Initial Evaluation of Posterior Cruciate Ligament Injuries: History, Physical Examination, Imaging Studies, Surgical and Nonsurgical Indications

Emilio Lopez-Vidriero, MD, PhD, David A. Simon, MD,* and Donald H. Johnson, MD, FRCSC†‡*

Abstract: Compared with anterior cruciate ligament injuries, posterior cruciate ligament injuries are a rare event. The mechanisms are predictable and a thorough physical examination is mandatory to rule out or define combined injury patterns. Stress radiography and magnetic resonance imaging studies are very helpful adjuncts. Acute and chronic injuries require slightly different approaches. As our understanding of normal and pathologic knee joint kinematics develops, nonoperative rehabilitation goals and operative techniques continue to evolve.

Key Words: posterior cruciate ligament, epidemiology, physical examination, image

(*Sports Med Arthrosc Rev* 2010;18:230–237)

EPIDEMIOLOGY

The overall epidemiology of posterior cruciate ligament (PCL) injuries is yet to be accurately defined. Incidence and prevalence estimations have been derived primarily from small single-center patient databases, therefore it is not surprising that the incidence of PCL injuries has varied between 1% and 44% of all knee ligament injuries in different reports.[1–4]

PCL injuries tend to occur in the setting of high-energy trauma such as motor vehicle collisions (approximately 45%) or lower-energy sports-related mishaps in young, active individuals (approximately 40%).[1] Work-related accidents and miscellaneous trauma are less common. In the largest reported series to date, Schulz et al[1] reported motorcycle accidents (28.1%) and soccer injuries (24.7%) to be the most common causes of PCL disruption. In terms of biomechanical mechanism, the "dashboard,"/anterior tibial blow with a flexed knee, was most common (38.5%), followed by falling on the flexed knee with the foot plantarflexed (24.6%), and sudden violent hyperextension of the knee (11.9%).

The PCL is most often injured in association with other ligamentous structures about the knee. The most common combined instability pattern involves the posterolateral corner (PLC) and PCL. Concurrent anterior cruciate ligament (ACL) and PCL tears are second followed by concurrent PCL and posteromedial corner (PMC) disruptions.

HISTORY AND PHYSICAL EXAMINATION

The patient history and a thorough physical examination are always of critical importance for making a complete and accurate diagnosis and for formulation of the management plan. This is especially true in the setting of suspected PCL injury because failure to identify subtle combined instabilities can lead to treatment failure.

Elucidating the mechanism of injury is a key to diagnose PCL involvement. Competitive athletes with sports-related injuries are usually able to provide an accurate description of the event. The most common injury is a direct blow to the front of the tibia with the knee flexed at 90 degrees. However, with low-grade injury, some athletes will continue to play and not seek medical attention in the immediate postinjury period. Patients with PCL injuries may complain of generalized pain around the knee and identify that "something is not right" but have difficulty being more precise. The sensation of knee instability with cutting or rapid deceleration movements is less common than with ACL-deficient patients, although patients may relate instability symptoms when performing activities on uneven ground.

In patients with chronic PCL-deficient knees, pain with prolonged walking and descending stairs is the main issue and is localized to the medial compartment or patellofemoral joint.

The physical examination begins by exposing both lower extremities and observing the patient's gait pattern. A varus thrust in combination with a hyperextended knee gait may indicate a chronic combined PCL and PLC injury. An antalgic or quadriceps avoidance gait may be present in the setting of ACL or combined ACL/PCL injury.

Note should be made of the overall alignment of the limbs, presence of any joint effusion, or previous surgical scars. At our institution, the patient is examined supine, prone, and when sitting with the legs flexed 90 degrees over the edge of the table. The examination is carried out in this sequence as limb positioning may influence the sensitivity and specificity of some special tests.

In the supine position, the patient is asked to rest their head on a pillow, which helps to relax the abdominals, quadriceps, and hamstrings. Achieving as much relaxation as possible is important as muscle guarding makes the examination more difficult and may lead to false-negative results. The knees are flexed to 90 degrees and the feet placed flat on the table. PCL injury may be suspected by observing and palpating the anterior joint line (Fig. 1).

From the *Department of Orthopaedics, The Ottawa Hospital; †Sports Medicine Clinic, Carleton University; and ‡Department of Orthopaedic Surgery, University of Ottawa, Ottawa, Ontario, Canada.
Fundacion Caja Madrid.
No support to be disclosed.
Reprints: Donald H. Johnson, MD, FRCSC, Department of Orthopaedic Surgery, University of Ottawa, 1125 Colonel By Drive, Ottawa, Ontario K1S 5B6, Canada (e-mail: johnson_don@rogers.com).

FIGURE 1. Palpation of the anteromedial joint line step-off.

Normally, the anterior border of the medial tibial plateau sits about 1 cm anterior to the medial femoral condyle. The normal step is easily palpable and compared with the contralateral side. PCL injuries are usually classified by the degree of posterior subluxation of the tibial plateau relative to the femoral condyle. With a grade I injury, the tibial plateau remains anterior to the condyle. A grade II injury, or partial tear, is likely when the anterior border of the tibia sits flush with the femoral condyle. When the anterior border of the tibial plateau rests posterior to the femoral condyle, a complete PCL tear (grade III) is present and associated PLC damage should also be suspected.

An assistant next holds the patients' feet by the heels with the hips and knees both flexed to 90 degrees, whereas the examiner observes for posterior sag from a lateral vantage point and compares side-to-side difference (Fig. 2). This is also known as Godfrey's test. In a PCL-deficient knee, gravity causes the tibia to rest in a posteriorly subluxed position compared with the intact knee. The tibial tubercle is a useful landmark for evaluating posterior sag.

With the feet back on the table and the knees flexed 60 degrees, the quadriceps active test is performed. The examiner stabilizes the foot and asks the patient to slide it down the examination table. As the quadriceps contract, the examiner will observe reduction of the posteriorly subluxated tibia. This test becomes more obvious with higher degrees of injury. The sensitivity and specificity of the quadriceps active test have been reported to be 58% and 97%, respectively.[5]

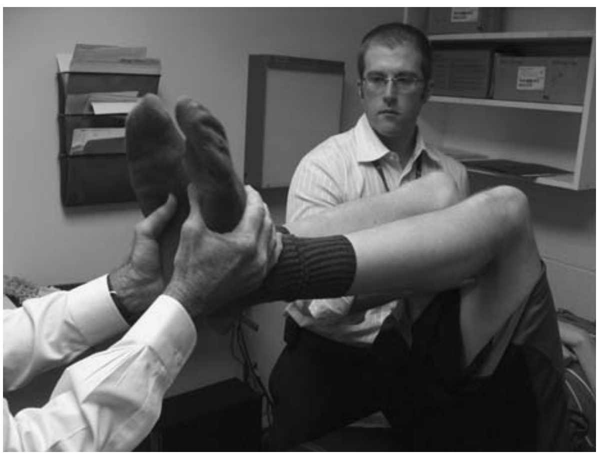

FIGURE 2. Observation of posterior sag from a lateral vantage point.

If posterior subluxation is confirmed, the affected knee must be reduced to its normal position to perform the posterior drawer test and measure it.

The posterior drawer test was performed with the knee at 90 degrees. As mentioned, the normal starting position is with the anterior border of the lateral tibial plateau 1 cm anterior to the lateral femoral condyle. With a posteriorly directed force, the change in relative position of the tibial plateau is compared with the uninjured knee. The posterior drawer test is 90% sensitive and 99% specific for the diagnosis of PCL injury.[6] The test should be repeated with the foot held in external rotation to evaluate for concurrent PLC damage. It is important to emphasize that without a proper starting position, the examiner may elicit a false-negative posterior drawer and a false-positive anterior drawer test leading to an incorrect diagnosis.

Originally described by Shelbourne et al,[7] the dynamic posterior shift test is performed by flexing the hip to near 90 degrees to control rotation of the femur and then passively extending the flexed knee. With extension, tightening of the hamstrings provides a dynamic axial load, which combines with gravity to subluxate the tibia posteriorly. In knees with posterior instability, the patient and examiner perceive a "clunk" when the posteriorly subluxated tibia suddenly reduces as the knee approaches full extension.

The reversed pivot-shift test may also be performed with the patient in the supine position. This maneuver commences with the patient's knee flexed to the chest, the tibia externally rotated at the foot, and by applying a valgus force. Palpate for the posteriorly subluxated lateral tibial plateau under the femoral condyle and observe for abrupt reduction of the tibia as the knee is brought into extension. This test has been reported to have a positive predictive value of 68% and a negative predictive value of 89% in determining PLC injuries.[8] In conjunction with the dial test, it may help to identify posterolateral rotatory instability of the knee because of associated injuries of PLC structures.

Still supine, the dial test is performed with the knees at 90 degrees. The examiner places the knees together and then externally rotates both tibias through the feet. If the side-to-side difference is greater than 10 to 15 degrees, a combined PCL/PLC injury should be suspected. If the dial test is positive only at 30 degrees of flexion, then an isolated PCL injury is likely. We do not recommend performing the supine dial test with the feet elevated unless an assistant is present to hold the knees together. This will prevent false-positive results because of additional external rotation through the hip joints.

The external rotation-recurvatum test complements the dial test. It is performed with the patient supine with both legs extended. The examiner grasps the great toes of both feet and simultaneously lifts both legs. A positive test shows increased recurvatum, varus, and external rotation of the tibia on the injured leg caused by posterolateral opening of the joint.

With the patient prone, the dial test is repeated at 30 and 90 degrees of knee flexion and comparison made to values obtained with the supine dial test (Fig. 3). The Whipple and Ellis test[9] may be performed with the patient prone and the knee flexed to approximately 70 degrees (Fig. 4). PCL

FIGURE 3. Prone dial test.

FIGURE 5. Sitting posterior drawer test.

insufficiency is showed by stabilizing the lower leg with 1 hand and posteriorly displacing the tibia by pushing on the tibial tubercle with the opposite hand. This test is analogous to the posterior drawer, but may improve accuracy by avoiding quadriceps contraction. Posterolateral or posteromedial instability may also be assessed with this method.

Finally, the patient is asked to sit on the examination table with the legs freely hanging over the edge to relax the hamstrings and quadriceps, which improves overall accuracy of the diagnostic maneuvers. Palpation and assessment of the amount of tibial step-off at the joint line is repeated and quantified. The posterior drawer test is repeated with the thumbs placed on either side of the tibial tubercle (Fig. 5). The posterior drawer test is also performed with internal and external tibial rotation to evaluate combined injury patterns. The dial test is also repeated.

We conclude the examination with KT-1000 arthrometer measurements in the sitting position with the knee at 90 degrees and the tibial plateau 1 cm anterior to the femoral condyle. Side-to-side comparison of the overall amount of posterior translation allows for classification of the injury grade I to III.

FIGURE 4. The prone posterior drawer known as the Whipple and Ellis test.

Practical examination tip: When performing a Lachman screening test, if there is increased anterior-to-posterior motion, but a negative pivot shift, think PCL injury.

RADIOGRAPHIC ASSESSMENT

Acute Imaging

Radiographic evaluation is necessary in patients whom an acute PCL injury is suspected on the basis of clinical history and physical examination findings. Acute imaging consists of a plain x-ray series including anteroposterior (AP), lateral, and oblique views. All radiographs should be scrutinized closely to rule out fractures of the tibial plateau, femoral condyles, and patella. The lateral projection may identify bony avulsion of the tibial PCL insertion (Fig. 6). An associated avulsion of the fibular insertion of the lateral collateral ligament may be apparent in the setting of a knee dislocation or high-energy trauma leading to multiple ligament injury. The Segond fracture, or lateral capsular avulsion, is associated primarily with isolated ACL injury. Comparison radiographs of the uninjured contralateral knee may prove useful. If a tibial plateau fracture is identified or suspected, then a computed tomography scan is indicated.

In difficult or borderline situations, stress radiography may be used to aid in making the diagnosis of PCL injury. It may help to differentiate between a partial and complete disruption, including in the context of unclear magnetic resonance imaging (MRI) findings. Stress radiographs may be performed manually or with the use of a mechanical device such as the Telos[10] (Fig. 7) to standardize the posterior force applied. Hewett et al[11] identified 8 mm of posterior translation of the tibia relative to the uninjured side when an 89-N load was applied to the proximal tibia with the knee flexed to 70 degrees as indicative of complete PCL rupture. At time of arthroscopy, stress radiography was found to be superior to both posterior drawer test results and KT-1000 arthrometer measurements for diagnosing PCL rupture in that study. More recently, Sekiya et al[12] used a 200 N posterior force applied to cadaveric knees flexed to 90 degrees. With sequential sectioning of the PCL and posterolateral structures, they concluded that posterior translation of 9.8 mm indicated complete PCL rupture. Posterior translation greater than 10 mm (average

FIGURE 6. Lateral x-ray image showing tibial-sided posterior cruciate ligament avulsion.

19.4 mm) was correlated with additional PLC disruption. Commercial stress radiography systems are available, and may also be used for preoperative and postoperative laxity comparisons. In the absence of specialized testing equipment, stress radiographs may be obtained by taking a lateral x-ray after placing the affected limb in a lateral position and applying a maximum-resisted hamstring contraction (Fig. 8).

It is important to be aware that patients may activate their quadriceps during stress radiography, thus producing a "guarding effect" which would cause underestimation of posterior laxity. Careful standardization of testing protocols, awareness of radiographic magnification, and staff training are also important elements in routine use of stress testing.

FIGURE 7. The Telos device for stress radiography.

FIGURE 8. Simulated stress radiography using maximal voluntary hamstrings contraction.

MRI is indicated to assess the PCL and any associated collateral ligament injury. Sagittal MRI images are highly accurate and reliable for the diagnosis and grading of complete PCL deficiency[13] (Fig. 9). It is useful in establishing the location (femoral peel, intrasubstance tear, and tibial avulsion) of PCL injury but is less sensitive in differentiating partial from complete tears.[14] MRI has the added advantage of allowing assessment of remaining intra-articular and supporting structures of the knee without patient exposure to radiation. Bone bruises and meniscal tearing are less common with PCL than ACL injury.[15] MRI also permits identification of concurrent osteochondral damage.

Computed tomography scanning has comparatively little role in the assessment of acute PCL injuries. Its utility is limited to assessment of tibial plateau fractures and characterization of the size/shape of tibial-sided PCL avulsion fragments for surgical planning.

Chronic Imaging

For patients presenting with a chronic PCL injury, the initial x-ray series should include a weight-bearing AP view, a true lateral projection at 45 degrees of flexion, and a tunnel view. These views usually identify a nonunited or malunited avulsion fracture of the tibial PCL insertion when this lesion is present. The lateral view may show significant posterior subluxation of the tibia in the setting of gross instability (Fig. 10). Posterolateral or posteromedial subluxation may be evident if the posterolateral or PMCs have been disrupted. A weight-bearing posteroanterior view at 45 degrees of flexion is more representative of true medial compartment joint space narrowing than a standard AP. A patellar skyline, or sunrise, view is obtained for completeness, particularly if concurrent patellofemoral pathology is suspected.

An old injury to the medial collateral ligament may be suspected by the calcified presence of the Pelligrini-Stieda lesion at the femoral epicondylar origin of the medial collateral ligament.

On MRI, a relatively normal-looking PCL is not uncommon in the setting of a chronic PCL tear, as it may be possible for some tears to heal in an elongated fashion.[3,16] The assistance of an experienced musculoskeletal

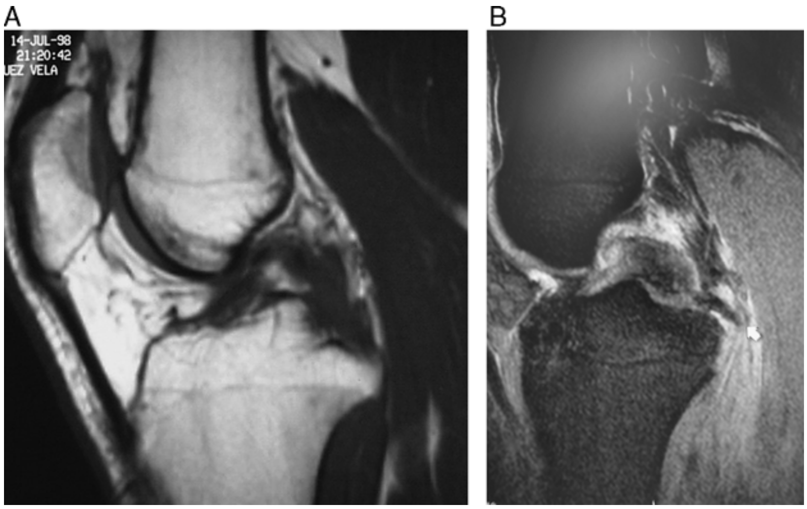

FIGURE 9. A, Sagittal MRI image of femoral-sided PCL injury. B, Sagittal MRI showing tibial-sided PCL avulsion injury. MRI indicates magnetic resonance imaging; PCL, posterior cruciate ligament.

radiologist or comparison MRI images of the normal contralateral knee may be a helpful adjunct in obtaining a diagnosis if history, physical examination, and imaging are not concordant or conclusive. Standard technetium bone scans may be of value for patients with chronic PCL deficiency who experience pain.[13] Increased uptake in the medial and patellofemoral compartments without arthritic changes on x-ray or at arthroscopy may influence the surgeon's decision to offer a patient late PCL reconstruction.[17,18]

NATURAL HISTORY OF PCL DEFICIENCY

The natural history of the PCL-deficient knee remains an area of debate. Several series have described intrinsic healing potential of the PCL, return to competitive sport, lack of symptomatic instability, and good outcomes at mid-term follow-up.[3,15,19–27] More recently, however, biomechanical studies have identified alterations in contact area and loads after PCL injury, particularly with flexion beyond 70 degrees.[28–32] These effects occur in the medial and patellofemoral compartments and some clinical series also suggest progressive disability and degenerative joint disease with chronic PCL deficiency.[33–35] Osteotomies to increase tibial slope in PCL-deficient knees reduced posterior tibial sag during axial loading of the knee in a cadaveric model but clinical data for this approach are lacking.[36] It has been difficult, however, to correlate subjective knee scores with clinical laxity and prognostics. The factors that predict which patients are most likely to quickly progress to degenerative joint disease have yet to be elucidated. Degenerative changes have also been observed in knees with isolated PCL injury despite the surgical restoration of clinical stability.[37–39]

In 1998, Dejour et al[40] summarized the suspected natural history of isolated PCL deficiency as occurring in 3 phases: (1) functional adaptation lasting 3 to 18 months, (2) functional tolerance continuing for 15 to 20 years, and (3) osteoarthritic deterioration that does not become disabling until after 25 years. This is a broad categorization and multiple patient/injury factors influence the relative time in each stage.

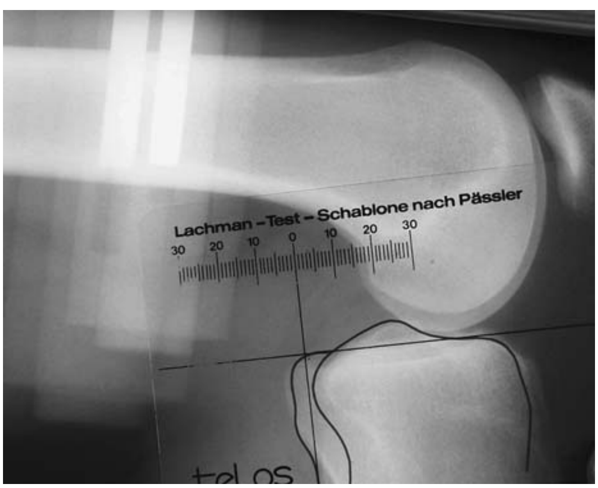

FIGURE 10. Lateral stress radiograph of gross posterior tibial translation with chronic posterior cruciate ligament deficiency using Telos device and measuring template.

ACUTE TREATMENT

When knee trauma generates combined PCL/PLC or combined PCL/PMC injury patterns, operative reconstruction is indicated in almost all patients. Exceptions include patients with very low daily physical demands or medical co-morbidities that would preclude a lengthy anesthetic.

Among the factors to consider in formulating a treatment plan include the acute versus chronic nature of the presentation, nature of the disruption (avulsion versus midsubstance tear), degree of laxity (grade I/II/III), the patients' symptoms and complaints, as well their activity level and athletic/occupational demands. Other important modifiers such as head injury, multiple trauma, vascular disruption, soft tissue status, and general medical comorbidities must be taken into account when applicable.

FIGURE 11. A pad is placed under the tibia in the knee immobilizer to counter the force of gravity.

Nonoperative Management

To be considered a truly isolated PCL injury the following criteria must be met: (1) a posterior drawer of less than 10 mm with the tibia in neutral rotation; (2) less than 5 degrees of abnormal rotary laxity at 30 degrees of knee flexion; and (3) no significant collateral injury causing varus-valgus laxity.[42]

At our institution, acute grade I isolated PCL injuries are managed nonoperatively. Nonoperative management is also recommended for most of acute grade II injuries. With an undisplaced distal PCL bony avulsion, nonoperative management is also a reasonable approach for small fragments, but some residual laxity is to be expected.

An optimal nonoperative rehabilitation program for isolated PCL injuries is yet to be defined.[43] Maximum intrinsic healing potential of the PCL is dependent upon maintaining the tibia in an anatomically reduced position. The limb is immobilized for an initial 2 to 4-week period by splinting the knee in extension to decrease tension on the anterolateral bundle.[21] A pad is placed under the tibia to counter the force of gravity[44] (Fig. 11). During the initial 6 weeks, the focus is on reduction of inflammation, prone lying passive flexion to maintain range of motion, and avoidance of hamstrings overactivity.[45] Physiotherapy modalities and electrical quadriceps stimulation are helpful to avoid significant quadriceps atrophy during this phase.

Alternatively, Jung et al[46] used 6 weeks of cylinder casting followed by 6 weeks of bracing before initiation of physiotherapy. Tibial support against posterior sag was used for the 12 weeks of immobilization. At 2 years of follow-up, overall knee stability was improved but some residual laxity was still present.

Rehabilitation ultimately focuses on proprioception and recovery of quadriceps strength with closed-chain exercises. PCL braces are available but quality data are lacking regarding their clinical efficacy. Return to sport is generally permitted when full quadriceps strength is regained, which usually takes 6 to 12 months. A successful protocol should result in improvement with a firm end-point on clinical examination and an anticipated decrease of 1 laxity grade within 6 months.[24,34] Although described as a postoperative rehabilitation protocol, guidelines outlined by Fanelli[47] are appropriate and may be ideal for nonoperatively managed patients as well. It should be emphasized that PCL rehabilitation progresses much slower than after ACL injury. Most patients with truly isolated injuries are likely to do well in the short-to-medium term.

Operative Treatment

Although specific timing, techniques, rehabilitation protocols, and outcomes are discussed elsewhere, operative treatment is indicated for the following PCL injuries:

(1) All grade III PCL injuries with combined instability patterns
(2) Isolated grade III injuries
(3) Distal bony avulsion with greater than grade I laxity requires open reduction and internal fixation using a posterior approach or arthroscopic technique.

Some isolated grade II lesions in high-demand athletes may be considered for PCL reconstruction. The senior author has had many professional athletes function well with grade II injuries managed without surgery. In fact, it has previously been noted that 2% of elite college football players attending professional combines had chronic PCL-deficient knees.[19] As such, individual treatment decisions for an isolated grade II PCL injury are based on surgeon experience and patient factors/desires. In the

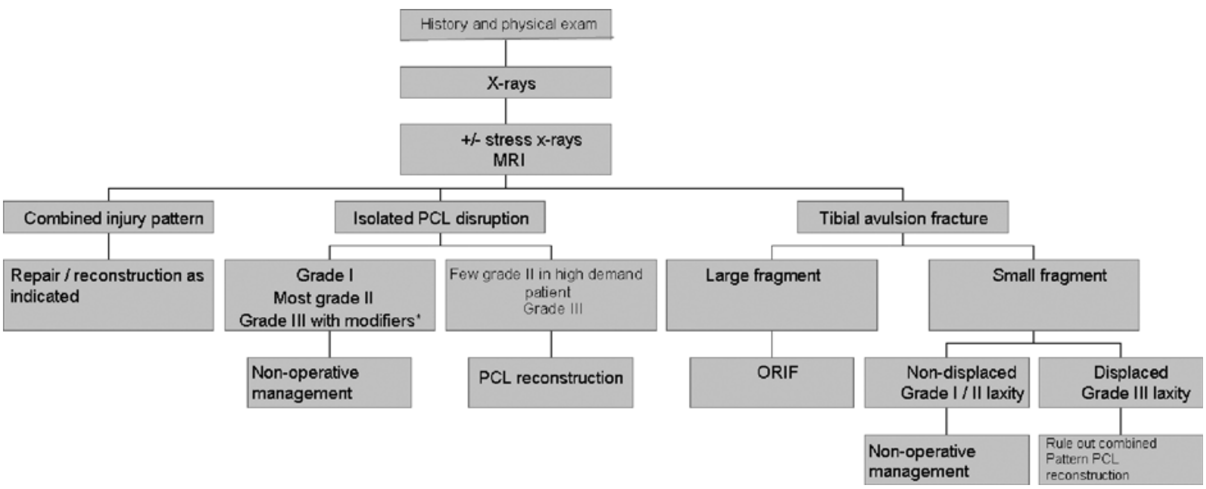

FIGURE 12. Management approach for acute posterior cruciate ligament (PCL) injuries. See text for details. *=modifiers discussed in text. MRI indicates magnetic resonance imaging; ORIF, open reduction and internal fixation.

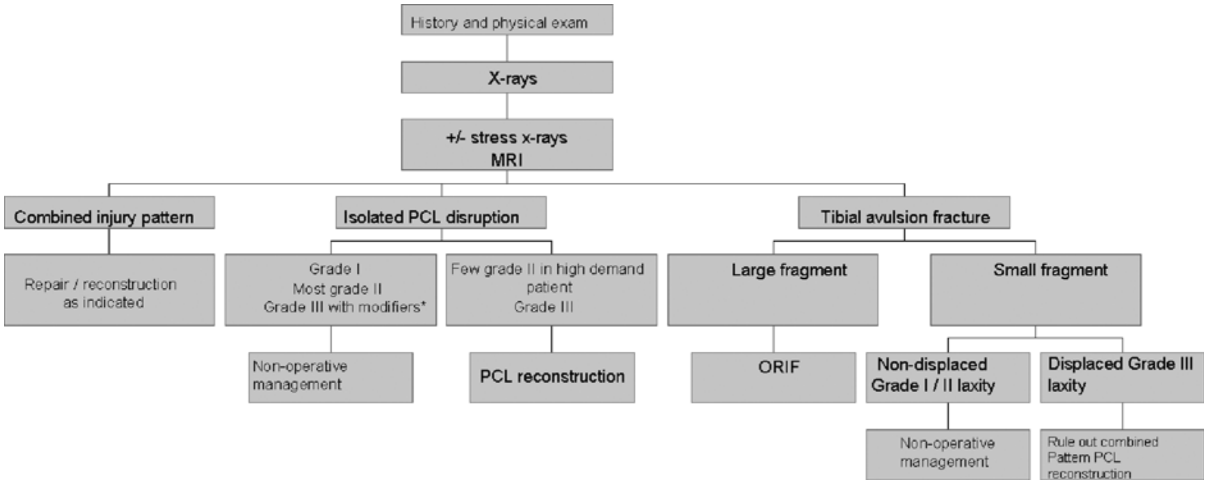

FIGURE 13. Management approach for chronic posterior cruciate ligament (PCL) injuries. See text for details. MRI indicates magnetic resonance imaging; ORIF, open reduction and internal fixation.

future, well-designed clinical trials may help to provide a clearer recommendation in this subset of patients.

Relative contraindications include the modifiers mentioned above, grade III injuries in elderly/sedentary low-demand patients, and inability to comply with postoperative regimens (Fig. 12).

CHRONIC TREATMENT

In the setting of chronic injury or late presentation of isolated grade III PCL injury, management efforts are directed primarily at rehabilitative quadriceps strengthening and activity modification where appropriate. Chief complaints, if present, are likely to include knee pain with prolonged walking/activity and retropatellar pain. Stiffness and difficulty squatting may be present. Overall, gross instability symptoms are uncommon. Unsteadiness on stairs or hills is more likely to be reported than overt giving way or buckling. A trial of bracing may be appropriate in this cohort. Patients should be followed with serial x-rays (including the 45-degree flexion posteroanterior view) to detect early arthritic changes. It is important to assess for concurrent symptomatic meniscal pathology. Bone scanning should be performed to assess the increased stress on the patellofemoral and medial compartments. Mechanical alignment of the limb should be carefully evaluated as corrective osteotomy may be indicated as part of the overall management strategy. When the patient complains of arthritic-type pain or investigations are suggestive of degenerative joint disease, diagnostic arthroscopy may be used.

Concrete criteria for failure of nonoperative management have yet to be defined, but delayed PCL reconstruction may be indicated for patients below 60 years of age with persistent symptoms of pain or instability. This may help to rebalance pressure and shear forces within the knee, slowing progression of degeneration of the medial compartment. Reducing posterior tibial translation with delayed reconstruction in selected cases also restores the mechanical advantage of the quadriceps mechanism, thereby reducing patellofemoral contact forces as well. However, it is currently unknown what overall effect delayed reconstruction may have on the knee with early degenerative changes (Fig. 13).

SUMMARY

Compared with ACL injuries, PCL injuries are a rare event. The mechanisms are predictable and a thorough physical examination is mandatory to rule out or define combined injury patterns. Stress radiography and MRI studies are very helpful adjuncts. Acute and chronic injuries require slightly different approaches. As our understanding of normal and pathologic knee joint kinematics develops, nonoperative rehabilitation goals and operative techniques continue to evolve.

REFERENCES

1. Schulz MS, Russe K, Weiler A, et al. Epidemiology of posterior cruciate ligament injuries. *Arch Orthop Trauma Surg*. 2003;123:186–191.
2. Fanelli GC. Posterior cruciate ligament injuries in trauma patients. *Arthroscopy*. 1993;9:291–294.
3. Fowler PJ, Messieh SS. Isolated posterior cruciate ligament injuries in athletes. *Am J Sports Med*. 1987;15:553–557.
4. Miyasaka KC. The incidence of knee ligament injuries in the general population. *Am J Knee Surg*. 1991;4:3–8.
5. Daniel DM, Stone ML, Barnett P, et al. Use of the quadriceps active test to diagnose posterior cruciate-ligament disruption and measure posterior laxity of the knee. *J Bone Joint Surg Am*. 1988;70:386–391.
6. Hughston JC, Norwood LA Jr. The posterolateral drawer test and external rotational recurvatum test for posterolateral rotatory instability of the knee. *Clin Orthop Relat Res*. 1980; 147:82–87.
7. Shelbourne KD, Benedict F, McCarroll JR, et al. Dynamic posterior shift test: an adjuvant in evaluation of posterior tibial subluxation. *Am J Sports Med*. 1989;17:275–277.
8. LaPrade RF, Terry GC. Injuries to the posterolateral aspect of the knee. Association of anatomic injury patterns with clinical instability. *Am J Sports Med*. 1997;25:433–438.
9. Whipple TL, Ellis FD. Posterior cruciate ligament injuries. *Clin Sports Med*. 1991;10:515–527.
10. Pugh L, Mascarenhas R, Arneja S, et al. Current concepts in instrumented knee-laxity testing. *Am J Sports Med*. 2009;37: 199–210.
11. Hewett TE, Noyes FR, Lee MD. Diagnosis of complete and partial posterior cruciate ligament ruptures: stress radiography compared with KT-1000 arthrometer and posterior drawer testing. *Am J Sports Med*. 1997;25:648–655.

12. Sekiya JK, Whiddon DR, Zhems CT, et al. A clinically relevant assessment of posterior cruciate ligament and posterolateral corner injuries. *J Bone Joint Surg*. 2008;90:1621–1627.
13. Harner CD, Hoher J. Evaluation and treatment of posterior cruciate ligament injuries. *Am J Sports Med*. 1998;26:471–482.
14. Patten RM, Richardson ML, Zink-Brody G, et al. Complete versus partial-thickness tears of the posterior cruciate ligament: MR findings. *J Comput Assist Tomogr*. 1994;18:793–799.
15. 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; 27:276–283.
16. Shelbourne KD, Jennings RW, Vahey TN. Magnetic resonance imaging of posterior cruciate ligament injuries: assessment of healing. *Am J Knee Surg*. 1999;12:209–213.
17. Fanelli GC, Giannotti BF, Edson CJ. Arthroscopically assisted combined posterior cruciate ligament/posterior lateral complex reconstruction. *Arthroscopy*. 1996;12:521–530.
18. Petrie RS, Harner CD. Evaluation and management of the posterior cruciate injured knee. *Oper Tech Sports Med*. 1999;7: 93–103.
19. Parolie JM, Bergfeld JA. Long-term results of nonoperative treatment of isolated posterior cruciate ligament injuries in the athlete. *Am J Sports Med*. 1986;14:35–38.
20. Torg JS, Barton TM, Pavlov H, et al. Natural history of the posterior cruciate ligament-deficient knee. *Clin Orthop*. 1989;246:208–216.
21. Cosgarea AJ, Jay PR. Posterior cruciate ligament injuries: evaluation and management. *J Am Acad Orthop Surg*. 2001;9: 297–307.
22. Shino K, Horibe S, Nakata K, et al. Conservative treatment of isolated injuries to the posterior cruciate ligament in athletes. *J Bone Joint Surg Br*. 1995;77:895–900.
23. Shelbourne KD, Gray T. Natural history of acute posterior cruciate ligament tears. *J Knee Surg*. 2002;15:103–107.
24. Shelbourne KD, Muthukaruppan Y. Subjective results of nonoperatively treated, acute, isolated posterior cruciate ligament injuries. *Arthroscopy*. 2005;21:457–461.
25. Fontebote CA, Sell TC, Laudner KG, et al. Neuromuscular and biomechanical adaptations of patients with isolated deficiency of the posterior cruciate ligament. *Am J Sports Med*. 2005;33:982–989.
26. Peterson DC, Thain LM, Fowler PJ. Posterior cruciate ligament imaging. *J Knee Surg*. 2002;15:121–127.
27. Tewes DP, Fritts HM, Fields RD, et al. Chronically injured posterior cruciate ligament magnetic resonance imaging. *Clin Orthop Relat Res*. 1996;335:224–232.
28. Van de Velde SK, Bingham JT, Gill TJ, et al. Analysis of tibiofemoral cartilage deformation in the posterior cruciate ligament-deficient knee. *J Bone Joint Surg Am*. 2009;91:167–175.
29. Gill TJ, DeFrate LE, Wang C, et al. The biomechanical effect of posterior cruciate ligament reconstruction on knee joint function. Kinematic response to simulated muscle loads. *Am J Sports Med*. 2003;31:530–536.
30. Li G, Papannagari R, Li M, et al. Effect of posterior cruciate ligament deficiency on in vivo translation and rotation of the knee during weightbearing flexion. *Am J Sports Med*. 2008;36: 474–479.
31. Gill TJ, DeFrate LE, Wang C, et al. The effect of posterior cruciate ligament reconstruction on patellofemoral contact pressures in the knee joint under simulated muscle loads. *Am J Sports Med*. 2004;32:109–115.
32. Skyhar MJ, Warren RF, Ortiz GJ, et al. The effects of sectioning of the posterior cruciate ligament and the posterolateral complex on the articular contact pressures within the knee. *J Bone Joint Surg Am*. 1993;75:694–699.
33. Boynton MD, Tietjens BR. Long-term followup of the untreated isolated posterior cruciate ligament-deficient knee. *Am J Sports Med*. 1996;24:306–310.
34. Clancy WG Jr, Shelbourne KD, Zoellner GB, et al. Treatment of knee joint instability secondary to rupture of the posterior cruciate ligament. Report of a new procedure. *J Bone Joint Surg Am*. 1983;65:310–322.
35. Cross MJ, Powell JF. Long-term followup of posterior cruciate ligament rupture: a study of 116 cases. *Am J Sports Med*. 1984;12:292–297.
36. Giffin JR, Stabile KJ, Zantop T, et al. Importance of tibial slope for stability of the posterior cruciate ligament deficient knee. *Am J Sports Med*. 2007;35:1443–1449.
37. Moore HA, Larson RL. Posterior cruciate ligament injuries. Results of early surgical repair. *Am J Sports Med*. 1980;8: 68–78.
38. Hughston JC, Bowden JA, Andrews JR, et al. Acute tears of the posterior cruciate ligament. Results of operative treatment. *J Bone Joint Surg Am*. 1980;62:438–450.
39. Richter M, Kiefer H, Hehl G, et al. Primary repair for posterior cruciate ligament injuries. An eight-year followup of fifty-three patients. *Am J Sports Med*. 1996;24:298–305.
40. Dejour H, Walch G, Peyrot J, et al. The natural history of rupture of the posterior cruciate ligament. *Rev Chir Orthop Reparatrice Appar Mot*. 1988;74:35–43. French.
41. Peccin MS, Almeida GJ, Amaro J, et al. Interventions for treating posterior cruciate ligament injuries of the knee in adults. *Cochrane Database Syst Rev*. 2005;2:CD002939.
42. Canale ST, Beaty JH Eds. *Campbell's Operative Orthopedics*. 11th Edition. Maryland Heights, MO: Elsevier; 2007:2552–2565.
43. Grassmayr MJ, Parker DA, Coolican MR, et al. Posterior cruciate ligament deficiency: biomechanical and biological consequences and the outcomes of conservative treatment. A systematic review. *J Sci Med Sport*. 2008;11: 433–443.
44. Johnson DH. My approach to posterior cruciate ligament injuries. *Oper Tech Sports Med*. 2009;17:167–174.
45. Fanelli GC, Boyd JL, Heckler MW. How I manage posterior cruciate ligament injuries. *Oper Tech Sports Med*. 2009;17: 175–193.
46. Jung YB, Tae SK, Lee YS, et al. Active non-operative treatment of acute isolated posterior cruciate ligament injury with cylinder cast immobilization. *Knee Surg Sports Traumatol Arthrosc*. 2008;16:729–733.
47. Fanelli GC. Posterior cruciate ligament rehabilitation: how slow should we go? *Arthroscopy*. 2008;24:234–235.