Posterior Cruciate Ligament

CME

Anatomy, Biomechanics, and Outcomes

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The optimal treatment of posterior cruciate ligament ruptures remains controversial despite numerous recent basic science advances on the topic. The current literature on the anatomy, biomechanics, and clinical outcomes of posterior cruciate ligament reconstruction is reviewed. Recent studies have quantified the anatomic location and biomechanical contribution of each of the 2 posterior cruciate ligament bundles on tunnel placement and knee kinematics during reconstruction. Additional laboratory and cadaveric studies have suggested double-bundle reconstructions of the posterior cruciate ligament may better restore normal knee kinematics than single-bundle reconstructions although clinical outcomes have not revealed such a difference. Tibial inlay posterior cruciate ligament reconstructions (either open or arthroscopic) are preferred by many authors to avoid the ''killer turn'' and graft laxity with cyclic loading. Posterior cruciate ligament reconstruction improves subjective patient outcomes and return to sport although stability and knee kinematics may not return to normal.

Keywords: posterior cruciate ligament; single bundle; double bundle; tibial inlay

Posterior cruciate ligament (PCL) ruptures are rare in isolation and more commonly occur in the multiligament-injured knee.[16,32,54,57,66,76,82] While patients may clinically tolerate a PCL-deficient knee, it has been well documented that this results in altered loads and kinematics during functional activities.[‖] Treatment algorithms have been published by multiple authors outlining the indications for surgical treatment.[11,34,54,57,82] The optimal PCL reconstruction continues to evolve in an attempt to best restore normal knee function. The purpose of this article is to review current basic science and clinical publications with regard to PCL anatomy, biomechanics, and outcome studies. Attention is given to individual PCL bundle anatomy and function, assessment for associated injuries, transtibial versus tibial inlay reconstructions, single-bundle versus double-bundle reconstructions, femoral tunnel position, and graft fixation.

‖References 17, 18, 35, 38, 51, 76, 77, 80.

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TABLE 1
Average Surface Area (in mm^2) of the Posterior Cruciate Ligament Attachments to the Femur and Tibia

	Overall	Anterolateral Bundle	Posteromedial Bundle
Femur	209 ± 33.82	118 ± 23.95	90 ± 16.13
Tibia	243 ± 38.2	93.1 ± 16.6	150.8 ± 31.0

ANATOMY

The anatomy of the PCL has been well described. The PCL is considered an intra-articular, extrasynovial structure because of a synovial sheath that lines the ligament. The dimensions of the PCL have been outlined by Girgis et al[20] and Harner et al.[23] It is 32 to 38 mm long with a cross-sectional area of 11 mm^2.[23] The bony insertion sites of the PCL are 3 times larger than its midsubstance. The average area of the PCL femoral and tibial footprints is shown in Table 1.[15,39,78] Recent anatomic descriptions have divided the PCL into an anterolateral (AL) and posteromedial (PM) bundle based on ligament function in flexion and extension.[42,54,58] Although the PCL may be more accurately described as a continuum of fibers that rotate during the knee flexion and extension cycle, the individual bundle terminology has been utilized in the description of various PCL reconstruction techniques.[13,65]

Proper knowledge of the topography of femoral and tibial insertion sites of the PCL assists in proper graft placement during single- and double-bundle reconstruction techniques (Figures 1 and 2). Several anatomic reference

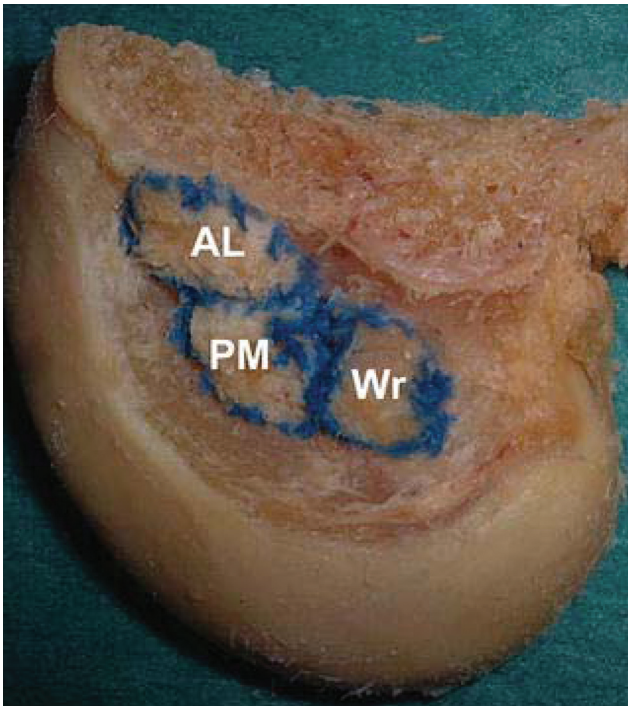

Figure 1. The posterior cruciate ligament is composed of 2 distinct bundles—anterolateral (AL) and posteromedial (PM). The cadaveric image displays the anatomic relationship of the 2 bundles on the wall of the medial femoral condyle. The variable meniscofemoral ligament of Wrisberg (Wr) is outlined. (Reprinted with kind permission from Springer Science+Business Media: Takahashi M, Matsubara T, Doi M, Suzuki D, Nagano A. Anatomical study of the femoral and tibial insertions of the anterolateral and posteromedial bundles of human posterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc*. Nov 2006;14:1055-1059.)

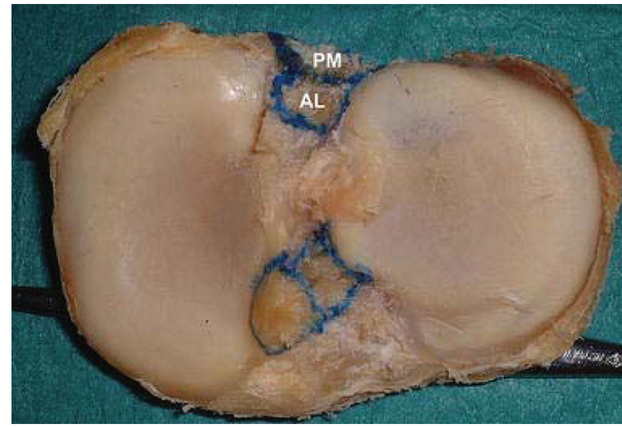

Figure 2. Anatomic dissection of the posterior knee in a cadaveric specimen. The image reveals the anterolateral (AL) and posteromedial (PM) bundle attachments of the posterior tibia. (Reprinted with kind permission from Springer Science+Business Media: Takahashi M, Matsubara T, Doi M, Suzuki D, Nagano A. Anatomical study of the femoral and tibial insertions of the anterolateral and posteromedial bundles of human posterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc*. Nov 2006;14:1055-1059.)

systems have been described in the literature to identify the femoral insertion sites. Takahashi et al[79] found the femoral attachment of the AL bundle is 9.6 mm and the PM bundle is 10.6 mm from the articular cartilage using a line drawn parallel to Blumensaat's line. Morgan et al[60] reported the AL bundle originates 13 mm posterior to the medial articular cartilage–intercondylar wall interface and 13 mm inferior to the articular cartilage–intercondylar roof interface. The PM bundle originates 8 mm posterior to the medial articular cartilage–intercondylar wall interface and 20 mm inferior to the articular cartilage–intercondylar roof interface. Forsythe et al[15] found in cadaveric specimens a constant "medial intercondylar ridge" that determines the proximal extent of the femoral PCL footprint. A less common bony landmark is the "medial bifurcate ridge" separating the 2 bundles.[39]

With regard to tibial topography, knowledge of the tibial insertion avoids too posterior of a tunnel placement, which can lead to breach of the posterior cortex and potential neurovascular injury. Too anterior tunnel placement may damage the posterior horn of the medial meniscus. The 2 PCL bundles insert as a confluent tendon into a facet on the posterior aspect of the tibia approximately 1.0 to 1.5 cm distal to the joint line.[14,54] The posterior horn of the medial meniscus serves as the anterior border of this facet. The center of the 2 fiber bundles is located, medial to lateral, 48% of the width of the tibial plateau.[14,54] Another radiographic study found the common insertion point of the PCL on the tibia is located at 51% of the mediolateral diameter of the tibial plateau with respect to the lateral border and 13% $\pm$ 2% inferior to the medial tibial plateau with respect to the sagittal diameter of the tibial plateau.[40] Moorman et al[59] concluded in a cadaveric study that the bulk of the PCL inserts in the posterior half of the PCL facet. In the sagittal plane, the center of the PCL lies 7 mm anterior to the posterior cortex of the tibia. Tunnel placement at the center of the original ligament can be measured along the PCL facet utilizing a true lateral radiograph.[59] At the tibial insertion, the AL bundle is attached to the superolateral portion of posterior intercondylar facet, and the PM bundle is attached to the inferomedial portion of the facet. These findings are consistent with those reported by other authors.[15,23,79]

The meniscofemoral ligaments originate from the posterior horn of the lateral meniscus and insert on the medial femoral condyle anteriorly (ligament of Humphrey) and posteriorly (Wrisberg) to the PCL. The PCL and meniscofemoral ligaments combine to make up the PCL complex.[23] The combined cross-sectional area of the anterior and posterior meniscofemoral ligaments makes up 17.2% of the PCL complex cross-sectional area.[61] At least 1 meniscofemoral ligament has been reported in up to 93% of knees.[4] Studies have suggested the meniscofemoral ligaments play a role as a secondary stabilizer of the knee against posterior tibial translation.[11]

Multiple recent articles have identified the anatomy of the posterior aspect of the knee as a critical factor in anatomically reconstructing the PCL-deficient knee, particularly when performing an open tibial inlay technique.[35,36,69] For example, LaPrade et al[36] stated the distal lateral aspect of the oblique popliteal ligament attachment to the tibia may be injured during the surgical approach. In addition, the posterior oblique ligament may play a role in preventing knee rotation and hyperextension and in preventing additional posterior translation in the PCL-deficient knee.[35,36,69]

PCL-DEFICIENT KNEE: PHYSICAL EXAMINATION AND CONSERVATIVE CLINICAL OUTCOMES

The posterior drawer test is perhaps the most valuable test in evaluating the PCL. It is performed with the knee flexed to 90°. The examiner first must confirm that the knee demonstrates a normal tibiofemoral relationship in that the anterior tibial condyles are approximately 10 mm anterior to their respective femoral condyles. If the examiner can then displace the tibia posterior 0 to 5 mm, it is considered grade I; 6 to 10 mm, grade II; and a grade III injury occurs when there is >10-mm posterior displacement.[67,82] The senior authors (T.L.W. and R.F.W.) commonly use a different grading system. Grade A is when the tibia can be displaced posteriorly but the tibial plateau remains anterior to the femoral condyles. Grade B implies the tibial plateau can be displaced flush to the corresponding femoral condyles and in grade C, the tibial plateau can be displaced posterior to the femoral condyles.[67] Comparisons should always be made to the contralateral knee.

The quadriceps active test can also be helpful in evaluating the PCL. This test is likewise performed supine with the knee at 90° of flexion. The patient is asked to contract the quadriceps muscle as the examiner's hand rests on the dorsal foot to resist leg extension. In the normal knee the tibia will translate posteriorly with muscle contraction. With a PCL injury, however, the tibia will initially be subluxated posteriorly (posterior tibial sag) and will then translate anteriorly with quadriceps contraction.

With any suspicion of PCL injury, the entire knee examination should be heavily scrutinized as isolated injuries are rare. Careful assessment of the posterolateral corner (PLC) must be performed with the dial test, external rotation recurvatum test, and/or the reverse pivot-shift test. This is especially true for any grade III PCL injury as it has previously been suggested that concomitant injury to the posterolateral structures may be necessary to allow posterior tibial translation greater than 10 mm.[74]

The consequences of an incompetent PCL continue to evolve in the literature. Older studies stated that the PCL-deficient knee is generally well tolerated and favored a conservative, nonoperative treatment approach with favorable outcomes in most cases.[16,66] Shelbourne and Muthukaruppan[76] followed 215 patients for a mean of 7.8 years with isolated PCL injuries treated conservatively. Subjective scores were independent of the grade of PCL laxity and mean scores did not decrease with time. In addition, no risk factors could be identified that would help determine which patients would develop a loss of knee function over time. The study was weighted toward patients with grade 2 laxity or less. These results were echoed by Patel et al,[67] who followed 57 patients with isolated PCL injuries for a mean of 6.8 years. Again, there was no correlation between grade of PCL laxity and Lysholm-II knee scores. Plain radiographs showed mild (grade I) medial compartment osteoarthritis (OA) in 7 knees, and moderate (grade II) medial compartment OA in 3 knees.

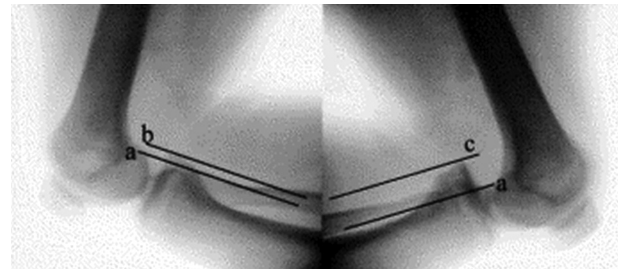

Figure 3. Stress radiographs of the lateral knee allow quantification of absolute posterior tibial displacement. Posterior displacement in excess of 8 mm indicates complete insufficiency of the posterior cruciate ligament (PCL). Greater than 10 mm of posterior tibial translation on stress radiography correlates with a combined posterolateral corner and PCL disruption. (Reprinted with permission from Margheritini F, Mancini L, Mauro CS, Mariani PP. Stress radiography for quantifying posterior cruciate ligament deficiency. *Arthroscopy*. 2003;19(7):706-711. ©2003, Elsevier Ltd.)

Although many patients may clinically tolerate a PCL-deficient knee, it has been well documented that the PCL-deficient knee results in altered loads and kinematics during functional activities. Skyhar et al[77] concluded that loads shift to the medial and patellofemoral compartments. Using open-access MRI, Logan et al[38] reported altered kinematics in the medial compartment of the knee during a weightbearing squat in PCL-deficient knees of 6 patients. Van de Velde et al[80] also found a change in tibiofemoral mechanics. When evaluated with MRI and fluoroscopy during a single-legged lunge, those with a PCL-deficient knee showed increased cartilage deformation in the medial compartment.

In addition to the alterations in the medial compartment, other authors have discovered the posterolateral structures of the knee are at increased risk for injury when the PCL is left untreated.[35] Jackman et al[29] and Margheritini et al[44] have emphasized the importance of stress radiographs in assessing the knee after PCL injury (Figure 3). An absolute posterior tibial displacement in excess of 8 mm indicates complete insufficiency of the PCL. When tibial displacement exceeds 12 mm, additional injury to the secondary posterolateral structures should be considered.[72] Most recently, Sekiya et al[74] concluded that a grade III on posterior drawer testing and >10 mm of posterior tibial translation on stress radiography correlate with a combined PLC and PCL disruption.

PCL RECONSTRUCTION BIOMECHANICS

General Principles

Knowledge of the biomechanical function of the native PCL and its individual bundles provides a framework for the understanding of the kinematic function in both the isolated PCL-deficient knee and in the multiligament injury state. Previous anatomic studies have mechanically characterized the individual bundles of the PCL, showing the normal AL bundle is more taut in flexion and more lax in extension.[20,81] The reverse is true for the PM bundle, which is relatively more taut in extension and more lax in flexion. Consequently, it has been postulated that the AL bundle functions independently in knee flexion and the PM bundle functions independently in knee extension. However, more recent studies suggest that, based on length and spatial orientation, the 2 bundles of the PCL may have a more synergistic relationship.[1,55,65]

The concept of a synergistic relationship between the AL and PM bundles has been further advanced by several authors who have suggested the 2 bundles of the PCL may have a codominant relationship rather than a reciprocal one. Ahmad et al[1] investigated the contribution of each bundle to posterior knee stability by studying the orientation and length characteristics of the individual bundles in a series of cadaveric knees. They reported that with increasing knee flexion, the AL bundle becomes tighter, a finding consistent with other historical data.[20,81] However, they also reported that with increasing knee flexion, the AL bundle becomes more vertically oriented, decreasing its ability to resist posterior tibial translation. The PM bundle, conversely, becomes more horizontal with increasing knee flexion. This orientation increased the ability of the PM bundle to resist posterior tibial translation. As a result of this codominance, neither bundle functioned independently in restraining posterior tibial translation at any specific knee flexion angle.

Papannagari et al[65] used MRI and a dual-orthogonal fluoroscopic system to measure the length, elevation, deviation, and twist of the PCL bundles during knee flexion in living subjects. They found that both bundles elongated and changed orientation up to 120° of knee flexion. They concluded that the bundles do not behave in the reciprocal fashion that traditionally had been postulated; rather, both elongate and function throughout knee range of motion (ROM). Mauro et al[55] identified the in situ force patterns of the individual components of a combined double-bundle PCL and PLC knee reconstruction using a robotic testing system by sequentially cutting and reconstructing the PCL and PLC. They found no differences in the in situ forces between the AL and PM bundles at any flexion angles, again suggesting that both bundles function through the ROM in a codominant fashion.

With the idea of codominance comes the difficulty of proper tensioning of the 2 PCL bundles. Carson et al[9] demonstrated an anatomic tibial inlay and 2-bundle approach with the AL bundle fixed at 90° and the PM bundle at 0° flexion best reproduced anatomic in situ graft forces. Two other testing conditions (AL/PM at 45°/45° and 90°/90°) produced excessive force in the PM bundle with lower degrees of flexion.

These biomechanical studies combined with the recent anatomic studies outlining the precise location of the PCL bundle insertions on the femur and tibia have led to the development of various PCL reconstructive options including arthroscopic transtibial single- and double-bundle reconstructions as well as open and arthroscopic tibial inlay techniques that attempt to restore posterior stability to the anatomic state. Varying graft types, tensioning methods, and modes of fixation make direct comparisons within the literature difficult.

Transtibial Versus Tibial Inlay Reconstructions

The most commonly reported PCL reconstruction has been the transtibial technique where the graft makes a sharp turn, the "killer turn," as it emerges from the tibial tunnel and courses toward the femur[6,7,53,54] (Figure 4). Because of this phenomenon, the tibial inlay technique was developed in an attempt to decrease attenuation of the graft as it made this turn (Figure 5). Bergfeld et al[7] were the first to biomechanically evaluate single-bundle transtibial and single-bundle tibial inlay reconstructions. They found less anterior-posterior laxity in the tibial inlay group after cyclic loading of the knee. Markolf et al[53] also found the tibial inlay reconstruction to be superior to the transtibial reconstruction when subjected to cyclic loading in a cadaveric model. Tibial inlay grafts had less attenuation or thinning (12.5% vs 40.6%, respectively) and decreased failure after cyclic loading (0 of 31 grafts vs 10 of 31 grafts, respectively) than tibial tunnel grafts. In a separate cadaveric study, McAllister et al[56] observed no significant difference in knee laxity at the time of initial graft fixation between tibial tunnel and inlay reconstructions, but the tibial tunnel group subsequently displayed increased posterior laxity after cyclic loading. Damage to the graft as a result of the "killer turn" was further highlighted by Weimann et al,[85] who reported less graft damage during cyclic loading by smoothing the tibial aperture.

Margheritini et al[45] evaluated in situ graft forces and knee kinematics after transtibial and tibial inlay reconstructions in a cadaveric knee using a robotic/universal force–moment sensor testing system. They found no differences between the 2 techniques in either posterior tibial translation or graft in situ forces at the time of initial fixation. Other authors have compared the tibial inlay and transtibial techniques and have also demonstrated no differences between the 2 techniques.[27,56,64] Zehms et al[88] compared double-bundle arthroscopic and open tibial inlay PCL reconstructions in 10 matched-pair cadaveric knees using clinical tests consisting of posterior drawer, Telos stress testing, and dial testing at both 30° and 90°. The authors found no significant difference in any of these tests between the 2 groups.

Biomechanical testing in the laboratory suggests that the arthroscopic transtibial and inlay techniques (arthroscopic or open) have similar stability at the time of initial fixation, but inlay techniques result in protected graft integrity and prevention of graft attenuation with cyclic

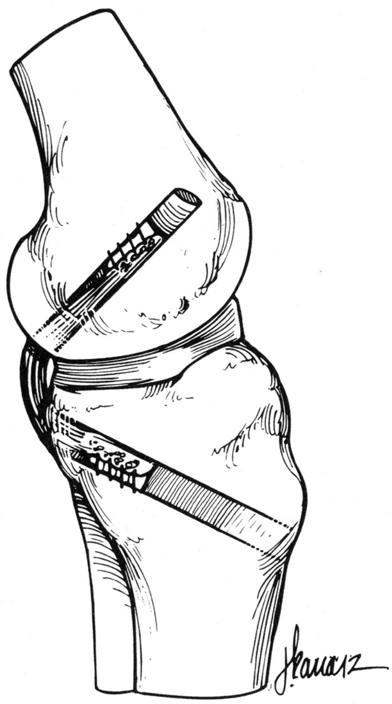

Figure 4. Lateral depiction of the transtibial technique of posterior cruciate ligament reconstruction where the graft must make a ''killer turn'' around the tibial plateau as it enters the knee. (Reprinted with permission from Bergfeld JA, McAllister DR, Parker RD, Valdevit AD, Kambic HE. A biomechanical comparison of posterior cruciate ligament reconstruction techniques. *Am J Sports Med*. 2001;29:129-136.)

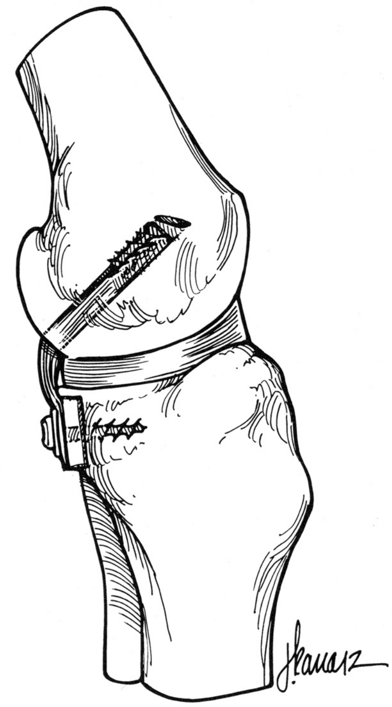

Figure 5. Lateral depiction of the open tibial inlay technique of posterior cruciate ligament (PCL) reconstruction. The tibial bone plug is secured at the PCL tibial footprint to avoid excessive graft abrasion. (Reprinted with permission from Bergfeld JA, McAllister DR, Parker RD, Valdevit AD, Kambic HE. A biomechanical comparison of posterior cruciate ligament reconstruction techniques. *Am J Sports Med*. 2001;29:129-136.)

loading. Both arthroscopic and open inlay reconstruction techniques behave with similar characteristics in preventing posterior translation. In selecting a surgical approach, the clinician should also consider that both inlay techniques are not without potential technical difficulties and danger to the posterior neurovascular bundle. The arthroscopic inlay technique requires screw placement all the way up the tunnel, while the open tibial inlay requires posterior dissection and retraction of the popliteal vessels.[54]

Single-Bundle Versus Double-Bundle PCL Reconstructions

Race and Amis[70] first demonstrated that a double-bundle graft could restore normal knee laxity across the full range of flexion, while an isometric graft leads to high graft tension during extension and laxity during flexion. Harner et al[24] evaluated single-bundle and double-bundle transtibial PCL reconstructions in cadaveric knees using a robotic/universal force–moment sensor testing system. They conclude the double-bundle reconstruction more closely mimics the intact knee posterior tibial translation and PCL in situ forces. Markolf et al[48] found the addition of a posteromedial graft improves stability between 0° and 30° knee flexion but in doing so creates higher than normal graft forces throughout knee ROM.

Other studies have compared single- and double-bundle reconstructions using tibial inlay techniques.[5,6,43,86,87] Bergfeld et al[6] found no difference in posterior tibial translation with respect to the number of bundles. Whiddon et al,[86] however, demonstrated measurable benefits in rotational and posterior stability with the double bundle in the setting of an untreated PLC injury. With the PLC intact, however, the double bundle offered no improved posterior stability and actually provided overconstraint to the knee at 30°. Likewise, cadaveric results by Wiley et al[87] also suggest overconstraint at 30° of flexion and beyond with the double-bundle technique. The authors found no significant differences between the intact knee compared with single bundle and the intact knee compared with the double-bundle. However, they did note that there was significantly less posterior laxity when double bundles were compared directly to single bundles. Apsingi et al[5] showed in 9 cadaveric knees using electromagnetic measurements of knee kinematics that single-bundle and double-bundle reconstructions equally restored normal knee laxity when combined with a modified Larson reconstruction for cadaveric combined PCL/PLC injuries. The authors concluded that the added complexity of the double-bundle technique provided no benefit over the single-bundle technique.

Biomechanical studies that include multiple variables of graft type, fixation, and reconstruction technique are conflicting as to the optimal graft configuration—single- versus double-bundle—that reproduces knee stability. We agree with the conclusion of Kohen and Sekiya that double-bundle PCL reconstructions may better control knee rotational stability in the setting of the combined PCL/PLC–deficient knee.[34]

Femoral Tunnel

Several studies have addressed the effect of femoral tunnel position on the biomechanics of the PCL-reconstructed knee. Oakes et al[63,64] examined the effect of a single-bundle femoral tunnel position on graft forces, demonstrating that graft forces did not differ significantly between eccentric and central tunnel positions. Markolf et al[49] investigated the effect of changes in the position of the femoral tunnel within the femoral footprint. They demonstrated that an anterolateral tunnel reproduced normal PCL force profiles, but was more lax than normal between 0° and 45° of flexion. The central tunnel best matched intact knee posterior laxity, but graft forces were higher than normal between 0° and 45° of flexion. The PM tunnel overconstrained posterior laxity and generated higher than normal graft forces between 0° and 45° of flexion.

Other authors have investigated the effect of changes in position of the femoral tunnels for a double-bundle reconstruction. Petersen et al[68] found that anterior femoral tunnel position in a double-bundle reconstruction restored normal knee kinematics more closely than did posterior tunnel position. Shearn et al[75] investigated how the location of the femoral attachment of a second bundle of a 2-bundle reconstruction affects the anterior bundle tension and the load distribution between the graft bundles. They found that when a second bundle was placed in a proximal position, the second bundle resulted in reciprocal loading (1 bundle functioned in flexion and 1 in extension). However, when the second bundle was placed in a middle or distal position, it resulted in a significant reduction in anterior bundle tension and in cooperative load sharing (both bundles functioning together).

Markolf et al[48] also investigated the effect of the location of a second graft in a double-bundle reconstruction. They found that although a single AL graft best reproduced the normal PCL forces, laxities were greater than normal from 0° to 30° of knee flexion. The addition of a PM graft reduced this laxity, but also resulted in higher than normal forces in the PM graft. The authors followed up this study with a recent investigation of the effect of femoral tunnel separation.[52] They found no biomechanical advantage in making the bone bridge between the 2 tunnels less than 3 mm.

Fixation

Several recent studies have evaluated graft fixation constructs on the biomechanics of PCL reconstructions. Markolf et al[47] evaluated the effect of orientation and position of the bone block from a bone–patellar tendon–bone graft within the tibial tunnel after cyclic loading. The study demonstrated that the optimal position for the bone block was flush with the posterior tunnel opening, with the bone block facing anteriorly in the tibial tunnel. This position resulted in less thinning and elongation of the graft over time.

Another study evaluated the performance of soft tissue grafts and bone–patellar tendon–bone grafts with various fixation methods under cyclic loading.[33] Using a porcine model, they evaluated a tendon/EndoButton reconstruction, a tendon-bone/interference screw reconstruction, and a tendon-bone/tibial inlay reconstruction using tensile testing and cyclic loading. They found that the tendon/EndoButton reconstruction performance was affected by the cyclic loading to a larger degree than the other fixation techniques.

Margheritini et al[46] investigated the effect of adding proximal tibial tunnel fixation to a distally fixed transtibial reconstruction using Achilles tendon. A reconstruction with combined proximal and distal fixation more closely restored intact knee kinematics and PCL in situ forces at initial fixation than did a reconstruction with distal fixation alone. A similar study looked at 4 different tibial-side graft fixation constructs using an Achilles tendon graft 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.[37] With cyclic loading, maximum load to failure and stiffness of the hybrid soft tissue fixations were similar to the bone plug fixation methods.

Other studies have investigated the biomechanical effects of tibial inlay fixation techniques.[8,21,71,88] Gupta et al[21] investigated the effect of utilizing bioabsorbable screw fixation with the tibial inlay technique, noting that it performed similarly to metallic fixation. Other recent studies have compared arthroscopic and open tibial inlay fixation techniques.[8,71,88] These studies have demonstrated that arthroscopic techniques with suture fixation provide comparable stability to the traditional open tibial inlay techniques.[7,71]

Combined With PLC

Several studies have evaluated the biomechanics of combined PCL and PLC injuries and reconstructions.[25,50,73,87] Using various models, these studies have demonstrated that an untreated PLC injury may result in increased loads in the PCL graft and subsequent PCL graft failure. Further, in the setting of a combined PCL and PLC injury, reconstruction of both structures better restores intact knee kinematics and native PCL in situ forces.[5,50,73] However, in one study, single-bundle PCL reconstruction was shown to be equivalent to double-bundle PCL reconstruction when performed in the setting of a modified Larson PLC reconstruction.[5] Another study demonstrated that PLC reconstructions in PCL-reconstructed knees resulted in constrained varus rotation compared to the intact knee.[51]

CLINICAL OUTCOMES

Posterior cruciate ligament reconstruction has repeatedly been shown to result in improved subjective knee scores.[¶] For example, Ahn et al[2] reported that by International Knee Documentation Committee scoring, all 61 of their patients achieved normal or near-normal knees. Jackson et al[30] reported 24 of 26 patients rated their knees as normal or near-normal while 25 reported no pain or giving way with moderate to strenuous activity. Mean Lysholm scores improved from 64 to 90 at a minimum of 10 years, indicating that excellent results can be maintained with long-term follow-up.

The majority of reports indicate that patient-reported outcomes are greatly improved from preoperative level of function. However, the results are less successful when compared with preinjury activity status. Hermans et al[26] reviewed 25 PCL reconstructions at an average of 9 years postoperatively and noted a decrease in Tegner scores from 7.2 preinjury to 5.7 at final follow-up. The authors conclude that while patients have a satisfactory return to daily activities, they are often forced to reduce sports activities.

Other authors have noted that objective knee scores seem to lag behind subjective self-reported scoring after surgical reconstruction. One possible explanation is residual laxity that has been demonstrated with many reconstructive techniques.[¶] Cooper and Stewart[12] reported on 44 cases of PCL reconstruction at mean 39 months' follow-up. Thirty-two cases were found to have a 1+ or 2+ posterior drawer and had an average side-to-side difference of 4.1 mm for posterior tibial translation using stress radiography. The authors noted that primary cases had less side-to-side difference at final follow-up than did revision cases. Noyes and Barber-Westin[62] found that posterior laxity was present during stress radiography in all 19 patients with a mean 5.5 mm compared with the contralateral knee. Similarly, MacGillivray et al[41] showed a mean side-to-side difference of 5.7 mm with KT-1000 arthrometer analysis. This residual posterior laxity is difficult to interpret considering the aforementioned large number of patients with excellent self-reported postoperative knee scores. Residual laxity potentially may affect only higher demand activities, such as sports participation, and may not be problematic in routine daily activities.

Gill et al[19] evaluated tibiofemoral and patellofemoral in vivo kinematic data following single-bundle PCL reconstruction. The study compared 7 patients during a single-legged lunge both preoperatively and postoperatively. The authors found no differences between the healthy knee and the PCL-reconstructed knee for ROM, rotational stability, anterior-posterior translation, or patellar flexion. There remained, however, an inability to fully restore mediolateral tibial translation as well as patellar rotation and tilt, all of which differed significantly from the healthy knee following PCL reconstruction. The authors thought these changes, although subtle, had implications for the well-documented development of medial compartment and patellofemoral compartment degenerative joint disease.

¶References 2, 3, 10, 12, 19, 26, 28, 30, 31, 34, 41, 57, 62, 83, 84.

It is not precisely clear to what degree posterior laxity, mediolateral tibial translation, and other factors influence the development of arthrosis. The medial and patellofemoral compartments are classically involved. There is some indication that perhaps surgical reconstruction may delay the progression of degenerative arthritis when compared to nonoperative treatment; however, few studies have formally evaluated this. Hermans et al[26] showed 18% to have only mild radiographic changes at 9 years provided no chondrosis was present at the time of surgery. This percentage is considerably less than most reports for nonoperative treatment. In patients with chondral damage noted at the time of surgery, however, 92% went on to develop mild or moderate degenerative changes, indicating the importance of considering chondral injury in the determination of prognosis.

The optimal surgical technique for PCL reconstruction is still being investigated. One area of interest is the type of tibial fixation. Tibial inlay techniques, both open and arthroscopic, have been developed in response to biomechanical data supporting the "killer turn" theory. McAllister et al[57] recommend the tibial inlay technique performed either arthroscopic or open. Clinical studies have failed to show any difference in surgical outcomes regarding transtibial or tibial inlay fixation.[2,31,41,62] Ahn et al[2] performed follow-up MRI at a mean 22.5 months in 42 of 61 patients with a transtibial PCL reconstruction technique and showed no graft disruption and no enhancing signal at the tibial insertion site in any patient. In addition, 42 of the 61 patients underwent second-look arthroscopy at a mean of 23.9 months that revealed good synovial coverage without any tearing or other effects of the "killer turn." Noyes and Barber-Westin[62] did comment that the tibial inlay seems to be an excellent choice for revision surgery, particularly when the previous surgeon used a transtibial technique.

The debate also continues with respect to the number of bundles. Several studies have offered comparisons between single-bundle and double-bundle reconstructive techniques. Results thus far have essentially shown no reproducible clinical differences.[28,31,34,83,84] Kim et al,[31] in a subgroup analysis, found that the posterior tibial translation was decreased for a double-bundle tibial inlay group as compared to a single-bundle transtibial group. However, other studies have reported similar results for subjective performance, functional assessment, residual laxity, and radiographic analysis.[28,34,83,84] Kohen and Sekiya[34] performed a systematic review comparing single-bundle versus double-bundle reconstructions and noted there may be some improved rotational stability with double-bundle techniques in the setting of unrecognized, subtle, or untreated PLC injuries based on cadaveric studies. However, they concluded that there is simply no published evidence demonstrating clinical superiority of a single-bundle or a double-bundle PCL reconstruction.

Two other recent systematic reviews have evaluated PCL clinical outcomes. Kim et al[32] reviewed isolated arthroscopic transtibial PCL reconstructions and determined that most patients will make a predictable return to recreational and athletic activity, although reconstruction does not reliably restore normal stability and does not seem to prevent degenerative OA. Patients can be expected to achieve 1 grade improvement in posterior knee laxity. Hammoud et al[22] reviewed both isolated and multiligament-injured knees and reinforced that, although good results are generally reported, long-term studies suggest that normal stability is not restored with current techniques.

CONCLUSION

The anatomy of the PCL has been categorized with respect to its distinct AL and PM bundles as well as the femoral and tibial footprints. The natural history of the PCL-deficient knee results in altered mechanics in the medial compartment. The importance of a good physical examination and stress radiographs have clearly shown a benefit in detecting associated PLC injuries. Various arthroscopic and open tibial inlay techniques have been outlined in the literature. Some biomechanical studies favor the double-bundle reconstruction. Tibial inlay reconstructions consistently result in reports of better graft protection with cyclic loading. Currently, the senior authors employ the arthroscopic single-bundle, transtibial reconstruction in most cases, tibial inlay (arthroscopic or open) in the revision setting, and a double-bundle reconstruction in the setting of a grade C or combined PLC injury. Clinical studies have been inconclusive as to which method of reconstruction is superior, and none fully recreate normal knee kinematics. Although surgical treatment provides improvement in subjective scores, many patients demonstrate residual laxity that may affect return to high-level athletics. In addition, there remains a great variety of graft selection, tensioning techniques, tunnel anatomy, and concomitant injury patterns that make true comparisons difficult to interpret.

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