Posterior Cruciate Ligament-Deficient Knee: Indications for Reconstruction

27

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27.1 Principles

The purpose of PCL reconstruction is to restore normal knee stability, in order to prevent the development of osteoarthritic changes in the joint [118]. Although PCL has a greater likelihood of spontaneous healing than the anterior cruciate ligament in the subacute or acute stages, residual laxity or PCL rupture associated with other injuries may necessitate surgical intervention [62, 76, 77]. The principles of PCL reconstruction are to identify and treat all pathology, accurately place tunnels to produce anatomic graft insertion sites and utilise strong graft material, mechanical graft tensioning, secure graft fixation and an appropriate post-operative rehabilitation program [26–30, 33, 34].

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27.2 Indications

The indications for a PCL reconstruction vary depending upon whether the injury is isolated or combined and whether the injury is acute or chronic [44, 124]. The cut-off between acute and chronic injuries is defined at 3 weeks since the initial injury. Isolated PCL tears have shown good outcomes with conservative management [58, 105, 119].

27.2.1 Acute PCL Tears

Acute isolated injuries with grade I tibiofemoral step-off and injuries with grade II step-off with firm end (type IIA) are amenable of conservative treatment. On the contrary, injuries with grade II step-off with soft end (type IIB) and with grade III step-off are better addressed by surgical treatment (Chap. 19) [30, 83, 86, 130]. Acute multiligament injuries involving the PCL, injuries of the PCL in conjunction with a knee dislocation or anteroposterior laxity >12 mm and complete PCL tears combined with repairable meniscal body or root tears are a possible indication for PCL reconstruction [4, 89, 110, 114, 115, 119, 126].

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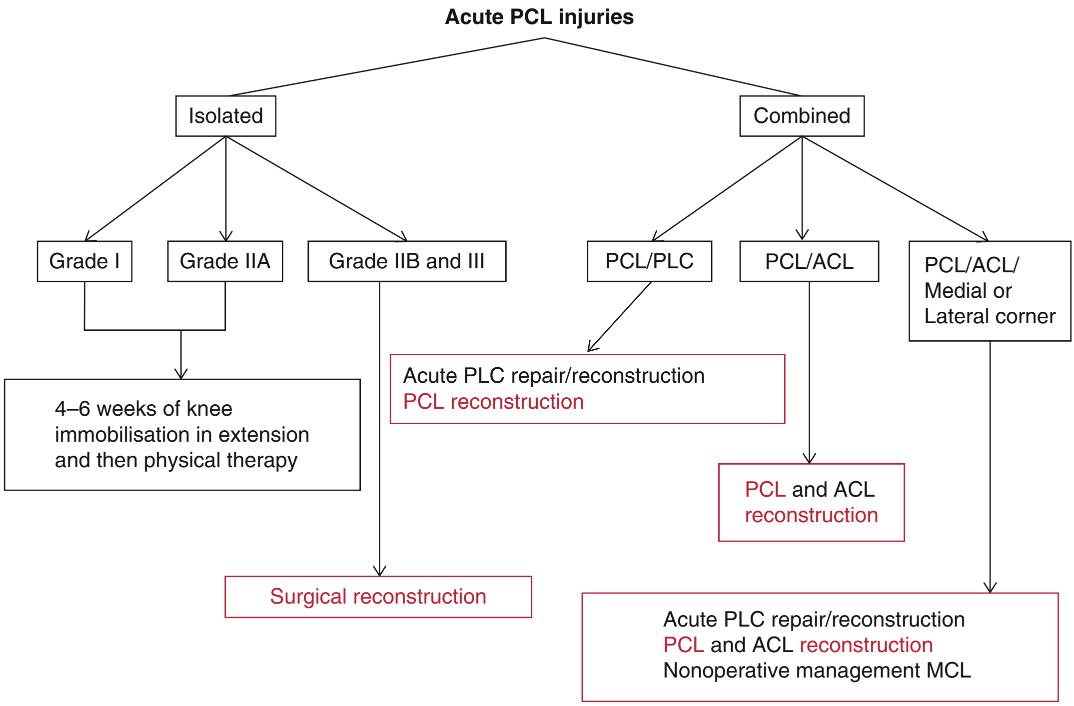

Fig. 27.1 Algorithm for the evaluation and treatment of acute posterior cruciate ligament tears (Modified from [30])

27.2.2 Chronic PCL Tears

Chronic PCL tears combined with grade IIB or III step-off, functional limitations, instability or pain directly related to the PCL injury, anteroposterior laxity >8 mm and the absence of contraindications to a ligament reconstruction are amenable for surgical repair [97].

To identify all associated pathologies, including ligament injuries, meniscal tears, chondral defects or degeneration and limb malalignment, is of capital importance for a correct surgical planning. Patients with chronic PCL or PLC (posterolateral corner) insufficiency may progressively develop medial compartment narrowing and genu varum. Limb malalignment must be corrected through osteotomy, performed in conjunction with ligament reconstructions either concurrently or in a staged fashion. Biplanar osteotomy can optimally control simultaneous correction of coronal malalignment and increase in posterior tibial slope for chronic PCL deficiency and should therefore be preferred [30, 73, 111].

Figures 27.1 and 27.2 provide a simple clinical algorithm for the evaluation and treatment of acute and chronic PCL tears.

27.3 Conservative Treatment

The PCL has intrinsic healing ability after injury, although this healing may occur in a lax or attenuated position [58, 105, 119, 120, 125]. Nonoperative treatment based on splinting and rehabilitation only can be used to address isolated acute grade I and IIA PCL injuries. The knee should be splinted in extension with a pad to counteract gravity pulling the tibia posteriorly for the first 4–6 weeks or protected in a brace that applies a constant or dynamic anterior force to counteract the posterior sag of the tibia [58, 59, 74, 87].

Full extension reduces the tibia, prevents posterior sag and diminishes the effects of gravity and hamstring muscle contraction on tibial translation. Moreover, in this position the anterolateral

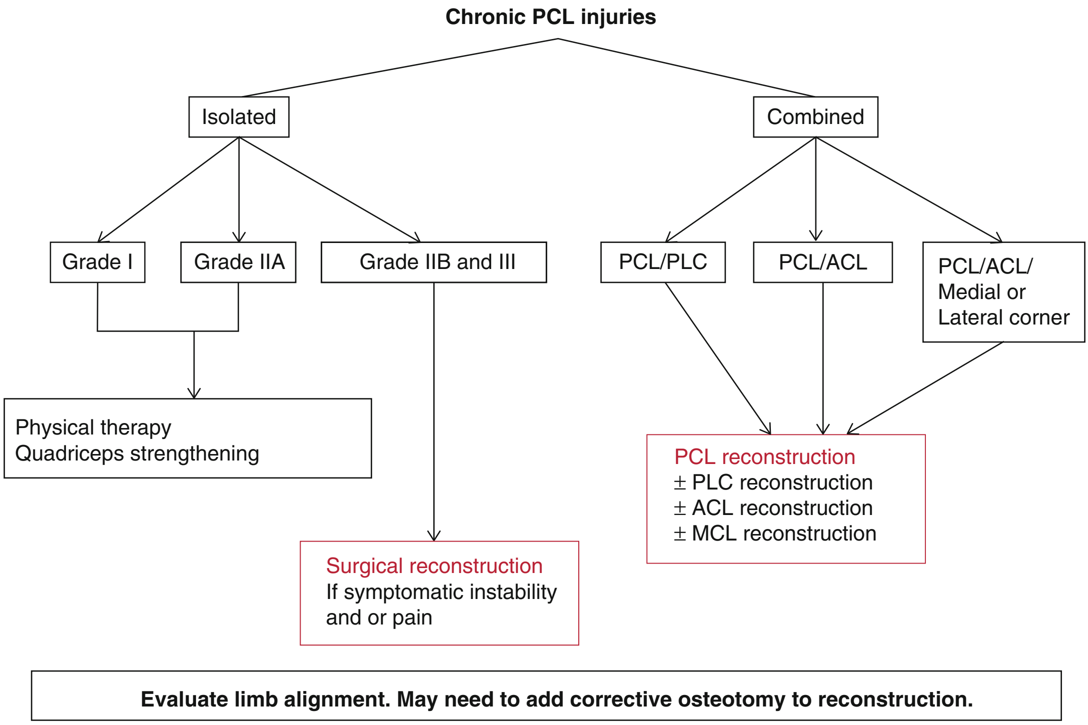

Fig. 27.2 Algorithm for the evaluation and treatment of chronic posterior cruciate ligament tears (Modified from [30])

component of the PCL is slack, allowing healing to occur in a more favourable position from the biomechanical point of view. During this period, quadriceps muscle-strengthening exercises are encouraged, whereas the use of the hamstring muscles is prohibited to minimise posterior tibial load. The patient is then started on progressive weightbearing, with active, assisted range of motion (ROM) exercises and quadriceps strengthening.

Goals of rehabilitation are allow PCL healing, minimise effusion, restore full ROM, strength and function allow return to previous activities. Rehabilitation principles are cooling and compression with elevation to reduce the effusion; exercises to restore full knee extension, flexion and strength; and stationary bicycle or stairclimbing machine to increase endurance. Functional activities and sport-specific training should precede the return to play [118].

In a similar fashion, chronic grade I and IIA PCL injuries can be treated nonoperatively with a physical therapy protocol, which consists in active, assisted ROM exercises and quadriceps strengthening.

27.4 Timing

Compromise of vascular structures, compartment syndrome or the presence of an open or irreducible joint can necessitate an urgent surgical intervention consisting of revascularisation, surgical reduction or compartment release. In high-energy PCL injuries which do not involve the aforementioned complications and in low-energy PCL injuries, to delay ligament reconstruction for a few weeks in an attempt to decrease swelling of the soft tissue envelope is preferred by most surgeons. Better outcomes have been associated to definitive ligament repairs and/or reconstructions performed within 2–3 weeks from the time of injury, while pericapsular stretching is seen at a higher incidence in chronic PCL tears [29, 35, 48, 77, 78, 129].

27.5 Procedures

27.5.1 Graft Choice

The grafts commonly used to reconstruct the PCL can be classified as indicated in Fig. 27.3. Each type of graft has advantages and disadvantages and can have a significant impact on the clinical management and outcomes.

27.5.1.1 Autografts

When compared to allografts, all autograft tissues exhibit faster incorporation with adjacent tissues and have no risk of immune-mediated tissue rejection or infectious disease transmission. Additionally, autograft tissues are not exposed to sterilisation or other processes, which could negatively impact on both the biomechanical and biological properties of the graft.

Donor-site morbidity represents a distinct disadvantage associated with autograft harvest [77].

Several autograft tissue options are available (Fig. 27.4) for harvest either in the ipsilateral or contralateral extremity, including bone–patellar tendon–bone (BPTB), hamstring (semitendinosus and/or gracilis) and quadriceps tendon–patellar bone (QTB). Each graft has its own strengths and weaknesses with regard to biomechanical properties, ease of harvest, morbidity, biology of healing and fixation [77]. Hamstring tendon appears to be the preferred among autografts, being used in 72 % of patients, followed by BPTB in 16 % and QTB in 12 % [53].

BPTB

In BPTB the patellar block is approximately 8 × 20 mm, the tibial block is 10 × 30 mm, and the main length of the tendon is 40–60 mm [18, 20].

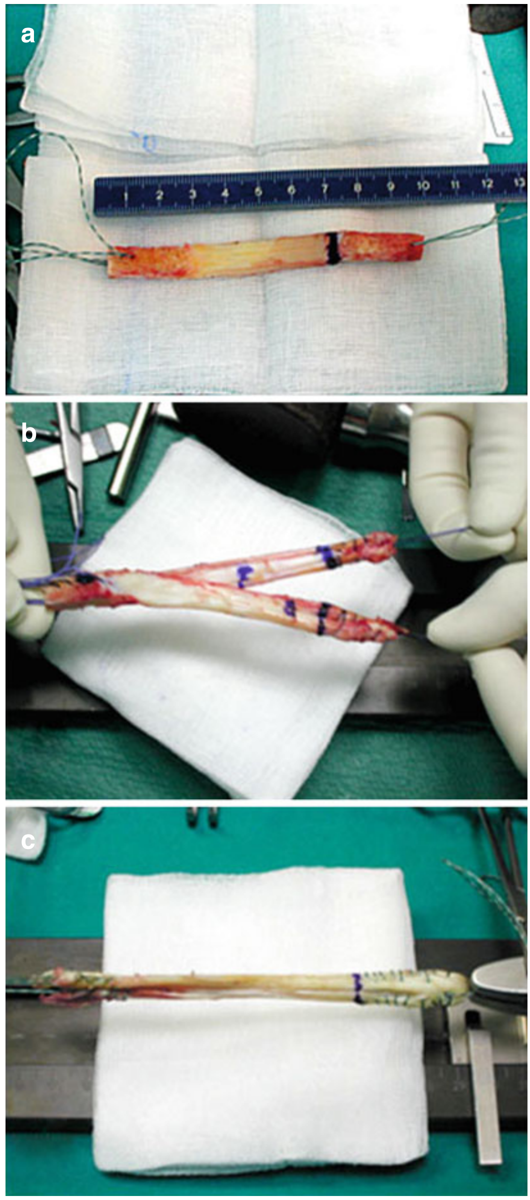

Fig. 27.4 Autografts available for PCL reconstruction, after preparation: BPTB (**a**), QTB (**b**), hamstrings (**c**)

AUTOGRAFTS
- Grafts with 2 bone blocks: BPTB
- Grafts with 1 bone block and a part of free tendon: QTB
- Free tendons: hamstrings

ALLOGRAFTS
- Grafts with 2 bone blocks: BPTB
- Grafts with 1 bone block and a part of free tendon: QTB, Achilles tendon
- Free tendons: hamstrings, anterior and posterior tibial tendons

ARTIFICIAL GRAFTS

Fig. 27.3 Types of PCL grafts available

BPTB allows stable and simple fixation, and the bone-bone healing promotes quick integration. Possible disadvantages are the arousal of anterior knee pain and worsening of patellofemoral osteoarthritis, patellar fractures, bone block fractures in case of difficult passage of the graft through the tibial tunnel or during fixation of the inlay and herniation of the infra-patellar fat pad through the tendon scar. In rare cases the patellar tendon can be too short to adequately reconstruct the PCL (especially with trans-tibial technique). For this reason the use of BPTB is to be avoided in patients with too short patellar tendon and after patellar fractures.

Moreover, the small section of the tendon might not permit to perform a double-bundle repair [51, 77].

QTB

QTB presents a tendon portion approximately 8–10 cm long, a bone block of 2.5–3 cm and a large cross-sectional area (12 × 8 mm) [16, 39]. QTB is a versatile graft: its bone block can be fixed either in the femoral or in the tibial tunnel, and its free tendon portion can be splinted to perform a femoral double-bundle surgical technique. QTB is therefore suitable for trans-tibial and tibial inlay techniques and for revision surgeries [51, 100, 140].

QTB is less popular than other graft options for the more demanding surgical technique, the possible arousal of anterior knee pain and worsening of patellofemoral osteoarthritis and the theoretical concern of weakening the quadriceps and the extensor mechanism in its harvesting [22, 136].

Hamstrings

Hamstrings are versatile graft: their harvest is low demanding, quick and does not damage the patellofemoral complex, and it's possible to perform all surgical techniques with easy passage of the graft through every type of bone tunnel. Disadvantages of the hamstrings are possible tendon rupture during harvest, hematoma of the soft tissues (more frequent if harvesting is performed "aggressively") and some difficulty in the tendon preparation. Worsening of the medial instability is a concern when using hamstrings; for this reason autograft hamstrings are contraindicated in sports, in which the medial structures are under tension (e.g. dancing) and in patients with a medial collateral ligament tear [51, 77].

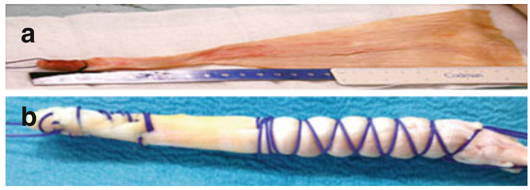

Fig. 27.5 Achilles tendon allograft before (**a**) and after preparation (**b**)

Good short- and long-term results have been reported for PCL reconstruction with QTB [16, 140], hamstring [14, 15, 52, 81, 116, 139, 144, 146] and BPTB autografts [63, 81, 116], with no significant difference found in direct comparisons of QTB with hamstrings or BPTB with hamstring grafts [16, 63, 81].

27.5.1.2 Allografts

Overall advantages of allografts compared to autografts are the broader choice of size and shape options, the elimination of any donor-site morbidity and any additional risk-associated tissue harvest and the reduction of total operative and tourniquet time. Distinct disadvantages are a small risk of infectious disease transmission, slower incorporation of graft tissue, potential for immunologic rejection and increased costs [3, 5–7, 38, 44, 46, 47, 49, 54–56, 77, 94, 99, 117, 123, 133].

The Achilles tendon is currently the most frequently used allograft, due to the presence of a bone block and thanks to its large size and wide sectional area (12 × 8 mm) which permit to easily splint it to perform a double-bundle repair (Fig. 27.5) [131]. Double-stranded anterior and posterior tibial tendons are also commonly used allografts. Other allograft options include BPTB, hamstrings, and QTB [77].

Artificial ligaments were also proposed for PCL repair [13, 17, 23, 36, 41, 82, 98, 127].

27.5.2 Surgical Techniques

Various techniques have been described to reconstruct the PCL. The main differences among

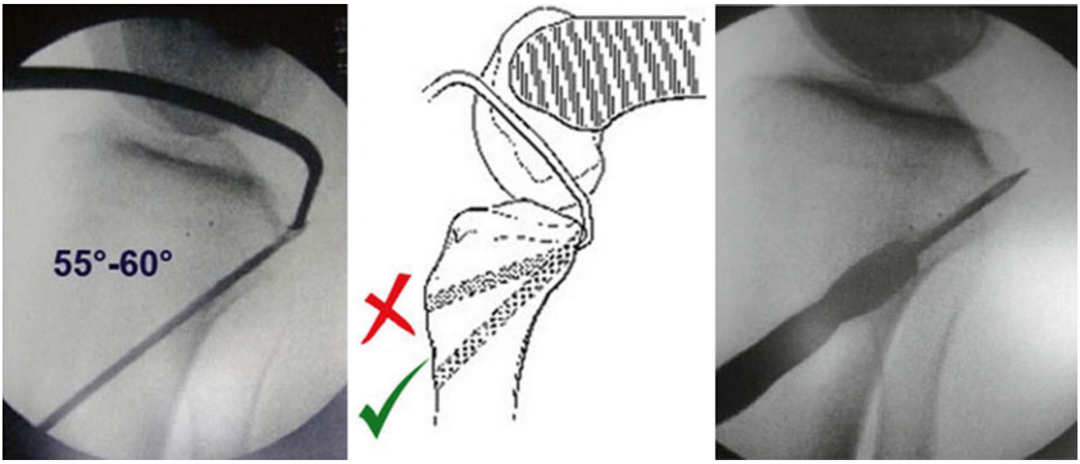

Fig. 27.6 Correct positioning of tibial guide and reamer in the trans-tibial technique

them are the tunnel placement technique (trans-tibial and tibial inlay for the tibial one; outside-in, inside-out and all-inside techniques for the femoral one), the number of femoral tunnels drilled (single-bundle and double-bundle) and the surgical approach (open or arthroscopic).

27.5.2.1 Setting, Portals and Diagnostic

The patient is placed supine. General or epidural anaesthesia may be used. Examination under anaesthesia is useful to confirm and classify ligamentous injuries (Chap. 19). Depending on surgeon's preferences, a leg holder may support the ipsilateral or the contralateral leg, and a lateral post can be used to control the surgical extremity; the use of a tourniquet may facilitate visualisation. Fluoroscopic imaging is recommended, although not routinely used by some authors. A 70° arthroscope may improve visualisation and should be available [30].

The arthroscopic instruments are inserted with the inflow through the superolateral patellar portal. Instrumentation and visualisation are positioned through inferomedial and inferolateral patellar portals and can be interchanged as necessary. Additional portals are established as necessary.

If blood clots or loose bodies are present, irrigation and debridement are performed. Routine diagnostic arthroscopy is first performed addressing meniscal and chondral pathology as encountered. Capsular or meniscal lesions are treated according to surgeon's preferred technique. The PCL tear is then documented and the insertion sites are debrided [28].

27.5.2.2 Tibial Graft-Positioning Techniques

Trans-tibial Technique

Any adhesions in the posterior aspect of the knee must be removed and the capsule elevated from the posterior tibial ridge with curved over-the-top PCL. This will allow accurate placement of the PCL drill guide and correct placement of the tibial tunnel. The arm of the PCL guide is inserted through the inferior medial patellar portal, and the tip of the guide is positioned at the inferior lateral aspect of the PCL anatomic insertion site. Many PCL guides have a graded intra-articular arm which enables the surgeon to accurately determine the distance from the joint surface, which must be 15–20 mm from the articular surface. The bullet portion of the guide is placed 1–2 cm below the tibial tubercle (7 cm below the joint line), after having retracted the pes anserinus tendons. The angle between this guide and the transverse plane of the tibial plateau must be 55–60° (at least 45°, Fig. 27.6); a more proximal positioning of the guide (which decreases the aforementioned angle and produces a horizontal tunnel) may cause difficulties in introducing the graft and increase the risk of injury to the neurovascular structures. Furthermore, a sharp angle between the intra-osseous and intra-articular portion of the graft may cause abrasion, attenuation and eventually failure of the graft at this "killer turn" [10, 11, 92].

Once the position of the bullet portion of the guide is decided, a blunt spade-tipped guide wire is drilled from anterior to posterior, and the appropriately sized standard cannulated reamer is used to create the tibial tunnel.

It is recommended, especially for less experienced surgeons, to use an image intensifier and maintain the instruments under constant visual control, to ensure the correct position of the guide wire and of the tunnel.

Tibial Inlay

All-arthroscopic tibial inlay technique combines the advantages of both the trans-tibial and open inlay techniques while obviating the disadvantages of each technique.

The tibial socket is created prior to the femoral tunnels at the PCL insertion site, using a guide pin and a retrograde drilling system (Fig. 27.7); the target for insertion of the guide pin is within the footprint and 7 mm distal to the proximal pole of the tibial footprint. Guide pin placement and reaming should be performed with assistance of fluoroscopy and under direct arthroscopic visualisation. Care must be taken to avoid plunging into the posterior structures of the knee. A graft with a bone block is then inserted arthroscopically from the anteromedial portal (which may need to be extended 1–2 cm to ease the passage of the graft). Arthroscopic passage of the bone block and tibial socket docking can be technically challenging.

After proof of the adequate press fit, the graft is secured with suspensory fixation [79, 135].

27.5.2.3 Femoral Graft-Positioning Techniques

Single-Bundle

The synovial membrane at the PCL femoral insertion must be removed in order to properly view the femoral PCL footprint. During this manoeuvre, care must be taken in preserving the meniscofemoral ligaments of Humphrey and Wrisberg, which act as PCL agonists.

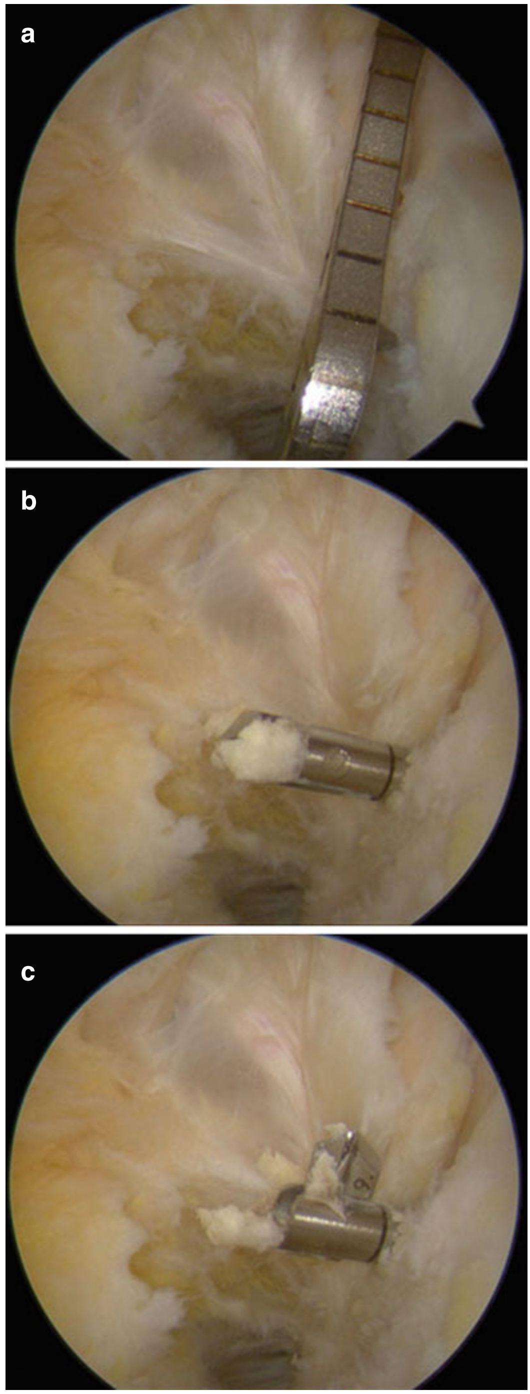

Fig. 27.7 Arthroscopic tibial inlay, creation of the tibial socket: the tip of the guide is positioned at the PCL insertion site (**a**); a retrograde drilling system is inserted (**b**) and activated (**c**)

Nonanatomic "isometric" reconstruction (entry point approximately 11 mm from articular surface, more proximal than anatomical entry point) has been reported to result in initial joint overconstraint and increased laxity over time [40, 44, 90, 91, 106, 108, 110, 128, 137]. Therefore, recent efforts have focused on an anatomic single-bundle reconstruction using arthroscopic and radiographic reference points [4, 61].

The authors prefer an eccentric position of the femoral tunnel. The intercondylar roof and the articular cartilage profile of the femoral condyle are used as anatomical landmarks, to place the entry point of the femoral tunnel at 11 o'clock position (right knee) and 8 mm distant from the articular cartilage. Eccentric placement of the tunnel allows reduction of tensile forces in hyper-extension and similar force distribution to native PCL [47, 84, 90, 102].

The "outside-in" technique is performed by creating an incision on the medial side of the knee with dissection through the vastus medialis oblique (VMO) muscle. A tunnel is then drilled from the medial cortex of the femur to the inter-condylar notch using an arthroscopically placed PCL femoral footprint guide. The guide arm is introduced trough the anteromedial portal and the tip of the guide is positioned 8 mm from the anterior medial femoral cartilage at 11 o'clock position (right knee). A 2–3 cm bone margin is considered safe to avoid phenomena of bone necrosis of the medial femoral condyle (Fig. 27.8).

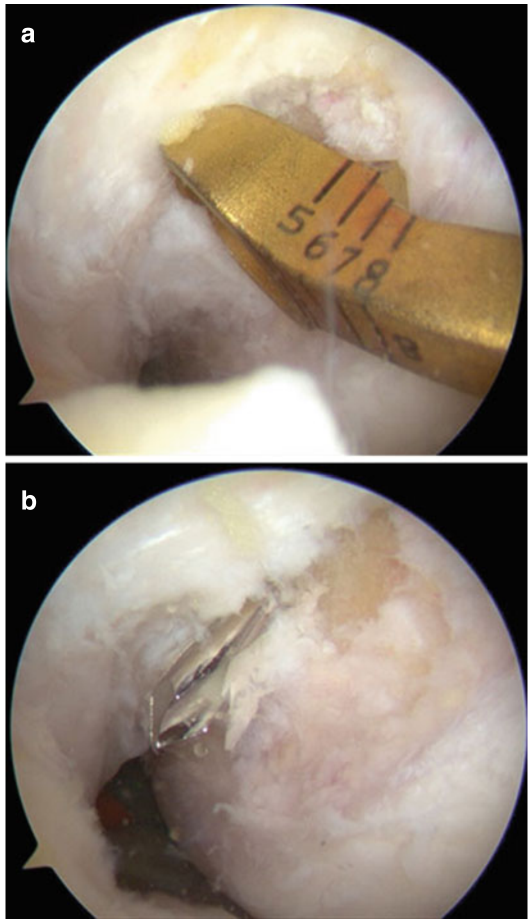

Fig. 27.8 Creation of the femoral tunnel, outside-in technique: the tip of the guide is positioned in the inter-condylar notch at the PCL insertion site (**a**); a guide pin is placed and afterwards an appropriately sized cannulated reamer is used to create the tunnel (**b**)

The "inside-out" technique is performed by creating an accessory inferolateral portal. Through this portal, a guide pin is inserted into the femoral footprint and then over-reamed through the femoral cortex, with the knee flexed to approximately 100° (90–120°). This position must not be changed during reaming. This technique causes less iatrogenic damage to the VMO and shows lower risk of subchondral bone fractures in comparison to outside-in technique.

The "all-inside" technique is performed using a guide pin and a retrograde drilling system to create the femoral tunnel with minimal damage to the medial cortex. The choice of the guide wire position is similar to the outside-in technique. The retrograde blade is then activated, and a femoral socket to a depth of 25 mm is drilled in a retrograde fashion (Fig. 27.9).

In all three techniques, care must be taken in avoiding the "second killer turn" (otherwise called the "critical corner" [43]). Excessive entry angle of the femoral tunnel is believed to cause graft lengthening and eventually failure [8, 24, 43, 69, 113].

Double-Bundle

Anterolateral and posteromedial bundles of the PCL act in codominant manner, a peculiar aspect which cannot be restored by a single-bundle PCL reconstruction [1, 65, 103, 137]. Anatomic double-bundle PCL reconstruction should there-

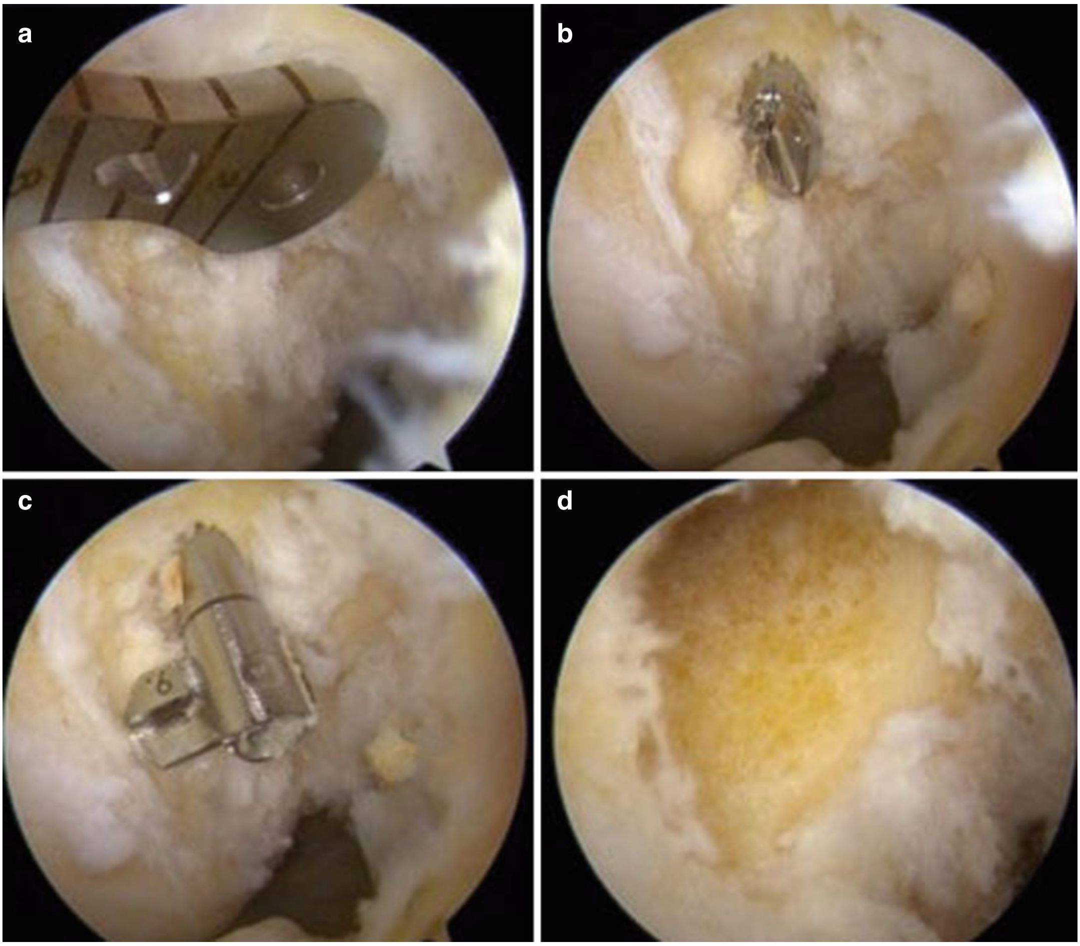

Fig. 27.9 Creation of the femoral tunnel, all-inside technique: the tip of the guide is positioned at the PCL insertion site (**a**); a retrograde drilling system is inserted (**b**) and activated (**c**); a half-tunnel of appropriate size is created (**d**)

fore restore native kinematics more closely than single-bundle technique.

Both tunnels can be performed either with outside-in, inside-out and all-inside techniques, depending on surgeon's preference and experience. A larger tunnel is created for the anterolateral and a smaller one for the posteromedial bundle [45, 95, 124, 137]. The footprint of the PCL is exposed first, and some of the fibres are preserved to aid placement of the femoral socket. The femoral entry point of the posteromedial bundle must be performed at 9 o'clock position and 8 mm from the articular cartilage, and the femoral hole of the anterolateral bundle must be performed at 10:30 position and 13 mm from the articular cartilage (right knee). To avoid tunnel collapse, at least 5 mm of the bone between the two PCL femoral tunnels must be preserved (Fig. 27.10) [79].

27.5.2.4 Graft Fixation Techniques

The purpose of graft fixation is to provide a mechanical link between the graft and the bone during the early post-operative period, until biological incorporation of the graft is complete. A wide variety of techniques for graft fixation in PCL reconstruction can be used [51].

For the femoral tunnel, interference screw within the bone tunnel (metal or bioabsorbable) and suspensory fixation on the cortex of the femoral condyle can be used (Fig. 27.11).

Fig. 27.10 At least 5 mm of bone between the two PCL femoral tunnels must be preserved to avoid tunnel collapse

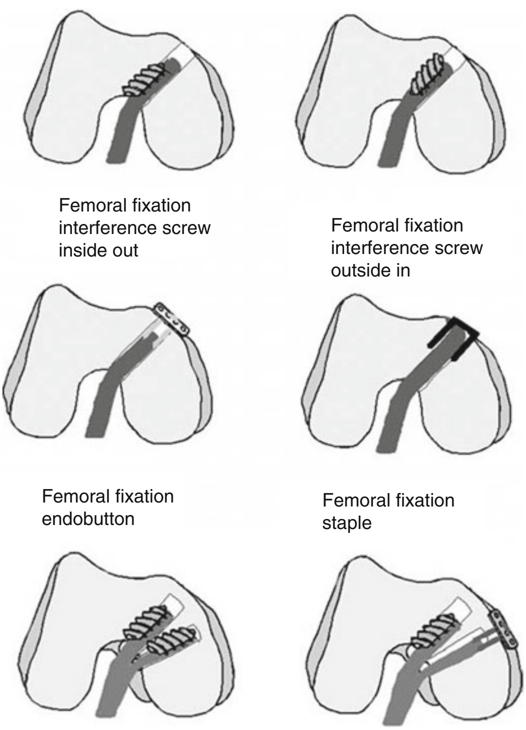

Fig. 27.11 Different options for femoral graft fixation (Reprinted from, Copyright © 2003 Springer, Höher et al. [51], with permission of Springer)

Tibial graft fixation can be achieved by metal or bioabsorbable interference screw, suspensory fixation, bicortical screw and flat washer (Fig. 27.12).

27.5.2.5 Post-operative Care

Rehabilitation plays a fundamental role in determining patient outcomes [25, 72, 138]. Osteointegration and revascularisation of the graft, control of the residual posterior laxity, preservation of correct knee biomechanics, development of optimal response to functional loads, protection of the graft, control of patellofemoral problems and avoidance of deficit in flexion are some of the key points rehabilitation should address.

Since PCL graft healing times have been reported to be almost double the time of anterior cruciate ligament (ACL) graft healing, it has been suggested that PCL reconstruction patients should be kept nonweightbearing for 6 weeks [9, 25, 44, 72]. The authors suggest a brace with posterior support and a pillow during the night.

A progressive, goal-oriented, five-phase rehabilitation program after PCL reconstruction has been proposed to improve stabilisation of posterior tibial translation, varus and external rotation stresses [101, 109].

The authors suggest nonweightbearing for the first week, partial weightbearing for the second and full weightbearing for the third week. Progressive ROM exercises are encouraged to gain full ROM within 4–6 weeks. Proprioception exercises begin at the sixth week, and return to sport is allowed, after dedicated training, from the ninth month.

If combined PCL and posterolateral reconstruction was performed, the brace is kept for 3 months (6 weeks full time), and progressive ROM exercises should proceed slower.

27.6 Complications

Neurovascular injuries can be a direct complication of the initial injury: vascular injury incidence ranges from 16 to 64 %; severity can vary from an intimal tear to a complete transection, requiring vascular surgery intervention. Common peroneal nerve injury incidence ranges from 10 to 40 %; severity can vary from neuropraxia to complete transection [42, 85, 107, 112].

Neurovascular injury is a rare but devastating intraoperative complication: injury may occur if

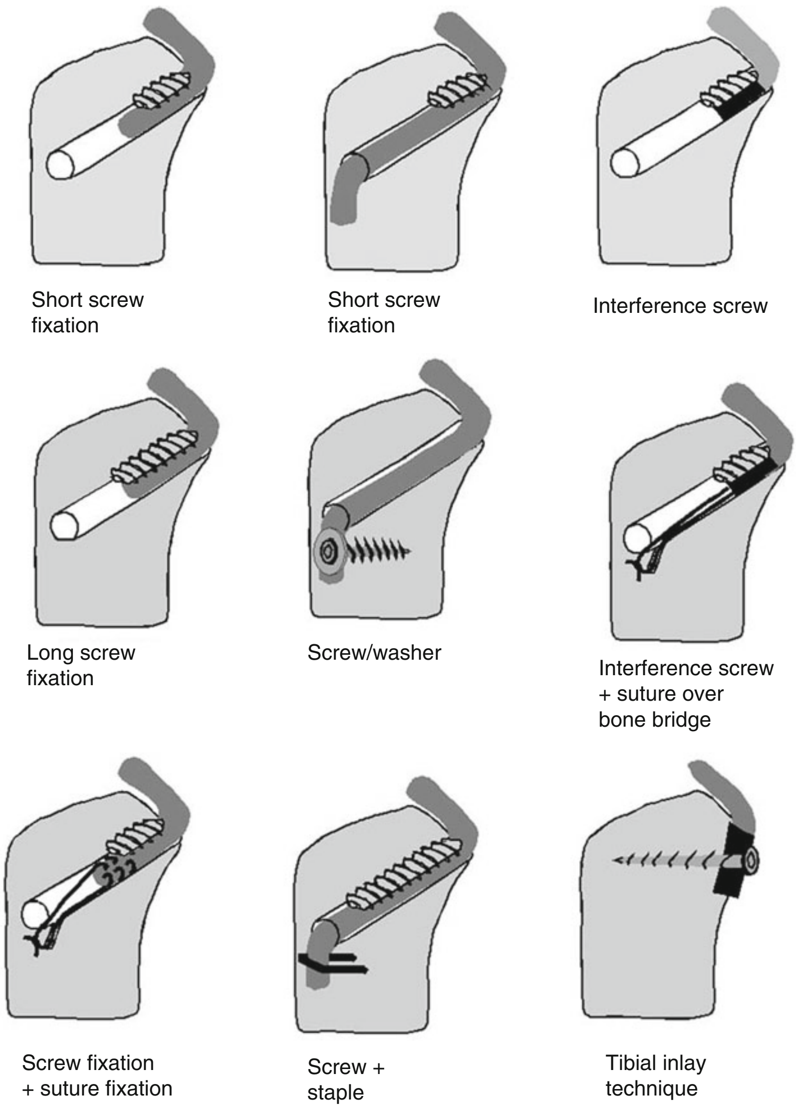

Fig. 27.12 Different options for tibial graft fixation (Reprinted from, Copyright © 2003 Springer, Höher et al. [51], with permission of Springer

the tibial guide pin or reamer overpenetrate the posterior tibial cortex [19, 96, 143]. The popliteal artery and tibial nerve lie posterior to the posterior horn of the lateral meniscus, separated from the knee joint by only the capsule. The popliteal artery passes approximately 7–8 mm posterior to the tibial insertion of the PCL [21, 93, 143]. To increase this distance and therefore lower the risk of injury, knee flexion to 100° and posterior capsular release of the proximal posterior tibia are recommended (Fig. 27.13) [2, 93]. Careful fluoroscopic control is recommended to monitor the position of the guide wire and reamer.

Other rare, specific intraoperative complications include posterior medial or lateral meniscal root avulsions [64], osteonecrosis of the medial femoral condyle [8] and tibial fractures [143].

The most commonly reported complications after PCL reconstructions are residual posterior laxity (usually defined as more than 4 mm of increased posterior translation on PCL stress radiographs) and flexion loss due to prolonged immobilisation of the knee in extension [124, 145].

The rate of ROM deficits ranges from 7 to 30 % [14, 57, 60, 122, 140, 144, 146]. Knee ROM

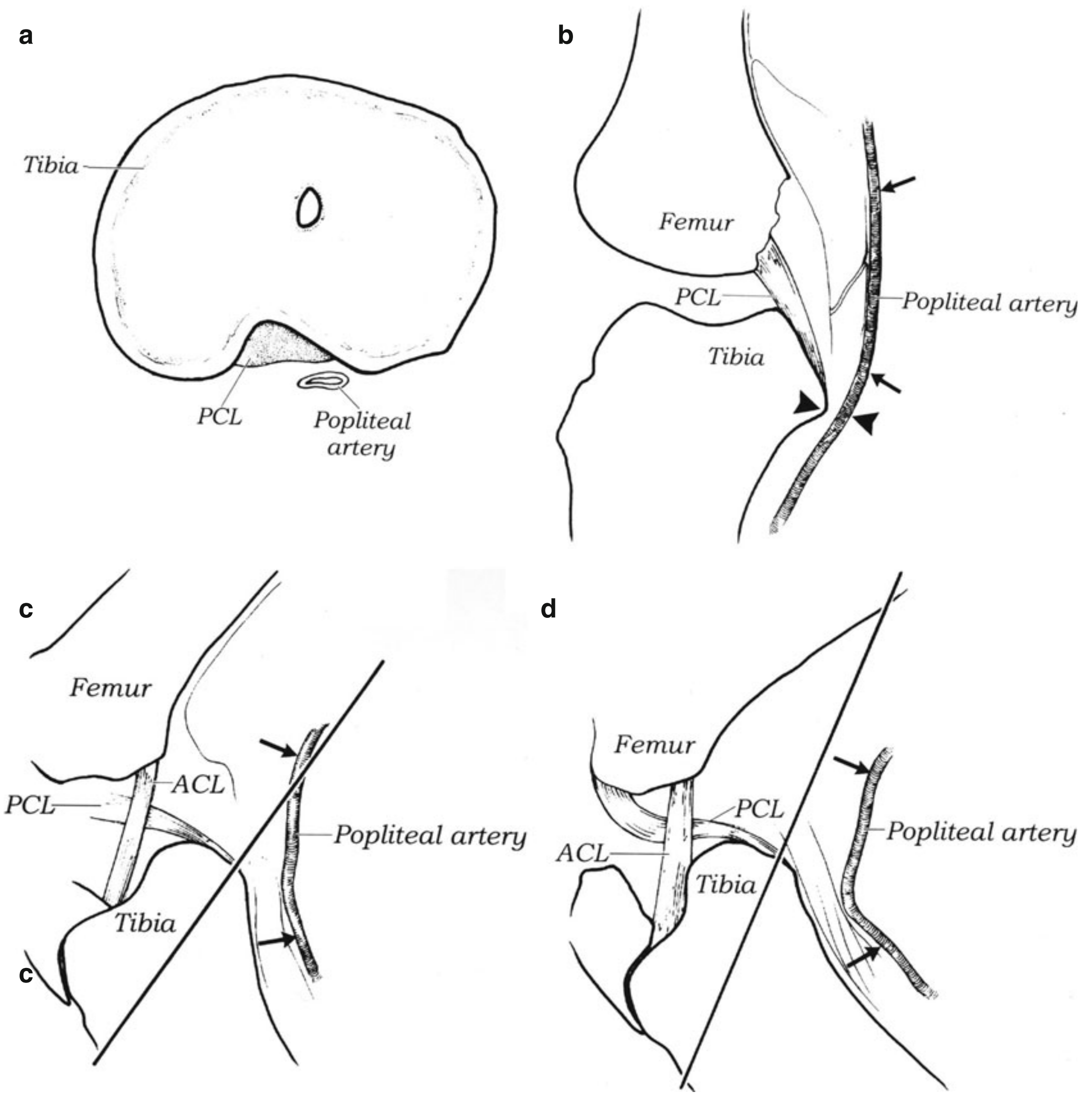

Fig. 27.13 Proximity of the posterior cruciate ligament insertion to the popliteal artery. Axial image showing distance relationships between the posterior edge of the tibial insertion of the PCL and the anterior margin of the popliteal artery (**a**). Knee in extension: the space between the black arrowheads represents the sagittal distance (**b**); knee flexed to 90° (**c**) and 100° (**d**): the line represents the path of a trans-tibial guide pin placed during PCL reconstruction (Reprinted from, Copyright © 2005 Elsevier Inc, Matthew et al. [93], with permission from Elsevier)

loss has been found to be related to the presence of osteoarthritis after ACL reconstruction [119, 121], and we would expect that ROM deficits after PCL reconstruction would also be related to development of osteoarthritis.

Other post-operative complications of PCL surgery are anterior knee pain, painful hardware, heterotopic ossification and infection [85, 143].

27.6.1 Literature Results

27.6.1.1 Nonoperative Treatment

PCL may heal in an attenuated fashion after conservative treatment; however, in spite of good subjective functional scores and a healed appearance of the PCL on magnetic resonance imaging, decreased objective outcomes have been reported at short-term follow-up [37, 125].

Incidence of osteoarthritis at long-term follow-up ranges from 17 to 53 % after nonoperative treatment, as compared with a range of 36–59 % with PCL reconstruction [12, 104, 105, 118, 119].

27.6.1.2 Operative Treatment

Significantly higher post-operative functional scores as compared with the preoperative ones and good rate of normal or nearly normal subjective function can be achieved by arthroscopic single-bundle trans-tibial PCL reconstruction. However, normal knee stability does not appear fully restored in most of the studies reporting this outcome [31, 32, 50, 66, 70, 75].

Significantly improved post-operative subjective scores and significant decrease in post-operative side-to-side posterior tibial translation have also been reported after isolated or combined trans-tibial double-bundle PCL reconstruction with follow-ups ranging from 25 to 45 months [66, 124, 141, 142].

Although early retrospective studies could not indicate differences [66, 71, 132], in more recent prospective studies, post-operative side-to-side posterior translation and objective International Knee Documentation Committee (IKDC) scores were significantly improved for trans-tibial double-bundle compared with single-bundle PCL reconstructions, suggesting that double-bundle PCL reconstruction may be able to more closely and objectively restore the knee to native levels than trans-tibial single-bundle reconstructions [80, 141].

Arthroscopic tibial inlay has showed promising results both in comparison to historical controls and to trans-tibial repairs [67, 68, 88, 134].

References

1. Ahmad CS, Cohen ZA, Levine WN, Gardner TR, Ateshian GA, Mow VC. Codominance of the individual posterior cruciate ligament bundles. An analysis of bundle lengths and orientation. Am J Sports Med. 2003;31:221–5.
2. Ahn JH, Wang JH, Lee SH, Yoo JC, Jeon WJ. Increasing the distance between the posterior cruciate ligament and the popliteal neurovascular bundle by a limited posterior capsular release during arthroscopic transtibial posterior cruciate ligament reconstruction: a cadaveric angiographic study. Am J Sports Med. 2007;35:787–92. doi:10.1177/0363546506297908.
3. Amiel D, Kleiner JB, Roux RD, Harwood FL, Akeson WH. The phenomenon of 'ligamentization': anterior cruciate ligament reconstruction with autogenous patellar tendon. J Orthop Res. 1986;4:162–72. doi:10.1002/jor.1100040204.
4. Anderson CJ, Ziegler CG, Wijdicks CA, Engebretsen L, LaPrade RF. Arthroscopically pertinent anatomy of the anterolateral and posteromedial bundles of the posterior cruciate ligament. J Bone Joint Surg Am. 2012;94:1936–45. doi:10.2106/JBJS.K.01710.
5. Arnoczky SP, Tarvin GB, Marshall JL. Anterior cruciate ligament replacement using patellar tendon. An evaluation of graft revascularization in the dog. J Bone Joint Surg Am. 1982;64:217–24.
6. Arnoczky SP, Warren RF, Ashlock MA. Replacement of the anterior cruciate ligament using a patellar tendon allograft. An experimental study. J Bone Joint Surg Am. 1986;68:376–85.
7. Arnoczky SP, Warren RF, Minei JP. Replacement of the anterior cruciate ligament using a synthetic prosthesis. An evaluation of graft biology in the dog. Am J Sports Med. 1986;14:1–6.
8. Athanasian EA, Wickiewicz TL, Warren RF. Osteonecrosis of the femoral condyle after arthroscopic reconstruction of a cruciate ligament. Report of two cases. J Bone Joint Surg Am. 1995;77:1418–22.
9. Bellelli A, Adriani E, Margheritini F, Camillieri G, Della Rocca C, Mariani PP. Synovial healing in reconstructed cruciate ligaments. Our personal experience compared in single interventions and combined reconstructions. Radiol Med. 1999;98:454–61.
10. Berg EE. Posterior cruciate ligament tibial inlay reconstruction. Arthroscopy. 1995;11:69–76. doi:10.1016/0749-8063(95)90091-8.
11. Bergfeld JA, McAllister DR, Parker RD, Valdevit AD, Kambic HE. A biomechanical comparison of posterior cruciate ligament reconstruction techniques. Am J Sports Med. 2001;29:129–36.
12. Boynton MD, Tietjens BR. Long-term followup of the untreated isolated posterior cruciate ligament-deficient knee. Am J Sports Med. 1996;24:306–10.
13. Cazenave A, Laboureau JP. Reconstruction of the anterior cruciate ligament. Determination of the pre- and perioperative femoral isometric point. Rev Chir Orthop Reparatrice Appar Mot. 1990;76:288–92.
14. Chan Y-S, Yang S-C, Chang C-H, Chen AC-Y, Yuan L-J, Hsu K-Y, Wang C-J. Arthroscopic reconstruction of the posterior cruciate ligament with use of a quadruple hamstring tendon graft with 3- to 5-year follow-up. Arthroscopy. 2006;22:762–70. doi:10.1016/j.arthro.2006.03.020.
15. Chen B, Gao S. Double-bundle posterior cruciate ligament reconstruction using a non-hardware suspension fixation technique and 8 strands of autogenous hamstring tendons. Arthroscopy. 2009;25:777–82. doi:10.1016/j.arthro.2009.01.017.
16. Chen CH, Chen WJ, Shih CH. Arthroscopic reconstruction of the posterior cruciate ligament: a comparison of quadriceps tendon autograft and quadruple hamstring tendon graft. Arthroscopy 2002;18:603–12.

17. Chiu FY, Wu JJ, Hsu HC, Lin L, Lo WH. Management of insufficiency of posterior cruciate ligaments. Zhonghua Yi Xue Za Zhi (Taipei). 1994;53:282–7.
18. Clancy WG, Shelbourne KD, Zoellner GB, Keene JS, Reider B, Rosenberg TD. Treatment of knee joint instability secondary to rupture of the posterior cruciate ligament. Report of a new procedure. J Bone Joint Surg Am. 1983;65:310–22.
19. Cohen SB, Boyd L, Miller MD. Vascular risk associated with posterior cruciate ligament reconstruction using the arthroscopic transtibial tunnel technique. J Knee Surg. 2004;17:211–3.
20. Cooper DE, Deng XH, Burstein AL, Warren RF. The strength of the central third patellar tendon graft. A biomechanical study. Am J Sports Med. 1993;21: 818–23; discussion 823–4.
21. Cosgarea AJ, Kramer DE, Bahk MS, Totty WG, Matava MJ. Proximity of the popliteal artery to the PCL during simulated knee arthroscopy: implications for establishing the posterior trans-septal portal. J Knee Surg. 2006;19:181–5.
22. Cross MJ, Roger G, Kujawa P, Anderson IF. Regeneration of the semitendinosus and gracilis tendons following their transection for repair of the anterior cruciate ligament. Am J Sports Med. 1992;20:221–3.
23. Dericks G. Ligament advanced reinforcement system anterior cruciate ligament reconstruction. Oper Tech Sports Med. 1995;3:187–205. doi:10.1016/S1060-1872(95)80009-3.
24. Engasser WM, Sousa PL, Stuart MJ, Levy BA. All-inside posterior cruciate ligament reconstruction. In: Fanelli MD, Fanelli GC, editors. Posterior cruciate ligament Inj. a Pract. Guid. to Manag. 2nd ed. Cham: Springer International Publishing; 2015. p. 147–56.
25. Fanelli GC. Posterior cruciate ligament rehabilitation: how slow should we go? Arthroscopy. 2008;24: 234–5.
26. Fanelli GC. Surgical treatment of combined PCL ACL medial and lateral side injuries (global laxity): acute and chronic, 2nd ed. Mult Ligament Inj Knee a Pract Guid to Manag. New York: Springer; 2013. doi:10.1007/978-0-387-49289-6.
27. Fanelli GC. Mechanical graft tensioning in multiple ligament knee surgery. In: Fanelli GC, editor. Mult. Ligament Inj. Knee a Pract. Guid. to Manag. 2nd ed. New York: Springer; 2013. p. 323–30.
28. Fanelli GC. Arthroscopic transtibial tunnel posterior cruciate ligament reconstruction. In: Fanelli MD, Fanelli GC, editors. Posterior cruciate ligament Inj. a Pract. Guid. to Manag. 2nd ed. Cham: Springer International Publishing; 2015. p. 111–21.
29. Fanelli GC, Beck JD, Edson CJ. Double-bundle posterior cruciate ligament reconstruction: surgical technique and results. Sports Med Arthrosc. 2010;18: 242–8. doi:10.1097/JSA.0b013e3181f2faa1.
30. Fanelli GC, Boyd JL, Heckler MW. How I manage posterior cruciate ligament injuries. Oper Tech Sports Med. 2009;17:175–93. doi:10.1053/j.otsm.2009.08.002.
31. Fanelli GC, Edson CJ. Arthroscopically assisted combined anterior and posterior cruciate ligament reconstruction in the multiple ligament injured knee: 2- to 10-year follow-up. Arthroscopy. 2002;18:703–14.
32. Fanelli GC, Edson CJ. Combined posterior cruciate ligament-posterolateral reconstructions with Achilles tendon allograft and biceps femoris tendon tenodesis: 2- to 10-year follow-up. Arthroscopy. 2004;20:339–45. doi:10.1016/j.arthro.2004.01.034.
33. Fanelli GC, Edson CJ, Reinheimer KN, Garofalo R. Posterior cruciate ligament and posterolateral corner reconstruction. Sports Med Arthrosc. 2007;15:168–75. doi:10.1097/JSA.0b013e31815afa25.
34. Fanelli GC, Giannotti BF, Edson CJ. The posterior cruciate ligament arthroscopic evaluation and treatment. Arthroscopy. 1994;10:673–88.
35. Fanelli GC, Orcutt DR, Edson CJ. The multiple-ligament injured knee: evaluation, treatment, and results. Arthroscopy. 2005;21:471–86. doi:10.1016/j.arthro.2005.01.001.
36. Ferkel RD, Fox JM, Wood D, Del Pizzo W, Friedman MJ, Snyder SJ. Arthroscopic ‘second look’ at the GORE-TEX ligament. Am J Sports Med. 1989;17: 147–52; discussion 152–3.
37. Fowler PJ, Messieh SS. Isolated posterior cruciate ligament injuries in athletes. Am J Sports Med. 1987;15:553–7.
38. Fu FH, Bennett CH, Lattermann C, Ma CB. Current trends in anterior cruciate ligament reconstruction. Part 1: biology and biomechanics of reconstruction. Am J Sports Med. 1999;27:821–30.
39. Fulkerson JP, Langeland RH. The central quadriceps tendon graft for cruciate ligament reconstruction. Oper Tech Orthop. 1996;6:135–7. doi:10.1016/S1048-6666(96)80012-7.
40. Galloway MT, Grood ES, Mehalik JN, Levy M, Saddler SC, Noyes FR. Posterior cruciate ligament reconstruction. An in vitro study of femoral and tibial graft placement. Am J Sports Med. 1996;24: 437–45.
41. Good L, Tarlow SD, Odensten M, Gillquist J. Load tolerance, security, and failure modes of fixation devices for synthetic knee ligaments. Clin Orthop Relat Res. 1990:190–6.
42. Gray JL, Cindric M. Management of arterial and venous injuries in the dislocated knee. Sports Med Arthrosc. 2011;19:131–8. doi:10.1097/JSA.0b013e3182191a9c.
43. Handy MH, Blessey PB, Kline AJ, Miller MD. The graft/tunnel angles in posterior cruciate ligament reconstruction: a cadaveric comparison of two techniques for femoral tunnel placement. Arthroscopy. 2005;21:711–4. doi:10.1016/j.arthro.2005.03.011.
44. Harner CD, Höher J. Evaluation and treatment of posterior cruciate ligament injuries. Am J Sports Med. 1998;26:471–82.
45. Harner CD, Janaushek MA, Kanamori A, Yagi M, Vogrin TM, Woo SL. Biomechanical analysis of a double-bundle posterior cruciate ligament reconstruction. Am J Sports Med. 2000;28:144–51.

46. Harner CD, Olson E, Irrgang JJ, Silverstein S, Fu FH, Silbey M. Allograft versus autograft anterior cruciate ligament reconstruction: 3- to 5-year outcome. Clin Orthop Relat Res. 1996;324:134–44.
47. Harner CD, Vogrin TM, Höher J, Ma CB, Woo SL. Biomechanical analysis of a posterior cruciate ligament reconstruction. Deficiency of the posterolateral structures as a cause of graft failure. Am J Sports Med. 2000;28:32–9.
48. Harner CD, Waltrip RL, Bennett CH, Francis KA, Cole B, Irrgang JJ. Surgical management of knee dislocations. J Bone Joint Surg Am. 2004;86-A:262–73.
49. Harner CD, Xerogeanes JW, Livesay GA, Carlin GJ, Smith BA, Kusayama T, Kashiwaguchi S, Woo SL. The human posterior cruciate ligament complex: an interdisciplinary study. Ligament morphology and biomechanical evaluation. Am J Sports Med. 1995;23:736–45.
50. Hermans S, Corten K, Bellemans J. Long-term results of isolated anterolateral bundle reconstructions of the posterior cruciate ligament: a 6- to 12-year follow-up study. Am J Sports Med. 2009;37:1499–507. doi:10.1177/0363546509333479.
51. Höher J, Scheffler S, Weiler A. Graft choice and graft fixation in PCL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2003;11:297–306. doi:10.1007/s00167-003-0408-1.
52. Houe T, Jørgensen U. Arthroscopic posterior cruciate ligament reconstruction: one- vs. two-tunnel technique. Scand J Med Sci Sports. 2004;14:107–11. doi:10.1111/j.1600-0838.2003.00318.x.
53. Hudgens JL, Gillette BP, Krych AJ, Stuart MJ, May JH, Levy BA. Allograft versus autograft in posterior cruciate ligament reconstruction: an evidence-based systematic review. J Knee Surg. 2013;26:109–15. doi:10.1055/s-0032-1319778.
54. Indelicato PA, Linton RC, Huegel M. The results of fresh-frozen patellar tendon allografts for chronic anterior cruciate ligament deficiency of the knee. Am J Sports Med. 1992;20:118–21.
55. Jackson DW, Corsetti J, Simon TM. Biologic incorporation of allograft anterior cruciate ligament replacements. Clin Orthop Relat Res. 1996;324:126–33.
56. Jackson DW, Grood ES, Goldstein JD, Rosen MA, Kurzweil PR, Cummings JF, Simon TM. A comparison of patellar tendon autograft and allograft used for anterior cruciate ligament reconstruction in the goat model. Am J Sports Med. 1993;21:176–85.
57. Jackson WFM, van der Tempel WM, Salmon LJ, Williams HA, Pinczewski LA. Endoscopically-assisted single-bundle posterior cruciate ligament reconstruction: results at minimum ten-year follow-up. J Bone Joint Surg (Br). 2008;90:1328–33. doi:10.1302/0301-620X.90B10.20517.
58. Jacobi M, Reischl N, Wahl P, Gautier E, Jakob RP. Acute isolated injury of the posterior cruciate ligament treated by a dynamic anterior drawer brace: a preliminary report. J Bone Joint Surg (Br). 2010;92:1381–4. doi:10.1302/0301-620X.92B10.24807.
59. Jansson KS, Costello KE, O'Brien L, Wijdicks CA, Laprade RF. A historical perspective of PCL bracing. Knee Surg Sports Traumatol Arthrosc. 2013;21:1064–70. doi:10.1007/s00167-012-2048-9.
60. Jenner JMGT, van der Hart CP, Willems WJ. Mid-term results of arthroscopic reconstruction in chronic posterior cruciate ligament instability. Knee Surg Sports Traumatol Arthrosc. 2006;14:848–53. doi:10.1007/s00167-006-0056-3.
61. Johannsen AM, Anderson CJ, Wijdicks CA, Engebretsen L, LaPrade RF. Radiographic landmarks for tunnel positioning in posterior cruciate ligament reconstructions. Am J Sports Med. 2013;41:35–42. doi:10.1177/0363546512465072.
62. Jung Y-B, Jung H-J, Kim SJ, Park S-J, Song K-S, Lee YS, Lee S-H. Posterolateral corner reconstruction for posterolateral rotatory instability combined with posterior cruciate ligament injuries: comparison between fibular tunnel and tibial tunnel techniques. Knee Surg Sports Traumatol Arthrosc. 2008;16:239–48. doi:10.1007/s00167-007-0481-y.
63. Jung Y-B, Tae S-K, Jung H-J, Lee K-H. Replacement of the torn posterior cruciate ligament with a mid-third patellar tendon graft with use of a modified tibial inlay method. J Bone Joint Surg Am. 2004;86-A:1878–83.
64. Kennedy NI, Michalski MP, Engebretsen L, LaPrade RF. Iatrogenic meniscus posterior root injury following reconstruction of the posterior cruciate ligament: a report of three cases. JBJS Case Connect. 2014;4:e20–e20. doi:10.2106/JBJS.CC.M.00175.
65. Kennedy NI, Wijdicks CA, Goldsmith MT, Michalski MP, Devitt BM, Årøen A, Engebretsen L, LaPrade RF. Kinematic analysis of the posterior cruciate ligament, part 1: the individual and collective function of the anterolateral and posteromedial bundles. Am J Sports Med. 2013;41:2828–38. doi:10.1177/0363546513504287.
66. Kim S-J, Jung M, Moon H-K, Kim S-G, Chun Y-M. Anterolateral transtibial posterior cruciate ligament reconstruction combined with anatomical reconstruction of posterolateral corner insufficiency: comparison of single-bundle versus double-bundle posterior cruciate ligament reconstruction over a 2- to 6. Am J Sports Med. 2011;39:481–9. doi:10.1177/0363546510385398.
67. Kim S-J, Kim T-E, Jo S-B, Kung Y-P. Comparison of the clinical results of three posterior cruciate ligament reconstruction techniques. J Bone Joint Surg Am. 2009;91:2543–9. doi:10.2106/JBJS.H.01819.
68. Kim S-J, Park I-S. Arthroscopic reconstruction of the posterior cruciate ligament using tibial inlay and double-bundle technique. Arthroscopy. 2005;21:1271. doi:10.1016/j.arthro.2005.08.004.
69. Kim S-J, Shin JW, Lee CH, Shin HJ, Kim S-H, Jeong J-H, Lee JW. Biomechanical comparisons of three different tibial tunnel directions in posterior cruciate ligament reconstruction. Arthroscopy. 2005;21:286–93. doi:10.1016/j.arthro.2004.11.004.

70. Kim Y-M, Lee CA, Matava MJ. Clinical results of arthroscopic single-bundle transtibial posterior cruciate ligament reconstruction: a systematic review. Am J Sports Med. 2011;39:425–34. doi:10.1177/0363546510374452.
71. Kohen RB, Sekiya JK. Single-bundle versus double-bundle posterior cruciate ligament reconstruction. Arthroscopy. 2009;25:1470–7. doi:10.1016/j.arthro.2008.11.006.
72. LaPrade CM, Civitarese DM, Rasmussen MT, LaPrade RF. Emerging updates on the posterior cruciate ligament: a review of the current literature. Am J Sports Med. 2015;43:3077–92. doi:10.1177/0363546515572770.
73. LaPrade RF, Johansen S, Agel J, Risberg MA, Moksnes H, Engebretsen L. Outcomes of an anatomic posterolateral knee reconstruction. J Bone Joint Surg Am. 2010;92:16–22. doi:10.2106/JBJS.I.00474.
74. LaPrade RF, Smith SD, Wilson KJ, Wijdicks CA. Quantification of functional brace forces for posterior cruciate ligament injuries on the knee joint: an in vivo investigation. Knee Surg Sports Traumatol Arthrosc. 2015;23:3070–6. doi:10.1007/s00167-014-3238-4.
75. Lee K-H, Jung Y-B, Jung H-J, Jang E-C, Song K-S, Kim J-Y, Lee S-H. Combined posterolateral corner reconstruction with remnant tensioning and augmentation in chronic posterior cruciate ligament injuries: minimum 2-year follow-up. Arthroscopy. 2011;27:507–15. doi:10.1016/j.arthro.2010.11.007.
76. Lee YS, Jung YB. Posterior cruciate ligament: focus on conflicting issues. Clin Orthop Surg. 2013;5:256–62. doi:10.4055/cios.2013.5.4.256.
77. Leong NL, Kabir N, McAllister DR. Graft selection in posterior cruciate ligament surgery. In: Fanelli MD, Fanelli GC, editors. Posterior cruciate ligament Inj. a Pract. Guid. to Manag. 2nd ed. Cham: Springer International Publishing; 2015. p. 101–10.
78. Levy BA, Dajani KA, Whelan DB, Stannard JP, Fanelli GC, Stuart MJ, Boyd JL, MacDonald PA, Marx RG. Decision making in the multiligament-injured knee: an evidence-based systematic review. Arthroscopy. 2009; 25:430–8. doi:10.1016/j.arthro.2009.01.008.
79. Levy BA, Fanelli GC, Miller MD, Stuart MJ. Advances in posterior cruciate ligament reconstruction. Instr Course Lect. 2015;64:543–54.
80. Li Y, Li J, Wang J, Gao S, Zhang Y. Comparison of single-bundle and double-bundle isolated posterior cruciate ligament reconstruction with allograft: a prospective, randomized study. Arthroscopy. 2014;30:695–700. doi:10.1016/j.arthro.2014.02.035.
81. Lien OA, Aas EJ-L, Johansen S, Ludvigsen TC, Figved W, Engebretsen L. Clinical outcome after reconstruction for isolated posterior cruciate ligament injury. Knee Surg Sports Traumatol Arthrosc. 2010;18:1568–72. doi:10.1007/s00167-010-1176-3.
82. Liu Z, Zhang X, Jiang Y, Zeng B-F. Four-strand hamstring tendon autograft versus LARS artificial ligament for anterior cruciate ligament reconstruction. Int Orthop. 2010;34:45–9. doi:10.1007/s00264-009-0768-3.
83. Lopez-Vidriero E, Simon DA, Johnson DH. Initial evaluation of posterior cruciate ligament injuries: history, physical examination, imaging studies, surgical and nonsurgical indications. Sports Med Arthrosc. 2010;18:230–7. doi:10.1097/JSA.0b013e3181fbaf38.
84. Mannor DA, Shearn JT, Grood ES, Noyes FR, Levy MS. Two-bundle posterior cruciate ligament reconstruction. An in vitro analysis of graft placement and tension. Am J Sports Med. 2000;28:833–45.
85. Marcus MS, Koh JL. Complications and PCL reconstruction. In: Fanelli MD, Fanelli GC, editors. Posterior cruciate ligament Inj. a Pract. Guid. to Manag, vol. 2. Cham: Springer International Publishing; 2015. p. 329–33.
86. Margheritini F, Mariani PP. Diagnostic evaluation of posterior cruciate ligament injuries. Knee Surg Sports Traumatol Arthrosc. 2003;11:282–8. doi:10.1007/s00167-003-0409-0.
87. Margheritini F, Rihn J, Musahl V, Mariani PP, Harner C. Posterior cruciate ligament injuries in the athlete: an anatomical, biomechanical and clinical review. Sports Med. 2002;32:393–408.
88. Mariani PP, Margheritini F. Full arthroscopic inlay reconstruction of posterior cruciate ligament. Knee Surg Sports Traumatol Arthrosc. 2006;14:1038–44. doi:10.1007/s00167-006-0086-x.
89. Mariani PP, Margheritini F, Christel P, Bellelli A. Evaluation of posterior cruciate ligament healing: a study using magnetic resonance imaging and stress radiography. Arthroscopy. 2005;21:1354–61. doi:10.1016/j.arthro.2005.07.028.
90. Markolf KL, Slauterbeck JR, Armstrong KL, Shapiro MS, Finerman GA. A biomechanical study of replacement of the posterior cruciate ligament with a graft. Part II: forces in the graft compared with forces in the intact ligament. J Bone Joint Surg Am. 1997;79:381–6.
91. Markolf KL, Slauterbeck JR, Armstrong KL, Shapiro MS, Finerman GA. A biomechanical study of replacement of the posterior cruciate ligament with a graft. Part 1: isometry, pre-tension of the graft, and anterior-posterior laxity. J Bone Joint Surg Am. 1997;79:375–80.
92. Markolf KL, Zemanovic JR, McAllister DR. Cyclic loading of posterior cruciate ligament replacements fixed with tibial tunnel and tibial inlay methods. J Bone Joint Surg Am. 2002;84-A:518–24.
93. Matava MJ, Sethi NS, Totty WG. Proximity of the posterior cruciate ligament insertion to the popliteal artery as a function of the knee flexion angle: implications for posterior cruciate ligament reconstruction. Arthroscopy. 2000;16:796–804.
94. McAllister DR, Joyce MJ, Mann BJ, Vangsness CT. Allograft update: the current status of tissue regulation, procurement, processing, and sterilization. Am J Sports Med. 2007;35:2148–58. doi:10.1177/0363546507308936.
95. McGuire DA, Hendricks SD. Comparison of anatomic versus nonanatomic placement of femoral tunnels in Achilles double-bundle posterior cruciate

ligament reconstruction. Arthroscopy. 2010;26:658–66. doi:10.1016/j.arthro.2009.09.008.
96. Miller MD, Kline AJ, Gonzales J, Beach WR. Vascular risk associated with a posterior approach for posterior cruciate ligament reconstruction using the tibial inlay technique. J Knee Surg. 2002;15:137–40.
97. Montgomery SR, Johnson JS, McAllister DR, Petrigliano FA. Surgical management of PCL injuries: indications, techniques, and outcomes. Curr Rev Musculoskelet Med. 2013;6:115–23. doi:10.1007/s12178-013-9162-2.
98. Nau T, Lavoie P, Duval N. A new generation of artificial ligaments in reconstruction of the anterior cruciate ligament. Two-year follow-up of a randomised trial. J Bone Joint Surg (Br). 2002;84:356–60.
99. Noyes FR, Barber-Westin SD. Reconstruction of the anterior cruciate ligament with human allograft. Comparison of early and later results. J Bone Joint Surg Am. 1996;78:524–37.
100. Noyes FR, Barber-Westin SD. Posterior cruciate ligament revision reconstruction, part 2: results of revision using a 2-strand quadriceps tendon-patellar bone autograft. Am J Sports Med. 2005;33:655–65. doi:10.1177/0363546504270456.
101. Nyland J, Hester P, Caborn DNM. Double-bundle posterior cruciate ligament reconstruction with allograft tissue: 2-year postoperative outcomes. Knee Surg Sports Traumatol Arthrosc. 2002;10:274–9. doi:10.1007/s00167-002-0300-4.
102. Oakes DA, Markolf KL, McWilliams J, Young CR, McAllister DR. The effect of femoral tunnel position on graft forces during inlay posterior cruciate ligament reconstruction. Am J Sports Med. 2003;31:667–72.
103. Papannagari R, DeFrate LE, Nha KW, Moses JM, Moussa M, Gill TJ, Li G. Function of posterior cruciate ligament bundles during in vivo knee flexion. Am J Sports Med. 2007;35:1507–12. doi:10.1177/0363546507300061.
104. Parolie JM, Bergfeld JA. Long-term results of nonoperative treatment of isolated posterior cruciate ligament injuries in the athlete. Am J Sports Med. 1986;14:35–8.
105. Patel DV, Allen AA, Warren RF, Wickiewicz TL, Simonian PT. The nonoperative treatment of acute, isolated (partial or complete) posterior cruciate ligament-deficient knees: an intermediate-term follow-up study. HSS J. 2007;3:137–46. doi:10.1007/s11420-007-9058-z.
106. Pearsall AW 4TH, Pyevich M, Draganich LF, Larkin JJ, Reider B. In vitro study of knee stability after posterior cruciate ligament reconstruction. Clin Orthop Relat Res. 1996;327:264–71.
107. Peskun CJ, Chahal J, Steinfeld ZY, Whelan DB. Risk factors for peroneal nerve injury and recovery in knee dislocation. Clin Orthop Relat Res. 2012;470:774–8. doi:10.1007/s11999-011-1981-0.
108. Petermann J, Gotzen L, Trus P. Posterior cruciate ligament (PCL) reconstruction – an in vitro study of isometry. Part II. Tests using an experimental PCL graft model. Knee Surg Sports Traumatol Arthrosc. 1994;2:104–6.
109. Pierce CM, O'Brien L, Griffin LW, Laprade RF. Posterior cruciate ligament tears: functional and postoperative rehabilitation. Knee Surg Sports Traumatol Arthrosc. 2013;21:1071–84. doi:10.1007/s00167-012-1970-1.
110. Race A, Amis AA. PCL reconstruction. In vitro biomechanical comparison of 'isometric' versus single and double-bundled 'anatomic' grafts. J Bone Joint Surg (Br). 1998;80:173–9.
111. Ranawat A, Baker CL, Henry S, Harner CD. Posterolateral corner injury of the knee: evaluation and management. J Am Acad Orthop Surg. 2008;16:506–18.
112. Rihn JA, Groff YJ, Harner CD, Cha PS. The acutely dislocated knee: evaluation and management. J Am Acad Orthop Surg. 2004;12:334–46.
113. Schoderbek RJ, Golish SR, Rubino LJ, Oliviero JA, Hart JM, Miller MD. The graft/femoral tunnel angles in posterior cruciate ligament reconstruction: a comparison of 3 techniques for femoral tunnel placement. J Knee Surg. 2009;22:106–10.
114. Schulz MS, Steenlage ES, Russe K, Strobel MJ. Distribution of posterior tibial displacement in knees with posterior cruciate ligament tears. J Bone Joint Surg Am. 2007;89:332–8. doi:10.2106/JBJS.C.00834.
115. Sekiya JK, Whiddon DR, Zehms CT, Miller MD. A clinically relevant assessment of posterior cruciate ligament and posterolateral corner injuries. Evaluation of isolated and combined deficiency. J Bone Joint Surg Am. 2008;90:1621–7. doi:10.2106/JBJS.G.01365.
116. Seon J-K, Song E-K. Reconstruction of isolated posterior cruciate ligament injuries: a clinical comparison of the transtibial and tibial inlay techniques. Arthroscopy. 2006;22:27–32. doi:10.1016/j.arthro.2005.08.038.
117. Shapiro MS, Freedman EL. Allograft reconstruction of the anterior and posterior cruciate ligaments after traumatic knee dislocation. Am J Sports Med. 1995;23:580–7.
118. Shelbourne DK. Nonoperative treatment and natural history of posterior cruciate ligament injuries, 2nd ed. Posterior cruciate ligament Inj a Pract Guid to Manag. Switzerland: Springer International Publishing; 2015. doi:10.1007/978-3-319-12072-0.
119. Shelbourne KD, Clark M, Gray T. Minimum 10-year follow-up of patients after an acute, isolated posterior cruciate ligament injury treated nonoperatively. Am J Sports Med. 2013;41:1526–33. doi:10.1177/0363546513486771.
120. Shelbourne KD, Davis TJ, Patel DV. The natural history of acute, isolated, nonoperatively treated posterior cruciate ligament injuries. A prospective study. Am J Sports Med. 1999;27:276–83.
121. Shelbourne KD, Urch SE, Gray T, Freeman H. Loss of normal knee motion after anterior cruciate ligament reconstruction is associated with radiographic arthritic changes after surgery. Am J Sports Med. 2012;40:108–13. doi:10.1177/0363546511423639.

122. Shon OJ, Lee DC, Park CH, Kim WH, Jung KA. A comparison of arthroscopically assisted single and double-bundle tibial inlay reconstruction for isolated posterior cruciate ligament injury. Clin Orthop Surg. 2010;2:76–84. doi:10.4055/cios.2010.2.2.76.
123. Simonds RJ, Holmberg SD, Hurwitz RL, Coleman TR, Bottenfield S, Conley LJ, Kohlenberg SH, Castro KG, Dahan BA, Schable CA. Transmission of human immunodeficiency virus type 1 from a seronegative organ and tissue donor. N Engl J Med. 1992;326:726–32. doi:10.1056/NEJM199203123261102.
124. Spiridonov SI, Slinkard NJ, LaPrade RF. Isolated and combined grade-III posterior cruciate ligament tears treated with double-bundle reconstruction with use of endoscopically placed femoral tunnels and grafts: operative technique and clinical outcomes. J Bone Joint Surg Am. 2011;93:1773–80. doi:10.2106/JBJS.J.01638.
125. Tewes DP, Fritts HM, Fields RD, Quick DC, Buss DD. Chronically injured posterior cruciate ligament: magnetic resonance imaging. Clin Orthop Relat Res. 1997;335:224–32.
126. Torg JS, Barton TM, Pavlov H, Stine R. Natural history of the posterior cruciate ligament-deficient knee. Clin Orthop Relat Res. 1989;246:208–16.
127. Trieb K, Blahovec H, Brand G, Sabeti M, Dominkus M, Kotz R. In vivo and in vitro cellular ingrowth into a new generation of artificial ligaments. Eur Surg Res Eur Chir Forschung Rech Chir Eur. 2004;36:148–51. doi:10.1159/000077256.
128. Trus P, Petermann J, Gotzen L. Posterior cruciate ligament (PCL) reconstruction – an in vitro study of isometry. Part I. Tests using a string linkage model. Knee Surg Sports Traumatol Arthrosc. 1994;2:100–3.
129. Tzurbakis M, Diamantopoulos A, Xenakis T, Georgoulis A. Surgical treatment of multiple knee ligament injuries in 44 patients: 2–8 years follow-up results. Knee Surg Sports Traumatol Arthrosc. 2006;14:739–49. doi:10.1007/s00167-006-0039-4.
130. Veltri DM, Deng XH, Torzilli PA, Warren RF, Maynard MJ. The role of the cruciate and posterolateral ligaments in stability of the knee. A biomechanical study. Am J Sports Med. 1995;23:436–43.
131. Wahl CJ, Nicandri G. Single-Achilles allograft posterior cruciate ligament and medial collateral ligament reconstruction: a technique to avoid osseous tunnel intersection, improve construct stiffness, and save on allograft utilization. Arthroscopy. 2008;24:486–9. doi:10.1016/j.arthro.2007.08.003.
132. Wang C-J, Weng L-H, Hsu C-C, Chan Y-S. Arthroscopic single- versus double-bundle posterior cruciate ligament reconstructions using hamstring autograft. Injury. 2004;35:1293–9. doi:10.1016/j.injury.2003.10.033.
133. Wascher DC, Becker JR, Dexter JG, Blevins FT. Reconstruction of the anterior and posterior cruciate ligaments after knee dislocation. Results using fresh-frozen nonirradiated allografts. Am J Sports Med. 1999;27:189–96.
134. Weber AE, Bissell B, Wojtys EM, Sekiya JK. Is the all-arthroscopic tibial inlay double-bundle PCL reconstruction a viable option in multiligament knee injuries? Clin Orthop Relat Res. 2014;472:2667–79. doi:10.1007/s11999-014-3796-2.
135. Weber AE, Sekiya JK. All-arthroscopic tibial inlay double-bundle posterior cruciate ligament reconstruction. In: Fanelli MD, Fanelli GC, editors. Posterior cruciate ligament Inj. a Pract. Guid. to Manag. 2nd ed. Cham: Springer International Publishing; 2015. p. 137–45.
136. West RV, Harner CD. Graft selection in anterior cruciate ligament reconstruction. J Am Acad Orthop Surg. 2005;13:197–207.
137. Wijdicks CA, Kennedy NI, Goldsmith MT, Devitt BM, Michalski MP, Årøen A, Engebretsen L, LaPrade RF. Kinematic analysis of the posterior cruciate ligament, part 2: a comparison of anatomic single- versus double-bundle reconstruction. Am J Sports Med. 2013;41:2839–48. doi:10.1177/0363546513504384.
138. Wilk KE. Rehabilitation of isolated and combined posterior cruciate ligament injuries. Clin Sports Med. 1994;13:649–77.
139. Wong T, Wang C-J, Weng L-H, Hsu S-L, Chou W-Y, Chen J-M, Chan Y-S. Functional outcomes of arthroscopic posterior cruciate ligament reconstruction: comparison of anteromedial and anterolateral trans-tibial approach. Arch Orthop Trauma Surg. 2009;129:315–21. doi:10.1007/s00402-008-0787-3.
140. Wu C-H, Chen AC-Y, Yuan L-J, Chang C-H, Chan Y-S, Hsu K-Y, Wang C-J, Chen W-J. Arthroscopic reconstruction of the posterior cruciate ligament by using a quadriceps tendon autograft: a minimum 5-year follow-up. Arthroscopy. 2007;23:420–7. doi:10.1016/j.arthro.2006.12.011.
141. Yoon KH, Bae DK, Song SJ, Cho HJ, Lee JH. A prospective randomized study comparing arthroscopic single-bundle and double-bundle posterior cruciate ligament reconstructions preserving remnant fibers. Am J Sports Med. 2011;39:474–80. doi:10.1177/0363546510382206.
142. Yoon KH, Bae DK, Song SJ, Lim CT. Arthroscopic double-bundle augmentation of posterior cruciate ligament using split Achilles allograft. Arthroscopy. 2005;21:1436–42. doi:10.1016/j.arthro.2005.09.002.
143. Zawodny SR, Miller MD. Complications of posterior cruciate ligament surgery. Sports Med Arthrosc. 2010;18:269–74. doi:10.1097/JSA.0b013e3181f2f4c2.
144. Zhao J, Huangfu X. Arthroscopic single-bundle posterior cruciate ligament reconstruction: retrospective review of 4- versus 7-strand hamstring tendon graft. Knee. 2007;14:301–5. doi:10.1016/j.knee.2007.03.008.
145. Zhao J, Huang-Fu X, He Y, Yang X. Single-bundle posterior cruciate ligament reconstruction with remnant preservation: lateral versus medial-sided augmentation technique. Orthop Surg. 2009;1:66–73. doi:10.1111/j.1757-7861.2008.00012.x.
146. Zhao J, Xiaoqiao H, He Y, Yang X, Liu C, Lu Z. Sandwich-style posterior cruciate ligament reconstruction. Arthroscopy. 2008;24:650–9. doi:10.1016/j.arthro.2008.01.005.