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SPORTS INJURIES AND REHABILITATION: GETTING ATHLETES BACK TO PLAY (R GALLO, SECTION EDITOR)

Return to Play after Posterior Cruciate Ligament Injuries

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Abstract

Purpose of Review Posterior cruciate ligament injuries can be treated conservatively with a structured rehabilitation program or with surgical reconstruction. Treatment algorithms are based on a variety of factors including the patient's presentation, physical exam, and desired level of activity. The goal is to return the patient to their athletic pursuits with a stable and pain-free knee. Return to play and activities should be individualized based on the patient's injury and progression through rehabilitation. This article provides a review of the current treatments for posterior cruciate ligament injuries and the respective rehabilitation protocols, outcomes after each treatment option, and specific return to play criteria.

Recent Findings Current research shows excellent outcomes and return to play with conservative treatment of isolated posterior cruciate ligament injuries. Return to play algorithms stress the importance of quadriceps strengthening throughout the recovery process and emphasize inclusion of plyometrics and sport-specific training.

Summary Rehabilitation plays a critical role in the outcome after posterior cruciate ligament injury and the ability to return to athletics. The primary focus of post-injury or post-operative rehabilitation is to restore function, as it relates to range of motion, strength, and proprioception, while mitigating swelling and pain. The patients' desired sport and level of play dictate return to play timelines. The literature supports the use of non-operative management of isolated PCL injuries in athletes and non-athletes with excellent functional and patient-reported outcomes.

Keywords Posterior cruciate ligament injury · Posterior cruciate ligament reconstruction · Rehabilitation · Return to play

Introduction

Isolated posterior cruciate ligament (PCL) injury is uncommon with an estimated annual incidence of 2 per 100,000 [1]. These injuries typically present as multi-ligament injuries, specifically grade III PCL tears, with involvement of the collateral ligaments and or the anterior cruciate ligament [2]. The most common mechanism of isolated PCL injury is direct anterior trauma to a flexed knee and typically involves motor vehicle accidents, with one study showing that 57% of PCL injuries were a result of traffic accidents [3]. PCL injury can also occur in contact sports or with a fall directly on the front of the knee with the ankle in plantarflexion. PCL tears account for 2% of all high school knee injuries [4].

Traditionally, isolated PCL injuries have been managed non-operatively and surgical reconstruction is recommended for persistent instability or multi-ligamentous knee injuries [5]. Chronic PCL deficiency can lead to altered knee biomechanics and studies show increased arthrosis in 10% of patients [6]. Outcomes after surgical treatment of PCL insufficiency are mixed, likely due to low numbers of procedures performed, complex anatomy, and the constant posterior gravity force on the PCL at rest [7]. There is limited data as this injury remains relatively rare [8] and, as a result, many studies on the management of PCL injuries and outcomes report on a low number of patients with little consensus.

Rehabilitation plays a critical role in the outcome of either treatment option or the ability to return to athletics. The primary focus of post-injury or post-operative rehabilitation is to restore function, as it relates to range of motion, strength, and

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proprioception, while mitigating swelling and pain [9]. Rehabilitation protocols after non-operative and surgical treatment of PCL injuries follow a step-wise progression, with full release to sports at 4–6 months and 9–12 months, respectively [10]. The patients' desired sport and level of play dictate return to play timelines and non-contact athletes can return on a faster timeline [11], with football players returning between 6 and 8 weeks after injury after focused rehabilitation and use of a PCL brace. Return to athletics after conservative management ranges from 80 to 91.3% [11–13], with a lower return noted for jumping/pivoting sports at 45% at 10-year follow-up[6]. The purpose of this review is to briefly discuss conservative and surgical treatment options for isolated PCL injuries and delve into rehabilitation principles, functional outcomes, and return to sport.

Treatment Options

The treatment of PCL injuries is based on several factors, including associated injuries, patient activity level, and injury grade. PCL injuries are graded based on the position of the tibial plateau relative to the medial femoral condyle or by the posterior translation of the tibial plateau compared to the uninjured knee. The grades of posterior translation of the tibial plateau are as follows: grade I shows 0–5-mm translation, grade II shows 6–10-mm translation, and grade III shows greater than 10-mm translation.

Non-operative

The first-line treatment for an isolated grade I or II PCL tear is non-surgical management. Patients with concomitant ligamentous injury or those with a chronic PCL tear with residual laxity and recurrent instability should consider surgery. Isolated grade III PCL injuries can be treated non-operatively in patients with mild symptoms or in patients with low activity demands [14]. Non-operative treatment has been shown to provide favorable outcomes in patients with low-grade PCL injuries, those with low activity demands, patients who can appropriately compensate for posterior tibial translation through secondary stabilizers, and those with increased tibial slope [14]. Specific attention should be directed to anatomic factors that affect the stability of the knee, such as posterior tibial slope, inherent knee laxity, pre-injury quadriceps strength, and posterior tibial translation [14, 15], as these patients will respond favorably to conservative management. Non-operative management focuses on regaining range of motion and strengthening with an emphasis on quadriceps activation. A thorough discussion of rehabilitation principles will be discussed in subsequent sections of this review. The PCL has been shown to heal with residual laxity [16, 17]; however, patients are often able to return to sports after successful completion of a strengthening program and specific return to play guidelines will also be discussed in subsequent sections.

Surgical

Operative management of PCL injuries is reserved for grade III injuries with ≥ 8mm of posterior tibial translation, displaced PCL avulsions, multi-ligament knee injuries, or chronic PCL injuries with symptoms of instability which occur typically with deceleration or descending an incline [18, 19]. Surgical techniques can be divided into transtibial and tibial inlay, with subsequent divisions into single-bundle and double-bundle reconstructions. Transtibial and tibial inlay techniques have been validated for PCL reconstruction and Panchal et al performed a review evaluating outcomes after both techniques and found no difference between transtibial or tibial inlay reconstruction [20]. Cadaveric studies have shown no statistically significant differences in measured posterior tibial translation between techniques. However, clinical studies comparing both techniques have shown differences in post-operative instrumented side-to-side posterior tibial translation; however, it is unclear if this difference in posterior tibial translation is clinically significant, as Qi et al and Lee et al have published high-level evidence suggesting no difference in clinical outcomes and function between techniques [21, 22].

Rehabilitation Principles

PCL rehabilitation follows similar principles as ACL rehabilitation with specific differences and it is generally slower. Patients initially work on hamstring and calf stretching and quadriceps strengthening while maintaining range of motion limitations to limit stress on the PCL. In the early stages of rehabilitation, it is also important to avoid active hamstring contraction to limit posteriorly directed forces on the tibia. The next phases gradually increase range of motion, weight bearing, and strengthening, with return to sport-specific exercises at 2–3 months after conservative management and 6–7 months after surgical treatment. It is clear that even in patients who do not have PCL reconstruction, effective non-operative rehabilitation is valuable. Table 1 provides the rehabilitation protocol used by the author's institution. This section will cover rehabilitation protocols in the literature for both non-operative and post-operative treatment of PCL injuries.

Non-operative

Rehabilitation protocols for non-operative management of PCL injuries are similar to those for operative management, but patients tend to progress more rapidly than patients who

Table 1 Posterior cruciate ligament rehabilitation protocol

Post-operative phase	Treatment recommendations	Criteria for advancement
Phase 1 Weeks 0–2	• Patient education for compliance with home exercise program (HEP) and weight bearing precautions • Gait: toe-touch weight bearing (TTWB) with brace locked at 0° with crutches • Patellar mobilizations • Hamstring and calf stretching • Passive extension (pillow under calf) • Quadriceps re-education (quadriceps sets with EMS or EMG) • Active-assisted knee extension/passive flexion exercise (ROM 0° → 70°) • SLR (all planes) with brace locked at 0°, with progressive resistance as tolerated • Proximal (hip) strengthening progressive resistance exercise (PRE) • Cryotherapy • Cardiovascular exercises (e.g., upper body ergometer (UBE)), as tolerated	• Knee ROM 0° → 70° • Ability to SLR without quadriceps lag • Demonstrate progressive improvement of patellar mobility and proximal strength
Phase 2 Weeks 3–6	• Patient education for compliance with home exercise program (HEP) and weight bearing precautions • Gait: progress from TTWB to 75% partial WB by 6 weeks with brace locked at 0° with crutches • Patellar mobilizations • Hamstring and calf stretching • Passive extension (pillow under calf) • Quadriceps re-education (i.e., quadriceps sets with EMS or EMG) • Active-assisted knee extension/passive flexion exercise (ROM 0° → 70°) ◦ Progress to 90° as tolerated, weeks 4–6 • Multiple angle quadriceps isometrics (ROM 60° → 20°) • SLR (all planes) with brace locked at 0°, with progressive resistance as tolerated • Proximal (hip) strengthening PRE • Leg press (ROM 60–0° arc) (bilaterally) • Proprioception training (bilateral weight bearing) • Cryotherapy • Short crank ergometry (when 85° flexion achieved) • Cardiovascular exercises (e.g., UBE), as tolerated	• Knee ROM 0° → 90° • Ability to bear 75% of weight on involved extremity • Ability to SLR without quadriceps lag • Continued improvement in patella mobility and proximal strength
Phase 3 Weeks 7–12	• Patient education regarding monitoring of response to increase in activity level • Gait training (discharge crutches when gait is non-antalgic) • Underwater treadmill system and/or pool for gait training • Retrograde treadmill ambulation • Brace changed to surgeon preference (e.g., off the shelf brace, patella sleeve, unloader brace) • Flexibility exercises • Foam rolling • Active assisted ROM exercises • Perturbation training • Active knee extension – OKC PRE 60° → 0° (monitor patellar symptoms) • Core and LE strengthening • Leg press (progress to eccentrics) and mini squats (ROM 60° → 0° arc) • Initiate forward step-up program • Initiate step-down program • Proprioception training ◦ Multiplanar support surfaces ◦ Progress to unilateral support and contralateral exercises with elastic band • Step machine • Consider BFR program with FDA approved device if patient cleared by surgeon and qualified therapist available • Cryotherapy • Progressive home exercise program • Standard ergometry (if knee ROM > 110°)	• Knee ROM 0° → 130° • Normal gait pattern • Demonstrate ability to ascend 8-inch step • Demonstrate ability to descend a 6-inch step • Single leg bridge holding for 30 s • Symmetrical squat to 60° • Balance testing and quadriceps isometrics (@ 60°) at 70% of contralateral lower extremity
Phase 4 Weeks 13–24	• Patient education regarding monitoring of response to increase in activity level • Cryotherapy and/or compression therapy • Flexibility exercises and foam rolling • Core and UE strengthening • Continue exercises from phase 2 • Continue foundational hip-gluteal progressive resistive exercises	• No swelling • Full LE ROM • Descending 8-inch steps without pain or deviation • Improved flexibility to meet demands of running and sport specific activities

Table 1 (continued)

Post-operative phase	Treatment recommendations	Criteria for advancement
	• Progress squats to 0–90° knee flexion, initiating movement with hips • Progress leg press 0–90° knee flexion (eccentrics, progressing to unilateral) • Progress to single leg squats • Forward step-up and step-down progression • Progress lateral step-ups, crossovers • Initiate lunges • Progress proprioception training • Progress cardiovascular conditioning • Stationary bicycle • Elliptical • Incorporate agility and controlled sports-specific movements • Initiate running progression at week 16 upon meeting criteria ◦ Full ROM/Ability to descend 8″ step without pain or deviations • Initiate plyometric progression • Knee ligament arthrometer exam at 6 months • Progressive home exercise program • Consider BFR program with FDA-approved device if patient cleared by surgeon and qualified therapist available	• Quantitative strength and functional assessments >85% of contralateral LE • Note: uninvolved side may be deconditioned; use pre-injury baseline or normative data for comparison, if available
Phase 5 Weeks 25+	• Address quadriceps and hamstring strength deficits • Gradually increase volume and load to mimic load necessary for return to activity • Progress movement patterns specific to patient's desired sport or activity • Progression of agility work • Progression of plyometric training • Increase cardiovascular load to match that of desired activity • Collaborate with ATC, performance coach/strength and conditioning coach, skills coach, exercise physiologist, and/or personal trainer to monitor load and volume as return to participation • Consult with referring surgeon on timing return to sport including any recommended limitations	• Quantitative strength and functional assessments ≥ 90% of contralateral lower extremity • Movement patterns, functional strength, flexibility, motion, endurance, power, deceleration, and accuracy to meet demands of sport

undergo PCL reconstruction. Published rehabilitation protocols follow similar principles, but vary in range of motion/strengthening restrictions and timing of each stage in the rehabilitation. Weight-bearing restrictions vary from full weight bearing with [13] or without [12] an assistive device to partial weight-bearing with crutches for 2 weeks with progression to full weight-bearing as tolerated between 6 and 12 weeks [15]. Several studies also recommend the use of a PCL Jack brace with full time wear recommendations varying from 12[10, 15] to 16 weeks [2, 13] after injury. During the first 2 to 4 weeks after injury, the brace is locked in extension to prevent hamstring activation during gait. ROM exercises are performed using the healthy (contralateral) leg via eccentric contraction of the quadriceps and upon achieving 70° (dangle position), the contralateral leg is utilized to passively flex the knee. Range of motion is started at 0 to 60° with progression to greater than 90° over the first several weeks after injury [23].

Strengthening exercises are recommended throughout the rehabilitation process and start immediately after injury. Exercises in the early post-injury phase include quadriceps re-education exercises: quadriceps setting with or without neuromuscular electrical stimulation (NMES), supine straight leg raises with progressive resistance (PRE), active assistive, active and isometric open kinetic chain quadriceps strengthening (70–0° arc). Additional strengthening exercises include hip abduction/abduction/extension PRE, closed kinetic chain (CKC) leg press and squatting inside a 70–0° range of motion, pool walking, calf raises and bilateral, progressing to unilateral balance exercises. Range of motion (ROM) restrictions are lifted at 4–6 weeks post-injury and as greater ROM is achieved, stationary cycling, deeper angle open kinetic chain (OKC), and closed kinetic chain (CKC) exercises are allowed. Functional exercises such as step ups and step downs are included using incremental step heights via a functional progression.

Concentric or eccentric contraction of the hamstring are avoided for 6 weeks post-injury to prevent posterior tibial subluxation or lengthening of the PCL [13] and isolated hamstring exercises can begin at 13 to 18 weeks post-injury [10, 13, 15]. A running program should begin when the patient can demonstrate sufficient strength and stability on one limb and typically starts after 16 weeks post-injury, but this can vary widely depending on the rate of progress [13].

If the patient can demonstrate full range of motion and sufficient lower extremity strength at 12 weeks, rehabilitation

begins to focus on sport specific exercises and return to play with strengthening, endurance, and neuromuscular control activities to avoid risk of reinjury. Plyometric exercises are emphasized and should work on power, strength, and speed with progression to single-limb work [15]. Return to sport is recommended once the patient demonstrates full active ROM, greater than 85–90% normal quadriceps strength, no evidence of instability or giving way, greater than 90% function on return to sport testing, a satisfactory quality movement assessment, and the athlete is mentally ready to return to sport and not timid or fearful of reinjury [10]. A full return to sport evaluation is typically performed prior to full release to activities and is performed after meeting set criteria with or without a brace, per physician preference.

Lu et al recently published a detailed 12-week rehabilitation protocol for conservative management of PCL injuries and followed patients throughout the recovery process [24]. Each patient received a training program of 1 h biweekly for 12 weeks with three sequential phases: initial phase (1st–4th week), intermediate phase (5th–8th week), and late phase (9th–12th week). Each session started with a stationary bike for 15 min at 70rpm, strengthening for 20 min, BOSU balance training for 15 min, and a post-training stretch for 10 min. Strength training intensity was set at a weight of 70% of the patient's 1-rep-maximum. After 12 weeks of this protocol, the authors found that proprioception and isokinetic muscle strength were significantly improved and comparable to the normal contralateral leg and all patients returned to pre-injury activities.

Surgical

There have been various protocols for rehabilitation described following PCL reconstruction, all with comparable outcomes. Rehabilitation generally follows the framework of regaining range of motion and strength, while protecting the PCL graft. Each phase focuses on different goals and patients are advanced based on their progress. At 4 weeks post-operatively, patients should have full quadriceps activation and work on a progressive weight bearing program utilizing crutches with their post-operative brace locked at 0° extension. At 8–10 weeks, patients should be working towards regaining full knee flexion and be able to control a single leg 8″ step-up. At 12–14 weeks, patients should have near full range of motion and demonstrate the ability to perform a pain-free, well-controlled 8″ step down. The final phases aim to improve proprioception, agility, and return to sports-specific activities [25]. The Surgical Timing and Rehabilitation (STaR) Trial is a prospective randomized multi-center clinical trial that is currently ongoing to investigate the timing of surgical and post-operative rehabilitation after multi-ligament knee injury [26].

Weight-bearing is generally progressed similarly between studies. Immediately post-operatively, patients use a PCL Jack Brace and are partial weight-bearing with crutches with progression to full weight-bearing within 6 weeks [2, 9, 27–29]. Brace wear recommendations vary across studies; however, most suggest a brace locked in extension post-operatively to protect against hamstring activation during normal gait. Kim et al reviewed 34 articles discussing PCL rehabilitation and found that 18% recommended a brace for 10–12 weeks, 32% for 6–8 weeks, and 41% for 4–6 weeks [9]. Kim et al. report that although conservative approaches to weight-bearing after PCL reconstructions are common, earlier weight-bearing might be beneficial due to the increased static stability of a two-leg stance [9]. The authors suggest that earlier weight bearing can potentially stimulate tunnel healing and graft incorporation, promoting the production of synovial fluid, with an added benefit of increased strengthening through walking. Shelburne and Pandy evaluated a gait model and noted that the tibia encounters an anterior shear force during gait, which would protect the PCL in early rehabilitation [30].

Range of motion exercises are performed passively for flexion and active-assisted for extension and are limited to 0 and 30–60° within the first week post-operatively and gradually increased to 90° by day 45 post-operatively with the goal of near full flexion by day 90 post-operatively [9, 29]. Recovery of flexion is achieved with passive range of motion exercises and flexion exercises should work the "braking" action of the quadriceps and should be limited to 90°, as biomechanical studies have shown increased sheer forces at the PCL beyond this [2, 31]. Patella mobilization is an important intervention in regaining flexion range of motion.

Quadriceps strengthening is a critical component in post-operative rehabilitation after PCL reconstruction [9]. Quadriceps sets, straight leg raises, and closed chain exercises are used in the early post-operative period, followed by open-chain kinetic exercises (OCKEs), with initiation varying from the second week [9, 29] and the eighth week post-operatively [9]. Hamstring strengthening should only be done above 30° of flexion; however, co-strengthening is possible with alternative exercises. Kim et al recommend using mini squats, calf raises, and short-arc leg press to strengthen both the quadriceps and hamstrings with little posterior stress on the PCL [9]. Open chain hamstring exercises should not be used until at least 6 months post-operatively [29] and in our opinion, it may be reasonable to wait a full year after surgery. A more comprehensive 5-phase protocol by Pierce et al. describes many of the exercises described above, with the addition of aquatherapy and stationary biking [10]. This protocol also specified a specific straight line jogging protocol, which progressed to single plane agility and then to multi-planar agility. Plyometric training and sport specific training can also be included for athletes starting at week 16 post-operatively if sufficient strength is demonstrated. Proprioceptive training is a critical to successful return to play and is integrated into the

rehabilitation program at 2 weeks after surgery via CKC[32], with progression from ground surfaces to unstable surfaces at 16 weeks after surgery.

Functional Outcomes

The clinical outcomes after PCL injury with both conservative and operative treatment are varied. Schroven et al recently published a meta-analysis including 27 studies with a variety of conservative treatment protocols and surgical techniques for the treatment of PCL insufficiency [33]. The authors found a greater reduction in posterior laxity with reconstruction (8mm vs. 1.4mm) and a decreased rate of medial compartment degenerative changes in patients undergoing reconstruction (21.5% at 6.8-year follow-up) versus conservative management (44.1% at 10-year follow-up). Both groups showed similar improvement in Lysholm scores. While patients undergoing conservative management had higher Tegner Activity scores, this cohort had a higher percentage of athletes, which confounds the final functional outcomes. Overall, patient reported outcome scores did not provide any conclusive evidence to suggest that a difference between conservative or surgical treatment of PCL injuries. These findings are consistent with a prior systematic review by Ahn et al [34]; however, large-scale studies are rare and studies that critically evaluate outcomes are generally limited to smaller patient cohorts and generally focus on patient reported outcomes scores, radiographic findings, and ability to return to desired activities. Additionally, the injury patterns are heterogeneous which makes comparisons challenging as well.

Patient Reported Outcomes after Non-operative Management

Studies evaluating outcomes after conservative management of PCL injury generally include patient cohorts with grade A and B injuries. Parolie et al and Shelbourne et al provide a historical perspective on athletes with non-operative treatment of PCL injuries [6, 11]. Parolie et al followed 25 patients with grade A, B, and C PCL injuries for an average of 6.2 years after injury and found 80% of patients were satisfied with the knee and 76% rated the knee as 75–100% compared to the non-injured knee, with no significant association between KT-1000 testing and satisfaction with the knee [11]. This cohort of patients had no difference in range of motion compared to the contralateral knee and there was no loss of >1cm of quadriceps diameter. Shelbourne et al followed a larger cohort of athletes for an average of 5.4 years and found similar results [6]. This cohort had no significant association between Lysholm and Tegner scores and KT-1000 laxity and no correlation between time from injury and outcome scores.

Several studies have been published focusing on outcomes of athletes treated with conservative management for isolated PCL injury and provide good evidence for this treatment protocol in high level athletics. Boynton et al provides the longest follow-up with 13-year follow-up of 38 patients, including 63% rugby athletes, undergoing conservative management of grade A, B, and C PCL injuries [35]. This study included 21% of patients who underwent procedures for associated meniscal pathology and provides an important comparison, as concomitant meniscal and chondral damage can occur with PCL injuries. Among patients without meniscal pathology, there was a trend towards a decrease in functional scores with increased time from injury and 74% of patients reported mild activity limitations; however, few reported symptoms of giving way or laxity. There was also a trend towards significance for decreased patient outcome scores in patients with meniscal damage. Interestingly, this study found similar outcome scores and radiographic outcomes in patients injured during athletics and in motor vehicle collisions. Although this study reports a lower rate of satisfaction with the injured knee at longer term follow-up, grade C injuries were included which are inherently more severe and often do worse with conservative management. Overall, the literature supports the use of non-operative management of isolated PCL injuries in athletes and non-athletes with excellent functional and patient-reported outcomes.

Patient Reported Outcomes after Surgical Management

Various surgical techniques and graft options are used in PCL reconstruction and the procedure is performed in either the acute, subacute, or chronic phase after injury. Goudie et al provides short-term (2 years) follow-up and Sekiya et al provide moderate-term (5.9 years) follow-up of chronic grade C PCL injuries that underwent surgical reconstruction with Achilles allograft [36, 37]. At the time of final follow-up, 83% and 57% of patients, respectively, rated the knee as normal or nearly normal, with 74% and 50% of patients, respectively, able to participate in moderate or strenuous activity. Sekiya et al did include a small cohort of patients who underwent reconstruction at <3 months after injury and found significantly improved knee function and activity level in patients treated in the acute and subacute periods [37]. Both studies also evaluated post-operative laxity and at both time points, only 50% of patients had grade 1 laxity. Additionally, only 43% of patients were able to achieve >90% hop test distance at 2-year follow-up and although there was significant improvement in flexion and extension peak torque at 24 months, both measurements remained significantly decreased compared to the non-injured leg at both 1- and 2-year follow-up.

Jenner et al and Hermans et al followed patients who underwent PCL reconstruction of chronic injuries with either allograft or autograft for a final follow-up of 3.3 years and 9.1 years, respectively [38, 39]. Both studies included Achilles allograft and bone-patellar tendon-bone autograft as graft options. Hermans et al found that Lysholm, IKDC, and VAS functional scores were all significantly improved at final follow-up of 9.1 years [39] and Jenner et al found that 78% of patients graded the surgical knee as normal or near-normal at 3.3 years [38]. At short-term follow-up, 83% of patients had a grade A posterior drawer; however, at longer follow-up, Hermans et al found that 80% of patients had a grade B/C posterior drawer and a significant difference in mean side-to-side difference in posterior laxity of 1.6mm on KT-1000 testing [39]. Both studies found improvement in the Tegner activity scale post-operatively, and Hermans et al noted a significant negative correlation between clinical findings and the Tegner score, suggesting that patients with an abnormal clinical exam had difficulties returning to activity [39]. Hermans et al included 13 patients with chondral damage noted at the time of surgery and found that all functional scores were significantly decreased in this patient cohort at 9.1-year follow-up, with no difference noted in KT-1000 testing [39]. There was no significant difference in outcome scores between graft types at 9-year follow-up. These studies highlight the concerns with recurrent laxity after PCL reconstruction, especially at longer-term follow-up, and the impact on functional outcomes.

Finally, Che et al evaluated 3-year outcomes of patients with grade 3 PCL injuries undergoing surgical reconstruction with quadriceps autograft [40]. Twenty-nine patients were followed and 83% had good or excellent Lysholm scores and 86% had normal or nearly normal IKDC subjective function scores at final follow-up. Strength and functional testing showed 69% of patients were able to achieve >90% hop test; however, only 45% of patients had recovered extensor strength >90% of the contralateral limb. This is consistent with Sekiya et al [37] and emphasizes the length of recovery required to regain symmetric knee flexion and extension after PCL reconstruction.

Patients who undergo PCL reconstruction have inferior functional and patient reported outcomes compared to those who have anterior cruciate ligament reconstruction (ACLR) and a higher percentage of patients have difficulty returning to their prior activities. Owesen et al investigated the improvement in Knee Injury and Osteoarthritis Outcome Score (KOOS) after ACLR and PCL reconstruction and found a comparable increase in KOOS score post-operatively; however, patients undergoing PCL reconstruction had a lower pre-operative score which resulted in a lower score at 2-year follow-up[41]. This underscores the importance of patient education after PCL reconstruction with respect to function and return to activity after surgery.

Return to Sports

The ability to return to sports after any injury is a critical point in the evaluation of any treatment protocol. High rates of return to sport can be achieved with both conservative and surgical treatment of isolated PCL injuries and literature supports both treatment options. Return to sport occurs at different time points based on a patient's activity level. Objective testing is an important part of return to play and should evaluate the patient's laxity, strength, endurance, and functional movements. Typically, functional hop tests and isokinetic tests are performed, in addition to a quality movement assessment [23]. The single-leg hop test for time and crossover hop tests have been noted to be the best to indicate sufficient functional performance of the limb [42, 43]. Schreier et al use return to sport testing and allow a return to competition when >90% function is noted on strength and functional tests and the patient is mentally ready to return to athletics [31]. Non-athletic individuals are cleared for activity at 6 months post-operatively, while athletes are cleared for full return to sports at 6–9 months in some papers, depending on return of strength and functional/proprioceptive skills but we recommend a year in general, depending on the specifics of the case [9, 28, 29].

Patel et al followed 58 patients with grade A/B PCL injuries treated non-operatively for an average of 6.9 years and found no difference in the Tegner activity scale at final follow-up, with 100% of elite athletes returning to the same level of play and 65% of patients returning to recreational activities, with 65% returning to the same level of play [44]. Shelbourne et al followed a large cohort of 133 athletes with non-operatively treated PCL injuries and found similar results, showing that regardless of knee laxity, only 17% of patients were unable to return to sport [6]. With longer term follow-up, Boynton et al found only a 13% return to athletics at 13 years after injury [35]; however, this data likely reflects the natural progression away from elite athletics as patients age.

Studies have also shown that athletes are able to return to play after a period of rehabilitation with minimal limitations. Toritsuka followed 16 rugby athletes who sustained grade A/B PCL injuries and were treated with a range of motion and strengthening protocol [12]. Eighty-eight percent of players were able to resume training at 2 months after injury, with 2 players unable to return due to persistent pain and subjective instability. The athletes completed a self-evaluation and noted near-normal knee function, with the most common complaint in high speed running and quick acceleration/deceleration. Agolley also followed rugby and soccer athletes with grade B/C PCL injuries who underwent conservative management with a 16-week rehabilitation program [13]. Patients returned to

training at an average of 10.6 weeks after injury and returned to full activity at 16.4 weeks after injury. There was no difference in return to practice or sport between grade B/C injuries. At 2-year follow-up, 91.3% of patients were playing at pre-injury level. The patients who returned to sport at a lower level had a higher percentage of grade C injuries. At 5-year follow-up, 82.6% of athletes were still playing competitive sports and 69.5% played at pre-injury levels.

Che et al [40] followed a cohort of patients who underwent PCL reconstruction with quadriceps autograft with an average of 3 year and Zayni et al [45] followed a similar cohort for 29 month follow-up. Both studies cited a lower return to sport rate when compared to populations undergoing non-operative management, with Che et al noting 60% of patients returning to strenuous activity at 3 years post-operatively [40]. Zayni et al reported a 71.5% return to pivoting and contact sports at 29 months post-operatively [45].

Tucker et al followed a military population of 188 servicemembers after isolated PCL reconstruction at 20-month follow-up and found that 35% were unable to continue military duties and were discharged from military service [46]. This cohort had a higher rate of disability in patients undergoing reconstruction at one of their lower volume institutions. An overall 26% complication rate and 12% revision rate were noted. This suggests that the military population with PCL injury is different than traditional athlete patient populations and the high activity demands placed on servicemembers likely subjects the PCL graft to high tensile loads and shear stress.

Studies evaluating patients treated surgically tend to report lower return to sport rates, which is likely tied to the higher injury grade and lengthy post-operative rehabilitation process. Schroven et al performed a meta-analysis of 27 studies which included both conservative and surgical treatment protocols and found a 74.8% return to pre-injury level of sports and an overall return to sport rate of 77.1% [33].

Conclusion

Isolated posterior cruciate ligament injuries are generally treated conservatively, with surgical reconstruction reserved for multi-ligamentous knee injuries or those with persistent instability. PCL rehabilitation focuses on early quadriceps activation, with hamstring and calf stretching and maintaining range of motion. Return to sport-specific exercises can begin at 2–3 months after conservative management and 6–7 months after surgical treatment. Patient outcomes after isolated PCL injuries and a discussion on return to play algorithms and decision-making are included to help clinicians as they guide patients through recovery after injury. When evaluating all treatment protocols, PCL injuries provide an acceptable return to sport rate after either conservative or surgical management.

Declarations

Conflict of Interest R.G.M. reports personal fees from the *Journal of Bone and Joint Surgery*, the *Journal of Bone and Joint Surgery Evidence Based Orthopedics*, Springer and Demos Health, and MEND Nutrition Inc., outside the submitted work. The remaining authors do not have any conflicts of interest to disclose.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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