritic knee, the knee would be stable after reconstruction, but it may remain painful and the outcome would be poor.

PCL Remnant Preservation or Excision

The PCL has better healing potential as compared with the ACL due to robust blood supply. Also, the presence of mechanoreceptors in the residual remnant aids in better proprioception from the knee.[42] Hence, some authors believe that preserving the elongated PCL remnant aids in mechanical support to the knee, protects new graft from killer turn at tibia and it heals together with newly reconstructed PCL giving better support to the knee.[43] Kim et al. did a retrospective study on PCL/PLC reconstruction with and without remnant preservation and opined that though the two groups did equally same on objective scale but subjective scores of remnant preservation were better.[44] However, strong objective evidence in favor of stump preservation is still lacking. When single bundle PCL is reconstructed while preserving the PCL remnant, the graft should be brought underneath the remnant otherwise the reconstructed part will be twisted. However, a recent cadaveric biomechanical study performed by Jung et al. suggested that a curved path over the remnant PCL will give more intra-articular length to reconstructed PCL and better isometry than under the PCL remnant.[45] So, based on their observation, they recommend passage of graft over the remnant. In conclusion, if one chooses to preserve the stump, it is preferable to pass the graft posterior and superior to the stump to preserve isometry of graft.

Graft Selection

The intra-articular length for PCL graft required is 4 cm and average length of the PCL graft should be 8–12 cm depending upon the technique used. The diameter of the graft selected should be a minimum of 9 mm as it has to counteract gravitational, abrasive (at killer angle), and elongation forces. Though the graft choice (auto/allograft) varies between quadruple hamstrings; bone-patellar tendon-bone; bone-quadriceps, tendoachilles-bone; tibialis anterior and posterior, there is no ideal graft for PCL as none of them can closely resemble its complex anatomy which can be replicated during reconstruction (**Figures 41.5A and B**). Availability of allograft is scarce especially in developing nations.

Quadruple Hamstring Graft (QHG) (Both Semitendinosus and Gracilis)

It can be used for single bundle (SB) or double bundle (DB) reconstruction. It heals by tissue to bone healing and is associated with less morbidity. Since, it is used as graft in tunnel technique; it is prone for failure at the killer turn. If diameter of QHG of index side of knee is less than 8 mm, the semitendinosus tendon of the other side must be harvested in order to increase the diameter of graft to prevent failure of graft during rehabilitation. This should be explained to the patient preoperatively and appropriate consent should be obtained preoperatively.

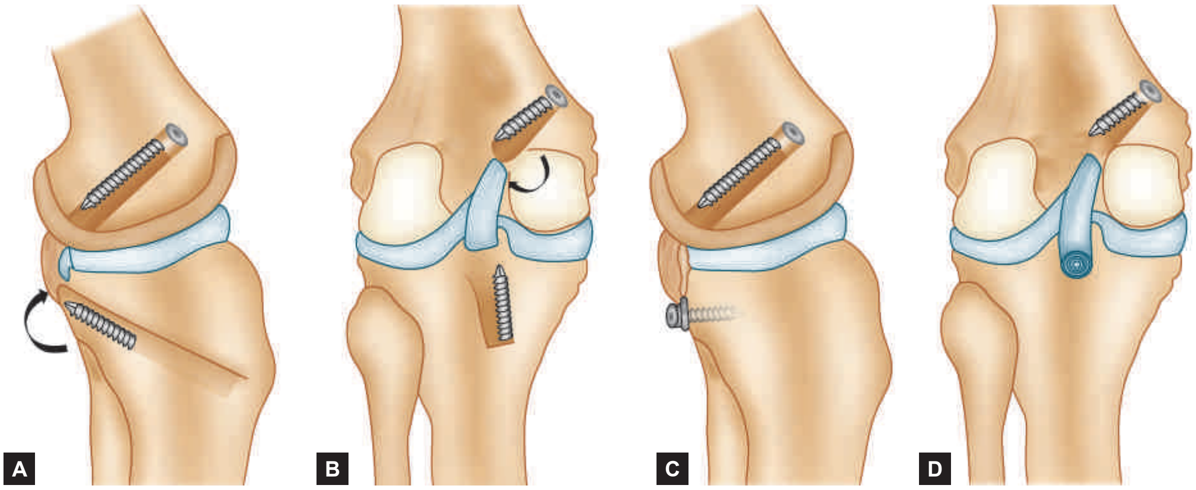
Bone-Patellar Tendon-Bone (B-PT-B)

It allows bone to bone healing and can be used both as inlay or tunnel technique. The morbidity and complications associated with this graft are well described.

Quadriceps Tendon-Bone Graft (Quad-B) and Tendoachilles

Bone also allows bone-to-bone healing at tibial end and soft tissue-bone at the femoral end. They have large

Figures 41.5A and B Image of a modified extension brace for posterior cruciate ligament (PCL) support. (A) Image shows a side view of a PCL support brace where 2-inch thick commercial sponge is glued over the distal aspect of brace where the tibia/leg rests. This acts as posterior support to the tibia preventing its subluxation. (B) Image shows the top view of brace. The central strap of brace is tied over the patella; the femoral straps are kept tight whereas tibial straps are kept loose



Figures 41.6A to D Diagrammatic representation of tunnel and inlay techniques. (A) Image shows lateral view of diagrammatic represents an acute 90° turn of graft behind the tibia to ascend upward toward femur (black arrow). (B) Image shows a posterior view of the posterior cruciate ligament (PCL) graft where it takes another 90° turn in the femoral tunnel (black arrow). (C) Image shows lateral view of the inlay technique showing the absence of acute turn of graft at the tibial end as graft is fixed in the PCL trough with a screw. (D) Image shows lateral view of the inlay technique

cross-sectional area and the soft tissue end can be split into two strands to be used as DB. Concern with B-PT-B and Quad-B is about anterior knee pain and weakening of synergist required in PCL deficient knee.

'Tibial Tunnel' or 'Inlay' Technique

The tunnel technique involves placement of graft through a transtibial tunnel. In the tunnel technique, the graft must make an acute 90° turn as it emerges out of the tibial tunnel at the back of the tibia to enter the knee joint. This acute 90° turn forms a killer turn as the graft is subjected to abrasive and elongation forces[46] (**Figures 41.6A and B**). Inlay technique involves open, anatomical placement of graft and fixation at tibia at PCL trough (**Figures 41.6C and D**). This technique avoids killer turn. Femoral placement remains essentially same in both techniques. Markolf et al. performed an *in vivo* experiment over 62 cadaveric knees in which 31 knees underwent PCL reconstruction by tibial inlay and other 31 by tibial tunnel technique using B-PT-B graft.[47] These knees were subjected to 2000 cyclical loading through 50–300 N force at an angle of 45°. All inlay grafts survived the test whereas 10 out of 31 of tunnel techniques failed the loading before 2000 cycles. The grafts fixed by inlay technique showed significantly less thinning (12.5% versus 40.6%) at acute angles and lengthening (5.9 mm versus 9.8 mm) as compared with the tunnel technique after cyclical loading. Bergfeld et al. also concluded in a cadaveric study on six paired knees that inlay technique results in better graft survival, lesser mechanical degradation and better placement of graft at the footprint as compared with the tunnel technique.[48]

Tunnel technique is all-arthroscopic, lesser morbidity and easy revision but higher chance of failure. Inlay technique involves open approach, more morbidity and difficult to revise with an implant at back of the knee. However, due to ease of graft preparation, lesser morbidity and surgeon's comfort, the tunnel technique seems to be more popular. The outcome of tunnel technique can be improved with thicker graft, appropriate tunnel placement, back-up/hybrid fixation and slower rehabilitation.

Single Bundle (SB) or Double Bundle (DB)

Single Tunnel AL Bundle (Technically Single Bundle)

This remains the most popular PCL reconstruction technique. Currently, the data comparing the two techniques is not enough to prove the superiority of one over other. SB scores over technical ease, less morbidity, cost effectiveness and easier revision.

Double-Bundle Technique

Wherein both ALB and PMB are reconstructed making two tunnels on the femoral footprint, seems to be more anatomical. But, it comes with a tag of technically demanding procedure, increased morbidity, difficult revision, and, of course, an increased cost of the procedure.

Various studies fail to prove the difference between the two. In a study on 42 patients of PCL reconstruction (tibial tunnel technique; 23 SB, 19DB) with a minimum follow-up of 2 years, Kim et al. concluded that there was no statistical difference between the two techniques when posterior and rotatory laxity, Lysholm, and IKDC scores were compared.[49] Kohen et al. did a systematic review on comparing two techniques of SB and DB PCL reconstruction and concluded that superiority of one procedure over other remains uncertain. The comparison between two remains complicated due to usage of different grafts, inlay or tunnel techniques and tensioning patterns.[13]

Fixation Option

The purpose of graft fixation is to provide mechanical support to the graft in the bone tunnel, while it heals with the bone during early postoperative phase. To achieve a strong fixation with optimal pull out strength and stiff construct, the knowledge of *in vivo* and *in vitro* forces over the PCL is necessary. Morrison et al. revealed that peak force in PCL varies in different position of the knee; 330 N in walking, 950 N during knee extension and 2500 during full squat and leg press.[50,51] So, fixation option for the PCL graft should be able to counteract such pullout forces and should be strong enough to let the graft heal in tunnel while the patient undergoes rehabilitation. Various options are described in the literature e.g., interference screw (metal/bioabsorbable), endobutton, staple, suture post and screw washer for PCL graft fixation. In various cadaveric studies, the pull out strength of these fixation options varies from 200–900 N in isolation. Hoher et al. concluded that alone metal interference screw on femoral side for 'hamstring graft' seems to have least pullout strength (242 ± 91 N) as compared with bioabsorbable screw (480 ± 133 N) and endobutton (520 ± 50 N). However, the pull out strength on tibia side between metal and bioabsorbable screw is nearly same for the hamstring graft (419 N versus 507 N). Screw and washer provide maximum pull out strength of 821 ± 219 N.[52] In conclusion, the pullout strength and stiffness of the construct can be increased by using backup fixation like staple, screw, and washer at the end of the graft especially on tibia side where the bone is softer due to its cancellous nature. If femoral side fixation is doubtful or bone seems to be soft, the back-up fixation on the femoral side too should be added up. The detailed biomechanical analysis of all the implants used in PCL graft fixation is out of scope this chapter.

Femoral End Graft Fixation

- *Anatomic fixation:* Inside-out/outside-in femoral tunnel: interference screw (metal/bioabsorbable).
- *Extra-anatomic fixation:* Endobutton, button on the cortex.
- *Over the cortex:* Staple, screw with washer.

Tibial End Graft Fixation

a. *Bone tunnel technique:*
   Anatomic—interference screw.
   Extra-anatomic—screw post, staple over graft tissue.
b. *Inlay technique*—lag screw with washer over the bone plug, staple.

SINGLE-BUNDLE TIBIAL TUNNEL TECHNIQUE PCL RECONSTRUCTION USING QUADRUPLED HAMSTRING GRAFT

Patient Position

After appropriate anesthesia, spinal or GA, pneumatic tourniquet is applied. Prophylactic antibiotic (1.5 gm intravenous cefuroxime) should be administered 30 minutes prior to inflation of tourniquet. Examination under anesthesia is performed to confirm the grade of posterior drawer and other associated injuries, if any. The medial and lateral tibiofemoral step-off of the injured and normal knee is palpated. This information is used during tensioning of the PCL reconstruction to confirm restoration of the injured knee to the 'neutral' position. It is particularly important to examine the medial and posterolateral ligamentous structures. Failure to treat associated ligamentous injuries is one of the most common causes of a failed PCL reconstruction as it increases stress on the reconstructed PCL by 30%.[27] A side-post on the side of thigh should be applied to support the thigh in flexed position while performing arthroscopy. Routine sterile preparation of the index limb should be done as per standard protocol. If autograft QHG harvest is planned from index knee, it may be prudent to keep the other limb also prepared as occasionally the graft diameter may be quite less (less than 8 mm) which is inappropriate for PCL reconstruction. We believe that PCL graft diameter should be at least 8 mm or preferably 9 mm in order to overcome the stress over the graft at the killer turn.

Standard Arthroscopy and Probing

After inflation of tourniquet, diagnostic arthroscopy is performed through a high AL portal that is close to patellar tendon (PT) and at the level of inferior pole of patella. Placing this portal at the height of the inferior pole of the patella places the arthroscope above the fat pad and allows a better view of the posteromedial (PM) aspect of the knee joint. Too far lateral and low AL portal will deflect the scope toward MFC making access toward PM recess difficult. The anteromedial (AM) portal is established under direct vision using an 18 gauge spinal needle to determine the optimal position. In general, this portal is as close as possible to the medial border of the PT and at the height of the inferior pole of the patella. It is important not to make this portal too low as this may cause difficulty when attempting to insert instrumentation through the AM portal into the PM compartment of the knee. After establishing the AL and AM portals, a standard arthroscopic examination of the knee joint is performed, and any meniscal and or chondral injuries are appropriately addressed. It is important not to mistake pseudolaxity of the ACL for a torn ACL. In chronic PCL tear, the PCL is replaced by fibrotic lax remnant tissue covered by synovium (unlike in chronic ACL tear where notch and lateral wall is empty) that remains lax after posterior drawer. In chronic PCL tear, 'lax ACL sign' is apparent (**Figure 41.7**). Because the tibia is subluxated posteriorly, the ACL remains lax and could be wrongly interpreted as chronic ACL tear. Taking down such an ACL could prove disastrous.

The PCL reconstruction is facilitated by the use of a PM portal. A PM portal is necessary to resect tissue at the PCL tibial attachment site. Viewing through a PM portal also provides the best view of the PCL tibial attachment site and eliminates the need to use a 70° arthroscope. The posteromedial portal is established during preparation of the PCL tibial attachment site and will be described later in the chapter.

Graft Harvest and Preparation

An inch long incision is made, 1 cm medial to tibial tuberosity. Pes anserinus fascia is incised and semitendinosus and gracilis tendon is harvested in standard fashion. The tendon is prepared in usual way and quadrupled. Minimum length of graft required for the tibial tunnel technique is 10 cm. Four centimeter is required for intra-articular portion of graft and 2.5 cm each for tibial and femoral tunnels. That makes it 9 cm. When tibia is pulled anteriorly while fixing the tibial side of graft, additional 1 cm is pulled inward making the length required to be 9 + 1 cm, i.e. 10 cm. Opposite side semitendinosus tendon should be harvested in order to increase the diameter of graft to a minimum of 8 mm if ipsilateral tendons fail to make it up to the minimum requirement.

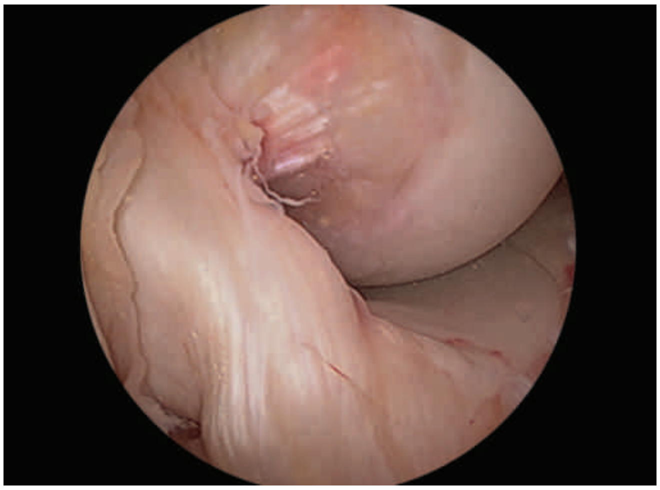


Figure 41.7 Arthroscopic view of the right knee with posterior cruciate ligament tear shows intact but lax anterior cruciate ligament

Fat Pad and Notch Debridement

The intercondylar area should be debrided of inferior plica and any synovitis. Retropatellar fad pad should be judiciously shaved off for easy visualization. The space between the PCL undersurface and MFC lateral wall should be cleared of synovium and loose fibers of PCL for easy access and visualization of PM recess.

Establish Posteromedial Portal

Once the scope is pushed into the PM recess, the posteromedial (PM) portal is established. 'PM portal is kept high and away from MFC.' The PM portal is created under direct vision. With the arthroscope in the AL portal, the arthroscope is first advanced past the medial border of the ACL and then between the medial border of the PCL and the MFC into the posteromedial compartment of the knee. This maneuver is often facilitated by hanging the leg over the side of the operating room table and applying a varus force to the foot. This will open up the space between the medial border of PCL and the MFC allowing the arthroscope to pass into the posteromedial compartment of the knee. With the arthroscope in the posteromedial compartment, the room lights can be turned down and the skin illuminated by the light from the arthroscope. This step will assist with locating the correct position for the skin puncture. It is important that the location of this portal not be too low. If the portal is placed too low, difficulty will be encountered reaching the distal part of the PCL tibial attachment site when the portal is used to introduce instrumentation into the back of the knee to prepare the PCL tibial attachment site. An 18 gauge spinal needle is used to locate the proper location for the portal. A #11 knife blade on a long handle is passed along the path of the spinal needle and is used to make a small incision in the posterior capsule. Care must be taken to avoid breaking or losing the knife blade in the knee joint or the posteromedial soft tissues. Failure to incise the posterior capsule will make it extremely difficult to pass a plastic cannula into the posteromedial compartment. Insertion of a 5.5/7 mm plastic cannula into the posteromedial compartment is facilitating by first inserting a switching stick into the knee joint and then screwing the cannula into place over the switching stick. Cannula insertion will prevent fluid leakage and repeated struggle to insert instrument or scope through the PM portal. Adequate distension of posterior compartment is the key of all arthroscopic technique of PCL reconstruction. Shift the scope into PM portal and visualize the PCL origin and also assess the extent of synovium, scar tissue and fat pad at the back of PCL remnant.

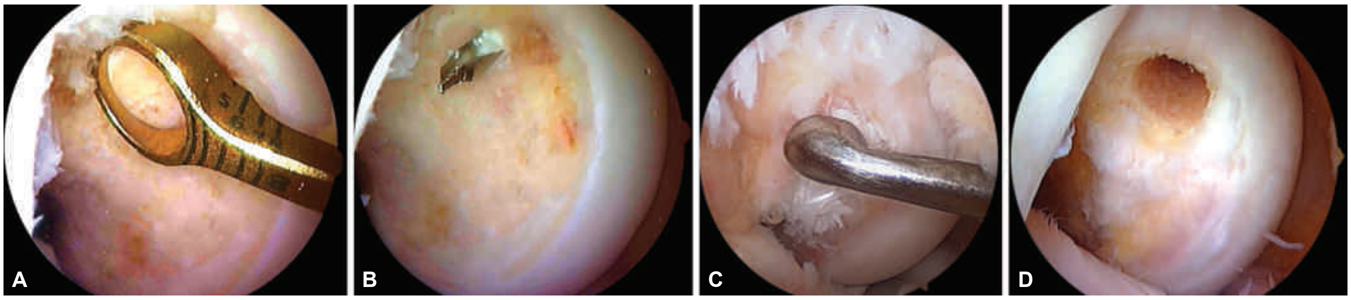
Preparation of PCL Tibial Attachment Site

While viewing the PM compartment with a 30° or 70° arthroscope in the AL portal, insert the 4.5 mm motorized shaver through the PM portal. Judicious debridement of scar tissue, synovium and fat pad should be done so that PCL tibial footprint should be adequately visualized. If the residual PCL stump has to be preserved, the footprint should not be disturbed. Otherwise, the whole mass of the defunct PCL should be taken down with help of PCL elevator (Smith and Nephew Endoscopy, Andover, MA), shaver, punches and occasionally radio frequency (RF) device. A PCL elevator is introduced through the anteromedial portal into the posteromedial compartment of the knee. The PCL elevator is carefully used to bluntly dissect the posterior capsule from the posterior aspect of the PCL and the back of the tibia. Blunt dissection with the PCL elevator is extended inferiorly along the back of the tibia until the tip of the elevator encounters a bony ridge, which represents the most inferior part of the PCL tibial attachment site. This point is usually reached when the PCL elevator is inserted to the 25 mm mark. This step frees the posterior capsule and allows the posterior capsule to displace with capsular distension from the back of the tibia and the PCL tibial attachment site, thus increasing the distance between the PCL and the posterior neurovascular structures. Under direct vision, a 4.5 mm curved motorized shaver blade is inserted through the PM portal cannula and the PCL remnant resected. It is important to resect the tissue until the shaver blade can be felt to be hitting the posterior cortex of the tibia. An RF probe can be used to further clear soft tissue at the PCL tibial attachment site. The area behind and around the PCL origin at the tibia should be debrided enough so that the tip of the PCL guide, guidewire and tibial drill coming off the tibial tunnel should be easily visualized. Nonvisualization of guidewire or tibial drill can endanger the safety of the neurovascular bundle in the popliteal fossa.

Tip—The face of shaver blade should be kept away from the posterior capsule. If the posterior capsule is opened, the fluid would leak into the posterior compartment of the leg and can cause compartment syndrome. Also, it can endanger the neurovascular bundle in the popliteal fossa.

Drilling of Tibial Tunnel

Whether to drill a femoral tunnel first or tibial is usually the surgeon's preference. We drill the tibial tunnel first and block the mouth of the tunnel with a plastic conical cap to prevent fluid loss. A 3 cm vertical skin incision is placed just medial to the tibial tuberosity. The PCL tibia aimer (Smith and Nephew Endoscopy, Andover, MA) is set at a 50°–55° angle and inserted through the AM portal onto the posterior cortex of the tibia. The aimer tip is positioned midway between the medial and lateral mammillary prominences that places the aimer in the middle of the PCL tibial attachment site in the medial-lateral direction. The 30° arthroscope and sheath are then inserted into the PM portal cannula. This approach gives an excellent view of the PCL tibial attachment site and eliminates the need to use a 70° arthroscope. While viewing through the PM portal, the tip of the PCL tibial aimer is advanced down the back of the tibia about 20 mm below the tibial articular surface to the posterior capsule attachment site (**Figure 41.8A**). Placing the tip of the tibial aimer in this location will result in the tip of the tibial guide pin lying 5 mm superior to site of the capsular attachment on the back on the tibia. The aimer bullet is inserted into the aimer handle and the aimer bullet advances through the anteromedial incision onto the anteromedial surface of the tibia. The PCL safety stop (Smith and Nephew Endoscopy, Andover, MA) is attached to the drill guide and a 2.4 mm PCL safety guide pin (Smith and Nephew Endoscopy, Andover, MA) drilled into the tibia until the laser mark on the guide pin contacts the PCL safety stop. These steps prevent the tibial guide pin from advancing beyond the tip of the PCL aimer. The PCL tibia aimer is backed away from the posterior cortex of the tibia and the tip of the guide pin tapped through the posterior tibial cortex with a small mallet (**Figure 41.8B**). The tibial guide pin position is confirmed with a lateral c-arm image (**Figure 41.8C**). It is important that the tibial guide pin not be positioned too proximal as this may result in insufficient bone proximal to the PCL tibia tunnel to prevent the PCL graft from migrating superiorly into the back of the knee joint when the PCL is loaded. All this time, a constant watch should be kept over the guide pin and should be protected with stylus over drill guide or a spoon from the PM portal. The PCL aimer should be removed and the PCL elevator is inserted through the anteromedial portal and the tip of the guide pin capped in the central recess of the elevator. The PCL tibial tunnel is drilled using a cannulated drill bit according to the size of graft. In order to ease the passage of the graft through the tibial tunnel,



Figures 41.8A to D Arthroscopic image of right knee for preparing tibial tunnel; (A) Tibial jig in place 20 mm below the tibial plateau at the posterior cruciate ligament footprint; (B) Guidewire in place protected by tip of tibial jig; (C) Intraoperative X-ray lateral view of right knee shows correct placement of guidewire for the tibial tunnel; (D) Rasp at the mouth of the tibial tunnel exit at the back of tibia smoothening the tunnel to prevent abrasive damage to graft at killer angle

it is recommended that the PCL tibial tunnel be drilled 1 mm greater than the measured diameter of the PCL graft. The PCL tibial tunnel is reamed under power until the resistance of posterior tibial cortex is felt. The remainder of the posterior cortex is drilled by hand. The superior edge of the tibial tunnel is chamfered with a rasp to prevent abrasive damage to the graft (**Figure 41.8D**).

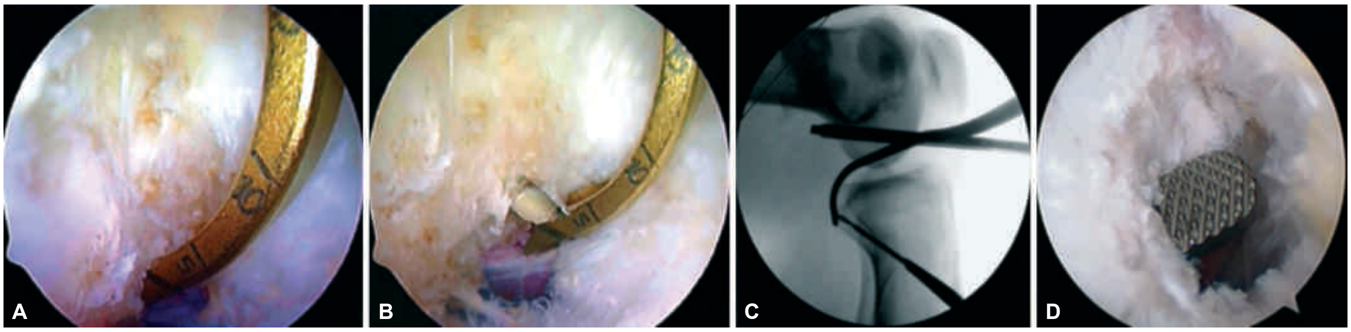
Once the tibial tunnel is drilled, tibial passing suture (No. 5 Ethibond, Ethicon, Johnson and Johnson, USA) should be placed with the help of an arthroscopic grasper at the posterior mouth. This loop end is further grasped by a long curved hemostat and pulled out from the AM portal. Suture passage at this point is much easier than later when fluid extravasation and posterior fossa swelling can make it difficult to visualize and triangulate. After the tibial tunnel is drilled, the tunnel mouth entry adjacent to tibial tuberosity should be plugged with commercially available conical plastic plugs to prevent saline leakage.

Drilling of Single Femoral Tunnel

Single bundle PLC reconstruction means reconstruction of the AL bundle of the PCL. The point selected over the MFC is high and shallow and about 8–10 mm behind the shallow cartilage margin. This marks the footprint of AL bundle (**Figure 41.9A**).

The femoral tunnel can be drilled inside-out or outside-in. The inside-out technique involves making of another accessory low AL portal that is used to mark and drill the femoral tunnel. After keeping the knee in 100°–110° flexion, the guide pin is placed at an appropriately marked point. Tunnel is drilled free hand, through and through so that the outer cortex can be kept intact depending upon which fixation method is planned. First, the tunnel can be drilled with 4.5 mm cannulated drill bit over the guide pin. Then over drilling is done with appropriate size femoral reamer. The advantage of inside-out is a precise placement of femoral tunnel and smaller incision on outer aspect of MFC. The disadvantage is the placement of a short tunnel and difficult visualization in the hyperflexed position.

The outside-in technique involves the usage of a femoral guide. The femoral guide is placed through the AM portal at the desired point. The angle of drill guide is kept between 55° to 60°. The incision is made over the skin of MFC along the axis of the knee and subcutaneous tissue dissected. Guide pin is drilled over guide sleeve. The exit of pin is observed with the scope in the AL portal. After the pin is placed in the desired position, the drill guide is removed (**Figure 41.9B**). The guide pin is over drilled with appropriate size femoral reamer, through and through. During this step, the tip of the guide pin is protected with a curette placed through the AM portal to prevent accidental over migration into the joint causing damage to the lateral femoral cartilage or over the scope lens (**Figure 41.9C**). Once the femoral tunnel is drilled, the lower part of the femoral tunnel inlet is rasped in order to blunt sharp edges. This prevents the graft from abrasive damage while insertion and further during rehabilitation. The average length of femoral tunnel is 35–40 mm. The final position of the single femoral tunnel in flexed position is described as shallow and high (**Figure 41.9D**).



Figures 41.9A to D Arthroscopic image of right knee for making of femoral tunnel; (A) Femoral jig in place; (B) Guidewire in place with outside-in drilling; (C) Protecting the guidewire tip with curette through the AM portal; (D) Femoral tunnel for the anterolateral bundle single bundle posterior cruciate ligament reconstruction; note shallow and high positions of the femoral tunnel

Femoral Passing Suture

Now the tibial passing suture loop is pulled into the femoral tunnel using the grasper.

Passage of Graft in Tibial Tunnel

The prepared graft is loaded over the passing/leading suture that is placed in the tibial and femoral tunnel. The suture is pulled gradually and slowly. The scope is placed now in the PM portal. The leading suture is grasped with arthroscopic grasper that is placed through the AM portal and suture is pulled in increments. The other end of suture remains in the femoral tunnel and the assistant keeps pulling the increments gained each time. This maneuver places least stress on leading suture and prevents graft abrasion at the back of tibial tunnel while pulling the graft. Once graft negotiates the killer turn of tibia, pulling into the femoral tunnel is easy. Once the 2.5 cm mark on the graft crosses the femoral inlet, graft should not be pulled further.

Fixation of Graft in the Femoral Tunnel

The guidewire is placed in the tunnel anterior (shallow) to the graft. Appropriate size bioabsorbable/titanium interference screw is selected (usually one size smaller than tunnel size) and inserted over the guidewire. Graft is pulled from the tibial end to check the adequacy of fixation. In case the fixation strength is doubtful, supplementary fixation can be performed. Sutures at the femoral end of the graft can be tied over a button/suture disk or screw and post. The graft can also be fixed on the femoral tunnel using endobutton (Smith & Nephew, Andover, USA) or tightrope (Arthrex, USA). Fixation options are according to the surgeon's preference. There is no method that is superior over other.

Tibial Fixation

The tibial end of graft suture can be marked as single knotted (semitendinosus) and double knotted (gracilis). Keeping all the sutures in tension (single and doubly knotted), the knee is taken into 10–15 motion cycle to take away the slack in the graft. Cycling of the knee should be performed if femoral fixation is performed using suspensory fixation (endobutton/tightrope) that helps in settling the button over the cortex. Holding the graft in tension and keeping the knee in anterior drawer, the graft is fixed in the tibial tunnel at 70° flexion with the help of interference screw. This screw should be advanced up to the mouth of the tibial tunnel posteriorly. Supplementary fixation in form of button/staple/screw-washer post should be used to improve the pullout strength and prevent graft slippage. The tension in the graft is confirmed by probing. If PCL is adequately tensioned and posterior translation is restored to normal, the ACL tension is restored which initially appeared lax (**Figure 41.10**).

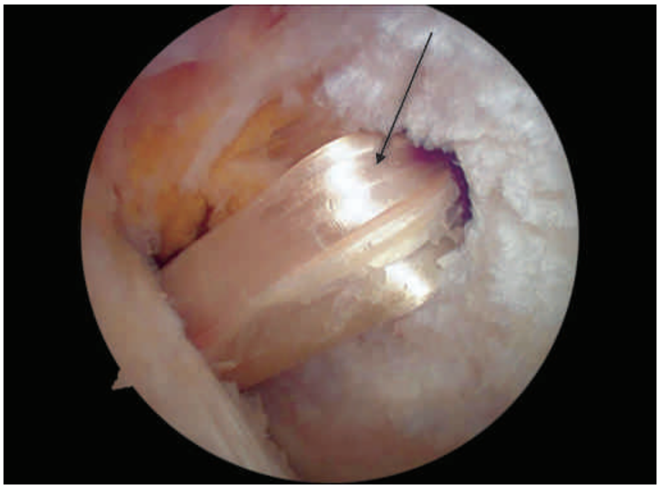


Figure 41.10 Arthroscopic image of right knee with the posterior cruciate ligament graft in place

Joint Irrigation and Wound Closure

Thorough irrigation of the joint is performed in order to remove the soft tissue and bony debris. The wound is closed in layers. Placing an intra-articular drain for 24 hours is debatable as no study has proven its efficacy. It remains the surgeon's or institutional preference. We believe that it should be used in combined ACL–PCL reconstruction where there are four tunnels opening into the joint and are potential for major hemarthrosis. Three layers of compression bandage should be applied which ensures minimal postoperative joint effusion.

Postoperative Care

The limb is placed in posterior tibial support splint after the surgery. Three-layer compression bandage is continued for 4 days. Drain is removed by 24–48 hours. IV antibiotic is continued till 24 hours. Appropriate analgesics should be continued for a week. Postoperative radiograph should be done to confirm the accurate placement of fixation device.

Rehabilitation

The PCL rehabilitation is way different than the ACL as the forces acting on the graft are completely different. There is active gravitational force and weight of the leg acting over the graft that can stretch and abrade the graft especially in the tunnel technique. So, the rehabilitation program is quite conservative till 12–16 weeks where the graft is allowed to heal in the tunnels and protected from stretching and abrasive forces. An aggressive rehabilitation can be lead to graft failure. Principles of PCL rehabilitation involve slow mobilization, activation and strengthening of quadriceps, avoiding activation of hamstring in early phase of rehabilitation and protection of graft from gravitational force. We follow slow rehabilitation protocol that is illustrated in **Table 41.1** and the outcome in last few years has been encouraging with conservative protocol. Fanelli too recommended a slow rehabilitation protocol for PCL.[53]

DOUBLE-BUNDLE PCL RECONSTRUCTION USING QUADRICEPS TENDON-BONE GRAFT

Introduction

Double-bundle PCL (DB PCL) reconstruction has been proposed as a possible surgical technique to improve the inconsistent results in restoring posterior stability historically reported for single-bundle PCL reconstructions that reconstruct only the ALB fibers. Although current clinical studies have not conclusively demonstrated a significant difference in restoring posterior stability between single- and DB PCL reconstructions, there are several theoretical advantages to performing a DB PCL reconstruction.[13] Similar to an ACL reconstruction, a DB PCL reconstruction will restore more of the native PCL femoral attachment site. The femoral attachment site of the PCL is very large making it difficult to restore with a single strand PCL graft.[54-56]

TABLE 41.1 Postoperative rehabilitation protocol

Weeks	*Movements*	*Weight bearing, brace*	*Strengthen*	*Avoid*
0–3	Knee brace in extension No movements allowed	Non weight bearing gait with axillary crutch, brace kept locked	Static isometric quadriceps, straight leg raising with brace	Knee flexion and weight bearing
4–6	Gradual passive knee flexion and active knee extension in lateral position	Partial weight bearing with axillary crutch and with brace kept locked in extension	Static isometric quadriceps, straight leg raising with brace	Sitting knee flexion or active knee flexion that activates hamstring
7–12	Aim to achieve full range of motion, mostly passive, in lateral position	Gradual full weight bearing. PCL brace if available	Quadriceps	Sitting knee flexion that activates hamstring
13–24	Full range of motion	PCL brace to continue	Quadriceps	Resisted hamstring
25–52	Progressive strength, agility, and proprioceptive training, return to sports when index knee is similar to normal knee in terms of strength, stability, range of motion, proprioception, and agility			

Abbreviation: PCL, posterior cruciate ligament.

Adding a second graft strand to the PCL replacement graft will restore a larger percentage of the native PCL attachment site by placing additional collagenous tissue within the PCL femoral attachment site.[56] The additional collagenous tissue will also increase the strength and cross-sectional area of the PCL graft. If the second PCL graft strand is placed in the appropriate location in the native PCL femoral attachment site, a load-sharing PCL graft construct can be created.[56,57] Having two graft strands share the tensile load will decrease the tensile force in each graft strand.[56,57] Decreasing the graft force in each PCL graft strand may decrease graft elongation and failure. Finally, biomechanical studies using human cadaveric knees have demonstrated that DB PCL reconstructions better restore posterior tibial translation and knee kinematics compared with single-bundle PCL reconstructions.[11,13] This is particularly true in combined PCL and PLC injuries.[13]

Indications for Double-Bundle (DB) PCL Reconstruction

- Young, active patients with isolated grade III PCL injury who desire, 'the best knee possible'
- Patients with grade III PCL with PLC injury.

Contraindications for DB PCL Reconstruction

1. *Knee dislocation:* Theoretical advantage of DB PCL reconstruction is offset by additional surgical time and complexity of procedure.
2. *Reconstruction for grade III PCL with combined MCL and posteromedial corner injury:* This requires drilling of tunnels in MFC for PCL femoral attachment, superficial MCL and posterior oblique ligament for reconstruction. This can increase risk of fracture of MFC. In this situation a single-bundle PCL reconstruction is performed.

Graft Selection

The optimal graft for DB PCL reconstruction should have a large cross-sectional area, be long enough to meet the longer length of the PCL, be able to be split into two graft strands, and should allow for secure fixation on both ends of the graft so that an early range of motion can be started in the immediate postoperative period. Of the autograft options available, the quadriceps tendon best meets these requirements.[56,58-60] The cross-sectional area of a 10 mm width, full-thickness quadriceps tendon graft is 1.8 times greater than a 10 mm width bone-PT-bone graft.[52,60] In most knees, a 10–12 mm width, full-thickness quadriceps tendon graft can be harvested with or without a patellar bone block. Harvesting a patellar bone block as part of the quadriceps tendon graft allows secure graft fixation to be achieved in the tibial tunnel with an absorbable interference screw and back-up suture screw/washer post fixation. The soft tissue end of the quadriceps tendon graft can be split into two graft strands that are passed into the two femoral tunnels. The donor site morbidity of the quadriceps tendon graft includes all of the issues seen with harvest of a bone-PT-bone graft. Similar to the bone-PT-bone grafts, donor site morbidity can be minimized by a meticulous surgical technique, harvesting a small 20–22 mm length patellar bone block and bone grafting of the patellar defect. A quadriceps tendon autograft is preferred in young patients with isolated grade III PCL injuries who require surgery and young patients with combined ACL/PCL and grade III PCL and MCL injuries.

In patients with combined grade III PCL and PLC injuries or knee dislocations, allograft tissue is preferred for the PCL, ACL and collateral ligaments. In these situations, allograft tissue has the advantages of eliminating donor site morbidity, unlimited size and length of the graft tissue and bone blocks, smaller incisions, less surgical dissection and decreased operative time. An Achilles tendon allograft with calcaneal bone block is the ideal allograft tissue for a DB PCL reconstruction. The calcaneal block allows for secure fixation of the PCL graft in the tibial tunnel with an absorbable interference screw and back-up suture screw/washer postfixation. The soft tissue end of the Achilles tendon allograft is long and wide and can be easily split into two strands. However, availability and high cost of allograft is an issue in most of the countries.

How to Harvest a Quadriceps Tendon Autograft?[61]

Graft Harvest

The quadriceps tendon graft should be harvested with the knee flexed to 90°. Flexing the knee to 90° creates tension in the extensor mechanism that facilitates graft harvesting. The graft is usually harvested with the tourniquet inflated. Prior to inflating the tourniquet, the suprapatellar pouch is injected with a mixture of 30 cc of local anesthesia and 30 cc of normal saline. The step inflates the suprapatellar pouch which helps identify the synovium during graft harvest. The quadriceps tendon is exposed through a vertical incision, centered slightly medial to the midline of the thigh (**Figure 41.11**). The incision starts at the superior pole of the patella and extends 5 cm in the superior direction. Sharp dissection is carried down through the skin and subcutaneous tissue until the investing fascia of the thigh and the prepatellar retinaculum are identified. The subcutaneous tissue is retracted with Army-Navy type retractors. The investing fascia of the thigh and prepatellar retinaculum is sharply incised exposing the quadriceps tendon and the superior pole of the patella. The prepatellar retinaculum is preserved for later closure. Incise and dissect the paratenon off the underlying quadriceps tendon. Using blunt and sharp dissection, identify the entire length of the quadriceps tendon up to the musculotendinous junction. Typically, a 70–80 mm soft tissue graft is required for single or DB PCL reconstruction. Additional tendon length can be obtained by using a Cobb periosteal elevator to dissect the superficial fibers of the vastus medialis and vastus lateralis off of the rectus femoris tendon. Identify and mark the center of the superior pole of the patella and the quadriceps tendon. A metal template of the appropriate width is useful to mark the quadriceps tendon. The template is centered at the superior pole of the patellar and at the center of the proximal portion of the quadriceps tendon. The template should be positioned parallel with the quadriceps tendon fibers. It is important to leave a 3–4 mm cuff of tendon medially. Failure to leave a medial cuff of quadriceps tendon intact will detach and weaken the VMO. In order to optimize the cross-sectional area of the PCL graft, it is necessary to harvest a full-thickness graft. For a DB PCL reconstruction, a full thickness, 10–12 mm width graft is harvested. This graft width will usually allow the soft tissue end of the graft to be split into two strands of equal width with each strand being approximately 7–8 mm in diameter after tubularization with a whipstitch. The medial edge of the tendon quadriceps tendon is incised with a #10 knife blade (**Figure 41.12A**). Typically, the cut can be made to the full depth of the scalpel blade. The tendon is incised down to the synovium, which is easily visible if the suprapatellar pouch was previously inflated with fluid. The lateral edge of the tendon graft is incised in a similar fashion. The superior border of the tendon is incised at the required graft length (**Figure 41.12B**). A large Allis clamp is used to grasp the proximal portion of the tendon and curved Metzenbaum scissors used to develop a tissue plane of the required depth down to the superior pole of the patella. Care should be taken not to enter the synovium. However, if the synovium is entered this is not a problem as a watertight closure can be obtained by suturing the synovium using a running, locked 2-0 absorbable suture. To harvest the patellar bone block, the knee is placed in extension and traction is applied to the quadriceps tendon using the Allis clamp. This will deliver the superior pole of the patella into the incision. A 10 or 11 mm width × 22 mm length bone block is marked on the superior surface of the

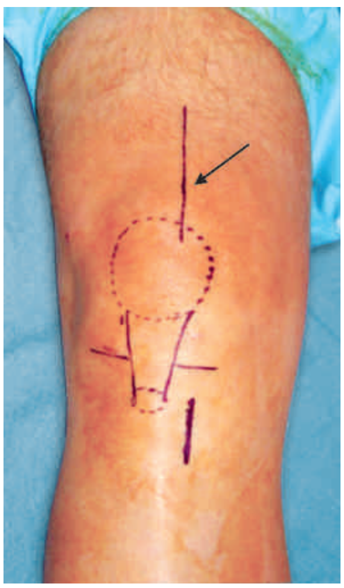
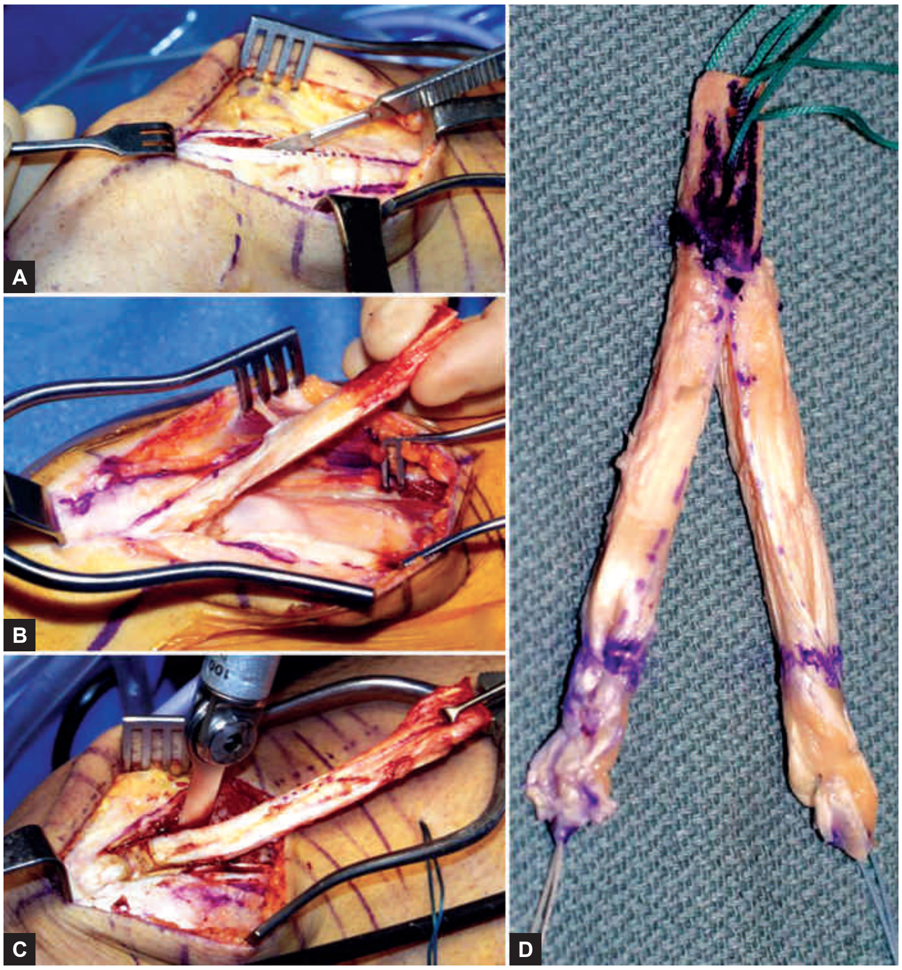


Figure 41.11 Black arrow pointing toward the incision for quadriceps tendon harvesting



Figures 41.12A to D Technique of quadriceps graft harvest; (A) Incision of quadriceps graft with #10 blade; (B) Appropriate length of quadriceps graft excised; (C) Osteotomy of patella bone plug; (D) Prepared quadriceps graft

patella using an electrocautery pencil. A microsagittal saw with a blade width of 10 mm is used to harvest the patellar bone block (**Figure 41.12C**). The anterior cortex is cut at an angle of 70° from the plane of the anterior surface of the patella to depth of 8 mm creating a trapezoidal bone block. The proximal end of the quadriceps tendon is retracted inferiorly, and the saw is used to undercut the superior pole of the patella in the coronal plane. This step helps prevent propagation of cracks into the articular surface when removing the bone block and also ensures that the entire quadriceps tendon attachment on the superior pole of the patella is removed with the soft tissue part of the graft. A 1/4-inch curved Lambotte type osteotome is used to gently remove the bone block. If the synovium is inadvertently entered it is closed with running, locked 2-0 absorbable suture.

Closure

The quadriceps tendon edges are loosely approximated in layers with interrupted 0 absorbable sutures. It is important to avoid over tightening the tendon as this may result in quadriceps tightness and restricted postoperative knee flexion and or an increase in patellofemoral contact pressure that can cause postoperative patellofemoral pain. Bone harvested with a coring reamer from the tibial tunnel is used to bone graft the patellar defect at the completion of the procedure. In order to restore the normal tension band effect of the anterior soft tissues of the extensor mechanism, it is important to close the prepatellar retinaculum securely. A small sponge is packed into the incision and the thigh wrapped down to the superior pole of the patella with a 4-inch elastic bandage. This step will help minimize fluid extravasation from the quadriceps tendon harvest site. After the PCL reconstruction is completed, it is important to close the subcutaneous tissue in layers with 2-0 and 3-0 absorbable sutures to optimize the cosmetic appearance of the incision. The skin is closed with a running 3-0 nylon pullout subcuticular suture.

Postoperative Care

Avoid applying Steri-strips to the incision in the early postoperative period until the soft tissue swelling has subsided. The postoperative fluid extravasation and soft tissue swelling may cause skin blisters to form at the site of application of the Steri-strips. Apply Steri-strips and vitamin E oil to the incision for 3 months to minimize spreading of the incision. The patient is instructed to avoid direct sunlight on the incision for 1 year. Patellar mobilization, electrical muscle stimulation to the quadriceps muscles and isometric quadriceps contractions are important to minimize scarring in the suprapatellar pouch. Quadriceps stretching is started at 3 months to prevent quadriceps tightness.

Double-Bundle PCL Quadriceps Tendon Graft Preparation

The patellar bone block is trimmed with a bone rongeur to fit through an 11 mm sizing block or tube. Three, evenly spaced 2 mm drill holes are placed in the bone block followed by three #5 nonabsorbable polyester sutures. High-strength sutures such as FiberWire, OrthoCord, or UltraBraid should not be used as these sutures may cut through the bone block when they are tensioned and tied around a screw and washer for backup tibial fixation. The full thickness of the quadriceps tendon graft is split into two equal width strands. Each strand is sutured over a distance of 25 mm using #2 FiberWire running locked whipstitches (**Figure 41.12D**). Each graft strand is sized and circumferentially marked with a surgical marker 25 mm from the free end. Insure that both graft strands and the entire quadriceps tendon graft and attached patellar bone block pass easily through an 11 mm sizing block or tube. The quadriceps tendon graft is wrapped in a moist sponge and placed on a graft tensioning board and pretensioned to 10–15 lb until the graft is ready to be inserted into the knee.

Operating Room Setup, Examination Under Anesthesia

The setup and examination are similar to single bundle reconstruction.

Establishing the Arthroscopic Portals and Diagnostic Arthroscopy

This is similar to the single bundle PCL reconstruction technique.

PCL Femoral Tunnel Location

In order to properly place the two PCL femoral tunnels, it is important to understand the native anatomy of the PCL femoral attachment site and the influence that different femoral tunnel locations have on the length-tension of the PCL graft. The goal of DB PCL reconstruction is to create a load-sharing graft. By creating a load-sharing PCL graft, each graft strand will carry part of the load, thus decreasing the load on each strand. The native PCL femoral insertion site extends from high in the notch (12 o'clock) along the lateral aspect of the MFC to approximately the 5 o'clock (right knee), 7 o'clock (left knee).[55,56,62] The PCL femoral attachment site extends high in the roof of the notch and the anterior portion follows within 2–3 mm of the distal articular cartilage border, moving away until it is around 5 mm from the distal cartilage border at the posterior part of the attachment site.[55,56,62] The proximal edge of the PCL attachment site is straight or oval and tapers in width along its posterior portion.

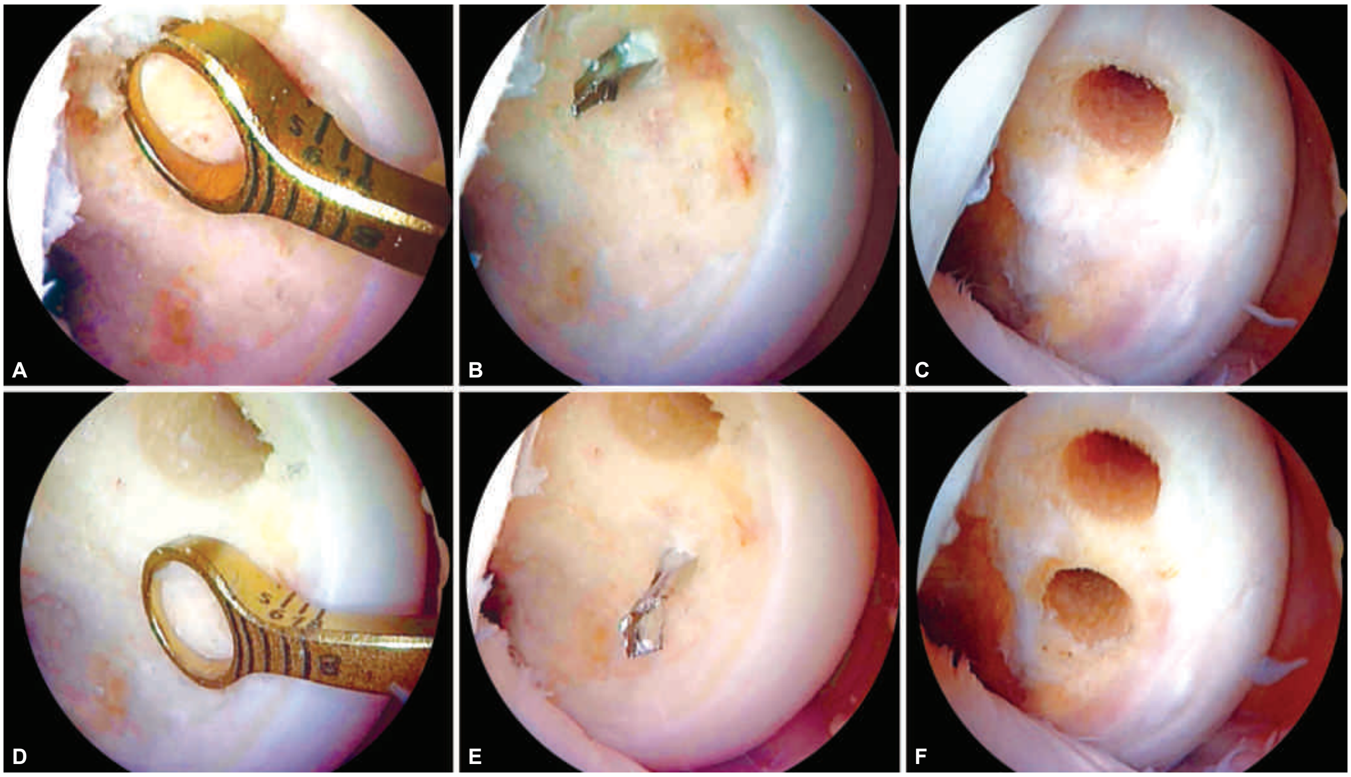
The femoral location of a PCL graft strongly influences graft tension and the ability of the reconstruction to restore posterior stability.[56,57,62] The proximal-distal location of a PCL graft within the PCL femoral attachment site is the most important factor determining the length-tension of the graft.[3] PCL grafts placed in the proximal part of the PCL attachment site tighten in extension and loosen in flexion, while PCL grafts placed in the distal part of the PCL attachment site tighten in flexion and loosen in extension.[55] The anterior-posterior placement of the PCL graft in the PCL attachment site has little influence on the tension in the graft and the ability of the PCL reconstruction to control posterior stability.[55] According to the biomechanical study of Shearn et al., placing one strand of the PCL graft at the anterior-distal part of the PCL attachment site and the second strand at the middle-middle or middle-distal part of the PCL attachment site will create a load-sharing PCL graft construct which restores posterior stability from 0° to 120° of flexion.[57] Positioning the two graft strands of the PCL reconstruction at these locations resulted in lower peak graft tension in each strand compared with a reciprocal loading graft placement.

Drilling the PCL Femoral Tunnels

When performing a single-bundle PCL reconstruction, it is often possible and desirable to preserve intact remnants of the PCL and the MFLs. Due to the large size of the two PCL graft strands; this is not usually possible when performing a DB PCL reconstruction using a quadriceps tendon autograft or Achilles tendon allograft. The PCL is viewed with the 30° arthroscope in the AL portal. The PCL is resected, leaving 3–4 mm at the femoral attachment site to aid with identification. The borders of the PCL femoral attachment site are marked with an RF probe.

An outside-in technique is preferred for drilling the two femoral tunnels as this approach allows for good visualization of the PCL graft strands at the time of femoral fixation with interference screws and allows backup suture/post fixation to be used on femoral side. The Acufex PCL femoral aimer (Smith and Nephew Endoscopy, Andover, USA) is inserted into the intercondylar notch through the anteromedial portal. The PCL femoral aimer is tentatively placed at the PCL femoral attachment site at the 1 o'clock position (right knee) or 11 o'clock position (left knee) and the aimer bullet inserted until the tip contacts the skin on the medial aspect of the distal thigh. The bullet should lie at least 15 mm proximal to the articular cartilage border of the MFC. The bullet location is marked on the skin with a surgical marker and the bullet removed from the aimer. If a quadriceps tendon autograft was harvested, it is often possible to retract the medial edge of the incision and expose the location of the aimer bullet. If this can be done without excessive traction on the skin, then it is not necessary to make an additional medial incision. If an Achilles tendon allograft is used for the PCL graft, or if excessive skin retraction of the quadriceps tendon harvest incision is required, then it is necessary to make a separate medial incision. A 3–4 cm incision is made parallel to the femoral shaft at the previously marked spot. Dissection is carried down to the VMO fascia that is split. A subvastus elevation of the VMO is made and a z-type retractor is used to retract the VMO, exposing the femoral shaft. The PCL femoral aimer is placed at the PCL femoral attachment site at a 1 o'clock position (right knee) in the notch. This will place the first PCL tunnel in the anterior third of the PCL femoral attachment site. The center of the PCL femoral aimer is placed 6 mm proximal to the articular cartilage border, placing the first tunnel in the distal third of the PCL femoral attachment site (**Figure 41.13A**). The bullet is advanced to the femoral cortex and a 2.4 mm drill tipped guide pin drilled into the PCL attachment site (**Figure 41.13B**). The tip of the guide pin is grasped with a curved hemostat and the first femoral tunnel drilled using a cannulated drill bit which matches the diameter of the PCL graft strand (**Figure 41.13C**). The intra-articular edges of the tunnel are beveled with an ACL chamfer rasp to decrease graft abrasion. The first femoral tunnel is plugged with a plastic tunnel plug.

The second PCL femoral tunnel is drilled in similar fashion. For the second PCL tunnel, the PCL femoral aimer is centered at a 4 o'clock position (right knee) in the notch (**Figure 41.13D**). This will place the second tunnel in the middle-posterior region of the PCL femoral attachment site. It is important to leave a 2–3 mm bone bridge between the two femoral tunnels. The center of the PCL femoral aimer is placed 8 mm proximal to the articular cartilage border, placing the second tunnel in the middle-third of the PCL femoral attachment site. The bullet is advanced to the femoral cortex. There should be at least a 1.5 cm



Figures 41.13A to F Arthroscopic image reveals placement of double femoral tunnels for double-bundle posterior cruciate ligament reconstruction; (A) Femoral jig in place; (B) Guidewire; (C) Tunnel for the anterolateral (AL) bundle; (D) Femoral jig in place for the posterolateral (PM) bundle; (E) Guidewire in place; (F) Final two tunnels for the AL and PM bundle

distance between the second guide pin and the first femoral tunnel (**Figure 41.13E**). The 2.4 mm drill tipped guide pin is drilled into the PCL attachment site and the second PCL femoral tunnel drilled as previously described (**Figure 41.13F**). After rasping the intra-articular edges of the second femoral tunnel, the tunnel is plugged with a plastic tunnel plug.

Establish Posteromedial Portal

Established as discussed in the SB technique section.

Preparation of the PCL Tibial Attachment Site

In order to ensure ease in passing the DB PCL graft, it is important to remove the entire native PCL remnant at the PCL tibial attachment site. Failure to remove this tissue can prevent the two graft strands from exiting the PCL tibial tunnel and passing into their femoral tunnels. Rest of the preparation is similar to single bundle technique section.

Drilling the PCL Tibial Tunnel

The PCL tibial tunnel is prepared in standard fashion as described in SB section. However, the PCL tibial tunnel is drilled using a cannulated drill bit if an Achilles tendon allograft is used or a coring reamer if a quadriceps tendon autograft has been harvested. The bone from the coring reamer is used to bone graft the defect in the superior pole of the patella. In order to ease passage of the two graft strands through the tibial tunnel, it is recommended that the PCL tibial tunnel be 1 mm greater than the measured diameter of the PCL graft.

PCL Graft Passage

While viewing through the AL portal, a looped 20-gauge wire is passed through the PCL tibial tunnel and retrieved with a grasper and advanced into the intercondylar notch up to the two femoral tunnels. A second grasper is passed down the first PCL femoral tunnel into the intercondylar

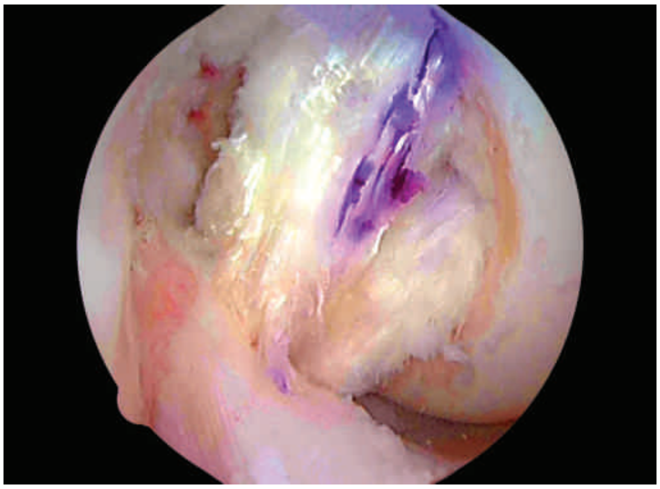


Figure 41.14 Arthroscopic image of double-bundle posterior cruciate ligament graft in the anterolateral and posterolateral tunnels of the right knee

notch and the wire loop pulled out through the medial incision. A #5 polyester suture is passed through the wire loop and the looped end of the suture pulled out the PCL tibial tunnel. This step is repeated using a different colored suture for the second PCL femoral tunnel. The two looped #5 polyester sutures exiting the PCL tibia tunnel are used to pass the whipstitches on each graft strand of the PCL graft across the knee joint and out the medial incision. The junction of the PCL bone block and the PCL soft tissue graft is marked circumferentially with a surgical marker. This mark is used to determine the depth of insertion of the bone block in the PCL tibial tunnel. The two PCL graft strands are passed together through the PCL tibial tunnel by applying tension to the whipstitches exiting the medial incision. The two graft strands are passed into their respective femoral tunnels (**Figure 41.14**). The PCL graft strands are pulled into their femoral tunnels until the previously placed mark on the PCL bone block is positioned at the exit of the PCL tibial tunnel. This will position the bone block at the back edge of the tibial tunnel, decreasing graft abrasion at the so-called 'killer angle.'

Graft Fixation and Tensioning

The bone block of the PCL graft is fixed in the tibial tunnel using an absorbable interference screw inserted inferior to the bone block. Typically a 9 × 25 mm screw is used.

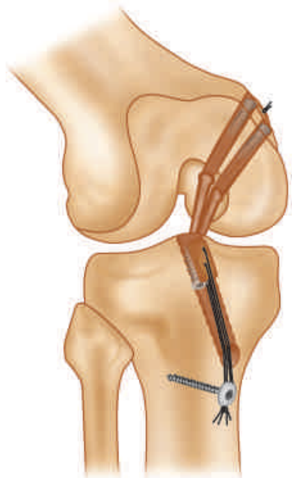


Figure 41.15

The #5 polyester sutures in the bone block are tied around a 3.5 mm AO screw and washer, thus providing double fixation on the tibial side (**Figure 41.15**). The knee is cycled 30 times with tension applied to the whipstitches of the two graft strands. The knee is flexed to 90°, neutral tibial rotation and an anterior tibial force applied against the posterior aspect of the calf to reduce the tibia. The tibiofemoral step-off of the normal knee that was measured at the beginning of the procedure is recreated. While maintaining tension on the whipstitches, each graft strand is fixed with a 9 × 25 mm absorbable interference screw. It is important that the screws be inserted until flush with the femoral cortex. Leaving the screws prominent will irritate the VMO and cause pain. The knee is taken through 0°–130° of flexion and the tibiofemoral step-off palpated at 90° of flexion.

Postoperative Care and Rehabilitation

The neurovascular status of the operative leg is confirmed to be normal before leaving the operating room. A sterile compression dressing and cold pack or Cryocuff (DJO Global Orthopaedics, Vista, CA) followed by a hinged knee brace or extension knee brace with posterior support for the tibia locked at 0° is applied in the operating room. The knee is elevated with a pillow placed under the calf to prevent posterior sagging of the tibia. Quadriceps isometrics, straight leg raises and ankle pumps are started immediately with the brace on. Passive knee flexion from 0° to 90°, three times a day with the tibia supported by the physical therapist is performed for the first 2 weeks. After the passive range of motion is increased to 0-120 degrees at 3-4 weeks and 0-135 degrees, active knee extension is started from 90-0 degrees. No active flexion is allowed for the first 12 weeks. The weight bearing status is determined by whether associated medial or posterolateral procedures have been performed. If associated medial or posterolateral procedures have been performed, the patient is kept toe-touch weight bearing for the first 6–8 weeks. For isolated PCL reconstruction, 25% weight bearing is allowed at 2 weeks if the patient has regained quadriceps control. For a detailed postoperative rehabilitation protocol consult reference.[63]

Factors Responsible for Poor Results after PCL Reconstruction

a. Nonanatomic graft placement.
b. Inadequate graft fixation.
c. Too thin graft.
d. Failure to correct the malalignment of the limb.
e. Failure to recognize and treat associated ligament injuries.
f. Presence of medial compartment or patellofemoral arthritis.
g. Poor rehabilitation.

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