LaPrade, R. F., Griffith, C. J., Coobs, B. R., Geeslin, A. G., Johansen, S., Engebretsen, L. (2014). Improving outcomes for posterolateral knee injuries. J*ournal of Orthopaedic Research, 32*, 485-491.

Improving Outcomes for Posterolateral Knee Injuries

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ABSTRACT

Until recently, the posterolateral corner of the knee was noted both for its complex anatomy and diagnostic challenges. To improve the understanding of the posterolateral knee, we completed a comprehensive and stepwise research program with a focus on five primary areas: (1) surgical approach and relevant anatomy; (2) diagnosis; (3) clinically relevant biomechanics; (4) natural history; and (5) surgical treatment. Based on this comprehensive research program, the diagnosis and outcomes following treatment of posterolateral knee injuries have been significantly improved comparing the preoperative state to the state of the knee at a minimum 2 year follow-up in the cases series presented here.

Keywords

posterolateral knee; fibular collateral ligament; popliteus tendon; popliteofibular ligament; varus stress X-rays; outcome studies

Treatment of injuries to the posterolateral corner of the knee has historically been challenging. Factors contributing to the difficulty in treating these injuries included poorly understood anatomy, ill-defined diagnostic techniques, and reconstructive procedures that were neither anatomically based nor biomechanically validated with reports of recurrent laxity and failures. Further, these often overlooked injuries commonly occur with cruciate ligament injuries, which frequently lead to cruciate ligament graft deficiencies and significant patient morbidity. [1] Few institutions were involved in the study and treatment of this complex problem. Our group therefore began a rigorous research approach to better understand and manage these difficult injuries. We started by reevaluating the qualitative and quantitative anatomy, investigating the clinically relevant biomechanics, and developing improved diagnostic techniques. Then, we developed and biomechanically validated anatomicbased reconstruction techniques. Finally, we confirmed the clinical utility of these anatomic-based reconstructions using patient based subjective and objective outcome measures.

CLINICALLY RELEVANT ANATOMY OF THE POSTEROLATERAL KNEE

Detailed qualitative and quantitative anatomic descriptions of the posterolateral knee were performed to improve the understanding of its intricate anatomy and serve as a foundation for anatomic-based surgical reconstructions. The qualitative studies were performed to define the surgical approach and relationships between structures.[2] The quantitative studies were performed to specifically define the landmarks, structure lengths, and provide a foundation for anatomic reconstructions.[3,4]

We found 28 separate structural components of the posterolateral knee.[2–5] For the fibular, or lateral, collateral ligament (FCL), we found that its femoral attachment was not to the lateral epicondyle, but rather to a small depression 1.4mm proximal and 3.1mm posterior to the lateral epicondyle.[4] This finding may explain the reported variations in outcomes for different surgical techniques because of the nonanatomic femoral attachment sites chosen for the FCL (Fig. 1). The FCL was most readily identified and accessed through a horizontal incision into the biceps bursa,[3] which has proven to be a valuable access point for surgical repairs and reconstructions of the FCL (Fig. 2).

The results of our biomechanical studies indicated that the popliteus tendon was an important primary static stabilizer against knee external rotation.[6] The average length of the popliteus tendon was 54.5mm (range, 50.5–61.2).[4] The most surgically relevant finding from our quantitative anatomy studies was that the average distance between the centers of the femoral attachment sites of the FCL and the popliteus tendon was 18.5mm[4] (Fig. 1). This clinically significant distance was an essential component to developing anatomic based surgical reconstructions. Furthermore, it demonstrated that reconstruction techniques that utilized a single femoral based graft for the FCL and popliteus tendon would result in nonanatomic locations for both structures, and be at a high risk for graft failure or overconstraint of the knee, similar to findings for nonanatomic cruciate ligament reconstructions.

Our quantitative definition of the popliteofibular ligament (PFL), previously called the arcuate ligament, clarified its course and attachments. We found that the PFL coursed from the musculotendinous junction of the popliteus in a distolateral direction at 38° from the vertical, and attached to the posteromedial aspect of the fibular styloid (Fig. 3).

DIAGNOSIS OF POSTEROLATERAL KNEE INJURIES

It has long been recognized that diagnosis of posterolateral knee injuries requires a synthesis of multiple clinical examination tests.[7–9] However, it is also recognized that many posterolateral injuries are either not recognized or misdiagnosed, necessitating a detailed assessment of clinical testing to improve diagnostic accuracy. No quantitative study of the correlation of PLC injury magnitude or associated ligamentous injury with lateral joint opening was available. Furthermore, specific clinical examination techniques had not specifically been analyzed for concurrent cruciate ligament injuries.

Development and Validation of Varus Stress Radiographs

Previously, the evaluation of lateral compartment gapping was solely subjective. Biomechanical studies that assessed the amount of varus that occurs with posterolateral knee structure sectioning had been performed,[10,11] although there were no studies that quantitatively measured the amount of increased lateral compartment gapping with applied loads. We performed a radiographic study of sequential sectioning of the FCL, popliteus tendon, and PFL.[12] Increased varus opening of 2.7mm was indicative of a complete tear of the FCL, while increased varus opening of 4mm or more was indicative of a grade III posterolateral knee injury[12] (Fig. 4). This information was critical in demonstrating that both the commonly used AMA and IKDC guidelines were primarily subjective and overestimated the amount of gapping present with a grade III posterolateral knee injury. Thus, we demonstrated that future posterolateral knee clinical studies would benefit from preoperative and postoperative varus stress radiographs for objective assessment of laxity.

MRI Protocols for Posterolateral Knee Injuries

Improved MRI diagnostic techniques were necessary to increase diagnostic accuracy and quantify postoperative treatment results more effectively. Since the majority of the important posterolateral structures attach to the fibular head and styloid,[2,4,5] it was essential to include this region on MRI scans. The posterolateral knee MRI technique we developed utilized a high field MRI scanner with 2mm slices that included the entire fibular head and styloid. Further, the addition of a coronal oblique imaging technique, angled along the course of the popliteus tendon, was demonstrated to provide the best view of these structures.[9]

We then performed a prospective study comparing the MRI appearance to the gold standard of arthroscopic and open surgery for 20 patients with grade 3 posterolateral knee injuries.[9] We validated that this MRI technique was effective for identifying posterolateral knee injuries and it is now utilized by most centers that treat complex knee injuries[9,13] (Fig. 5).

DEVELOPMENT OF AN IN VIVO NATURAL HISTORY MODEL OF POSTEROLATERAL KNEE INJURIES

While it has been commonly accepted that grade 3 posterolateral corner injuries do not heal, and patients with this injury pattern who are not treated develop functional limitations and osteoarthritis,[14] until recently, there was no animal model to verify this observation. We chose to develop an animal model to test these observations and establish the natural history of untreated posterolateral knee injuries.

We first attempted to utilize the rabbit and goat animal models for posterolateral knee ligament injuries. [15–19] Unfortunately, due to the small size of the rabbit and a fused tibiofibular joint in the goat, these were unsuccessful models for study of this injury pattern. Ultimately, the canine knee was chosen for an animal model, and the bony and soft tissue anatomy was studied in detail.20 First, we verified that the canine knee had an articulating tibiofibular joint, the lateral tibial plateau was convex in shape, and that the canine posterolateral structures were similar to the human knee20 (Fig. 6). Subsequently, an in vivo study of surgically induced posterolateral instability (without a violent injury mechanism) was performed. Early arthritic changes were found at 6 months postoperatively on both histologic and 7 T MRI T1 rho analysis in the medial compartment of the canine knee.[21,22]

Three important conclusions were drawn from these animal models of posterolateral instability. First, we validated that grade 3 posterolateral injuries did not heal. Second, we identified a possible explanation for the difference in healing of medial versus posterolateral knee injuries in humans. We believe the two convex opposing surfaces of the femur and tibia in the lateral compartment creates an inherent bony instability precluding posterolateral injury healing whereas the concave medial tibial plateau is inherently stable due to articular congruency, supporting injury healing. Finally, we confirmed that the laxity due to an injured posterolateral corner leads to medial compartment knee arthritis.

CLINICALLY RELEVANT BIOMECHANICS OF THE POSTEROLATERAL KNEE

An essential clinical problem was that a large number of patients with chronic posterolateral knee injuries also had failed anterior and/or posterior cruciate ligament reconstructions. To determine if the untreated posterolateral injuries contributed to these ligament reconstruction failures due to combined instability, two studies were performed that evaluated the effects of untreated posterolateral knee injuries on forces in both ACL and PCL reconstruction grafts.

Our first study in a cadaveric model measured the forces on an ACL graft during applied loads following sectioning of the posterolateral structures. We found significant increases in forces on the ACL reconstruction graft for both varus loads and combined varusinternal rotation loads at 0° and 30° of knee flexion, which could contribute to ACL graft failure.[23] Thus, we confirmed our clinical observations and found that posterolateral knee injuries must be repaired or reconstructed concurrently with ACL tears to prevent ACL graft failure.

Our next study examined the effects of untreated grade 3 posterolateral corner injuries on forces in a posterior cruciate ligament (PCL) reconstruction graft.[24] Significant increases in force on the PCL graft were found for both varus loads and for coupled posterolateral rotation loads at all tested knee flexion angles.[24] A careful preoperative assessment for potential combined PCL and posterolateral knee injuries is needed in patients requiring a PCL reconstruction given the high risk for PCL reconstruction graft failure if the posterolateral knee injury is not concurrently treated.[24]

DEVELOPMENT OF ANATOMIC BASED AND BIOMECHANICALLY VALIDATED POSTEROLATERAL KNEE RECONSTRUCTIONS

Based on our quantitative anatomy studies of the distance between the femoral attachments of the FCL and popliteus tendon[4] and the results from the aforementioned biomechanical studies,[25] we believed that an improved anatomic posterolateral knee reconstruction technique was necessary to both resume normal load sharing and also to restore the normal anatomic relationships among posterolateral knee structures. Thus, the development of our anatomic posterolateral corner reconstructions was driven by the results of our quantitative anatomy4 and biomechanical studies.[25]

Nine different reconstruction techniques were piloted to explore and validate the best method to restore normal knee kinematics. Prior to testing, the surgical approach was first performed on 10 whole cadavers to verify that it would be reliably surgically accessible and reproducible.[26] Once a reproducible reconstruction technique was devised, biomechanical testing was performed. In our technique, an Achilles tendon allograft was divided into two grafts with two separate bone plugs used to anatomically reconstruct the FCL, popliteus tendon, and PFL.[26]

Biomechanical testing in human cadaveric knees of our anatomic reconstruction technique was performed in the intact state, after structure sectioning, and following the anatomic posterolateral knee reconstruction. We demonstrated that our anatomic posterolateral reconstruction technique restored static laxity to the knee for all applied loads[26] (Fig. 7).

Development of an Anatomic FCL Reconstruction

It is well recognized that primary repairs of an isolated FCL tear were not always possible and that these patients may not require a full anatomic posterolateral knee reconstruction procedure.[26] Anatomic[4] and biomechanical studies[27,28] were utilized to determine a technique to anatomically reconstruct the fibular collateral ligament.

With the quantitative anatomy defined,[4] we performed a biomechanical study to determine the failure strengths of the posterolateral structures to determine the necessary strength for FCL reconstruction grafts.[28] We found that the average ultimate strength of the popliteus tendon was 700N and the FCL was 298 N. Comparing these results to those of other studies evaluating the failure strengths of human tendons,[29] we concluded that an autogenous semitendinosus graft would provide sufficient strength to reconstruct the FCL. Further, the semitendinosus tendon was preferred over a patellar tendon graft[30] because the average length of the patellar tendon was 48mm,[31] while the length of the native FCL was 71mm.[3] Thus, we concluded that a semitendinosus graft served as the best graft source around the knee to restore the native strength and length of the FCL.

We then developed and biomechanically validated an anatomic reconstruction of the FCL using a semitendinosus tendon.[27] Tunnels were placed at the anatomic attachment sites of the FCL on the femur and fibula. After fixation in the femoral tunnel, the graft was fixed in the fibular head with an interference screw at 20° of knee flexion, and with the knee in neutral rotation.[27] Biomechanical testing revealed that this anatomic FCL reconstruction restored the native function of the FCL to all applied loads[27] (Fig. 7).

CLINICAL OUTCOMES FOLLOWING TREATMENT OF POSTEROLATERAL CORNER INJURIES OF THE KNEE

Outcomes of an Anatomic Posterolateral Reconstruction for Chronic Posterolateral Injuries

Our two centers (the University of Minnesota and the University of Oslo) then performed a prospective outcomes study of 64 patients with grade 3 chronic posterolateral instability who had normal or corrected varus alignment treated with our anatomic posterolateral knee reconstruction technique.[32] Patients were evaluated using the Cincinnati subjective and IKDC objective scores[31]; 54 patients were available for follow-up at an average of 4.3 years postoperatively. The average Cincinnati score at follow-up was 65.7. Significant improvements were seen between the preoperative and postoperative IKDC objective parameters of varus opening at 20°, external rotation at 30°, reverse pivot shift and single-leg hop. Thus, we validated that our anatomic posterolateral reconstruction technique both restored objective laxity and improved patient outcomes.[31,32]

Outcomes of an Anatomic FCL Reconstruction

We subsequently performed a prospective study of 20 referral patients with an anatomic FCL reconstruction. Patients were evaluated preoperatively and postoperatively with the Cincinnati and IKDC subjective scoring systems, IKDC objective subscores for laxity, and varus stress radiographs.[33] Sixteen patients were available for follow-up at an average of 2 years postoperatively. The average preoperative Cincinnati score was 28.2 and the average IKDC subjective score was 34.7. Postoperatively, there was a significant improvement in both the Cincinnati score (to 88.5) and the IKDC subjective score (to 88.1). Preoperative varus stress radiographs demonstrated an average increased lateral compartment gapping of 3.9mm and at final follow-up, this average lateral compartment gap was reduced to _0.4mm.[31] Thus, we validated that an anatomic FCL reconstruction resulted in improved patient outcomes and objective laxity in patients with symptomatic grade 3 FCL tears.

Outcomes of Acute Grade 3 Posterolateral Knee Injuries

Recent studies of primary repairs of acute PLC injuries report failure rates of approximately 40%.[34,35] In 2005, we began a prospective study of patients with a grade-III PLC injury that were treated with an anatomic repair and/or reconstruction of all injured structures.[36] Midsubstance tears required a reconstruction, whereas avulsions were considered for repair with suture anchors. All patients were evaluated preoperatively with subjective questionnaires (Cincinnati and IKDC), IKDC objective evaluation, and varus stress radiographs; these assessments were repeated at regular intervals for all patients with >2 years of follow-up. The mean Cincinnati and IKDC subjective outcomes scores improved from 21.9 to 81.4 and from 29.1 to 81.5, respectively at an average of 2.4 years postoperatively. Varus stress radiographs improved from a side-to- side difference of 6.2mm preoperatively to 0.1mm at final follow-up. All IKDC objective subscores for posterolateral laxity were grade-A ("normal") except for the single patient that required a revision reconstruction. This study validated a treatment strategy for acute PLC injuries that included sound repair methodology for appropriate injuries combined with reconstruction of torn structures, according to techniques defined in our laboratory.[6,27,37,38]

CONCLUSIONS

Proper treatment of grade 3 posterolateral knee injuries requires a comprehensive understanding of the anatomy and clinically relevant biomechanics to synthesize the various clinical exams utilized to diagnose these injuries. The utilization of stress radiographs, MRI scans, or arthroscopy may be required to help confirm the diagnosis. Operative treatment of grade 3 posterolateral knee injuries is necessary to prevent residual laxity and the development of medial compartment osteoarthritis. Utilization of a hybrid of acute repairs and anatomic reconstructions for midsubstance injuries with grade 3 acute posterolateral knee injuries results in significantly improved patient outcomes. For chronic injuries, prior to any soft tissue reconstructions, correction of varus alignment is necessary to prevent subsequent failure of reconstruction grafts. Surgical treatment of chronic injuries should utilize anatomically based and biomechanically validated reconstructions to restore the patient's anatomy. Addressing both acute and chronic grade 3 FCL and posterolateral knee tears through biomechanically validated reconstruction techniques resulted in significantly improved patient subjective and objective outcomes comparing preoperative to postoperative results at a minimum 2-year follow-up. Further level 1 or 2 prospective studies comparing these anatomic-based techniques to other techniques are recommended. We believe our comprehensive research has clarified the ambiguities and misunderstandings related to this complex area of the knee and led clinicians to improved diagnoses, care, and outcomes for their patients.

ACKNOWLEDGMENTS

This research was partially supported by a Career Development Grant from the Orthopaedic Research and Education Foundation and Summer Medical Students Research Grants from the Minnesota Medical Foundation. None of the authors received anything of benefit related to the subject matter in this work.

The primary author wishes to express his extreme gratitude in respect to the Father of Sports Medicine, the late Jack Hughston, MD, who provided invaluable guidance and wisdom about how to base one's academic and surgical career. The step-by-step principles, which Dr. Hughston reviewed as dogma with Dr. LaPrade were followed in this manuscript and have led to novel reconstruction techniques and improved clinical outcomes. The authors wish to thank Glenn Terry, MD, Fred Wentorf, PhD, Andrew Tso, MS, Cathy Carlson, DVM, PhD, Thuan Ly, MD, Timothy Bollom, MD, Andrew Bernhardson, MD, Patrick Morgan, MD, Stanislav Spiridonov MD, Coen Wijdicks, PhD, and multiple other orthopedic surgery residents, fellows, and medical students for their assistance in this work over the last decade. The assistance of Conrad Lindquist is also greatly acknowledged for his engineering skills on multiple projects related to this work.

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Figure 1.

Femoral and fibular attachment sites of the popliteus tendon and fibular collateral ligament are outlined. (Reprinted with permission from Am J Sports Med. 2003; 31: 854–860.)

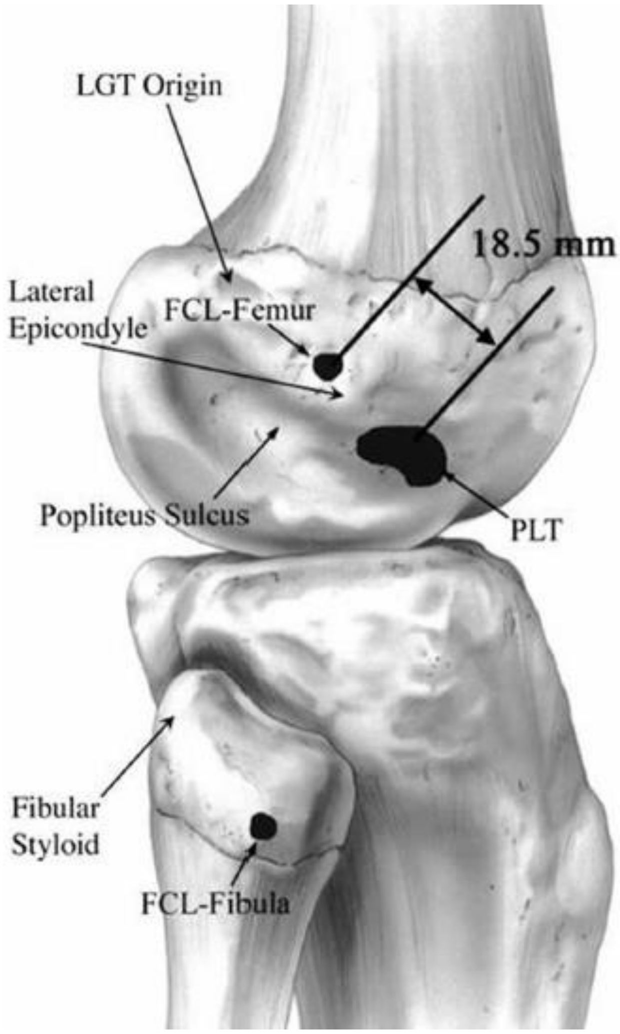


Figure 2.

Photograph of the course of the fibular collateral ligament between its femoral and fibular attachments. The suture is in the FCL at the biceps bursa and the forceps are holding the FCL near its femoral attachment (lateral aspect, left knee).

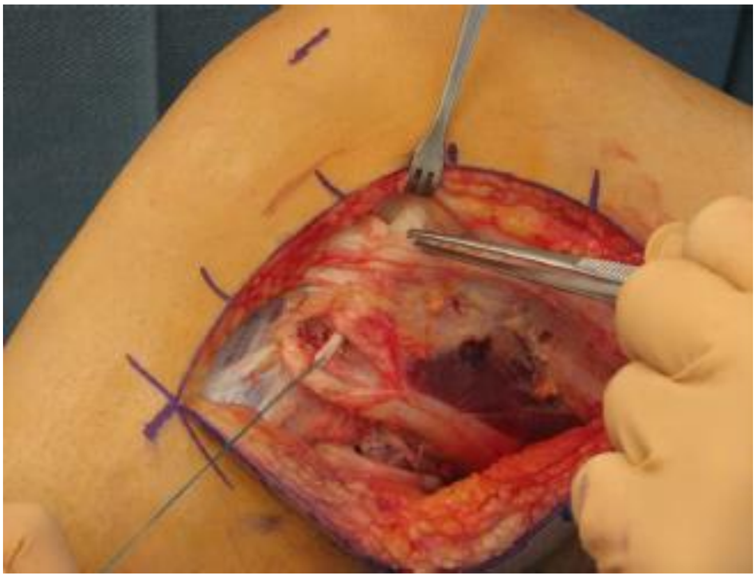
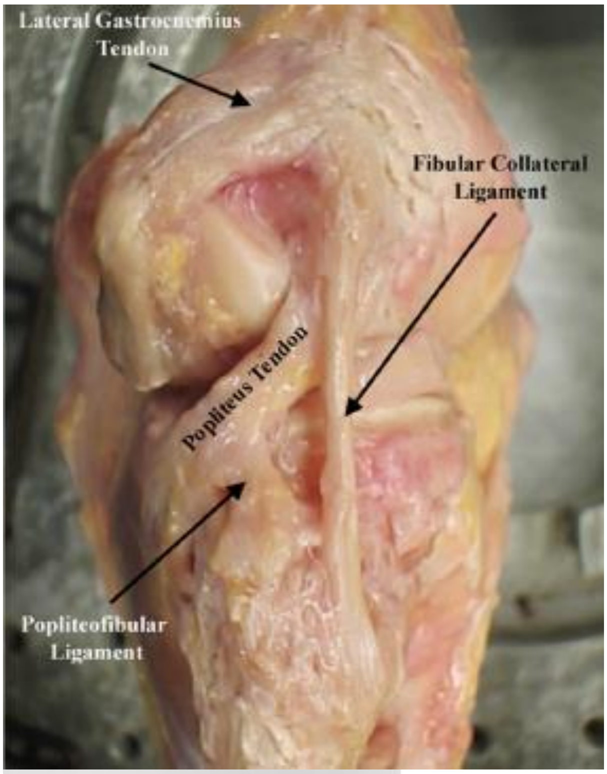


Figure 3

Photograph (a) and Illustration (b) demonstrating the isolated fibular collateral ligament, popliteus tendon, popliteofibular ligament, and lateral gastrocnemius tendon (lateral view, right knee). (Reprinted with permission from Am J Sports Med. 2003; 31:854–860.)



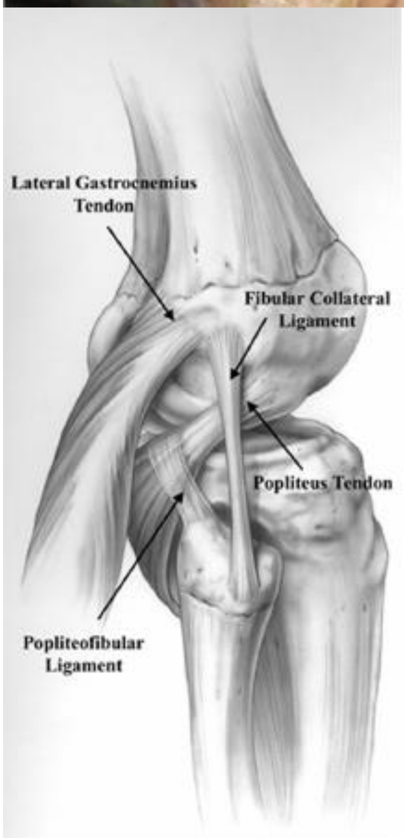


Figure 4

Varus stress fluoroscopic image made after lateral structure sectioning and measurement of lateral compartment gapping (note magnification grid) on the varus stress radiograph. (Reprinted with permission from J Bone Joint Surg 2008; 90:2096–2076.)

Figure 5
Coronal MRI demonstrating a tear of the fibular collateral ligament (left knee).

Figure 6
Photograph of the posterolateral corner of a canine left knee demonstrating the fibular collateral ligament (FCL), popliteus tendon (PLT), and popliteofibular ligament (PFL). The morphology of the main structures of the posterolateral canine knee is very similar to that of the human knee.

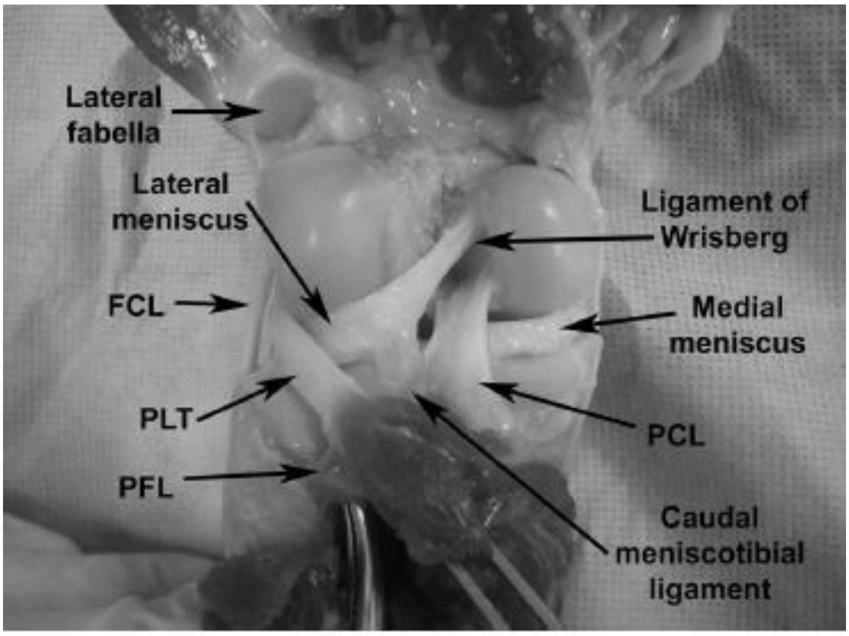


Figure 7
Forces measured on the fibular collateral ligament, popliteus tendon, and popliteofibular ligaments to an applied 5 Nm external rotation load. Note the reciprocal relationship to preventing external rotation between the fibular collateral ligament and the popliteus components. (Reprinted with permission from Am J Sports Med 2004; 32:1695–1701.)