Knee Anatomy

1

Laurenie Louissaint
and Aditya Raghunandan

Learning Objectives

- To recognize normal anatomy of the knee adapting a layered approach.
- Understand the function of anatomical structures.

Introduction

Conceptually, the knee can be seen as being composed of two joints: the tibiofemoral joint and the patellofemoral joint. The overall stability of the knee is dependent on static (cruciate and collateral ligaments) and dynamic (hamstring muscles, extensor mechanisms, and the popliteus muscle) stabilizers, muscle attachment sites, menisci, the joint capsule, and the knee's bony topography. As we dive into its anatomy, readers will gain an understanding of how all these structures reinforce the knee stability and function.

L. Louissaint (✉)
Department of Human Performance and Rehabilitation, Icahn School of Medicine, Mount Sinai Hospital, New York, NY, USA

A. Raghunandan
Department of Rehabilitation Medicine, Long School of Medicine at the University of Texas Health Science Center at San Antonio, San Antonio, TX, USA
e-mail: raghunandan@uthscsa.edu

M. Leong et al. (eds.), *A Case-Based Approach to Knee Pain*,
https://doi.org/10.1007/978-3-031-15356-3_1

The Anterior Knee

Anterior Knee Joints

The knee is a hinged capsular joint with three separate articulations: the patellofemoral, medial, and lateral tibiofemoral joints (Fig. 1.1).

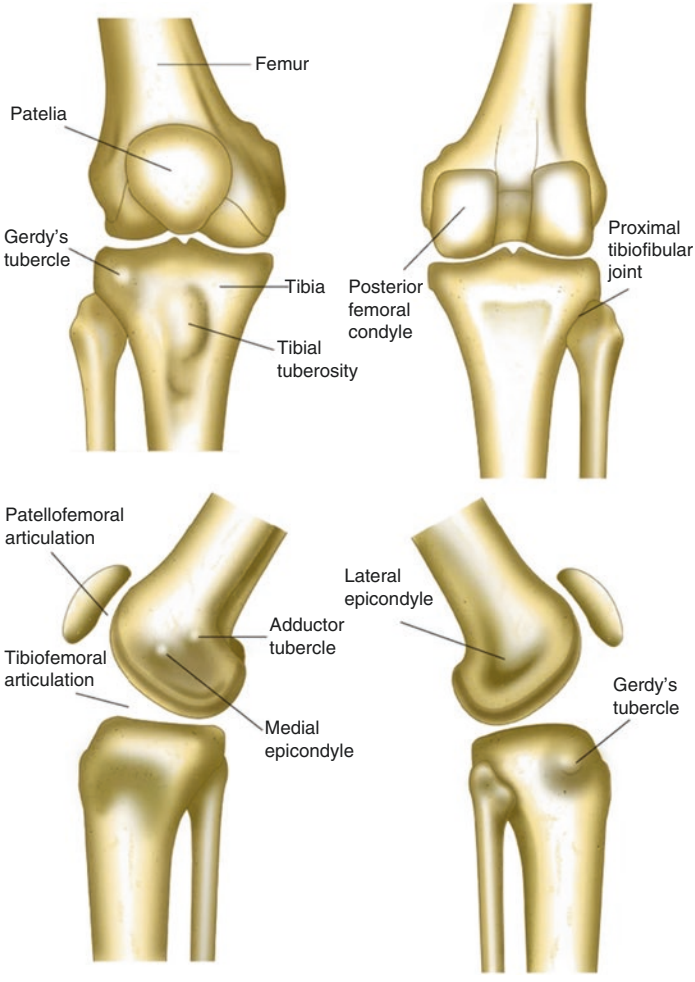

Fig. 1.1 Bones of the knee: anterior and posterior view, side view medial and lateral [3]

The tibiofemoral joint is a hinge joint that aids in some of the knee's primary functions, such as transmission of body weight from the femur to the tibia by allowing sagittal plane rotation and a small degree of tibial axial rotation [1]. The medial and lateral femoral condyles are the femur's distal convex surfaces that articulate with the tibia's medial and lateral tibial plateau, respectively. The medial tibial plateau has a concave articular surface while the lateral plateau has an anteroposterior convexity. This topography accounts for the "screw-home mechanism" or internal rotation of the femur, on the fixed tibia as the knee approaches extension [2].

The patellofemoral joint, a gliding joint, is the articulation between the patella and the femoral sulcus. The patella is the body's largest sesamoid bone. It has a concave superficial surface and an articular surface with a vertical central ridge that separates the medial and lateral facets which articulate with the femur. It has a distal attachment to the deep layer of the patellar tendon and a proximal attachment to the vastus intermedius [1].

Extensor Mechanism

The patellofemoral articulation is also referred to as the extensor mechanism, which is composed of the quadriceps muscle group, the patella, and the patellar tendon (Fig. 1.2). Disruption of any of these components impedes a person's ability to actively extend the knee or resist passive flexion.

The quadriceps muscle group forms the primary motor unit of the extensor mechanism. The rectus femoris merges with vastus medialis obliquus, vastus medialis, vastus lateralis, vastus lateralis oblique which terminate in an aponeurosis; these in turn merge into the anterior-third joint capsule's retinacular layer that extends to form the quadriceps tendon attachment to the patella [2]. The patellar tendon originates at the inferior pole of the patella and inserts at the tibial tubercle, the distal component of the extensor mechanism. Rectus femoris' attachment at the anterior inferior iliac spine allows it to also function as a hip flexor. The quadriceps muscle group is innervated by the femoral nerve (L2–L4) and receives vascular supply from femoral artery [5].

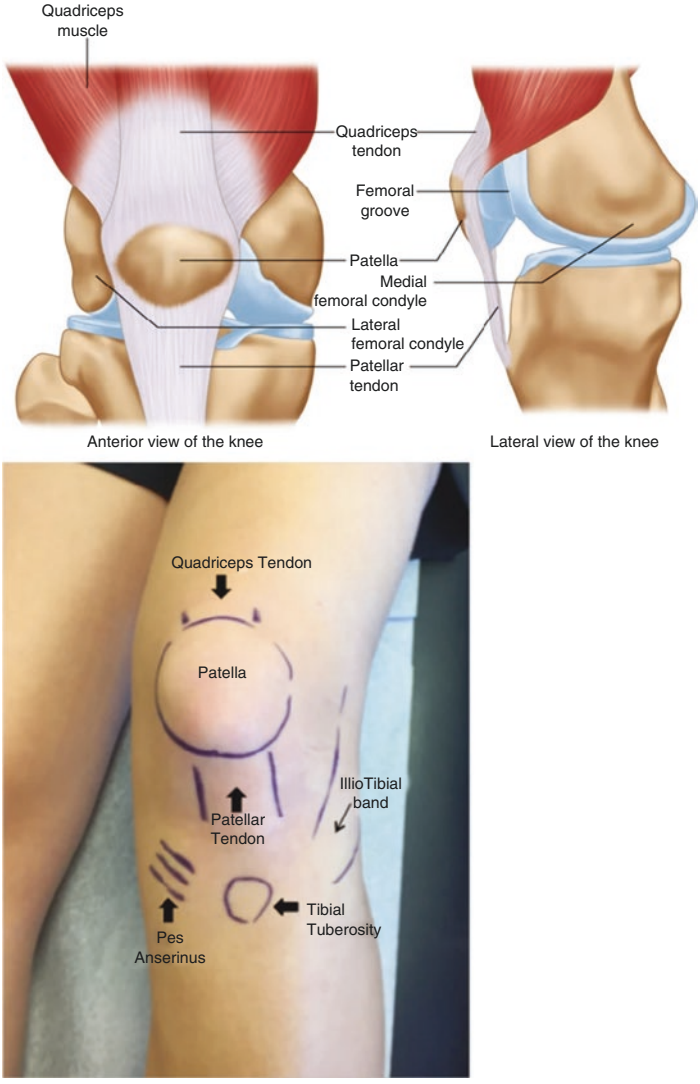

Fig. 1.2 The extensor mechanism [4]

Bursae are small fluid-filled sacs that reduce friction between moving parts in your body's joints. There are two anterior bursae; the prepatellar bursa lies superficial to the patella and the infrapatellar bursa lies between the patellar tendon and underlying tibia.

Articular Cartilage and Capsular Ligaments

The knee's articular surfaces are covered with hyaline cartilage which aids in reducing friction during joint movements. The meniscus is another form of articular cartilage known as fibrocartilage. The medial and lateral menisci are interposed in the tibiofemoral joint (Fig. 1.3).

Menisci play a crucial role in load-bearing, load transmission, shock absorption, as well as lubrication and nutrition of articular cartilage [6]. The medial meniscus is C-shaped and less mobile while the lateral meniscus is saucer-shaped in cross-section and more mobile [2, 5].

The meniscus receives its vascular supply from the superior and inferior medial and lateral geniculate arteries with most of vascular supply distributed to its peripheral outer third. The

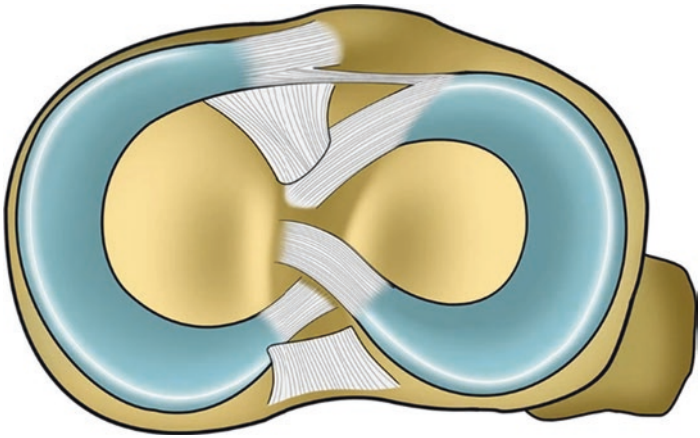

Fig. 1.3 Top view of the medial and lateral meniscus [3]

meniscus may thus be described into three zones according to its vascularity: firstly the outer (red) zone, which is red and rich in blood vessels, secondly the inner (white) zone is avascular, and lastly its intermediate (red-white) zone. The distribution of this vascular supply has great significance in meniscal injuries as tears in the outer zone (red zone) heal while most tears to the inner (white) zone mostly do not heal [5]. The knee joint is innervated by the posterior articular branch of the posterior tibial nerve and the terminal branches of the obturator and femoral nerves [7]. Similar to its vascular supply, the outer third of the body of the meniscus is more densely innervated than the middle third [8].

A capsule, which is part of the retinacular layer, surrounds the entire joint and extends into the suprapatellar pouch. It contains a synovial lining that also covers the cruciate ligaments, making them intra-articular but extrasynovial [5]. The four ligaments branch off the retinacular layer. The medial and lateral patello-femoral ligaments course along the distal and deep structures of the vastus medialis obliques and the vastus lateralis obliquus, then attach at superior poles of the patella. Attached to the inferior poles are the medial and lateral patellotibial ligaments [1]. The Arciform layer, the most superficial layer, is a thin peritendinous membrane which blends anteriorly into the patellar tendon [1]. The plica is a remnant of embryonic development. Its size varies from one person to another. It can be tissue paper thin but can thicken, scar down, and become contracted (plica syndrome) [1].

Ligaments of the Anterior Knee

The anterior cruciate ligament (ACL) is one of the most important ligaments in the anterior knee (Table 1.1). Some of its primary functions are preventing anterior translation of the tibia on the femur and preserving normal biomechanics of the knee motion to prevent meniscal damage [2, 5]. It originates between the intercondylar eminences of the tibia, courses posteriorly, and attaches to the posteromedial portion of the lateral femoral condyle

Table 1.1 Anterior structures of the knee

Ligament	Attachment	Function/comment
Anterior cruciate ligament (ACL) Anteromedial bundle (AMB) Posterolateral bundle (PLB)	Origin: between the intercondylar eminences of the tibia Insertion: posteromedial portion of the lateral femoral condyle	– Prevents anterior translation of the tibia on the femur – AMB is tight in knee flexion, lax in extension – PLB is tight in knee extension, lax in knee flexion
Anterior intermeniscal ligaments	Connects both anterior horns of the menisci to tibia	Stabilizes the menisci
Anterior plica	Distal femoral articulation	– Remnant of embryonic development – It can be tissue paper thin but can thicken, scar down, and become contracted (plica syndrome)
Infrapatellar fat pad	Posterior to the patellar tendon	Separates the patellar tendon from the underlying tibia and acts as a cushion. Can be a source of knee pain once fibrotic or impinged (Hoffa syndrome)

(Fig. 1.4). The ACL is innervated by the tibial nerve which provides mechanoreceptors that contribute to its proprioceptive function. It receives vascular supply primarily from the middle genicular arteries [2].

The anterior intermeniscal ligament is another structure within the anterior knee that attaches transversely across the anterior aspects of the convex margins of the medial and lateral menisci [5]. The posterior collateral ligament (PCL) inserts at the posterior intercondylar fossa of the tibia and its primary function is in the posterior joint. The PCL will be discussed in more detail in a later section.

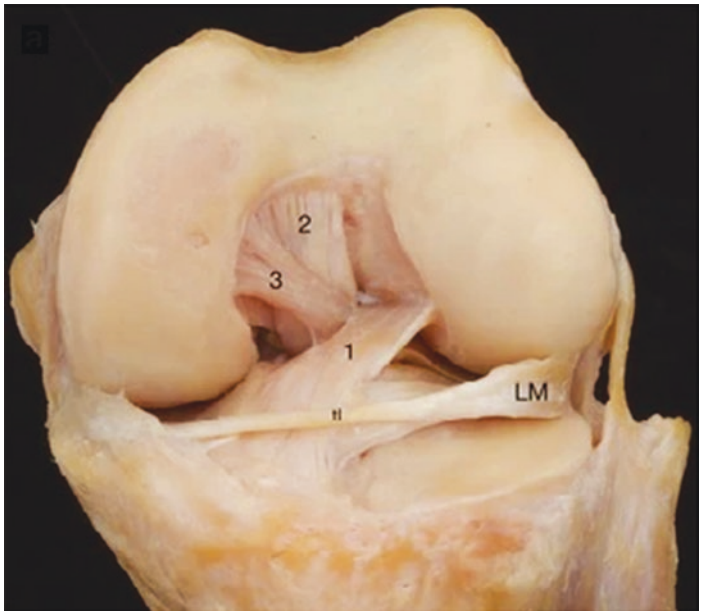

Fig. 1.4 Cadaveric specimen of human left knee joint. (*1*) Anterior cruciate ligament (ACL). (*2*) Posterior cruciate ligament (PCL). (*3*) Anterior meniscofemoral ligament. *LM* lateral meniscus, *tl* transverse ligament [9]

Posterior Knee

Popliteal Fossa and Posterior Knee Structures

It is important to note the anatomy of the popliteal fossa when evaluating posterior knee pain (Fig. 1.5). We will start by discussing its anatomic boundaries (Table 1.2) which include the following: Superomedially, the semimembranosus and semitendinosus muscle, superolaterally, the bicep femoris short and long heads, and inferomedially and inferolaterally, the medial and lateral heads of the gastrocnemius muscle, respectively [5].

The popliteal fossa is composed of nerves (posterior femoral cutaneous, common peroneal, and tibial), vascular structures (small saphenous vein, popliteal artery, and popliteal vein), bursae, lymph nodes, and fat [11]. The posterior cruciate ligament

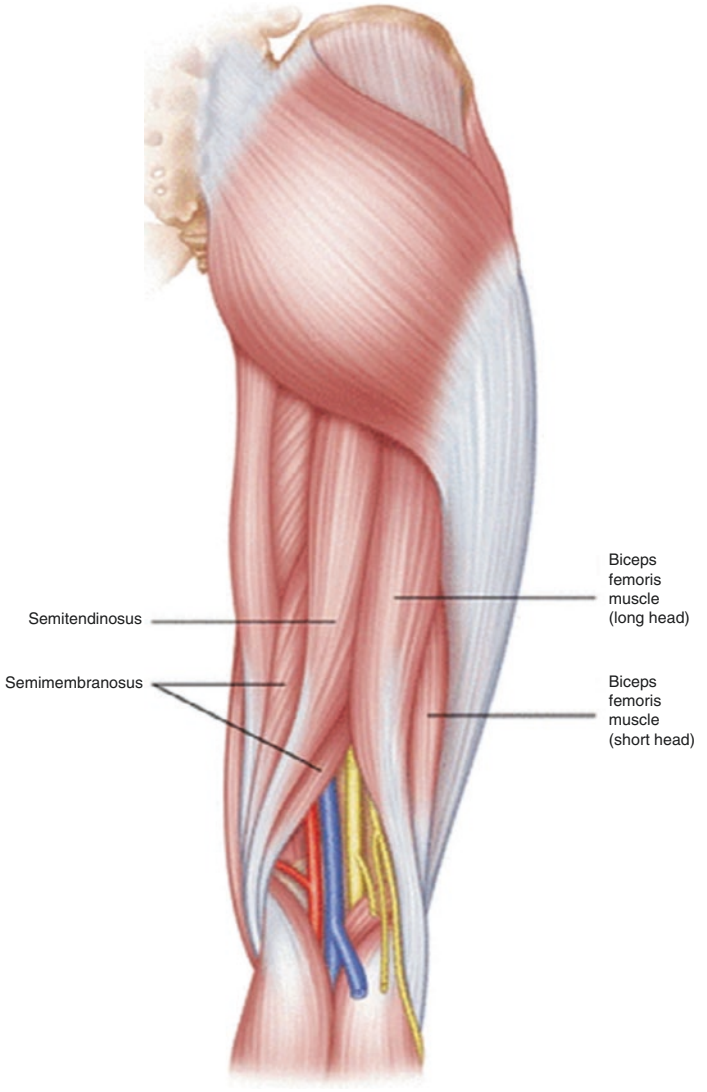

Fig. 1.5 Anatomy of popliteal fossa [10]

Table 1.2 Muscles within the popliteal fossa

Borders	Muscle(s)	Attachment Origin (O) Insertion (I)	Innervation	Vascular supply
Supero-medial	Semi-membranosus Semi-tendinosus	O: Ischial tuberosity I: Posterior medial tibial condyle I: Proximal medial tibia (pes anserinus)	Sciatic N. (tibial branch)	Branches of the profunda femoris, inferior gluteal artery, and popliteal artery
Supero-lateral	Bicep femoris Long head O: Short head	O: Fibular head I: Ischial tuberosity O: Linea aspera I: Tibial (Gerdy's) tubercle	Sciatic N: – Tibial N. branch – Peroneal N. branch	Deep femoral artery
Infero-medial	Medial gastrocnemius	O: Medial femoral condyle I: Calcaneus	Tibial N.	Medial sural artery
Infero-lateral	Lateral gastrocnemius	O: Lateral femoral condyle I: Calcaneus	Tibial N.	Lateral sural artery

(PCL) is the primary ligament of the posterior knee. It originates on the lateral aspect of the medial femoral condyle and inserts at the tibia's posterior intercondylar fossa between its plateaus (Fig. 1.6). The PCL's primary function is to prevent posterior translation of the tibia relative to the femur. Its primary vascular supply is the middle genicular artery. The PCL is innervated by both the tibial and obturator nerves which primarily provide a proprioceptive function. Another important set of ligaments are the ligaments of Humphrey and Wrisberg, which serve as secondary stabilizers to posterior translation. They originate from the

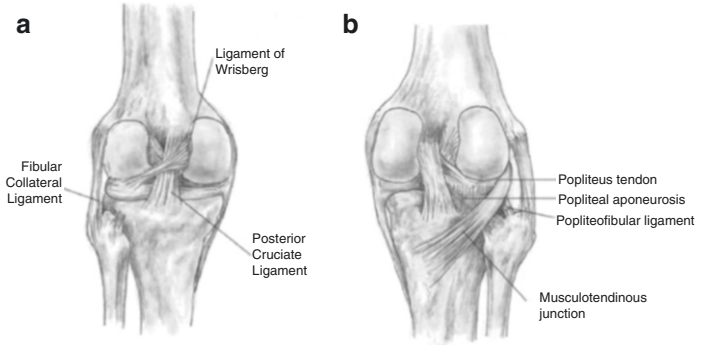

Fig. 1.6 (**a**) Left knee posterior view of PCL with overlying ligament of Wrisberg. (**b**) Right knee posterior view of PCL with other surrounding popliteal structures identified [12]

Table 1.3 Posterior knee

Ligaments	Attachment	Comments
Posterior cruciate ligament (PCL) Anterior bundle Posterior bundle	Origin: lateral aspect of the medial femoral condyle Insertion: tibia's posterior intercondylar fossa between its plateaus	– Prevent posterior translation of the tibia relative to the femur – Secondary stabilizer to prevent external rotation to the tibia and excessive varus and valgus angulation of the knee – Tight in knee flexion, lax in extension – Tight in knee extension, lax in flexion
Meniscofemoral ligament Ligament of Humphrey Ligament of Wrisberg	Origin: posterior horn of the lateral meniscus Insertion: medial femoral condyle Humphrey: Anterior to PCL Wrisberg: Posterior to PCL	– Secondary stabilizers to posterior translation – Contributes to PCL function and stabilizes menisci

posterior horn of the lateral meniscus and insert at the medial femoral condyle while surrounding the PCL both anteriorly and posteriorly (Table 1.3).

An additional layer composed of the capsular ligaments provide additional tibiofemoral stability. The medial and lateral midthird and posterior capsular ligaments cup and buttress the entire posterior medial and posterolateral corner of the knee. They essentially prevent any subluxation of the femoral condyle on the tibial plateaus. The posterolateral corner will be discussed in more detail in a later section [5, 11, 13].

Lateral Knee

The lateral knee is composed of three bony structures: the distal femur, proximal tibia, and fibular head. The lateral tibiofemoral joint's convex-on-convex structures contribute to the joint's inherent instability [14]. There are multiple structures that contribute to the static and dynamic stability of the lateral knee. The three primary static stabilizers include the fibular collateral ligament (FCL) also known as the lateral collateral ligament (LCL), popliteofibular ligament (PFL), and the popliteus tendon (PLT) [14] (Fig. 1.7). These structures compose the posterolateral corner (Table 1.4), which prevent varus stress, external rotation, internal rotation, and posterior tibial translation [5]. Injury to any or all of these structures may subsequently result in residual instability of the knee. Posterolateral corner injuries are commonly associated with ACL or PCL tears, with only 28% of all PLC injuries occurring in isolation [15].

The iliotibial band is a broad band of fascial structure that connects the pelvis to the tibia and covers the lateral thigh [14]. It primarily inserts at the lateral (Gerdy) tubercle, which is the lateral condyle of the proximal tibia. It is important to mention that portions of the anterior arm of the short head of the bicep femoris also insert at Gerdy's tubercle. The anterior arm has anatomic relevance as it is responsible for lateral avulsion fractures (Segond fracture or lateral capsular sign commonly associated with ACL injury). Also coursing through the posterolateral corner are its neurovascular structures, the common peroneal nerve, and the lateral inferior genicular artery [14].

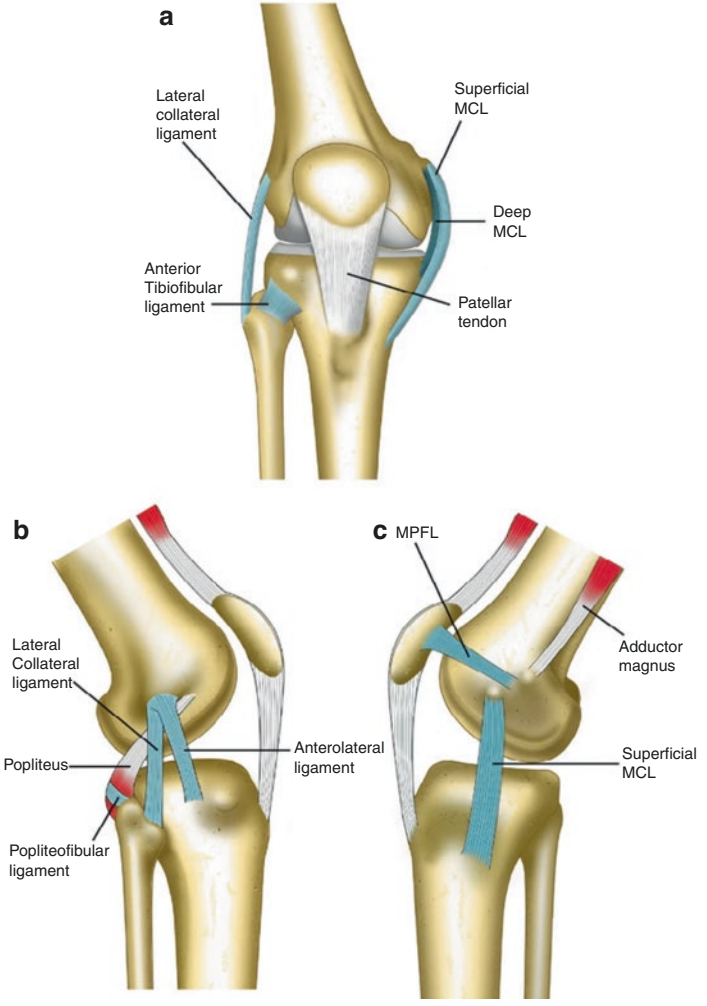

Fig. 1.7 Extra-articular ligaments of the knee. (**a**) Anterior, (**b**) lateral, (**c**) medial view [3]

Table 1.4 The posterolateral corner

Structure	Attachment	Neurovascular supply	Function/ comment
Fibular/lateral collateral ligament	Origin: lateral epicondyle proximal Insertion: medial fibular head	Innervation: tibial nerve Vascular: branches of the superior and inferior lateral genicular arteries [17]	Primary restraint to varus stress, also resists external rotation
Popliteus muscle and tendon	Inserts anterior and distal to the LCL origin	Innervation: tibial nerve Vascular: inferior medial and lateral genicular arteries	Initiating the flexion of the fully extended ("locked") knee Resist tibia external rotation, varus and posterior translation
Popliteofibular ligament	Inserts at popliteus musculotendinous junction to fibula head	Innervation: tibial nerve Vascular: inferior medial and lateral genicular arteries	Primary static restraint to external rotation

The deepest layer of the lateral knee is composed of the mid-third capsular ligament, LCL, popliteus tendon, among other structures (Fig. 1.8). The lateral patellofemoral ligaments and lateral patellar retinaculum make up the middle layer.

The iliotibial band and the bicep femoris make up the most superficial layer of the lateral compartment of the knee. The LCL originates at the lateral epicondyle proximally and posterior to the PLT's attachment [5]. The popliteus muscle courses obliquely in the posterior and inferior direction and wraps around the posterior capsule in the medial direction. The LCL has anterior and posterior divisions that attach to the tip of the fibular styloid process.

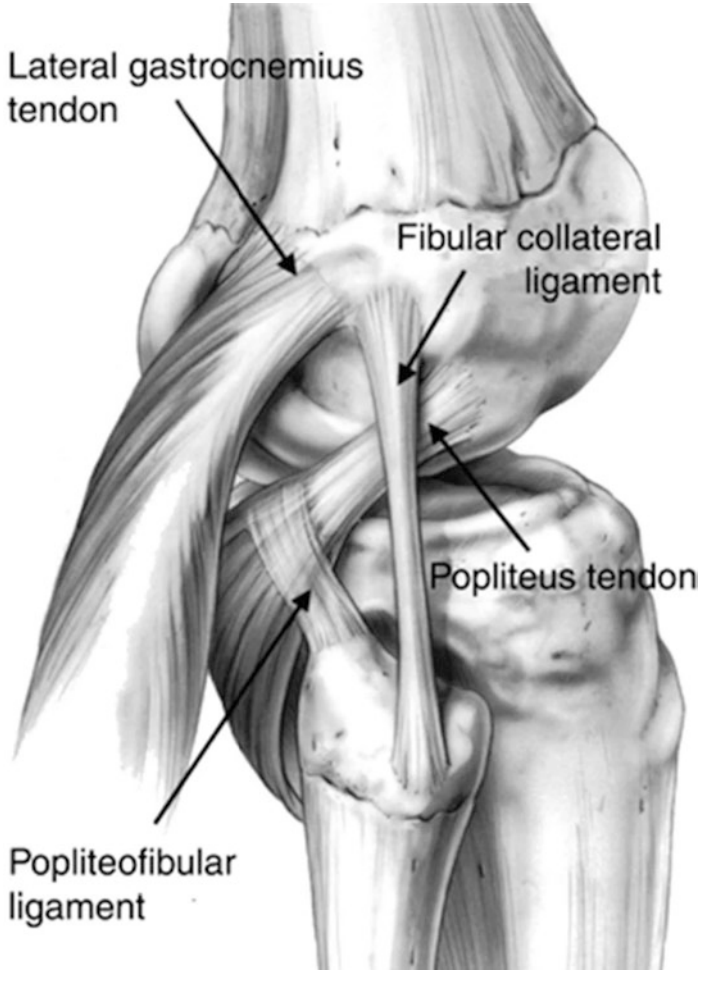

Fig. 1.8 Deepest layer of lateral knee [16]

Medial Knee

Bony Anatomy

In the medial view of the knee, we find the medial tibiofemoral joint. The medial epicondyle's concave articular surface is the most anterior and distal osseous prominence over the medial aspect of the convex medial femoral condyle [18]. There are two important bony prominences of anatomical significance: the medial supracondylar line and the adductor tubercle. The medial supracondylar line is a distal continuation of the linea aspera. It ends below the summit of the medial condyle, in a small tubercle, the adductor tubercle. The adductor tubercle is the common attachment site for the abductor magnus tendon (AMT), medial patellofemoral ligament (MPFL), medial gastrocnemius tendon (MGT), and posterior oblique ligament (POL) [5].

Connective Tissue

The ligaments of the medial knee are the superficial medial collateral ligament (sMCL), deep medial collateral ligament (dMCL), and POL. The MCL has both a deep and superficial layer to help maintain medial knee stability. The sMCL or tibial collateral ligament has two attachment sites: proximally at the medial femoral condyle and distally at the tibial joint line. The dMCL has both a meniscotibial and meniscofemoral component which run parallel and deep to the sMCL [5, 18].

The MCL is innervated by the medial articular nerve, a branch of the saphenous nerve and the branches of the superior and inferior genicular arteries provide its vascular supply [19]. The POL attaches from the adductor tubercle to multiple sites: the posterior tibia, posterior horn of the medial meniscus, and the posterior capsule [11] (Table 1.5).

Other Important Structures

The semimembranosus, a more superficial structure medially, is the dynamic motor structure of the medial knee. In a counterclockwise approach, the capsular, anterior/tibial, direct, inferior,

Table 1.5 Medial knee structures

Ligament	Attachment Origin (O) Insertion (I)	Function/comment
Medial collateral ligament (MCL) Superficial MCL (sMCL) Deep MCL (dMCL): Meniscotibial and meniscofemoral component that run parallel and deep to sMCL	Origin: medial femoral condyle (deep to pes anserinus) Insertion: tibial joint line O: both tibial and femoral I: medial meniscus and tibia plateau	– Primary restraint to valgus forces, especially at 30° – Secondary stabilizer to anterior translation and internal rotation – Stabilizes the meniscus—also known as the medial capsular ligaments or middle 1/3 capsular ligament
Posterior oblique ligament	O: adductor tubercle to the posterior tibia I: posterior horn of the medial meniscus, and blend into the posterior capsule	– Static stabilizer against valgus forces – Lax in flexion but tightens dynamically due to semimembranosus
Medial patellofemoral ligament (MPFL)	O: medial patella I: medial femoral epicondyle	Functions as an important patellar stabilizer as it assists in sustaining the patella within the trochlear groove

and posterior arms cover the medial and posterior portions of the joint and merge together to form the semimembranosus tendon [11] (Fig. 1.9).

Another important structure is the pes anserine. It is located near the anteromedial aspect of the proximal tibia. The pes anserine is formed by the tendons of the sartorius, gracilis, and semitendinosus. These tendons essentially form the roof of the pes anserine bursa. The pes anserine is a common site of anterior knee pain due to secondary bursopathy in the setting of friction [18].

The MPFL functions as an important patellar stabilizer as it assists in sustaining the patella within the trochlear groove. The vastus medialis obliquus (VMO) muscle is the main origin of the abductor magnus tendon (AMT).

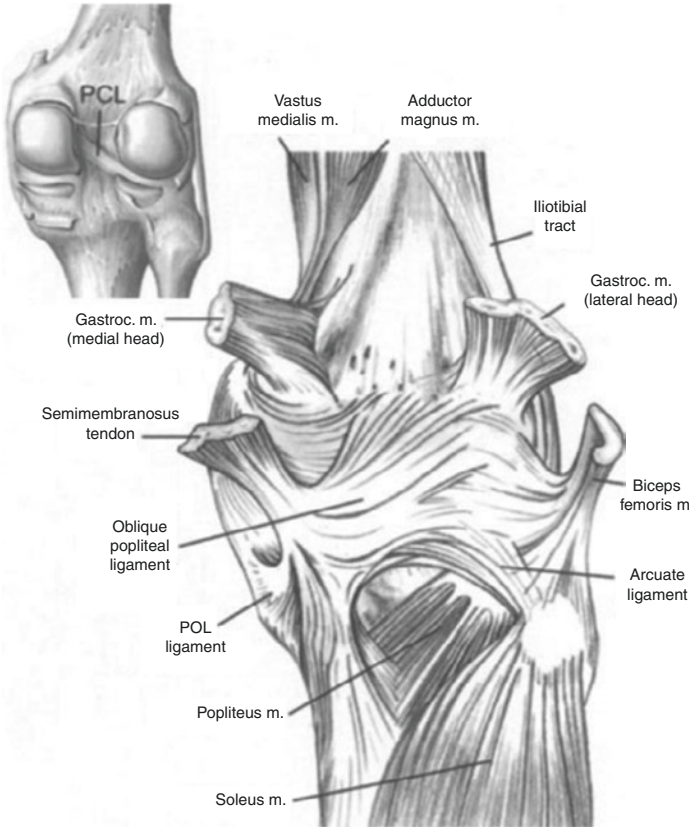

Fig. 1.9 Semimembranosus tendon [12]

The VMO attaches along the proximal edge of the MPFL and the AMT. The VMO applies a medially directed force that has particular importance in relation to the patella, since any injury to this structure disrupts the medial stabilization of the patella [18].

Neurovascular Structures

The saphenous nerve division of the femoral nerve branches off between the gracilis and semitendinosus tendons. It pierces through the sartorius muscle then curves into a close horizontal

path medial to the patellar tendon. The medial inferior genicular arteries branch off the main femoral artery. They supply the upper end of the tibia and the knee joint, anastomosing with the lateral inferior and medial superior genicular arteries which supply structures of the lateral and medial knee, respectively [18].

References

1. Flandry F, Hommel G. Normal anatomy and biomechanics of the knee. Sports Med Arthrosc Rev. 2011;19(2):82–92. https://doi.org/10.1097/JSA.0b013e318210c0aa.
2. Hassebrock JD, Gulbrandsen MT, Asprey WL, Makovicka JL, Chhabra A. Knee ligament anatomy and biomechanics. Sports Med Arthrosc Rev. 2020;28(3):80–6. https://doi.org/10.1097/JSA.0000000000000279.
3. Panayiotou Charalambous C. Knee clinical anatomy. In: The knee made easy. Cham: Springer; 2022. https://doi.org/10.1007/978-3-030-54506-2_2.
4. Lowenstein NA, Matzkin EG. Anterior knee pain: diagnosis and treatment. In: Schoenfeld AJ, Blauwet CA, Katz JN, editors. Principles of orthopedic practice for primary care providers. Cham: Springer; 2021. https://doi.org/10.1007/978-3-030-74625-4_28.
5. Thompson JC, Netter FH. Netter's concise orthopaedic anatomy. Philadelphia: Saunders; 2010.
6. Gao SG, Zhang C, Zhao RB, Liao Z, Li YS, Yu F, et al. Effect of partial and complete posterior cruciate ligament transection on medial meniscus: a biomechanical evaluation in a cadaveric model. Indian J Orthop. 2013;47(5):493–9.
7. Brindle T, Nyland J, Johnson DL. The meniscus: review of basic principles with application to surgery and rehabilitation. J Athl Train. 2001;36(2):160–9.
8. Fox AJ, Bedi A, Rodeo SA. The basic science of human knee menisci: structure, composition, and function. Sports Health. 2012;4(4):340–51. https://doi.org/10.1177/1941738111429419.
9. Śmigielski R, Zdanowicz U. Anatomy of ACL insertion: ribbon. In: Nakamura N, Zaffagnini S, Marx R, Musahl V, editors. Controversies in the technical aspects of ACL reconstruction. Berlin: Springer; 2017. https://doi.org/10.1007/978-3-662-52742-9_15.
10. Napolitano J, Gupta A. Hamstring injury. In: Coleman N, editor. Common pediatric knee injuries. Cham: Springer; 2021. https://doi.org/10.1007/978-3-030-55870-3_18.
11. English S, Perret D. Posterior knee pain. Curr Rev Musculoskelet Med. 2010;3(1–4):3–10. https://doi.org/10.1007/s12178-010-9057-4.

12. LaPrade RF, Bollom TS. Anatomy and biomechanics of the posterolateral aspect of the knee. In: Fanelli GC, editor. Posterior cruciate ligament injuries. New York: Springer; 2001. https://doi.org/10.1007/978-0-387-21601-0_2.
13. Marais JJ. Anatomy of the posterior cruciate ligament. SA Orthop J. 2009;8(4):23–9.
14. James EW, LaPrade CM, LaPrade RF. Anatomy and biomechanics of the lateral side of the knee and surgical implications. Sports Med Arthrosc Rev. 2015;23(1):2–9. https://doi.org/10.1097/JSA.0000000000000040.
15. Chahla J, Moatshe G, Dean CS, LaPrade RF. Posterolateral corner of the knee: current concepts. Arch Bone Jt Surg. 2016;4(2):97–103.
16. Servien E, Magnussen R, Neyret P, Butcher C. Posterolateral corner and lateral collateral ligament reconstruction. In: Neyret P, Butcher C, Demey G, editors. Surgery of the knee. Cham: Springer; 2020. https://doi.org/10.1007/978-3-030-19073-6_9.
17. Yaras RJ, O'Neill N, Yaish AM. Lateral collateral ligament knee injuries. Treasure Island: StatPearls; 2022.
18. LaPrade MD, Kennedy MI, Wijdicks CA, LaPrade RF. Anatomy and biomechanics of the medial side of the knee and their surgical implications. Sports Med Arthrosc Rev. 2015;23(2):63–70. https://doi.org/10.1097/JSA.0000000000000054.
19. Juneja P, Hubbard JB. Anatomy, bony pelvis and lower limb, knee medial collateral ligament. Treasure Island: StatPearls; 2022.