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Popliteus Bypass and Popliteofibular Ligament Reconstructions Reduce Posterior Tibial Translations and Forces in a Posterior Cruciate Ligament Graft

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Abstract

Purpose—To measure the abilities of popliteus tendon (POP) and popliteofibular ligament (PFL) graft reconstructions to limit posterior tibial translations and alter forces in a PCL graft reconstruction after posterior cruciate ligament (PCL) and lateral collateral ligament (LCL) reconstruction.

Methods—Fifteen fresh frozen cadaveric knees underwent anterior-posterior (AP) laxity testing with 200 N of applied anterior and posterior tibial force. Forces in the native PCL were recorded during passive extension from 120° to 0° with an applied 100-N posterior tibial force. The popliteus tendon was released at its femoral origin, the PFL and LCL were cut, and the PCL was sectioned, creating a combined grade 3 PCL and posterolateral corner injury. The PCL was reconstructed with a single-bundle inlay graft tensioned to restore intact knee laxity to within 1 mm at 90°, and the LCL was reconstructed with an anatomically placed graft. Testing was repeated with POP and PFL posterolateral reconstructions in addition to the PCL and LCL reconstructions.

Results—PCL + LCL grafts alone matched intact knee laxities between 20° and 90° of flexion; mean laxity was 3.5 mm greater than intact at 0° and 2.2 mm greater at 10°. The addition of a POP reconstruction to PCL + LCL reconstructions significantly reduced AP laxities from −2.4 mm (0° flexion) to −1.4 mm (90° flexion). Mean laxities with POP and PFL grafts were not significantly different from the intact knee or from each other. Mean PCL graft forces with the PCL + LCL reconstructions alone were not significantly different than those with the native PCL. Mean PCL graft forces with POP and PFL reconstructions were not significantly different from each other; both means were significantly less than those for the PCL + LCL reconstructions alone at flexion angles greater than 55°.

Conclusions—After PCL and LCL reconstruction, the popliteus bypass and popliteofibular ligament reconstructions not only eliminated excessive posterior laxity and returned the knee to a normal laxity profile but also resulted in substantial decreases in PCL graft forces.

Clinical Relevance—These results provide further rationale for reconstructing torn posterolateral structures with a grade 3 posterolateral injury in combination with a PCL reconstruction.

Keywords

Posterior cruciate ligament; Posterolateral corner; Biomechanics; Popliteus; Popliteofibular ligament; Lateral collateral ligament

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Injuries to the posterolateral structures are commonly found in association with a posterior cruciate ligament (PCL) injury.[1–3] Normally, ruptures of the lateral collateral ligament (LCL) are easily recognized, and an anatomic graft reconstruction is straightforward to restore varus stability. However, additional injuries to the popliteus tendon (POP) and popliteofibular ligament (PFL) are often unappreciated. The POP has an origin on the lateral femoral condyle and passes through the lateral capsule to a muscular insertion on the posterior surface of the tibia. The popliteus bypass reconstruction typically uses a tendon graft, with an origin at the POP footprint on the lateral femoral condyle, that passes beneath the lateral capsule and into a tunnel drilled approximately 1 cm beneath the lateral tibial plateau.[4,5] The PFL has an attachment to the styloid process of the head of the fibula and a diffuse connection to the posterolateral complex via attachment to the popliteus; it has no direct attachment to the femur.[6,7] The PFL reconstruction uses a tendon that originates at the POP footprint center and passes through a tunnel drilled at the fibular styloid; this reconstruction has direct bone to bone attachments, unlike the native ligament it is replacing.[8]

Prior biomechanical studies with applied posterior tibial force have shown that forces in the native PCL[9] and a PCL graft[10,11] increase significantly when the posterolateral structures are cut. However, there are relatively few biomechanical studies on posterior knee stability after the posterolateral structures have been reconstructed.[8,12–14] The purpose of this study was to measure the abilities of POP and PFL graft reconstructions to limit posterior tibial translation and alter forces in a PCL graft reconstruction in response to an applied posterior tibial force after PCL and LCL reconstruction. We hypothesized that significant differences exist between PCL/LCL reconstructions, PCL/LCL + POP reconstructions, and PCL/LCL + PFL reconstructions.

METHODS

Fifteen fresh frozen cadaveric knees were used for this study. The mean age was 35.1 years (range, 17 to 65); 13 were male and 2 were female. The femoral origin of the posterior cruciate ligament was mechanically isolated by using a cylindrical coring cutter. The cap of bone containing the ligament footprint was incorporated into a cast cylindrical construct of polymethylmethacrylate acrylic, which contained a threaded metal core for attachment to a load cell.[15] With this technique, the bone cap remained in its anatomic position. The load cell was specifically designed and fabricated in our laboratory to record 3 components of force applied to the end of the bone cap by the ligament fibers. The resultant force was computed in real time from the 3 measured force components by the data-acquisition software.[16] Some displacement of the bone cap occurred as the ligament was loaded during the applied posterior force tests because of the inherent flexibility of the load cell construct. However, the bone cap never contacted the tunnel wall, ensuring that all force applied to it was recorded by the load cell. The error in computed resultant force has been estimated to be less than 9%. During anterior-posterior (AP) laxity testing, a precisely sized spacer was inserted into the gap between the cylindrical bone cap construct and wall of the tibial tunnel to prevent relative motion between the 2 as posterior force was applied.

AP laxity testing with 200 N of applied anterior and posterior applied tibial force was performed with the posterior cruciate ligament intact at 0°, 10°, 30°, 45°, 70°, and 90° of flexion. At each flexion angle, the tibia was locked at its midrange of internal-external tibial rotation during testing.[17] Resultant posterior cruciate ligament force was recorded as the knee was passively extended from 120° to 0° with a 100-N posterior tibial force. The testing apparatus used to apply these tibial loads was specially designed and has been used in prior studies from our laboratory.[18]

The PCL was cut, and a single-bundle tibial inlay PCL graft reconstruction was performed using a 10-mm patellar tendon allograft obtained from a tissue bank (Musculoskeletal Transplant Foundation, Edison, NJ). The femoral end of the graft was placed in the anatomic footprint of the PCL's anterolateral bundle. The PCL graft was tensioned to restore AP laxity at 200 N to within ±1 mm of the intact knee at 90° of flexion. After the PCL reconstruction, the popliteus tendon was released from its femoral origin, and the LCL and PFL were cut creating a grade 3 posterolateral corner injury. The LCL was reconstructed by using a portion of an Achilles' tendon allograft obtained from a tissue bank (Musculoskeletal Transplant Foundation). A 1 cm × 1 cm calcaneal bone block was fixed into a square mortised recess centered over the LCL's femoral footprint. The tissue was sized to fit within a 6-mm tunnel drilled at the LCL's fibular insertion. A high-strength, low-stretch synthetic fish line, sutured into the free end of the graft tissue by using a whip stitch, passed through a split clamp attached to the posterior tibia (Fig 1).

Another portion of the same Achilles' tendon allograft was fixed into a square recess near the POP's femoral footprint; the tissue was sized to fit within a 7-mm tunnel. This graft was used for both POP and PFL reconstructions. When used as a PFL graft, the tendon entered a tunnel drilled into the styloid of the fibula (Fig 1). When used as a POP graft, the tendon passed into a tibial tunnel 1 cm inferior to the lateral tibial plateau; the suture line attached to the free end of the graft passed through a separate split clamp on the anterior tibia (Fig 1).

To select isometric femoral locations for the LCL and POP/PFL bone blocks, relative length changes were recorded between trial locations on the lateral femoral condyle and distal graft tunnel sites. A suture (fixed at a trial site) passed through the center of a metal cylinder placed in each tunnel and through a split clamp. A dial caliper was used to measure the relative length change between the split clamp and a forceps attached to the suture at a fixed distance from the split clamp. An optimum isometric femoral point for both grafts was selected based on minimum relative length change of the suture (i.e., the most isometric point on the surface of the lateral femoral condyle) as the knee was taken through a 90° range of motion. The bone block was placed such that the leading edge of the graft tissue on the bone block was centered over the OIP; the surface of the bone block was flush with the surface of the lateral femoral condyle. For the LCL reconstruction, the center of the 1 cm × 1 cm calcaneal bone block was located (on average) 2.4 mm anterior to the anatomic center of the LCL femoral footprint. For the POP and PFL reconstructions (same graft used for both), the mean bone block center was 2.7 mm proximal and 11 mm anterior to the POP footprint center. Mean relative length changes of in situ LCL, POP, and PFL grafts with these bone block placements were less than 1.5 mm from 0° to 90° flexion.

The LCL graft was then tensioned to 30 N and fixed at 30° of flexion with the tibia locked in neutral rotation. AP laxity tests and posterior tibial loading tests were repeated with (1) PCL + LCL grafts alone, (2) PCL + LCL + POP grafts, and (3) PCL + LCL + PFL grafts; the order of adding POP and PFL grafts was randomized. The POP and PFL grafts were also tensioned to 30 N at 30° of flexion for these tests. Data were recorded first with the POP or PFL graft tensioned and then with the tension released. Details of the load cell installation, PCL graft placement, PCL graft tensioning, and specimen testing can be found in prior publications from our laboratory.[18,19]

A repeated-measures analysis of variance, with pair-wise comparisons, was used to analyze differences in mean graft forces and laxities between the following test conditions: intact knee, PCL + LCL reconstructions, PCL + LCL + POP reconstructions, and PCL + LCL + PFL reconstructions. The level of significance was $P < .05$.

RESULTS

PCL + LCL reconstructions alone matched intact knee laxities between 20° and 90° of flexion; mean laxity was 3.3 mm greater than intact at 0° and 2.1 mm greater at 10° (Table 1). Mean laxities with the PCL + LCL + POP and PCL + LCL + PFL reconstructions were not significantly different from those for the intact knee or from each other (Table 1). The addition of a POP reconstruction to PCL + LCL graft reconstructions significantly reduced AP laxities at all flexion angles; mean laxity reductions ranged from −1.5 mm (0°) to −1.3 mm (90°) (Table 1). Mean laxity reductions with the PFL reconstruction were not significantly different than those with the POP reconstruction (Table 1).

Mean PCL graft forces with the PCL + LCL reconstructions were not significantly different than those with the native PCL at any flexion angle (Fig 2). Mean PCL graft forces with PCL + LCL + POP and PCL + LCL + PFL reconstructions were significantly less than those with a PCL reconstruction alone at flexion angles greater than 55°. Mean PCL graft forces with PCL + LCL + POP reconstructions were not significantly different from those with PCL + LCL + PFL reconstructions.

DISCUSSION

This study measured the abilities of posterolateral reconstructions to limit posterior tibial translation and reduce graft forces in the PCL + LCL reconstructed knee. Achilles' tendon grafts were used for all posterolateral reconstructions.

Protocols for tensioning posterolateral grafts are not well described in the literature. Lee et al.[20] tensioned a split graft used to reconstruct the LCL and PFL with the knee at 30° flexion and internal rotation. Sekiya and Kurtz[21] also used a split graft tensioned at 30° with valgus stress and an internal tibial torque. Stannard et al.[22] described a modified 2-tailed technique to reconstruct the POP and LCL: the graft was tensioned with the knee flexed to 30° and the foot internally rotated. None of these authors mention the level of graft tension applied or the amount of internal tibial rotation when the graft was tensioned. Our graft tension level of 30 N was thought to be a reasonable amount that would be applied to a posterolateral graft in clinical practice. The AP laxities and PCL graft forces measured in this study have relevance for the immediate postoperative period. Relaxation of tension in all grafts would be expected with time, which could result in slightly greater laxities than measured here.

Theoretically, a PFL graft should be slightly more effective in controlling posterior tibial translation than a POP graft because it is more favorably aligned to resist posterior tibial force. This was not observed because both grafts had equivalent effects on AP laxities and PCL graft forces for the same level of pretension. Although our study design did not permit testing with combined POP and PFL reconstructions, it is possible that dual reconstructions could produce even greater reductions in AP laxities and PCL graft forces than those measured here. Clinically, it is assumed that the ultimate goal of surgical reconstruction is to restore normal laxity and graft forces. After reconstruction in the clinical setting, there is likely some stretch out of the graft tissues that occurs postoperatively. Thus, it may be desirable to have some overconstraint at the time of surgery. However, it is currently unclear what amount of overconstraint (if any) is desirable on the operating room table.

Kanamori et al.[8] measured posterior tibial translations from an applied 134-N posterior tibial force before and after reconstruction of the POP with a doubled gracilis tendon graft; details of graft tensioning were not provided. The native PCL was intact for these tests. They reported that posterior tibial translations with the POP grafts were significantly less than those for the intact knee; mean decreases were −1.3 mm (0° flexion), −2.0 mm (30° flexion), and −2.8 mm (90° flexion). Corresponding decreases from adding a POP graft in our study (with a reconstructed PCL) were −2.4 mm (0° flexion), −2.4 mm (30° flexion), and −1.4 mm (90° flexion).

Nau et al.[12] measured posterior tibial translations from an applied 100-N posterior tibial force at 30° and 90° of flexion for knees in the intact state and with LCL + PFL and LCL + PFL + POP graft reconstructions (using semitendinosis tendons); the PCL was not reconstructed for these tests. The POP and PFL grafts were tensioned to 10 N at 30° flexion, with the tibia in neutral rotation. The LCL graft was tensioned to 10 N at 90°, with neutral tibial rotation. They found no significant differences in posterior tibial translations between intact knees, knees with all posterolateral structures sectioned, or knees with posterolateral reconstructions.

Nau et al.[13] measured posterior tibial translations from an applied 100-N posterior tibial force for knees before and after POP and POP + PFL graft reconstructions. The PFL and POP grafts were tensioned to 10 N at 30° flexion, with the tibia in neutral rotation. For these tests, the LCL was intact, and the PCL was reconstructed with a patellar tendon graft tensioned to 70 N at 90° of flexion. They found that the PCL reconstruction restored posterior tibial translations to normal levels at 30° and 90°. The addition of POP or POP + PFL grafts did not significantly change posterior tibial translations compared with the PCL reconstructed knee.

It is possible that the 10-N posterolateral graft tension used for both of Nau's studies[12,13] was not sufficient to produce the significant laxity reductions observed in our study in which POP and PFL grafts were tensioned to 30 N. It should also be noted that our laxity measurements were performed with ±200 N of applied tibial force, in contrast to the previously mentioned studies that recorded posterior tibial translations at 100 N of applied posterior tibial force.

Sekiya et al.[14] evaluated 10 cadaver knees that underwent double-bundle PCL reconstruction, popliteus tendon repair, and popliteofibular ligament reconstruction. Both posterolateral grafts were tensioned to 67 N at 30° of flexion. After combined double-bundle PCL and posterolateral corner reconstructions, posterior tibial translations at 134 N of applied posterior tibial force were significantly less than the intact knee at 0°, 30°, 60°, and 90°. Releasing the posterolateral grafts significantly increased posterior tibial translation at all 4 flexion angles; increases ranged from +1.6 mm at 0° to approximately 5 mm at 90°. Releasing the PLC reconstruction did not significantly affect force in the double-bundle PCL graft reconstruction.

There are important differences in methodology between the study by Sekiya et al.[14] and our current study that make direct comparison of results difficult. They used a double-bundle tibial tunnel graft reconstruction, whereas we used a single-bundle tibial inlay PCL reconstruction technique. They used the same level of PCL graft tension for all knees, whereas we used a laxity-match graft pretension strategy that resulted in the proper amount of tension applied to each PCL graft to restore AP laxity to within 1 mm in each knee. They used a robotic-UFS test system, whereas we used a custom knee-testing apparatus that allowed direct measurement of forces in the native PCL and the PCL graft reconstruction. In addition, they evaluated 1 method of PLC reconstruction, whereas we evaluated 2 similar methods and compared them.

There are experimental limitations to our tests that deserve comment. The distal end of the POP/PFL graft was whip stitched with a low-stretch synthetic fishing line (135-lb test). This particular line was selected because of its extremely low elongation under load. However, there was some unavoidable compliance of the whip-stitched graft composite as the posterolateral grafts were loaded. Visually, the stitched graft tissue appeared to be a rigid mass of string and tissue and any elongation under load appeared to occur within the graft tissue itself rather than within the stitched portion. We believe that this construct was stiffer than a surgical suture wrapped around a post but not as stiff as an interference screw fixed within a tibial or fibular tunnel. A stiffer construct would likely lead to more constraint of posterior tibial laxity.

Our AP laxity measurements were performed with tibial rotation locked in the midrange of internal-external rotation. This was done to simulate the clinical laxity examination in which straight posterior displacement of the tibia is desired. Even though a clinical examiner attempts to prevent tibial rotation during the test, some rotation is possible. Our in vitro test prevented tibial rotation, and laxity values could differ with unconstrained tibial rotation.

CONCLUSIONS

The popliteus bypass and popliteofibular reconstruction operations are normally performed to limit external tibial rotation. However, both reconstructions place the graft in an alignment favorable for restraining posterior tibial translation. We found that a knee with PCL + LCL reconstructions showed excessive AP laxity at 0° and 10° of flexion. The addition of either a POP or PFL reconstruction to PCL + LCL reconstructions eliminated this excessive laxity and returned the knee to a normal laxity profile. Both graft reconstructions acted to off load the PCL graft beyond 55° of flexion when a posterior force was applied to the tibia. This reduction in PCL force was substantial at 90° of flexion, averaging −52 N with the POP graft and −62 N with the PFL graft. This presents further justification for repairing and reconstructing torn posterolateral structures in the PCL reconstructed knee.

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References

1. Clancy WG Jr, Sutherland TB. Combined posterior cruciate ligament injuries. Clin Sports Med 1994;13:629–647. [PubMed: 7954888]
2. Fanelli GC, Edson CJ. Posterior cruciate ligament injuries in trauma patients: Part II. Arthroscopy 1995;11:526–529. [PubMed: 8534292]
3. Harner CD, Hoher J. Evaluation and treatment of posterior cruciate ligament injuries. Am J Sports Med 1998;26:471–482. [PubMed: 9617416]
4. LaPrade RF, Johansen S, Wentorf FA, Engebretsen L, Ester-berg JL, Tso A. An analysis of an anatomical posterolateral knee reconstruction: An in vitro biomechanical study and development of a surgical technique. Am J Sports Med 2004;32:1405–1414. [PubMed: 15310564]
5. Müller, W. The Knee: Form, Function, and Ligament Reconstruction. Berlin: Springer-Verlag; 1983.
6. Brinkman JM, Schwering PJ, Blankevoort L, Kooloos JG, Luites J, Wymenga AB. The insertion geometry of the posterolateral corner of the knee. J Bone Joint Surg Br 2005;87:1364–1368. [PubMed: 16189309]
7. LaPrade RF, Ly TV, Wentorf FA, Engebretsen L. The posterolateral attachments of the knee: A qualitative and quantitative morphologic analysis of the fibular collateral ligament, popliteus tendon, popliteofibular ligament, and lateral gastrocnemius tendon. Am J Sports Med 2003;31:854–860. [PubMed: 14623649]
8. Kanamori A, Lee JM, Haemmerle MJ, Vogrin TM, Harner CD. A biomechanical analysis of two reconstructive approaches to the posterolateral corner of the knee. Knee Surg Sports Traumatol Arthrosc 2003;11:312–317. [PubMed: 12937893]
9. Vogrin TM, Hoher J, Aroen A, Woo SL, Harner CD. Effects of sectioning the posterolateral structures on knee kinematics and in situ forces in the posterior cruciate ligament. Knee Surg Sports Traumatol Arthrosc 2000;8:93–98. [PubMed: 10795671]
10. Harner CD, Vogrin TM, Hoher J, Ma CB, Woo SL. Biomechanical analysis of a posterior cruciate ligament reconstruction. Deficiency of the posterolateral structures as a cause of graft failure. Am J Sports Med 2000;28:32–39. [PubMed: 10653541]

11. LaPrade RF, Muench C, Wentorf F, Lewis JL. The effect of injury to the posterolateral structures of the knee on force in a posterior cruciate ligament graft: A biomechanical study. Am J Sports Med 2002;30:233–238. [PubMed: 11912094]
12. Nau T, Chevalier Y, Hagemeister N, Deguise JA, Duval N. Comparison of 2 surgical techniques of posterolateral corner reconstruction of the knee. Am J Sports Med 2005;33:1838–1845. [PubMed: 16157848]
13. Nau T, Chevalier Y, Hagemeister N, Duval N, deGuise JA. 3D kinematic in-vitro comparison of posterolateral corner reconstruction techniques in a combined injury model. Knee Surg Sports Traumatol Arthrosc 2005;13:572–580. [PubMed: 15703964]
14. Sekiya JK, Haemmerle MJ, Stabile KJ, Vogrin TM, Harner CD. Biomechanical analysis of a combined double-bundle posterior cruciate ligament and posterolateral corner reconstruction. Am J Sports Med 2005;33:360–369. [PubMed: 15716251]
15. Markolf KL, Slauterbeck JR, Armstrong KL, Shapiro MS, Finerman GA. A biomechanical study of replacement of the posterior cruciate ligament with a graft. Part 1: Isometry, pre-tension of the graft, and anterior-posterior laxity. J Bone Joint Surg Am 1997;79:375–380. [PubMed: 9070526]
16. Markolf KL, Gorek JF, Kabo JM, Shapiro MS. Direct measurement of resultant forces in the anterior cruciate ligament. An in vitro study performed with a new experimental technique. J Bone Joint Surg Am 1990;72:557–567. [PubMed: 2324143]
17. Markolf KL, Burchfield DM, Shapiro MM, Davis BR, Finerman GA, Slauterbeck JL. Biomechanical consequences of replacement of the anterior cruciate ligament with a patellar ligament allograft. Part I: insertion of the graft and anterior-posterior testing. J Bone Joint Surg Am 1996;78:1720–1727. [PubMed: 8934488]
18. Markolf KL, Burchfield DM, Shapiro MM, Cha CW, Finerman GA, Slauterbeck JL. Biomechanical consequences of replacement of the anterior cruciate ligament with a patellar ligament allograft. Part II: Forces in the graft compared with forces in the intact ligament. J Bone Joint Surg Am 1996;78:1728–1734. [PubMed: 8934489]
19. Markolf KL, Feeley BT, Jackson SR, McAllister DR. Biomechanical studies of double-bundle posterior cruciate ligament reconstructions. J Bone Joint Surg Am 2006;88:1788–1794. [PubMed: 16882903]
20. Lee MC, Park YK, Lee SH, Jo H, Seong SC. Posterolateral reconstruction using split Achilles tendon allograft. Arthroscopy 2003;19:1043–1049. [PubMed: 14608330]
21. Sekiya, JK.; Kurtz, CA. Posterolateral corner reconstruction of the knee: Surgical technique utilizing a bifid Achilles tendon allograft and a double femoral tunnel; Arthroscopy. 2005. p. 1400.e1-1400.e5.Available online at www.arthroscopyjournal.org
22. Stannard JP, Brown SL, Robinson JT, McGwin G Jr, Volgas DA. Reconstruction of the posterolateral corner of the knee. Arthroscopy 2005;21:1051–1059. [PubMed: 16171629]
23. Markoff KL, Graves BR, Sigward SM, Jackson SR, McAllister DR. How well do anatomic reconstructions of the posterolateral corner restore varus stability to the PCL reconstructed knee? Am J Sports Med. In Press

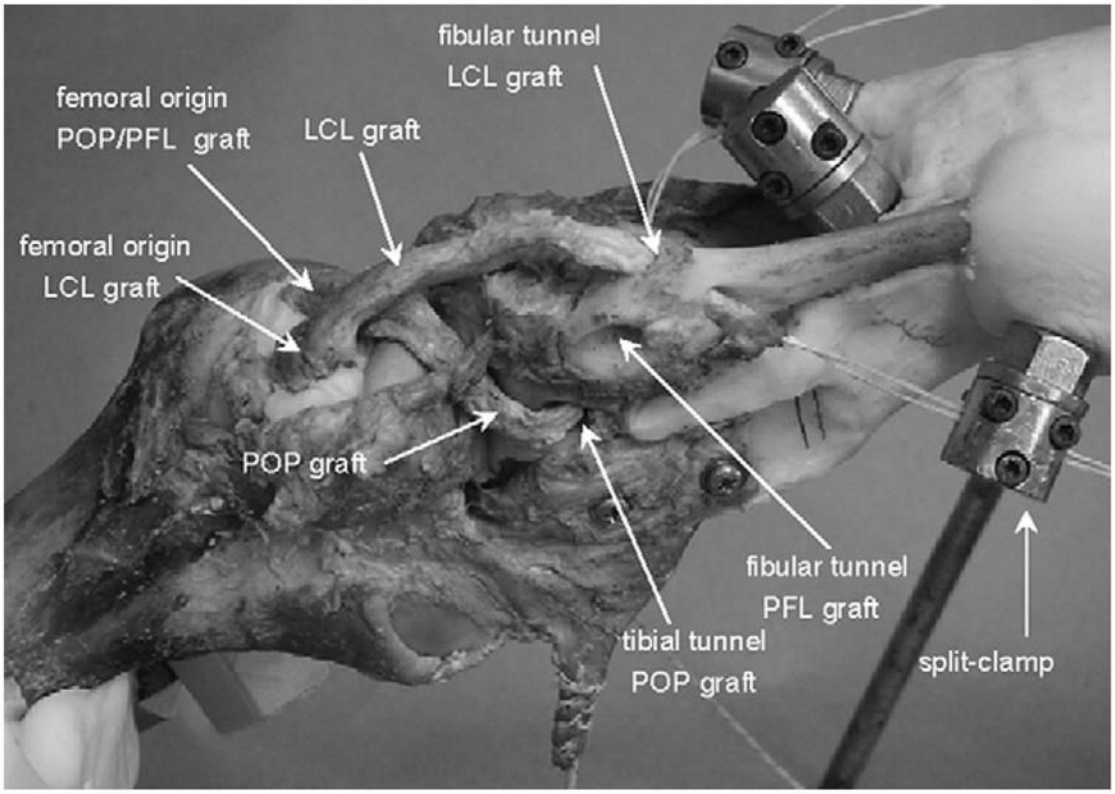

Figure 1.

The combined LCL + POP reconstruction; the femur is at the lower left and the tibia at the upper right. The bone block of the LCL graft is fixed on the lateral femoral condyle at the center of the LCL's native footprint; the distal end of the graft passes through a tunnel on the fibular head. Low-stretch lines sutured to the end of the graft pass through a split clamp for graft tensioning and fixation. The bone block of the POP graft is centered and fixed at the POP footprint on the lateral femoral condyle (shown anterior to the LCL the block) and passes through a tunnel drilled 1 cm inferior to the lateral tibial plateau. When used for a PFL reconstruction, the same graft passed through a tunnel drilled at the fibular styloid (shown near the tunnel for the LCL graft). (Reprinted with permission.[23])

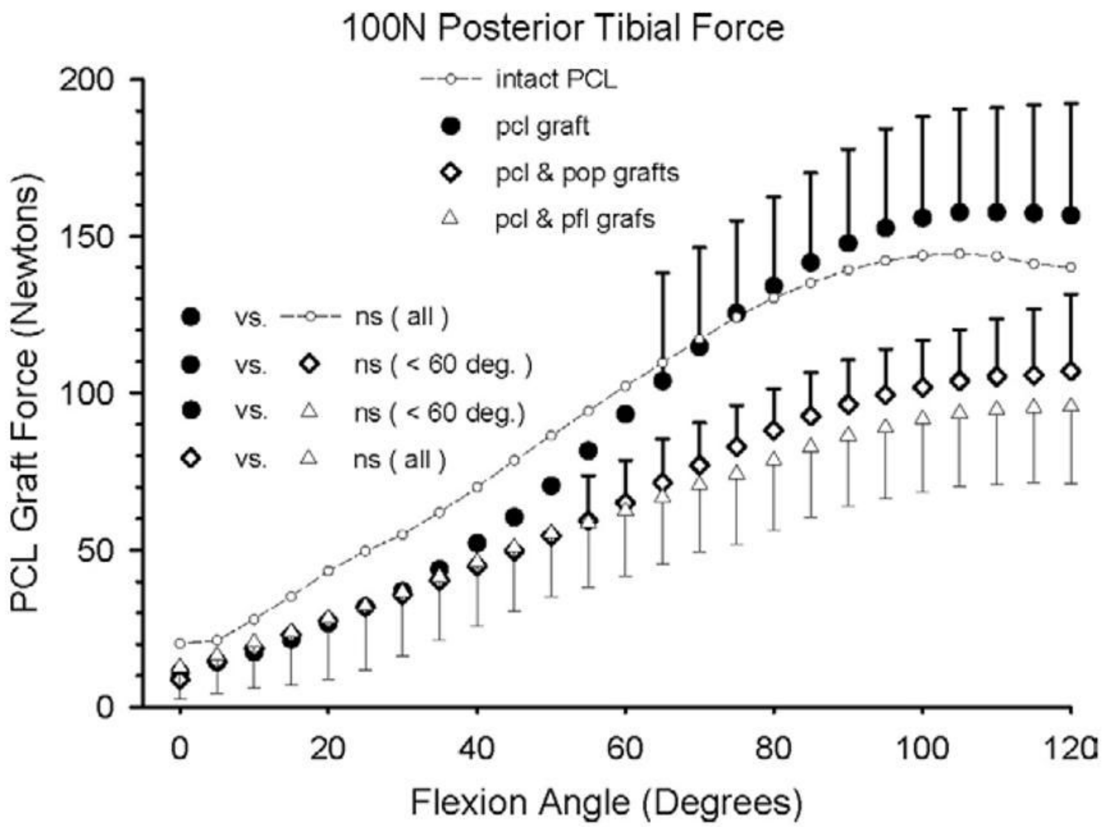

Figure 2.

Mean curves of resultant PCL graft force versus knee-flexion angle produced by application of a 100-N posterior tibial force. Mean curves are shown for (1) native PCL, (2) PCL + LCL grafts, (3) PCL + LCL + POP grafts, and (4) PCL + LCL + PFL grafts. All indicated comparisons between graph symbols are significantly different ($P < .05$) unless indicated by ns (not significant).

Table 1

Mean Anterior-Posterior Laxity Measurements (mm) at Various Knee-Flexion Angles in the Intact Knee After PCL Graft Reconstruction Alone, After PCL and POP Graft Reconstruction, and After PCL and PFL Graft Reconstructions

AP laxity (mm) Flexion angle	0°	10°	30°	45°	70°	90°
Intact knee						
Mean	9.1	12.4	14.2	13.8	12.8	12.8
SD	1.5	1.9	2.5	2.2	2.3	2.4
PCL + LCL grafts alone						
Mean	12.4†	14.5†	14.8	13.8	13.0	12.7
SD	2.9	2.4	2.7	2.2	1.5	1.5
PCL and POP grafts						
Mean	**10.9***	**11.9***	**12.5***	**11.7***	**11.6***	**11.4***
SD	**1.6**	**1.6**	**2.3**	**1.5**	**1.5**	**1.3**
PCL and PFL grafts						
Mean	**10.2***	**12.0***	**13.0***	**12.0***	**11.5***	**11.3***
SD	**2.9**	**1.9**	**2.2**	**1.7**	**1.3**	**1.1**

*Significant differences when compared with the PCL graft alone; they are shown in bold.

†Significant differences ($P < .05$) when compared with the intact knee.