Anatomy and Biomechanics of the Posterolateral and Posteromedial Corners of the Knee and Their Surgical Implications

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Posterolateral Corner Anatomy

Introduction

Injury to the posterolateral corner (PLC) of the knee is common; however, it may often be missed during a diagnostic workup due to the lack of understanding of PLC anatomy. The PLC consists of three primary static stabilizers: the fibular collateral ligament (FCL), popliteus tendon (PLT), and popliteofibular ligament (PFL; Fig. 3.1) [1, 2]. In addition, the iliotibial band, biceps femoris, and peroneal nerve are important surgical landmarks (Fig. 3.2). The common peroneal nerve is located approximately 2–3 cm posterior to the long head of the biceps femoris and must be protected during any PLC surgical procedure (Fig. 3.3). Recent advances in PLC anatomy have facilitated the development of anatomic-based repair and reconstruction techniques, which in turn have led to improved outcomes in patients following anatomic PLC repair and reconstruction procedures [3–7].

Fibular (Lateral) Collateral Ligament

The FCL courses proximal to distal along the lateral aspect of the knee and averages 69.6 mm in length [1]. The FCL proximal attachment is located on the femur in a small bony depression approximately 1.4 mm proximal and 3.1 mm posterior to the lateral epicondyle [1]. On anteroposterior radiographs, Pietrini et al. reported that the FCL femoral attachment was located 27.1 mm proximal to the femoral condylar line [8]. LaPrade et al. reported that the average distance between the FCL and PLT femoral attachments was 18.5 mm (Figs. 3.4 and 3.5). At its distal insertion, the FCL inserts 28.4 mm distal to the tip of the fibular styloid in a small bony depression that can be accessed through an incision in the biceps bursa (Fig. 3.6) [1]. On anteroposterior radiographs, the FCL was reported to attach 34.7 mm distal to the tibial plateau [8]. Supplemental FCL fibers have also been described and extend distally along the peroneus longus fascia.

Popliteus Tendon

The PLT emerges from the popliteus muscle in the lateral third of the popliteal fossa before becoming intra-articular and coursing proximolaterally around the lateral femoral condyle through the popliteal sulcus [1]. The PLT attaches on the anterior fifth and proximal half of the popliteal sulcus, deep and anterior to the FCL (Fig. 3.7). On radiographic anteroposterior views, the PLT has been reported to attach 14.5 mm proximal to the femoral condylar line [8]. On lateral radiographic views, the PLT attached 14.2 mm anterior to the femoral attachment of the FCL. As the knee cycles through flexion, LaPrade et al. reported that the PLT disengaged from the popliteal sulcus near extension and reengaged with the sulcus at 112° of flexion (Fig. 3.8) [1]. The length of the tendon was also measured to be 54.5 mm from the popliteus musculotendinous junction to the femoral attachment.

Popliteofibular Ligament

The PFL originates at the musculotendinous junction of the popliteus muscle and consists of an anterior and posterior division [1]. The PFL extends distolaterally before inserting onto the fibular head. The anterior division inserts 2.8 mm distal to the tip of the fibular styloid on the anteromedial downslope. By contrast, the posterior division inserts 1.6 mm distal to the tip of the fibular styloid on the posteromedial downslope. The width of the posterior division is larger than the anterior division at 5.8 and 2.6 mm, respectively. On anteroposterior radiographic views, the PFL was reported to insert

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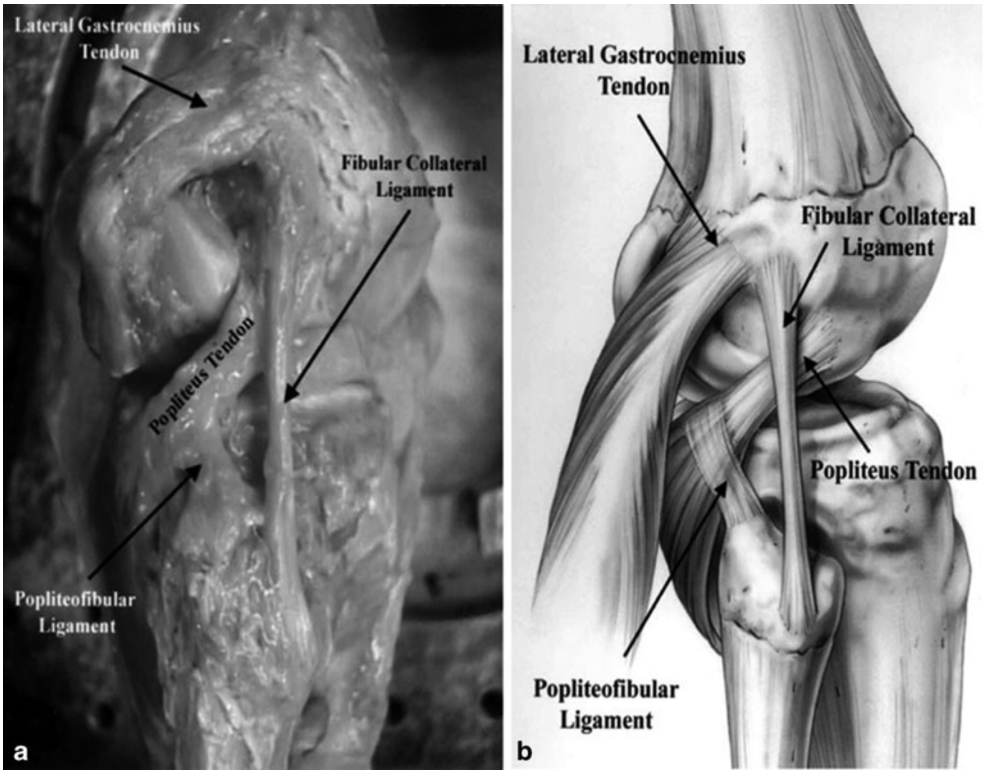


Fig. 3.1 A cadaveric photograph (**a**) and illustration (**b**) of the fibular collateral ligament, lateral gastrocnemius tendon, popliteofibular ligament, and popliteus tendon. (From LaPrade et al. 2003 [1]. Reproduced with permission)

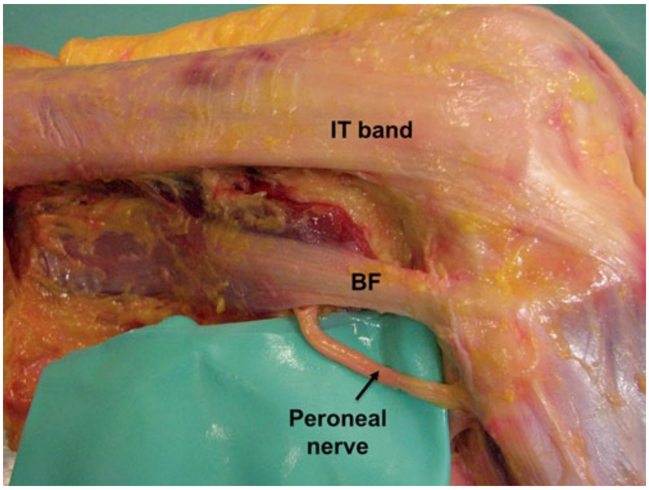


Fig. 3.2 A gross anatomic view of the lateral knee including the iliotibial band, biceps femoris, and peroneal nerve. *BF* biceps femoris, *IT band* iliotibial band

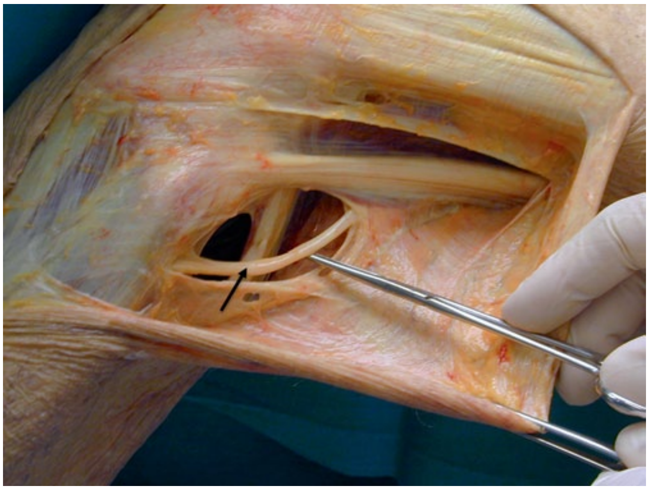


Fig. 3.3 The common peroneal nerve is located approximately 2–3 cm posterior to the long head of the biceps femoris and courses distally along the lateral aspect of the fibular head

21.0 mm distal to the tibial plateau joint line on the fibular head and 14.1 mm proximal to the fibular insertion of the FCL [8].

Summary

The primary PLC structures include the FCL, PLT, and PFL. Improved quantitative understanding of PLC anatomy has been essential for developing improved diagnostic techniques and anatomic-based repair and reconstruction techniques.

PLC Biomechanics

Introduction

In addition to basic anatomy, the biomechanics of PLC structures have been extensively studied. A comprehensive understanding of PLC biomechanics is necessary to understand the functional consequences of injury, develop improved diagnostics, and validate repair and reconstruction techniques. While the PLC consists of numerous static and

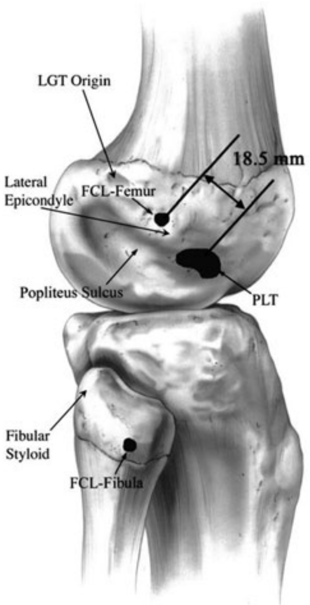


Fig. 3.4 The popliteus tendon and fibular collateral ligament femoral attachments are spaced by an average of 18.5 mm. (From LaPrade et al. 2003 [1]. Reproduced with permission)

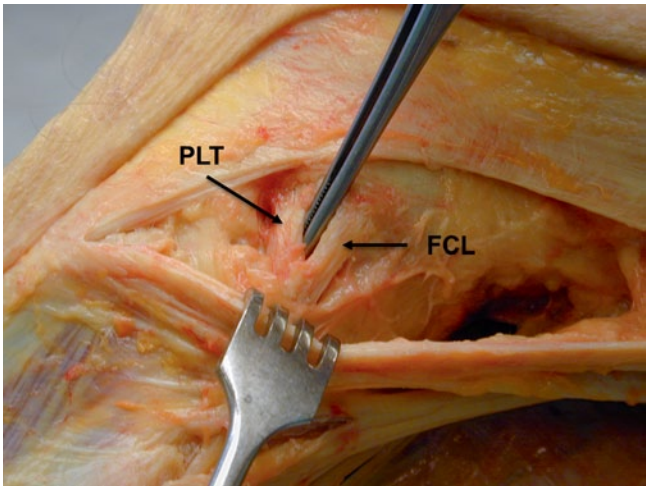


Fig. 3.5 The femoral attachment of the fibular collateral ligament is located through a longitudinal incision in the iliotibial band and is separated from the popliteus tendon attachment by 18.5 mm. *FCL* fibular collateral ligament, *PLT* popliteus tendon

dynamic components, this section highlights the biomechanical properties of the primary static stabilizers, including the FCL, PLT, and PFL.

Fibular (Lateral) Collateral Ligament

The FCL functions as the primary static varus stabilizer in the knee at 0 and 30° of knee flexion and a secondary stabilizer to external rotation [2, 9, 10]. When the FCL is injured, static varus stability is compromised, leading to a varus thrust gait pattern, medial compartment osteoarthritis, and medial meniscus tears [11]. LaPrade et al. reported that a clinician-applied varus stress resulted in an increase of 2.7 mm of side-to-side lateral compartment gapping after an isolated FCL tear [12]. In addition, Coobs et al. reported significantly increased varus rotation and internal rotation at 0, 15, 30, 60, and 90° of knee flexion and external rotation at 60 and 90° after sectioning of the FCL in comparison to the intact knee [13].

Popliteus Tendon

While the popliteus complex combines both static and dynamic functional components, the PLT functions in a ligament-like manner. Under a clinician-applied varus stress, sectioning of the PLT and FCL increased the lateral compartment by 0.8 mm in comparison to the isolated FCL sectioning [12]. The sectioning of both structures resulted in 3.5 mm of lateral gapping in comparison to the intact knee. Isolated sectioning of the PLT has also been reported to result in significant increases in external rotation at 30, 60, and 90° of knee flexion; internal rotation at 0, 20, 30, 60, and 90°; varus angulation at 20, 30, and 60°; and anterior translation at 0, 20, and 30° [7]. No significant differences were noted for posterior translation at any angle. These results lead the

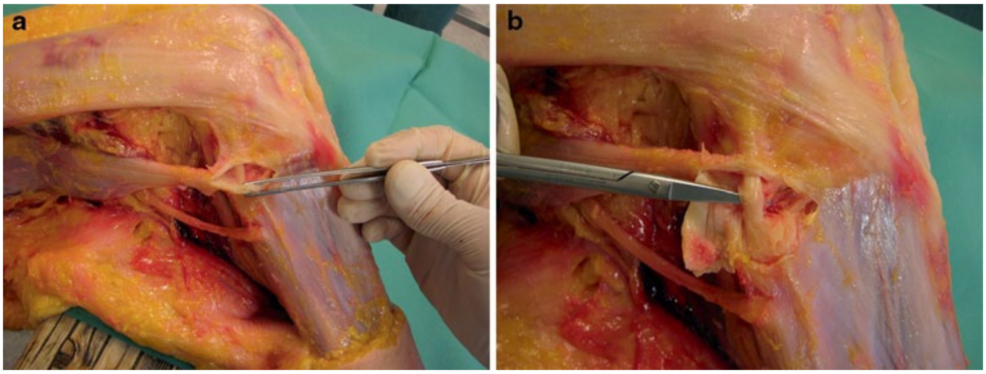


Fig. 3.6 Visualization of the distal FCL attachment is made through the biceps bursa (**a**) (*forceps*) and attaches along the lateral aspect of the fibular head (**b**) (*scissors*). *FCL* fibular collateral ligament

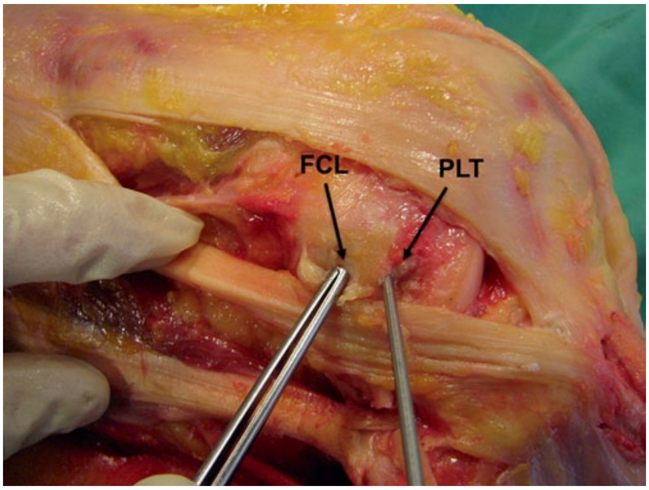


Fig. 3.7 A cadaveric photograph showing the relationship of the fibular collateral ligament and popliteus tendon footprints with both structures removed. *FCL* fibular collateral ligament, *PLT* popliteus tendon

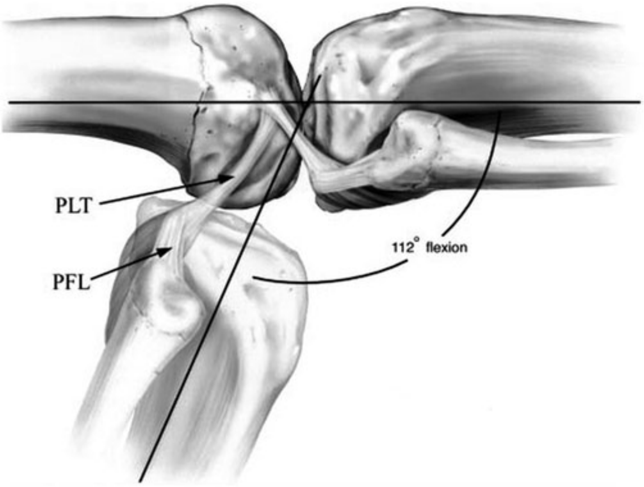


Fig. 3.8 The popliteus tendon engages with the popliteal sulcus at an average of 112° of flexion. (From LaPrade et al. 2003 [1]. Reproduced with permission)

authors to propose that the PLT functions as the "fifth ligament" of the knee by providing primary static stability to external rotation and performing a smaller but significant function with respect to internal rotation, varus angulation, and anterior translation. Therefore, repair or reconstruction of the PLT is essential to restore stability to patients with injuries in the PLC of the knee.

Popliteofibular Ligament

The PFL functions as a stabilizer for external rotation, especially from 30 to 60° of knee flexion [2, 14, 15]. In addition, the PFL functions as a secondary stabilizer against varus gapping with the most pronounced effect at 30° of knee flexion [15]. In light of these functional contributions, McCarthy et al. demonstrated that a PFL tibial component is required to reproduce native knee kinematics during a PLC reconstruction. LaPrade et al. reported that sectioning of the PFL, PLT, and FCL, representing a grade III posterolateral injury, resulted in increased lateral gapping of 4.0 mm in comparison to the intact knee [12]. A grade III posterolateral injury resulted in 0.4 mm of increased lateral gapping in comparison to the FCL- and PLT-sectioned state (PFL intact); however, this increase was not deemed to be significant.

Summary

Together, these three posterolateral structures function as essential stabilizers for the PLC of the knee. These structures limit varus laxity, tibial internal rotation, external rotation, and posterior translation. By understanding the biomechanics of posterolateral knee structures, the diagnosis of injuries is improved. In particular, the use of varus stress radiographs has been shown to yield reproducible results that may aid diagnosis of these injuries. Lastly, by understanding native knee biomechanics, repair and reconstruction techniques can be compared to the functional properties of various intact and sectioned states.

PLC Surgical Implications

Introduction

The PLC of the knee consists of both static and dynamic stabilizers that together provide stability to the lateral compartment of the knee. Injuries to the PLC structures are commonly associated with damage to numerous structures. It has been reported that 56% of PLC injuries include two or more of the major PLC structures, while 70% of PLC injuries are combined with an anterior cruciate ligament (ACL) tear [16]. Untreated PLC injuries often do not heal due to the convex-on-convex contours of the lateral femoral condyle articulating on the lateral tibial plateau, leading to residual instability and increased risk for medial compartment osteoarthritis (Fig. 3.9) [17]. In addition, biomechanical studies have reported that simulated PLC injuries significantly increase the forces on both ACL and posterior cruciate ligament (PCL) grafts [18, 19]. These increased forces after PLC injury have, therefore, been validated as contributors to graft failure after cruciate ligament reconstruction. For this reason, proper diagnosis is imperative to optimize outcomes in patients with isolated or combined PLC injuries to prevent secondary complications to other structures in the knee.

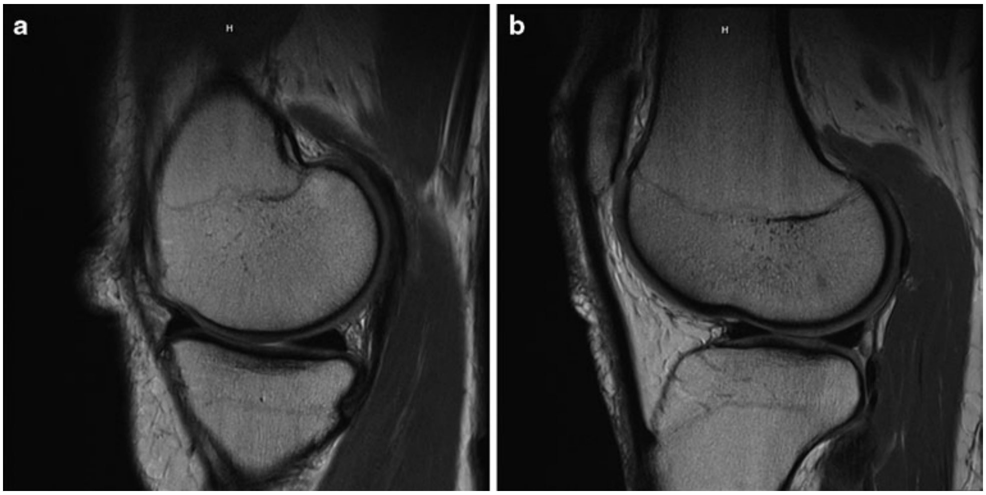


Fig. 3.9 **a** The medial tibiofemoral compartment has convex-on-concave articulating surfaces, providing increased stability to the medial compartment. **b** The lateral tibiofemoral compartment has convex-on-convex articulating surfaces creating an inherent degree of instability (**b**)

Physical Exam

A thorough physical examination of both the injured knee and uninjured knee is essential to diagnose PLC injuries. Inspection and palpation of the PLC should be performed followed by passive and active range-of-motion testing. Special tests include the posterolateral drawer test, dial test, varus stress test, reverse pivot shift test, and standing apprehension test [11]. The external rotation recurvatum test is used to assess for combined PLC and cruciate ligament injuries [20, 21]. Peroneal nerve dysfunction has been reported in 15 % of PLC injuries and must always be considered [22]. Nerve function is evaluated by looking for numbness in the first dorsal web space and weakness to dorsiflexion, foot eversion, and great toe extension. Two widely accepted classification systems for posterolateral knee injury include the Fanelli scale based on the location of injury [23] and the Hughston scale based on the grade of instability [24]. Finally, the results of physical examination can be used to determine injury patterns and develop a treatment plan.

Fig. 3.10 A long-leg radiograph demonstrating a varus weight-bearing axis (**a**); a close view showing the weight-bearing axis point passing medial to the medial tibial eminence (**b**)

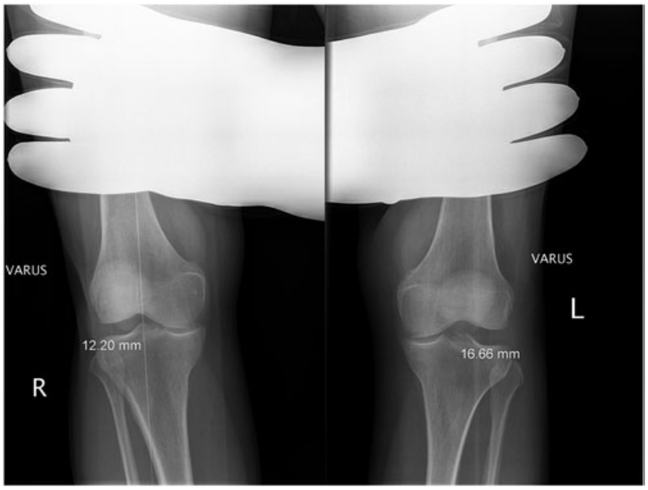


Fig. 3.11 Varus stress radiographs are an objective and a retrievable method of assessing lateral compartment stability

Imaging

Imaging is an important diagnostic tool to augment the assessment of posterolateral knee injury. Plain radiography is used to rule out the presence of avulsions and tibial plateau fractures. In chronic cases, long-leg radiographs should be obtained to assess for the presence of a varus mechanical axis deformity (Fig. 3.10). Varus stress radiographs at 0 and 20° offer an objective and retrievable assessment of lateral compartment gapping. The mean side-to-side difference in lateral compartment gapping in isolated grade III FCL injuries is 2.1 and 2.7 mm at 0 and 20°, respectively (Fig. 3.11) [12]. The side-to-side difference in lateral compartment increases to 3.4 and 4.0 mm in knees with a complete grade III PLC injury. In addition, intra- and interobserver reliability is high, indicating that varus stress radiography is a reliable tool in the diagnostic armamentarium [12, 25].

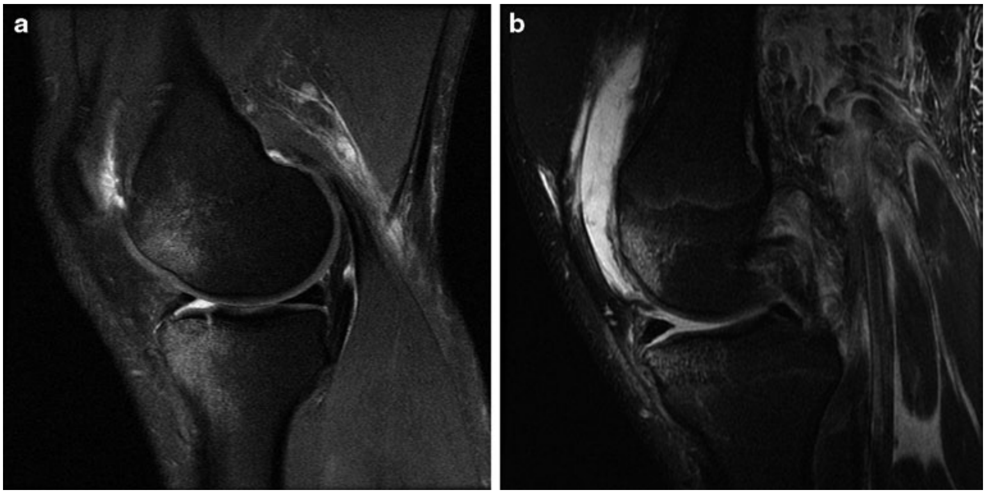


Fig. 3.12 Magnetic resonance images demonstrating bone bruising on the anteromedial femoral condyle (**a**) and bone bruising on the anteromedial femoral condyle plus a fracture on the anteromedial tibial plateau (**b**)

Magnetic resonance imaging (MRI) is essential to further assess PLC structural integrity in the FCL, PFL, PLT, cruciate ligaments, and medial and lateral menisci. High sensitivities have been reported for the detection of injury to the FCL and PLT femoral attachment (94.4 and 93.3 %, respectively); however, the sensitivity of the PFL has been reported to be much lower (68.8 %). In addition, while the FCL has been reported to have a specificity of 100 %, the femoral attachments of the PLT and PFL have been reported to have lower specificity values (80 and 66.7 %, respectively) [26]. It is also important to assess for the presence of bone bruise patterns on MRI, which often present as a secondary sign of a PLC injury (Fig. 3.12). In a prospective series of 102 acute PLC injuries, 55 % of patients had a bone bruise on the anterior aspect of the medial femoral condyle [4]. Together, imaging results should be synthesized with findings on physical exam to identify structural and functional deficits and to assist with formulating a treatment plan.

Surgical Indications

In acute injuries, primary repair of the PLT or FCL avulsions may be performed within the first 2–3 weeks after injury. Primary repair is contraindicated for midsubstance tears, with reconstruction yielding superior outcomes [27, 28]. Nonoperative management should be considered for the initial management of grade I and II injuries, focusing on edema management, range of motion, and quadriceps muscle exercises [11]. However, many patients with low-grade injury may not always present for treatment.

Patients with combined acute or chronic PLC and cruciate ligament injury should undergo posterolateral reconstruction to avoid recurrent instability and the risk of cruciate ligament graft failure [18, 19]. Therefore, PLC reconstruction functions in two major ways: (1) to eliminate symptomatic lateral knee instability that leads to increased stress on the medial compartment of the knee [4] and (2) to protect concurrent cruciate ligament reconstructions by limiting the strain on reconstruction grafts [18, 19].

While primary reconstruction is indicated in patients with acute grade III injuries [11, 29], limb alignment must be assessed first in patients with chronic posterolateral knee injuries. In chronically injured knees, limb alignment must be assessed during surgical planning. Failure to correct underlying varus alignment places the soft tissue posterolateral reconstruction grafts at a high risk of failure. When varus alignment is detected, a proximal tibial opening wedge osteotomy can be used, which resolved posterolateral instability without reconstruction in 38 % of patients in one case series [30].

Surgical Techniques

Grade III injuries to the FCL, PFL, and PLT almost always require repair or reconstruction. Numerous techniques have been described that can be divided into nonanatomic procedures, including the “arcuate complex” advancement [31], biceps femoris tenodesis [32], anterior or posterior tibialis allograft reconstruction [28], single femoral tunnel reconstruction [33], and anatomic procedures utilizing two femoral tunnels with or without popliteus bypass and PFL reconstruction [3, 34–36]. The authors prefer an anatomic reconstruction utilizing a split Achilles tendon allograft to reconstruct the FCL, PFL, and PLT, which has been validated to improve clinical outcomes after surgery [3, 5, 15].

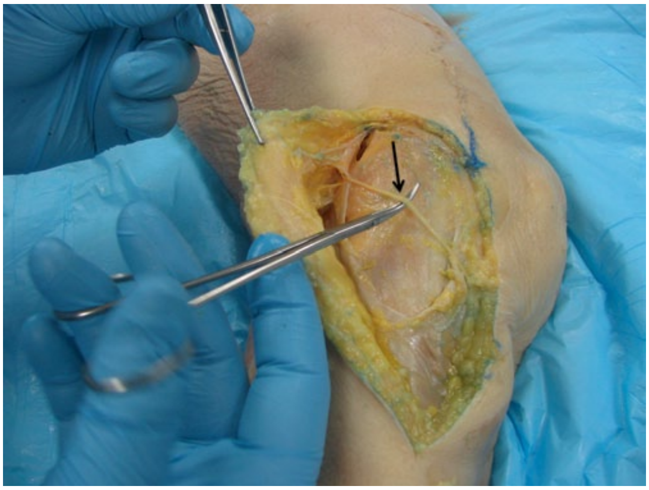


Fig. 3.13 The saphenous nerve courses across the medial aspect of the knee and may be at risk of iatrogenic injury during medial knee surgery (*arrow*)

Posteromedial Corner Anatomy

Introduction

The posteromedial corner (PMC) of the knee is a very commonly injured area of the knee. The most clinically relevant structures of the PMC are the superficial medial collateral ligament (sMCL), the deep medial collateral ligament (dMCL), and the posterior oblique ligament (POL) [37]. In addition, the saphenous nerve courses through the medial aspect of the knee and must be avoided during medial knee surgery (Fig. 3.13). The understanding of the anatomy of each of these ligamentous structures as well as relevant bony landmarks of the medial knee has continued to evolve, which has resulted in a more refined approach to repairing and reconstructing these ligaments.

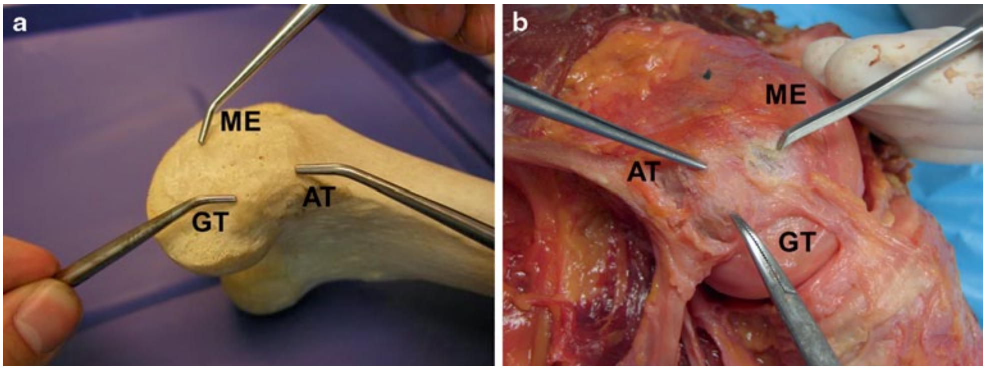
Medial Femoral Bony Landmarks

The qualitative and quantitative anatomy of the prominent femoral bony landmarks of the medial epicondyle, adductor tubercle, and gastrocnemius tubercle has helped to allay the confusion in the literature regarding the attachment sites of the PMC ligaments [38–41]. LaPrade et al. examined the relationship of all three bony landmarks and reported the qualitative and quantitative relationships among these structures [40]. The medial epicondyle is the most anterior and distal of the three medial bony landmarks (Fig. 3.14). The adductor tubercle is at the distal edge of the medial supracondylar line on the distal aspect of the femur, located 12.6 mm proximal and 8.3 mm posterior to the medial epicondyle. The newly described gastrocnemius tubercle can be referenced off either the medial epicondyle or the adductor tubercle. This structure is 9.4 mm distal and 8.7 mm posterior to the adductor tubercle and adjacent to a depression where the medial gastrocnemius tendon attaches. In addition, it can be located 6.0 mm proximal and 13.7 mm posterior to the medial epicondyle.

Superficial Medial Collateral Ligament

The anatomy of the sMCL was first reported by Brantigan and Voshell, which they termed the tibial collateral ligament [42]. The authors reported that the sMCL attached to the femur at the medial epicondyle and split into two separate attachments on the tibia. Later reports clarified that the sMCL has one femoral attachment and two tibial attachments (Fig. 3.15) [40]. The femoral attachment is located in a depression 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle and 26.8 mm proximal to the femoral joint line (Fig. 3.16). The authors reported that there was no functional attachment between the sMCL and dMCL or any bursae between the two structures. In addition, Wijdicks et al. reported the sMCL attachments in relation to radiographic reference points [43]. The femoral attachment of the sMCL was reported to be 30.5 mm distal to the femoral

Fig. 3.14 Bony medial knee landmarks (**a**–**b**) can be readily identified during a medial knee dissection. *AT* adductor tubercle, *GT* gastrocnemius tubercle, *ME* medial epicondyle



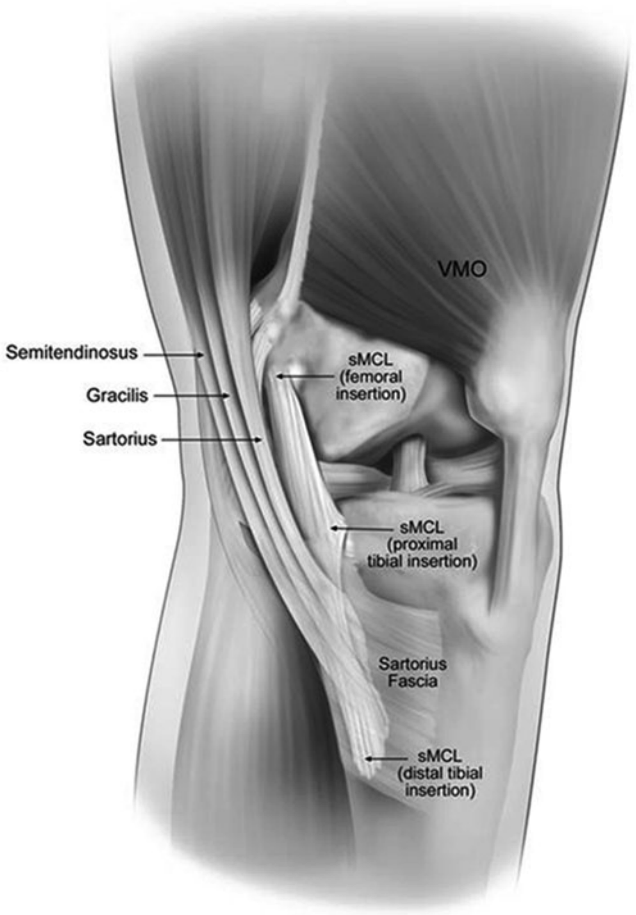


Fig. 3.15 An illustration of the anatomic orientation of the superficial medial collateral ligament, sartorius, gracilis, semitendinosus, and VMO. *sMCL* superficial medial collateral ligament, *VMO* vastus medialis obliquus

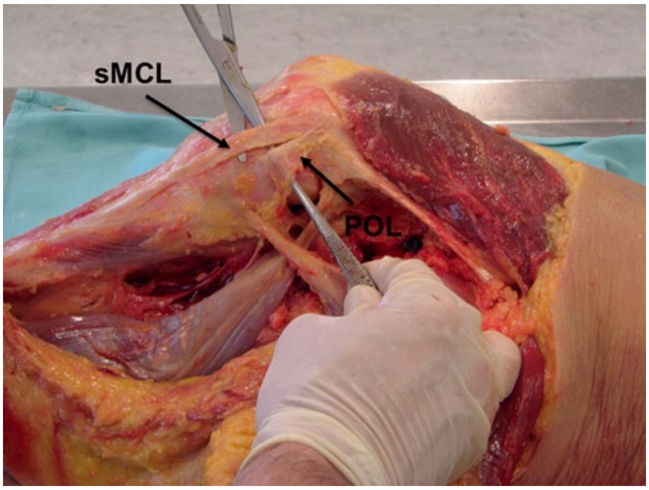


Fig. 3.16 The sMCL consists of one femoral and two tibial attachments; femoral attachments of other ligamentous and tendinous attachments in relation to the sMCL. *MGT* medial gastrocnemius tendon, *MPFL* medial patellofemoral ligament, *sMCL* superficial medial collateral ligament, *VMO* vastus medialis obliquus

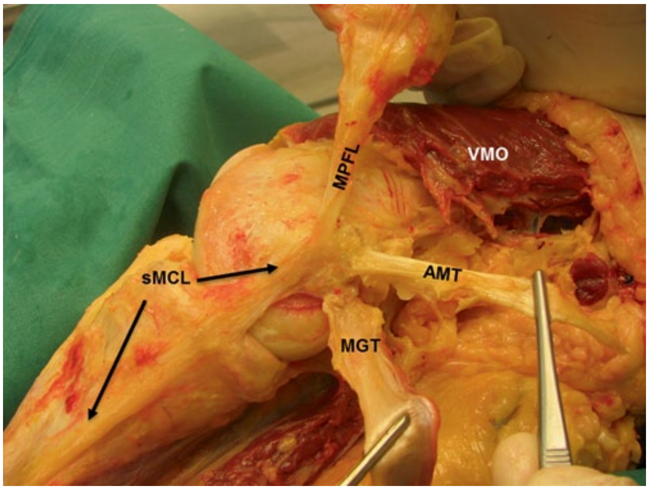


Fig. 3.17 The deep medial collateral ligament consists of a proximal meniscofemoral division and a distal meniscotibial division. *MF* meniscofemoral division, *MFC* medial femoral condyle, *MM* medial meniscus, *MT* meniscotibial division, *sMCL* superficial medial collateral ligament

condylar line on anteroposterior views and 6.0 mm from the medial epicondyle on lateral views.

The tibial attachments of the sMCL are separated from the tibia by the inferior medial genicular artery and vein, fascia, and adipose tissue [41]. The proximal attachment of the sMCL attaches primarily to the deep soft tissue, which was reported to mostly consist of the anterior arm of the semimembranosus tendon. LaPrade et al. reported that the proximal tibial attachment was 12.2 mm distal to the tibial joint line [40], and a similar distance of 11.2 mm distal to the tibial joint line was found on anteroposterior radiographic views [43]. The distal tibial attachment of the sMCL inserts anterior to the posteromedial crest of the tibia within the pes anserine bursa. This attachment was located 61.2 mm distal to the tibial joint line in one study. Wijdicks et al. reported that on anteroposterior radiographic view, the distal attachment was 60.1 mm distal to the tibial joint line [43].

Deep Medial Collateral Ligament

The dMCL is a distinct thickening of the medial joint capsule [40]. This thickening is most distinct along the anterior aspect of the joint capsule, which parallels the fibers of the anterior sMCL. LaPrade et al. reported that the dMCL is consisted of meniscofemoral and meniscotibial ligament components (Fig. 3.17). The meniscofemoral attachment of the dMCL is longer than the meniscotibial attachment and located, an average of 15.7 mm, proximal to the femoral joint line. The meniscotibial attachment, which was reported to be shorter and thicker, attaches only 3.2 mm distal to the tibial joint line.

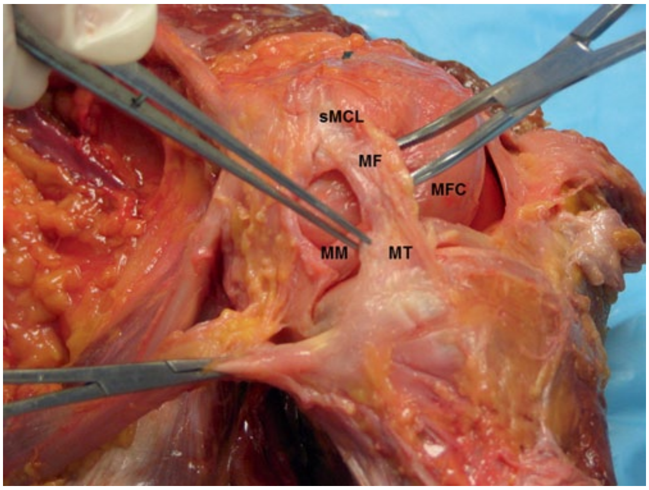


Fig. 3.18 The POL is located posterior to the sMCL and attaches adjacent to the gastrocnemius tendon. *POL* posterior oblique ligament, *sMCL* superficial medial collateral ligament

Posterior Oblique Ligament

The POL was originally considered to be confluent with and the posterior aspect of the sMCL [37, 38, 42, 44]. However, later reports by Hughston et al. defined the POL as a thickening of the capsular ligament that attaches proximally to the adductor tubercle and posterodistally to the tibia, which is anatomically and functionally distinct from the sMCL (Fig. 3.18) [39]. This study also differentiated the POL into three different arms: (1) the central arm that attaches adjacent to the articular cartilage of the posterior tibial plateau, (2) the superior or capsular arm that is continuous with the posterior capsule and the proximal oblique popliteal ligament, and (3) the inferior or superficial arm that attaches both distally to the soft tissue covering the semimembranosus tendon and distally to the semimembranosus tendon insertion. Current literature has quantitatively assessed the relationships of the POL to the main clinically relevant bony landmarks of the medial femur. The POL was found to be much closer to the newly defined gastrocnemius tendon than the adductor tubercle [40]. LaPrade et al. reported that the femoral POL attachment is 1.4 mm distal and 2.9 mm anterior to the gastrocnemius tubercle, and 7.7 mm distal and 6.4 mm posterior to the adductor tubercle. These findings were later confirmed radiographically [43].

The central arm is the largest and thickest portion of the POL [41], and it courses from the distal semimembranosus tendon to provide reinforcement to the posteromedial capsule and medial meniscus. The central arm may be differentiated from the sMCL due to the posterior orientation of its fibers, in comparison to the sMCL fibers that run anteriorly. Distally, the central arm is reported to attach to the posteromedial medial meniscus, meniscotibial dMCL, and posteromedial tibia without a direct bony attachment site.

The capsular arm and superficial arms of the POL are both much thinner than the central arm [37, 41]. The capsular arm is a thin fascial expansion off the anterior and distal semimembranosus tendon, which runs posterolateral to the meniscofemoral dMCL. The capsular arm has no osseous attachment and instead attaches to the soft tissue over the medial gastrocnemius tendon, adductor magnus tendon femoral attachment, and adductor magnus tendon expansion to the medial gastrocnemius. Lastly, the superficial arm of the POL is a thin fascial expansion that runs medially to the anterior arm of the semimembranosus. Proximally, the superficial arm courses into the central arm, while distally the superficial arm follows the posterior border of the sMCL until it blends into the distal tibial attachment of the semimembranosus tendon.

Summary

The sMCL, dMCL, and POL, all have a unique anatomy that in many cases, have only recently been clarified through quantitative studies. The authors believe that the three bony landmarks on the femur—the adductor tubercle, medial epicondyle, and the recently defined gastrocnemius tubercle—are essential for understanding the native anatomy of these structures. As with almost all structures in the knee, the knowledge of this anatomy is essential for developing repair and reconstruction techniques for after injury.

PMC Biomechanics

Introduction

An appreciation for the biomechanics of the posteromedial knee structures is critical for understanding which injured structures need repair or reconstruction. In addition, this understanding will allow for accurate intraoperative and postoperative assessment of the function of reconstructed structures. This section highlights the static and dynamic forces that the sCML, dMCL, and POL have on native knee function.

Superficial Medial Collateral Ligament

The sMCL is the largest medial knee structure, and is composed of proximal and distal divisions. These divisions are conjoined, but function as distinct structures [45, 46]. Sequential sectioning studies and force generation studies have demonstrated that the proximal division not only acts as a primary static stabilizer to valgus motion in all knee flexion angles, but also contributes to internal and external rotation restraint. The proximal division acts as a secondary restraint to external rotation at 90° of knee flexion, and a secondary internal rotation restraint at 0, 30, and 90°. The distal division of the sMCL is a primary stabilizer of internal rotation at all knee flexion angles, a primary stabilizer of external rotation at 30° flexion, and a secondary stabilizer of external rotation at 0, 20, and 60° of knee flexion [45]. In load response testing, the proximal division of the sMCL demonstrated force against valgus stress at all knee flexion angles [46]. However, the distal division of the sMCL varied its force depending on the knee flexion angle, with its highest valgus restraint force at 60° of knee flexion. Therefore, the two divisions of the sMCL function independently and share load depending on knee flexion angle and stress directions. Due to the separate functions of the two divisions of the sMCL, these structures must be treated as distinct ligaments in order to properly restore native knee function in injured ligaments.

Deep Medial Collateral Ligament

The dMCL also has two distinct divisions separated by the attachment to the medial meniscus [45, 46]. The meniscofemoral division of the dMCL functions as a primary restraint to internal rotation at 20, 60, and 90° of knee flexion; a secondary internal rotation restraint at 0 and 30° of flexion; a secondary valgus stabilizer at all knee flexion angles; and a secondary external rotation restraint at 30 and 90° of knee flexion. The meniscotibial division of the dMCL is a secondary valgus stabilizer at 60° of knee flexion, and a secondary internal rotation restraint at 0, 30, and 90° of knee flexion. Therefore, these divisions both have several roles in knee stabilization, but the only primary function is internal rotation restraint by the meniscofemoral division of the dMCL.

Posterior Oblique Ligament

The POL is a thickening of the joint capsule posterior to the MCL, which courses from anterosuperior to posterodistal. The main function of the POL is as a primary stabilizer of internal rotation at all knee flexion angles [45, 47]. It also serves as a secondary external rotation restraint at 30° of knee flexion, a secondary valgus stabilizer at 0 and 30°, and a restraint to posterior tibial translation in extension [37, 47]. Force studies have shown that the POL and sMCL have a shared load response at all knee flexion angles, with significant force generation in internal rotation, external rotation, and valgus stress [46, 48, 49]. This dynamic relationship displays the importance of both the sMCL and the POL in native knee mechanics.

Summary

Together, the two divisions of the sMCL, two divisions of the dMCL, and the POL function as distinct structures within the PMC of the knee. These are the primary knee structures to limit valgus laxity, internal rotation, external rotation, posterior tibial translation in extension, and anterior tibial translation at 90° of flexion. Due to the distinct functions of the individual structures, one must carefully evaluate each structure in an injured knee to properly determine which may need repair or reconstruction.

PMC Surgical Implications

Introduction

The PMC of the knee is a complex arrangement with several distinct structures and functions. Injuries to the medial knee are the most common ligamentous knee injury, and often occur with concomitant cruciate or PLC injury. One study showed that 22 of 23 (96%) patients with combined ACL and sMCL injuries also tore their POL. In addition, 8 out of 23 (35%) had complete PMC injury to the sMCL, dMCL, and POL [50]. Untreated laxity of the medial and posteromedial knee can result in subjective instability, higher stress on native or allograft ACLs and PCLs, and contribute to late cruciate ligament graft failure [47]. The sMCL is widely known to have an abundant vascular supply with strong healing potential [37, 47]. However, it remains unclear whether other structures of the PMC of the knee share this trait or are at higher risk of persistent laxity. Therefore, careful examination and imaging must be considered before a treatment plan is developed for medial knee injury.

Physical Exam

A comprehensive physical exam should be conducted to assess for osseous injury and to determine the integrity of all ligamentous structures of the knee. Initial inspection and palpation may reveal ecchymosis on the medial knee and tenderness to palpation over the superficial MCL or POL. Patients with medial-sided knee injury will have increased laxity with valgus stress. Specifically, the widest opening will be present at 30°, but can also be appreciated at full extension. Joint space opening on valgus stress testing with the knee at full extension indicates injury to the capsule, POL, or both [47]. Valgus opening at 30°, but not at 0°, makes POL injury less likely. A widely accepted grading system for medial knee injury is the American Medical Association Standard

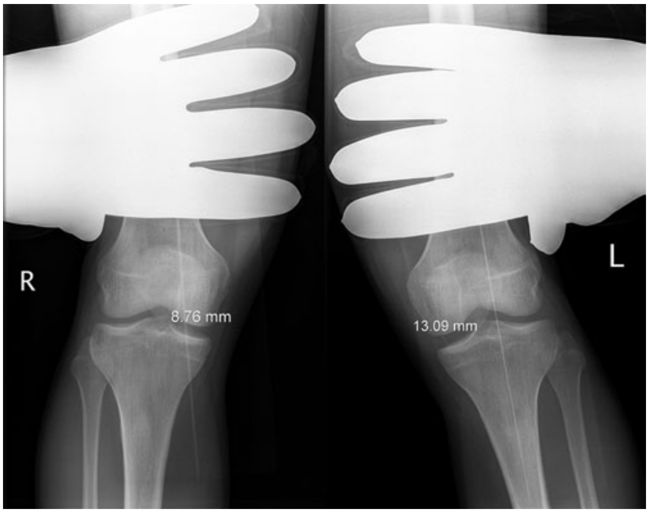


Fig. 3.19 Valgus stress radiographs offer an objective means to quantify medial compartment gapping and correlate with medial knee injury

Nomenclature of Athletic Injuries Scale [51]. In this system, grade I injury shows tenderness to palpation over the medial knee, but no laxity on valgus stress. Grade II injury displays partial tears of the medial knee and laxity with a firm endpoint, while grade III injury displays complete ligamentous disruption and subjective gapping to valgus stress. In addition, medial knee injury is qualitatively described by the grade 1+, 2+, and 3+ system. Grade 1+ has a subjective increase of 3–5 mm of valgus opening, 2+ has an increase of 6–10 mm, and grade 3+ has greater than 10 mm of medial opening with valgus stress compared to the contralateral side [51]. However, it is important to recognize that the American Medical Association (AMA) grading system is based upon subjective data and does not represent the true objective amount of medial compartment gapping with a medial knee injury which is most objectively documented with the use of valgus stress radiographs. The dial test, anteromedial drawer test, Lachman maneuver, posterior drawer test, and varus stress test should also be performed. The synergistic result of these maneuvers will display the likely pattern of injury and involved structures.

Imaging

Simple and advanced imaging modalities are important in the assessment of medial and PMC knee injury. Valgus stress radiographs at 0 and 20° are essential to objectively quantify valgus laxity. An isolated grade III sMCL injury has been reported to result in 1.7 and 3.2 mm of increased gapping with valgus stress at 0 and 20° compared to the contralateral side, respectively. With complete tear to both structures of the MCL and POL injury, valgus opening increases to 6.5 and 9.8 mm at 0 and 20°, respectively (Fig. 3.19) [52]. In addition, plain anteroposterior and lateral radiographs can rule out associated osseous injury, heterotopic ossification (Pellegrini-Stieda disease), tibial plateau fracture, or avulsion. In chronic cases, long-leg radiographs should be obtained to assess for the presence of a valgus mechanical axis deformity. MRI is critical to directly assess for medial-sided ligamentous integrity and to evaluate for concomitant ACL, PCL, and lateral-sided knee injury. Studies have reported that MRI can reliably predict MCL injury in 87 % of patients [53]. These results will confirm physical exam findings and aid in the development of a treatment plan.

Surgical Indications

Acute, isolated medial knee injuries have been clinically proven to have strong healing potential due to the robust vasculature of the sCML [54–56]. Numerous natural history studies have also reported a strong healing potential of the MCL when the other ligaments in the knee are uninjured [57–59]. Therefore, there is a general consensus that acute, isolated grade I, II, or III medial knee injuries should initially be treated nonoperatively with protected range of motion and an acute rehabilitation program. Combined ACL or PCL injury with grade I or II medial knee injury should first be treated conservatively to allow the medial and PMC to heal prior to surgical reconstruction of the cruciate ligaments.

Combined acute grade III injury to the medial knee with grade III gapping in full extension with an ACL or a PCL tear is often an indication for repair or reconstruction of the medial knee. Medial knee laxity may increase the risk of cruciate graft failure if untreated [37, 47]. Therefore, the medial knee must be repaired or reconstructed not only to correct symptomatic valgus instability but also to reduce the strains placed upon cruciate reconstruction grafts.

Chronic medial knee injury with symptomatic valgus laxity or severe, acute medial and posteromedial knee injury are also indications for surgical repair or reconstruction [37, 47]. In chronically injured knees, nonoperative management is unlikely to result in spontaneous healing and reconstruction is generally necessitated. In severe, acutely injured knees including disruption of the POL, nonoperative management is less likely to result in a return to native knee mechanics. Therefore, surgery may be considered depending on the characteristics of the patient and risk factors for surgery.

Surgical Techniques

In a PMC injury where the sMCL, dMCL, and POL are disrupted, repair or reconstruction is often necessary. Several techniques have been developed to reconstruct these ligaments including direct repair [39], primary repair with augmentation [60], pes anserine transfer [39, 61], and autograft or allograft reconstruction [62, 63]. If the POL is deemed repairable, the authors prefer acute repair of the POL with possible augmentation at full extension. If unrepairable, two allografts for reconstruction of both the sMCL and POL are performed [63]. The POL should be fixed at full extension and the sMCL at 30° of flexion according to previous biomechanical studies [44, 47, 63].

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