Curr Rev Musculoskelet Med (2013) 6:115–123
DOI 10.1007/s12178-013-9162-2

KNEE (SL SHERMAN, SECTION EDITOR)

Surgical management of PCL injuries: indications, techniques, and outcomes

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Published online: 21 February 2013

Abstract The ideal treatment for posterior cruciate ligament (PCL) injuries is controversial and remains an active area of orthopedic research. The indications for surgery and the ideal method of reconstruction continue to be evaluated in biomechanical and clinical studies. Recent research has provided information on the anatomy and biomechanics of the PCL, and the merits and drawbacks of the transtibial compared with the tibial inlay technique, the use of single vs double-bundle reconstruction, and different graft options for reconstruction. This review discusses important factors in the surgical treatment of PCL injuries, with attention to the most current literature on these topics.

Keywords Posterior cruciate ligament · Knee · Arthroscopy · Sports medicine

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Introduction

The treatment of posterior cruciate ligament (PCL) injuries remains controversial. In contrast to anterior cruciate ligament (ACL) tears, PCL injuries are relatively infrequent and thus information on the natural history and treatment outcomes have been limited [1, 2]. However, continued research on the topic has led to an improved understanding of the biomechanics of the PCL and has provided information on controversial topics in PCL injury management including operative indications, transtibial vs tibial inlay reconstruction, double vs single bundle reconstruction, graft choice, and rehabilitation protocols. The following review discusses the important considerations in the evaluation and management of PCL injuries with a focus on the most recent literature addressing PCL injury (Table 1).

Diagnosis, nonoperative management and indications for surgery

History and physical examination

In contrast to ACL injuries, which most commonly occur via a non-contact mechanism, PCL injuries most often occur via a posteriorly directed force to the tibia. This most frequently occurs during athletics or traumatic injuries, yet PCL injuries rarely occur in isolation [3, 4]. In a recent analysis of 106 patients with multi-ligamentous knee injuries, the most common injury pattern (43 %) was a combined disruption of the anterior cruciate ligament, posterior cruciate ligament, and posterolateral corner [5]. PCL injuries also occur concomitantly with peri-articular fractures of the knee, in which they are missed over 60 % of the time [6]. In contrast to ACL injury, patients with chronic PCL insufficiency often complain of anterior knee pain, difficulty with stairs, and less commonly, instability [7].

Table 1 Current additions to posterior cruciate ligament research

Topic	Author, Year	Summary
Epidemiology	Becker, 2012	Description of multi-ligamentous knee injury patterns; most common injury identified was combined ACL, PCL, and PLC.
	Kim, 2012	Evaluation of PCL injuries in combination with periarticular fractures of the knee; overall incidence of PCL injury was 7.8 % in this population.
Biomechanics and anatomy	Goyal, 2012	Asymptomatic patients with isolated grade II PCL tears underwent Dynamic Stereo X-Ray of both knees during level running and stair ascent; altered kinematics were observed in the swing phase of running and the swing and early stance phase of stair climbing.
	Aroen, 2012	Comparison of preop knee function in PCL injured patients compared to those with ACL injuries; decreased preop knee function and greater delay to surgery in PCL group despite fewer meniscus and articular cartilage injuries.
	Petrigliano, 2012	Cadaveric study on the effect of tibal slope on instability in PCL/PLC deficient knees; increasing posterior tibial slope decreased translation with posterior drawer but had no effect on dial and RPS tests. Decreasing posterior slope resulted in increased translation with posterior drawer and RPS.
	Osti, 2012	Cadaveric study of AL and PM bundles; determined depth and height of the center of the insertion of each bundle on the femur and tibia using plain radiographs so as to develop radiographic reference points for tunnel placement.
	Tsukada, 2012	Cadaveric study comparing anterolateral bundle reconstruction (ALR), posteromedial bundle reconstruction (PMR), and double bundle reconstruction; DB reconstruction resisted posterior tibial load better than the anterolateral single bundle at 0° and 30° of knee flexion and better than the posteromedial single bundle at 30°, 60°, and 90° of knee flexion.
Rehabilitation	Pierce, 2012	Comprehensive review of PCL rehabilitation programs; a specific protocol is recommended based on the findings of the review.
	Jacobi, 2012	Patients with isolated grade I or II PCL tears were treated in a dynamic anterior drawer brace for 4 mo; posterior sag was decreased from 7.1 mm to a mean of 2.3 mm at 12 mo and 3.2 mm after 24 mo.
Single vs double bundle	Fanelli, 2012	Comparison of clinical results of transtibial single-bundle and double-bundle reconstruction in PCL-based multiple ligament injured knees; no difference in stability using stress radiography or KT-1000 measurements or with Lysholm, Tegner, and Hospital for Special Surgery Knee ligament rating scales.
	Yoon, 2011	Prospective comparison of single and double-bundle reconstruction; decreased posterior tibial translation by 1.4 mm in DB group compared with SB, no difference in subjective scores.
Remnant preservation	Kim, 2012	Retrospective comparison of combined PCL/PLC reconstruction with and without remnant preservation; No difference in posterior tibial translation, Lysholm knee score, return to activity, and objective IKDC grade; improved results in the remnant preservation group with regard to final Tegner activity scale, near-return to activity, and subjective IKDC score.
Graft choice	Maruyama, 2012	Retrospective comparison of patients treated with transtibial PCL reconstruction using bone patellar tendon bone, and semitendinosus and gracilis tendons; no difference in Lysholm or stress radiographs; 2 patients in the BTB group showed no improvement in posterior drawer grade after surgery.
New techniques and revision surgery	Ahn, 2012	Prospective study of 30 patients undergoing PCL reconstruction with bioabsorbable cross-pin tibial back side fixation; Lysholm and IKDC knee scores, and posterior instability improved compared with preop at a mean follow-up of 47 mo. Tibial cysts occurred in 20 % of patients.
	Lee, 2012	Revision reconstruction was performed in 22 patients using a double femoral tunnel, modified tibial inlay, and Achilles tendon allograft; improved clinical scores and posterior translation were observed at a minimum follow-up of 24 mo.

ACL anterior cruciate ligament, *AL* anterolateral, *BTB* bone-tendon-bone, *DB* double bundle, *IKDC* International Knee Documentation Committee, *PCL* posterior cruciate ligament, *PLC* posterior lateral corner, *PM* posteromedial, *RPS* reverse pivot shift, *SB* single bundle.

The posterior drawer test is the most accurate physical examination test to assess PCL injury, with a sensitivity of 90 % and specificity of 99 % [8, 9]. The degree of posterior translation is used to determine the grade of injury: Grade I: 1 to 5 mm; grade II: 6 to 10 mm; grade III: >10 mm. To avoid incorrectly diagnosing an ACL injury in lieu of a PCL tear, the examiner must position the tibia in its natural position, with the medial femoral condyle resting approximately 1 cm anterior to the femur before applying the posteriorly directed force. The posterior sag test and quadriceps active tests are helpful adjuncts to the posterior drawer test. The dial test is employed to evaluate for concomitant injuries to the posterolateral corner (PLC). Increased external rotation at 30° implies an isolated PLC injury, whereas increased rotation at both 30° and 90° of flexion suggests a combined PCL and PLC injury. Collateral ligament testing and gait analysis should also be included in the initial exam to rule out a combined injury.

Imaging

Plain radiographs are performed to assess posterior tibial subluxation, avulsion fractures, posterior tibial slope, and tibial plateau fractures. A medial Segond's fracture, which is a bony avulsion off the medial tibial plateau, can be seen on plain radiographs and may be associated with a medial meniscus tear [10–12]. Tibial tubercle avulsion fractures can also be identified on plain films. To assess lower extremity alignment, long leg hip-to-ankle cassette views are often performed. Varus malalignment is common in chronic PCL injuries. Although stress radiographs are not required to diagnose a PCL injury, they may be helpful to differentiate between complete and partial PCL tears and are commonly used for research purposes [13, 14].

Magnetic Resonance Imaging (MRI) can assist in the diagnosis of acute PCL tears and combined injuries with a sensitivity of up to 100 % [15–17]. However, MRI is less accurate in diagnosing chronic PCL tears [18, 19]. The condition of the menisci, articular cartilage, and other ligaments in the knee are also assessed on MRI, as concomitant injuries are common and can affect the treatment plan [20]. Bone bruises are seen in over 80 % of acute Grade II and III PCL injuries on MRI. In contrast to the bone bruises associated with ACL tears, which commonly occur on the posterior tibia and lateral femoral condyle, the location of bone bruises observed with PCL injuries is less predictable [21].

Effect of PCL deficiency on knee biomechanics

Several studies have suggested that knee kinematics are significantly affected in the PCL deficient knee. In particular, increased forces are observed in the medial and patellofemoral compartments [22, 23], which may explain the pattern of patellofemoral and tibiofemoral arthrosis observed in cases of chronic PCL deficiency. Logan et al. [22] evaluated the effect of PCL rupture on tibiofemoral motion during squatting using MRI and found that PCL deficiency is similar to a medial meniscus resection, resulting in posterior subluxation of the medial tibial plateau. Similarly, using Dynamic Stereo X-Ray, Goyal et al. [24] found activity dependent changes in knee kinematics in patients with isolated Grade II PCL injuries, demonstrating increased antero-posterior motion and velocity of motion during the swing phase of running and the swing and early stance phase of stair climbing in PCL deficient knees when compared with the contralateral knee. The authors hypothesized that the resulting shear motion might expose the loaded joint to abnormal and potentially harmful forces. No differences were observed during ground level walking.

Additionally, it has been found that surgically treated knees with an isolated rupture of the PCL have worse knee function preoperatively when compared with knees with an isolated ACL injury, despite fewer meniscus and articular cartilage injuries [25]. Although reasons for this difference were unclear, the authors suggested that PCL rupture may cause alterations in biomechanical loading of the knee cartilage and to the posterolateral corner, resulting in decreased knee function. In addition, the authors suggested that preoperative management of the isolated PCL injury could be improved by dynamic bracing or by preoperative quadriceps strengthening, which has been shown to improve outcomes in patients undergoing ACL reconstruction [26].

Non-operative management and indications for surgery

Although knee kinematics and biomechanics are altered by PCL injury, successful non-operative treatment of isolated PCL injuries has been reported in several studies. Parolie and Bergfeld [27] found that 80 % of patients were satisfied with their knee function and the majority returned to sport after non-operative treatment of isolated PCL tears with a mean follow-up of 6 years [27]. Interestingly, knee instability did not correlate with return to sport or knee satisfaction. Similarly, Shelbourne and Muthukaruppan [28] observed that subjective outcome scores did not correlate with the degree of laxity. These results were confirmed by Patel et al. [29], who also found no correlation between knee function and the extent of PCL laxity, concluding that most patients with acute, isolated PCL tears will have good outcomes without surgical intervention.

Good results seen with non-operative management in these studies are likely in part explained by the inclusion of patients primarily with grade I or II injuries. There are also secondary restraints to posterior tibial translation to compensate for PCL injury. Portions of the PCL remain intact in lower grade injuries, which may help maintain knee function. Tibial slope has also recently been identified as an important contributor to stability in the PCL deficient knee [30]. In a cadaveric study, increasing the posterior tibial slope decreased the static posterior translation of the PCL/PLC-deficient knee as assessed by posterior drawer. Furthermore, decreasing the tibial slope increased posterior translation with both posterior drawer and reverse pivot shift testing [30].

Although favorable non-operative results have been observed, the long term consequences of isolated PCL deficiency remain unknown. Boynton and Tietjens [31] have observed deterioration at extended follow-up of non-operative treatment despite good early results. In 38 patients with isolated tears with a mean follow-up of 13.4 years, 8 patients had subsequent meniscal injuries and surgery. Of the remaining 30 patients with normal menisci, over 80 % had occasional pain and over 50 % had occasional swelling. With time, an increase in articular cartilage degeneration was seen on plain radiographs. Based on the current data, non-operative management is generally recommended for the treatment of acute and chronic isolated grade I and II PCL injuries [32]. Operative management is reserved for acute or chronic isolated grade III PCL injuries with symptoms of pain or instability which have failed an adequate course of conservative treatment, or PCL insufficiency in the setting of a multiligamentous knee injury. Of note, some authors have suggested that a grade 3 posterior drawer examination and >10 mm of posterior tibial translation on stress radiography indicate a posterolateral corner injury in combination with a complete disruption of the posterior cruciate ligament [33]. Accordingly, the examiner should have a high index of suspicion for a concomitant injury in the setting of grade 3 laxity. Finally, an acute avulsion fracture of the PCL from its tibial insertion is treated with open reduction and internal fixation in the acute period.

Rehabilitation of the PCL injured knee focuses on quadriceps strengthening to counteract the force of the hamstrings and gravity, which displace the tibia posteriorly. Pierce et al. performed a comprehensive review of non-operative and operative rehabilitation protocols after PCL injury [34] and suggested a 3 phase rehabilitation protocol for non-operative management. In phase I, which includes the first 6 weeks after injury, patients are partial weight-bearing and hamstring and gastrocnemius stretching with quadriceps strengthening is emphasized. The knee can be immobilized in extension using a knee brace [35], a cylindrical leg cast with a posterior support to prevent posterior displacement of the tibia [36], or the use of a brace with a dynamic anterior drawer to apply an anterior force on the posterior proximal tibia [37]. Treatment with a dynamic anterior drawer brace has been shown to significantly reduce posterior tibial translation in patients with isolated acute grade 1+ or 2+ PCL injuries [38•]. Phase II, 6–12 weeks after injury, emphasizes continued quadriceps strengthening, re-establishment of full range of motion, and improving proprioception. Running and sports specific training is allowed in phase III, 13–18 weeks after injury, and return to sports is allowed 4–6 months after the initial injury when full quadriceps strength has been achieved.

Surgical management, techniques, and outcomes

Several studies have reported on outcomes of isolated PCL reconstruction. Interpretation of these studies is limited as most are small case series with short term follow-up with significant heterogeneity in patient population and surgical technique.

Two studies have recently been published evaluating outcomes of isolated PCL reconstruction with follow-up approaching 10 years [38•, 39]. Hermans et al. [38•] followed a series of 25 patients who underwent isolated anterolateral bundle transtibial PCL reconstructions with an average follow up of 9.1 years. The final International Knee Documentation Committee (IKDC), Lysholm, and functional visual analog scale (VAS) scores were significantly better than preoperative scores but less than half of patients had normal or near normal clinical findings according to the IKDC guidelines. These findings may be explained by residual laxity after reconstruction. At final follow-up, the mean difference in posterior translation compared with the contralateral knee was 4.7 mm. Decreased subjective scores were associated with greater than 1 year of preoperative symptomatic instability and chondrosis at the time of surgery.

Similarly, Jackson et al. [39] evaluated the long-term outcome of isolated endoscopically-assisted trans-tibial posterior cruciate ligament reconstruction in 26 patients using hamstring tendon autograft. At 10 year follow-up, the mean IKDC score was 87 and participation in moderate to strenuous activities was possible for 88 % of patients postoperatively compared with just 27 % preoperatively. The mean Lysholm score improved from 64 to 90 at 10 years. However, radiographically, 4 patients had grade 2 changes with loss of joint space and another 4 patients showed osteophyte formation with moderate joint space narrowing.

Transtibial tunnel vs tibial inlay techniques

Controversy exists regarding the use of transtibial vs tibial inlay techniques of PCL reconstruction. In the transtibial technique, the tibial and femoral tunnels are drilled and the graft must make an acute turn as it surfaces from the tibial tunnel and changes direction before entering the knee joint. Subsequent graft abrasion and attenuation may result in graft rupture or laxity [40]. This sharp turn has been implicated in the residual posterior knee laxity observed clinically after transtibial PCL reconstruction. The tibial inlay was developed as an alternative to the transtibial technique to avoid this problem. In tibial inlay reconstruction, the graft is fixed directly to the PCL's native insertion site on the tibia.

The transtibial and tibial inlay techniques have been compared in several cadaveric studies. A time zero, McAllister et al. [41] found no significant differences in mean knee laxities between the tibial tunnel and tibial inlay techniques. Yet, increased laxity was found in the tibial tunnel specimens with cyclic loading. Similarly, Bergfeld et al. [42] found minimal differences in anterior-posterior laxity when comparing tibial inlay to transtibial reconstruction from 30° to 90° of knee flexion and after repetitive loading at 90° of knee flexion. At the conclusion of the study, graft thinning and attenuation was observed in the tibial tunnel group. These results were supported by a separate cadaveric cyclic loading study comparing the 2 techniques [43]. Over 30 % of grafts undergoing cyclic loading in the tibial tunnel group failed at the acute angle before 2000 cycles of testing could be completed. In contrast, all grafts in the inlay group survived testing.

Despite the consistent in vitro findings describing graft attenuation with the tibial tunnel technique, results of comparative clinical studies between transtibial and tibial inlay techniques have been equivocal. In head-to-head comparisons, no difference in clinical outcome scores between the 2 techniques has been observed. MacGillivray et al. [43] reviewed a cohort of 20 patients, including 13 treated with transtibial reconstruction and 7 with the tibial inlay technique. At a mean follow-up of 5.7 years, no difference was observed between the 2 groups with regard to posterior drawer, KT-1000, or subjective clinical scores. Similar results were observed by Seon and Song [44], who performed a retrospective comparison of 21 isolated transtibial and 22 tibial inlay reconstructions. Although Kim and colleagues [45•] found decreased posterior tibial translation in patients undergoing double bundle tibial inlay reconstruction compared with those treated with the single bundle transtibial technique, clinical scores and range of motion were comparable. To date, no clinical studies have demonstrated the superiority of either technique.

A number of authors have also described arthroscopic tibial inlay PCL reconstruction [46–48]. Proposed advantages of this technique include avoiding the open posterior approach to the tibia while simultaneously avoiding unwanted effects of the acute angle on graft abrasion in tibial tunnel reconstruction. In a cadaver study, Campbell et al. compared a simulated open inlay reconstruction with 2 4.0 mm cancellous lag screws and a simulated arthroscopic approach using 2 No. 5 Ethibond sutures tied over a button on the anterior tibial cortex [49]. Ultimate load to failure was greater in the screw fixation group, but this did not reach statistical significance. Additional outcomes including load at 3 mm and 5 mm displacement, stiffness, and response to cyclic loading were comparable between the 2 methods. Similarly, Zehm and colleagues compared cadaver knees undergoing simulated arthroscopic double-bundle PCL inlay reconstruction and open double-bundle inlay reconstruction in both PLC intact and deficient states [50]. Although radiographic posterior tibial translation was increased in the arthroscopic group in both the PLC intact and deficient states, the difference was not statistically significant, leading authors to conclude that arthroscopic inlay results in comparable stability to open inlay reconstruction.

To date, minimal clinical data exists on the outcomes of arthroscopic inlay reconstruction. In Kim's comparison of 3 PCL reconstruction techniques discussed above, the arthroscopic tibial inlay double-bundle reconstruction yielded improved results with regard to posterior tibial translation compared with transtibial single-bundle reconstruction, while no differences were observed between the arthroscopic inlay single-bundle group and the transtibial single-bundle group [45•]. Although improved or equivalent results were seen when using arthroscopic inlay reconstruction compared with the transtibial technique, no comparison was made in this study between arthroscopic and open tibial inlay reconstruction. Potential disadvantages of arthroscopic inlay reconstruction include the technical difficulty of the procedure, the use of suture fixation instead of screw fixation on the tibial side, and risk to the neurovascular structures behind the knee during passage of guide pins for use of a retrograde reamer.

Single bundle vs double bundle reconstruction

The PCL is comprised of an anterolateral bundle and a posteromedial bundle. The anterolateral bundle is thicker and biomechanically stronger than the posteromedial bundle. It is taut in knee flexion and becomes relatively lax in extension, while the posteromedial bundle is tight in knee extension and becomes lax in flexion. Due to the strength of the anterolateral bundle, PCL reconstructions have primarily focused on recreation of this bundle. Yet, in vitro studies have demonstrated the importance of both bundles in knee function. Cadaveric studies have suggested that both bundles contribute to posterior stability throughout knee range of motion [51, 52]. Although the anterolateral bundle is tight in flexion, the posteromedial bundle is more horizontally oriented during flexion and thus better positioned to resist posterior tibial translation [51]. In an attempt to approximate the biomechanics and anatomy of the native PCL, double-bundle reconstructions were introduced.

Osti and colleagues [53•] set out to define the anatomy of the PM and AL bundles of the PCL and to define radiographic landmarks that correlate with the PCL double bundle anatomy that may be used for intraoperative and postoperative assessments of anatomic graft tunnel placement. In cadaveric knees, the overall length and diameter of the PCL averaged 36.08 mm and 11.03 mm, respectively. The digitally calculated cross-sectional area of the femoral and tibial footprints of the AL bundle averaged 0.53 cm^2 on the femur and 0.62 cm^2 on the tibia whereas the average cross-sectional area of the PM bundle was 0.55 cm^2 at the femoral insertion and 0.54 cm^2 at the tibial insertion. They also determined the mean absolute and relative depth and height of the center of the insertion of each bundle on the femur and tibia using plain radiographs so as to develop radiographic reference points for tunnel placement.

Improved biomechanics have been observed in some cadaveric studies comparing single and double-bundle PCL reconstruction [54–56]. When compared with single bundle reconstruction in cadaver knees, double bundle reconstruction resisted posterior tibial load better than the anterolateral single bundle at 0° and 30° of knee flexion and better than the posteromedial single bundle at 30°, 60°, and 90° of knee flexion , leading the authors to conclude that double bundle reconstruction reduces laxity in extension [56]. However, the biomechanical advantage of double bundle reconstruction may only be important in combined PCL and PLC injuries [57]. Excessive rotational constraint and increased PCL graft forces are potential drawbacks to double bundle reconstruction [57–59]. In addition, some authors have found no difference between the 2 techniques in vitro [60].

To date, clinical studies have shown no significant differences in subjective and objective results between single- and double-bundle PCL graft reconstructions [61–63]. In the largest study to date comparing the 2 techniques, Fanelli and colleagues performed a retrospective comparison of 45 single-bundle PCL reconstructions and 45 double-bundle reconstructions using the transtibial technique in a cohort of PCL-based multiple ligament injured knees [64]. No statistically significant differences were observed between the 2 techniques using stress radiography at 90° of knee flexion, or KT-1000 measurements at 90°, 70°, and 30° of knee flexion. Nor were there any differences in Lysholm, Tegner, and Hospital for Special Surgery Knee scores. These results are consistent with previous studies comparing single and double bundle reconstruction in vivo [62, 63, 65••, 66]. Although Yoon and colleagues observed a decrease of 1.4 mm in posterior translation in patients treated with double bundle reconstruction, no differences were observed in subjective clinical outcome scores [65••].

In addition to double bundle reconstruction, remnant preserving reconstruction has also been proposed. Due to the relatively robust blood supply to the PCL, the ligament has improved healing potential compared with the ACL and remnant fibers are often seen on preoperative MRI or during surgery [67•]. Given that knee ligaments contain mechanoreceptors that may be important for proprioception; some surgeons have advocated that remnant preservation during reconstruction may improve outcomes. To test this hypothesis, Kim et al. [67•] compared single-bundle PCL reconstruction with posterolateral corner reconstruction with and without remnant preservation. Remnant preservation resulted in improved final Tegner activity scale, near-return to activity, and subjective IKDC score outcomes compared with those of approaches without remnant preservation. However, no differences were observed in posterior tibial translation, Lysholm knee score, return to activity, and objective IKDC grade. Furthermore, a recent study by Jung et al. has provided insight on the ideal graft passage during remnant preserving PCL reconstruction [68]. The magnitude of the length change between the femoral and tibial tunnels for PCL reconstruction is up to 9.8 mm during knee range of motion, which surpasses the range of failure strain. Using a cadaveric study, authors found that the curvature of the PCL compensates for the length change observed between 0º and 60º of flexion, indicating that a more curved PCL path has better isometry in terms of length change and excursion during knee range of motion. Furthermore, it was found that passing the graft over the remnant PCL fibers resulted in increased intra-articular length and decreased excursion, indicating improved isometry compared with a straight path under the PCL.

Graft choice and fixation

PCL reconstruction can be performed using autograft or allograft. Autograft options include bone-patellar tendon-bone, hamstring, and quadriceps tendon. The Achilles tendon and anterior and posterior tibial tendons are commonly used allografts. The extensor mechanism acts synergistically with the PCL to prevent posterior tibial translation and thus weakening the quadriceps is a concern when using it as an autograft [69]. Benefits of allograft include avoiding donor site morbidity and reducing operating time, but there is a small risk of disease transmission and disadvantages with regard to cost and availability. Achilles tendon allograft, with its large cross sectional area, is currently the most frequently used graft for acute (43 %) and chronic (50 %) PCL reconstructions [70]. Recently, Maruyama compared bone-tendon-bone with semitendinosus and gracilis tendon autograft in single bundle transtibial PCL reconstruction. No differences in improvement in functional scores or posterior laxity were observed [71]. However, 2 patients in the bone-tendon-bone group failed to show improvement in posterior drawer grade, suggesting graft failure in these patients.

The ideal fixation method for PCL reconstruction is also an active area of research. Bone block position flush with the tunnel and anteriorly oriented in the tibial tunnels, and combined proximal and distal tibial fixation have been found to improve biomechanics in cadaver models of PCL reconstruction [72, 73]. Lim et al. compared 4 different fixation methods in a porcine model: cross-pin fixation with bone blocks, interference screw fixation with bone blocks, cross-pin fixation of soft tissue with backup fixation, and interference screw fixation of soft tissue with backup fixation on the tibia [74]. Although cross-pin fixation with backup fixation had a higher maximum failure load and stiffness, tendon graft displacement was increased compared with bone-block fixation. Gupta and colleagues compared bioabsorbable to metallic screws for inlay fixation and found no difference in failure load or linear stiffness [75].

New techniques and revision reconstruction

In addition to advances in research assessing traditional techniques of PCL reconstruction, new surgical procedures have recently been proposed and evaluated. Ahn and colleagues evaluated the results of patients undergoing transtibial posterior cruciate ligament (PCL) reconstruction using rigidfix (RIGIDfix system: Mitek, Johnson & Johnson, Norwood, Massachusetts), a bioabsorbable cross-pin tibial back side fixation, which allows for the use of different graft types and lengths [76]. Improved functional scores and stability were observed, but a high rate of tibial cysts was also seen. Little data is available on revision PCL reconstruction. Posterolateral rotary instability and improper graft tunnel placement have been identified as factors contributing to primary PCL reconstruction failure [77•]. Arthroscopic revision PCL reconstruction with use of a modified tibial-inlay double-bundle technique improved knee stability post-operatively, as measured with posterior stress radiography and clinical outcomes. The authors cautioned that concomitant posterolateral rotatory instability must be surgically corrected during PCL reconstruction to prevent graft failure [77•].

Authors' recommendations and preferred techniques

Based on the current data on the natural history of PCL injury and the outcomes of operative treatment, we currently recommend non-operative management for isolated grade I or II PCL tears. Operative management is reserved for PCL avulsion fractures, PCL tears associated with additional knee ligament injuries, and isolated grade III PCL tears which fail non-operative management. Of the multiple methods described to surgically reconstruct the PCL, we currently perform single bundle open tibial inlay reconstructions using Achilles tendon allograft. Inlay reconstruction is performed to avoid graft elongation and failure which has been observed with cyclic loading in biomechanical studies. Single bundle reconstruction is currently favored due to the lack of clinical data supporting double-bundle reconstruction and the increased complexity of double-bundle reconstruction in both the primary and revision setting. Although early biomechanical and clinical data suggests comparable outcomes of arthroscopic inlay reconstruction, well powered biomechanical studies and long term clinical outcomes are not yet available on this technique, thus we continue to perform inlay reconstruction through an open posterior approach to the tibia for isolated PCL injuries.

Conclusions

A number of controversies remain in the treatment of posterior cruciate ligament injuries. Biomechanical studies have demonstrated specific advantages and disadvantages regarding different techniques in PCL reconstruction. However, clinical studies to date have not shown definitive superiority between transtibial and tibial inlay techniques, single or double bundle reconstruction, or the ideal graft or graft fixation. Continued clinical research with long term outcomes are necessary to further advance our knowledge on the many important variables and considerations in the treatment of PCL injuries.

Conflict of interest S. R. Montgomery declares that he has no conflict of interest. J. S. Johnson declares that he has no conflict of interest. D. R. McAllister declares that he has no conflict of interest. F. A. Petrigliano declares that he has no conflict of interest.

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