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Posterolateral and Posteromedial Corner Injuries of the Knee

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KEYWORDS

• Knee • Posterolateral • Posteromedial • Corner • Injuries

KEY POINTS

- Posterolateral and posteromedial corners of the knee are complex anatomic regions; detailed knowledge of anatomic structures and relationships is necessary for appropriate assessment at imaging.
- Association between untreated posterolateral and posteromedial corner injuries of the knee and failure of central support structure reconstruction has been established. Accurate diagnosis and characterization of these injuries will improve clinical and surgical outcome.
- Posterolateral and posteromedial corner injuries of the knee may be difficult to diagnose clinically. Classic magnetic resonance imaging patterns allow noninvasive diagnosis that can guide management.

INTRODUCTION

The posterolateral (PLC) and posteromedial (PMC) corners of the knee are anatomic units composed of a complex arrangement of structures. As referenced in their names, they extend both posteriorly[1] and along the lateral and medial aspects of the knee, respectively (**Fig. 1**). As the posterior extension of the lateral and medial supporting structures, they act in conjunction with the central supporting ligaments (anterior and posterior cruciate ligaments) to provide static (capsular and noncapsular ligaments) and dynamic (musculotendinous units and their aponeuroses) articular stability.[2,3] The delineation of fine anatomic detail in these regions and identification of delicate structures are particularly challenging at imaging because of composite anatomy, orientation, and small size of their components. Pathology might be overlooked or misdiagnosed without clear knowledge of the regional morphology, biomechanics, and specific patterns of injury. Moreover, PLC and PMC injuries uncommonly occur in an isolated fashion, more often associated with concomitant injuries that may dominate the clinical picture. Untreated PLC injuries can lead to chronic posterolateral instability[4,5] and PMC deficiencies may cause persistent valgus instability[6]; both conditions lead to poor outcome of anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) reconstruction. It is therefore imperative, in

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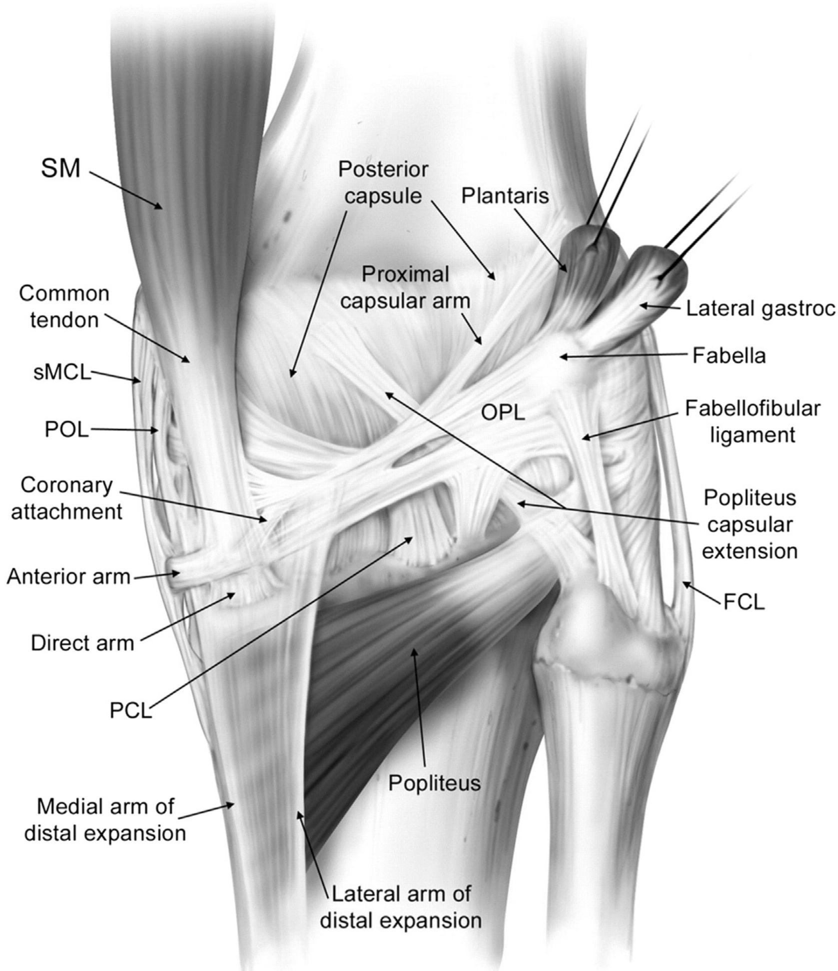

Fig. 1. Posterior aspect of the knee after removal of medial and lateral gastrocnemius muscles and neurovascular structures. SM, semimembranosus muscle; sMCL, superficial medial collateral ligament; FCL, fibular (lateral) collateral ligament; lateral gastroc, lateral gastrocnemius; OPL, oblique popliteal ligament; PCL, posterior cruciate ligament; POL, posterior oblique ligament. (*From* LaPrade RF, Morgan PM, Wentorf FA, et al. The anatomy of the posterior aspect of the knee. An anatomic study. J Bone Joint Surg Am 2007;89(4):758–64; with permission.)

a postinjury or preoperative setting, to provide the referring physician with an accurate description (when possible) of the PLC and PMC structures. The characterization of structural alteration at imaging will allow a reference for clinical evaluation that can guide surgical approach and interrogation, facilitating optimal treatment, and thereby improving patient outcome. Magnetic resonance imaging (MRI) currently is the gold standard imaging strategy in the evaluation of the soft tissues; therefore, the authors focus mainly on this technique. Ultrasound scan has been established as a complementary technique.[7] Plain films and computed tomography play a role in the evaluation of osseous lesions (bony avulsions, cortical stress changes related to chronic injury). This article discusses the anatomy, basic biomechanics, and common injuries of the PLC and PMC complexes, presenting the reader with a systematic approach for their evaluation.

POSTEROLATERAL CORNER OF THE KNEE

Anatomy, Biomechanics, and Mechanism of Injuries to the Posterolateral

Seebacher and colleagues[8] in 1982 introduced a three-layered approach in the anatomic description of the lateral supporting structures of the knee, using a similar three-layer concept previously assumed in their description of the medial side supporting structures (**Fig. 2**).[9] In Seebacher's original description of the lateral supporting structures, the *superficial layer (I)* consists of the iliotibial tract and its expansion anteriorly and the biceps

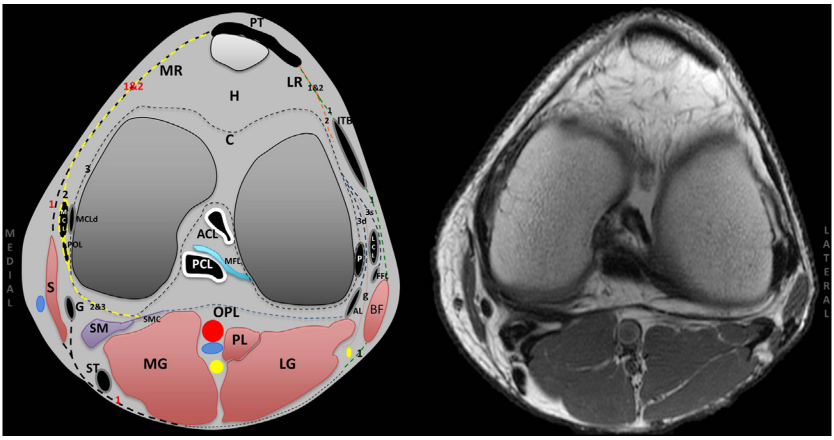

Fig. 2. Axial diagram (*left*) shows layers and anatomic components at the level of the joint line with a corresponding axial T2-weighted MRI (*right*). 1 = first layer, 2 = second layer, 3 = third layer, 3s = third layer (superficial lamina), 3d = third layer (deep lamina), AL, arcuate ligament; BF, biceps femoris and its tendon; C, capsule and H, Hoffa's fat pad; FFL, fabellofibular ligament; G, gracilis muscle tendon; g, lateral inferior genicular artery; ITB, iliotibial band; LCL, lateral collateral ligament; LG, lateral gastrocnemius muscle; LR, lateral retinaculum; MCL, medial collateral ligament; MCLd, deep medial collateral ligament; MFL, meniscofemoral ligament (Humphrey's); MG, medial gastrocnemius muscle; MR, medial retinaculum; OPL, oblique popliteal ligament; P, popliteus muscle tendon; PL, plantaris muscle; POL, posterior oblique ligament; PT, patellar tendon; S, sartorius muscle and its tendon; SM, semimembranosus muscle tendon; SMC, semimembranosus tendon (capsular arm); ST, semitendinosus muscle tendon.

femoris tendon (BFT) and its expansion posteriorly. The peroneal nerve lies deep to it, posterior to the BFT. The *middle layer (II)* is incomplete and consists of the lateral patellar retinaculum anteriorly and the 2 patellofemoral ligaments posteriorly. The proximal patellofemoral ligament joins the lateral intermuscular septum, the distal patellofemoral ligament attaches to the fabella (when present) or at the femoral insertion of the posterolateral joint capsule or lateral head of the gastrocnemius. Included in the middle layer is the patellomeniscal ligament, which travels from the patella to the lateral meniscus, reaching inferiorly the lateral tibial tubercle of Gerdy, running deep to the iliotibial tract. The *deepest layer (III)* is composed of the lateral extent of the joint capsule and is attached to the edges of the tibia and femur. Posterior to the overlying iliotibial tract, the capsule divides into 2 laminae (superficial and deep). The superficial lamina travels superficial to the lateral collateral ligament and ends posteriorly at the fabellofibular ligament. The deeper lamina travels deep to the lateral collateral ligament, passes along and attaches to the edge of the lateral meniscus, giving rise to the coronary ligament and ultimately reaching the arcuate ligament. The deep and superficial laminae of the posterolateral capsule are always separated from each other with the lateral inferior genicular artery, considered an anatomic landmark, between them (see **Fig. 2**). Further cadaveric,[10] MRI[11–18] and ultrasound scan[7,19] evaluations of specific PLC anatomy followed Seebacher's original work to delineate the imaging counterpart of his anatomic description. Because of the increasing interest in the anatomy and biomechanics of the PLC corner of the knee in the orthopedic literature, the need for standardization and a systematic approach to the nomenclature of the lateral complex structures and PLC has been addressed.[20,21] For a systematic approach to these structures we consider the superficial layer (first layer) comprising the lateral fascia, iliotibial band and biceps femoris tendon. The middle layer (second layer) comprises the patellar retinaculum, and patellofemoral and patellomeniscal ligaments. The deep layer (third layer) consists of the *lateral collateral ligament* (fibular collateral ligament), the *lateral coronary ligament* (lateral meniscotibial ligament), the *arcuate ligament*, the *popliteus tendon-muscle unit*, the *popliteofibular ligament*, the *fabellofibular ligament*, and the lateral joint capsule with its attachment to the lateral meniscus edge. The deep layer is the most anatomically variable of the 3 layers and the one constituting the posterolateral corner of the knee complex.[20] We briefly describe the components of the third inner layer and their anatomic relations.

The lateral collateral ligament (fibular collateral ligament), is an extracapsular structure, has a tubular shape, and measures approximately 3–4 mm in diameter and 7 cm in length. It originates from the lateral femoral condyle, arising from a small depression posterior to the lateral femoral epicondyle and 2 cm proximal to the joint line. It courses distally and posteriorly to attach to the posterior portion of the lateral aspect of the fibular head (see **Fig. 1**).

The lateral coronary ligament (or meniscotibial portion of the midthird lateral capsular ligament or lateral meniscotibial ligament) attaches the lateral meniscus to the lateral tibial plateau and functions as a meniscal stabilizer. The lateral coronary ligament is composed of short confluent ligamentous bands attached to the peripheral portion of the meniscal body and to the lateral tibia several millimeters inferior to the articular surface, occasionally resulting in a small synovial recess.[22,23]

The arcuate ligament has an inverted Y shape. The 2 superior arms consist of a lateral limb (upright), coursing upward along the joint capsule and extending to the lateral femoral condyle, and a medial limb (arcuate), crossing over the popliteal tendon, attaching to the posterior capsule, and merging with the oblique popliteal ligament. The lower limb attaches to the fibular head.[24] The arcuate ligament lies deep to the lateral inferior genicular artery, and its presence is variable, ranging from 24% to 80% in previous studies.[8,25,26]

The popliteus muscle originates from the lateral aspect of the lateral femoral condyle, attaches to the posterior horn of the lateral meniscus via the popliteomeniscal fascicles (anteroinferior, posterosuperior, posteroinferior) and to the apex of the fibula via the popliteofibular fascicles, extending distally to the posteromedial aspect of the tibial shaft (see **Fig. 1**). The popliteus muscle is always present, whereas the posteroinferior popliteomeniscal fascicle may be absent.[26,27]

The popliteofibular ligament originates at the level of the musculotendinous junction of the popliteus muscle and courses distally and laterally to insert on the fibular styloid. The popliteofibular ligament is a wide tendinous band, approximately the same width or wider than the popliteus tendon,[28–31] and is reportedly present in between 94% and 98% of the population.[25,26] The proximal myotendinous portion of the popliteus muscle and the popliteofibular ligament originating from it form an inverted Y-shaped structure. Therefore, the 3 arms of the inverted Y are the superior portion of the popliteus myotendinous unit, the popliteofibular ligament, and the inferior portion of the popliteus myotendinous unit distal to the origin of the popliteofibular ligament.

The fabellofibular ligament is the distal edge of the capsular arm of the short head of the biceps femoris muscle, and, as such, is present in all knees. Usually, it is a delicate structure but is more robust in appearance when the bony fabella is present but less consistent and more subtle in nature when a cartilaginous fabellar analog is present. We would like to reinforce the concept addressed from LaPrade[21] regarding the presence of at least a fabellar cartilaginous analog in every knee. When the fabella is present, the fabellofibular ligament arises from the lateral margin of the fabella, and, when absent, it originates from the posterior aspect of the supracondylar process of the femur.[32] Extending from the fabella or the fabellar analog, the fabellofibular ligament extends toward the fibula, parallel to the lateral collateral ligament, and inserts distally on the lateral aspect of the tip of the fibular head styloid process, posterior to the fibular insertion of the biceps femoris tendon (see **Fig. 1**). Previous studies addressed the variable presence of the fabellofibular ligament, ranging from 51%–87%.[8,26]

Biomechanically the PLC structures resist varus and external rotation forces. With regard to varus forces the lateral collateral ligament is considered the major stabilizer, with a minor contribution from the posterior cruciate ligament and the posterolateral capsule; a minor secondary contribution is made from the anterior cruciate ligament. In relation to external rotation forces, the lateral collateral ligament, popliteofibular ligament, fabellofibular ligament, capsular attachment of the short head of the biceps femoris muscle, and the popliteus tendon play a fundamental role in resisting stress. A role of the PLC in resisting posterior translation of the tibia has been addressed, establishing the popliteomeniscal fascicles as stabilizers of the posterior horn of the lateral meniscus. Isolated injuries of the PLC tend to be rare and commonly occur in conjunction with cruciate ligament lesions. The association of lateral collateral ligament and deep PLC structure injuries increases varus angulation and tibial external rotation, also causing anteroposterior instability of the knee. Deep PLC lesions (preserved lateral collateral ligament), in conjunction with anterior cruciate ligament deficiency, increase anterior translation of the tibia without causing external rotation of the tibia or varus angulation of the joint. When deep PLC structures fail and lateral collateral ligament and anterior cruciate ligament injuries are present, anterior and varus instability with external rotation of the tibia occur. Deep PLC structure deficiency, with lateral collateral ligament and posterior cruciate ligament injury, cause posterior translation, varus angulation, and external rotation of the tibia.[33–42] Posterolateral corner injuries are frequently associated with acute posterior cruciate ligament tears and have been reported in 62% of patients.[43] Therefore, when a posterior cruciate ligament injury is observed, particular attention should be paid to the PLC area. Injuries of the PLC are less common than injuries of the PMC, but because this anatomic area is subject to a greater stress during motion than the medial side, they tend to be more disabling.[13] PLC injuries most commonly occur via a direct blow to the anteromedial aspect of the proximal tibia in the fully extended knee, with the force directed in a posterolateral direction, but can also occur from a hyperextension injury with external rotation.[41,44] Anterior rotatory dislocations (varus stress and hyperextension) and posterior rotatory dislocations (varus stress, posteriorly directed blow to proximal tibia and flexion), are also common mechanisms of injury,[20,45] the latter known as a "dashboard injury." An undetected PLC injury can lead to chronic instability and failure of efforts to reconstruct the central supporting structures because of deficiency of PLC in resisting biomechanical stress.[34,46–49] Testing of the PLC resistance to stress involves varus and external rotation stress tests at different degrees of flexion.[35] The posterolateral rotation test (dial test) is one commonly used for posterolateral instability, assessing increasing external rotation of the tibia in relation to the femur at 30° of knee flexion.

INJURIES TO THE POSTEROLATERAL COMPLEX

Soft-tissues Injuries of the Posterolateral

Lateral collateral ligament (fibular collateral ligament)

Alterations to the lateral collateral ligament are a common feature of PLC injuries. In vitro studies addressed the role of the lateral collateral ligament (LCL) as a restraint to PLC instability and varus angulation in static testing. Nielsen and colleagues[50] noted an increase in varus joint opening with marked posterolateral rotatory instability when an LCL lesion is associated with a posterolateral capsule transection rather than an LCL injury alone. Grood and coworkers[51] addressed the increase of varus angulation at partial knee flexion when a PCL injury is combined with an LCL injury. Gollehon and colleagues[52] showed the principal role of the LCL and PLC deep ligament complex in preventing varus and external rotation of the tibia and the increase of varus rotation and posterior translation in combined injuries of the LCL, PCL, and deep lateral complex. However, LaPrade and Terry[33] evaluated 71 patients presenting with a PLC knee injury and signs of instability but at surgery found an injured LCL in only 23% of the knees. Based on this finding, they suggest that an LCL injury should not be the sole determining factor when diagnosing PLC injuries. Lateral collateral ligament injuries consist of structural alterations that include thickening, tears, soft-tissue avulsions from the femoral attachment, and soft-tissue avulsions (with or without a bony component) from the fibular head. LCL injuries are best visualized in the axial and coronal plane at MRI examination (**Fig. 3**).[5,13,53]

Popliteus muscle and its tendon

Injuries to the popliteus muscle can be intra-articular (at the femoral insertion or at the level of the popliteal hiatus) or extra-articular (muscular or myotendinous portion) in nature, the latter being more frequent. An avulsion at the femoral attachment may appear as an irregular contour of its tendon at the level of the popliteal hiatus with surrounding edema. Partial tears of the myotendinous junction present with increased T2 signal at the level of the muscle-tendon junction on fat suppressed, fluid-sensitive sequences at MRI examination. Complete tendon tears may present as an interruption of the muscle belly appearing as a masslike lesion with surrounding edema.[13] Enlargement of the muscle belly or disruption of muscle fibers may be apparent. Only 8% of all popliteus injuries occur in an isolated fashion,[54]

Fig. 3. Coronal proton density (PD) image with fat saturation (FS) of the knee in a patient after reduction of a knee dislocation shows a displaced arcuate fracture fragment (*black arrow*). Additionally, there is disruption of the midportion of the LCL (*white arrowhead*), avulsion of the lateral meniscotibial ligament (soft tissue Segond injury, *black arrowhead*), and a bone contusion at the peripheral aspect of the medial femoral condyle (*white arrow*).

with isolated cases of muscle or tendon lesions reported in skiers,[55] football,[55–57] soccer,[58,59] rugby,[60] and polo players.[61] Lesions of the popliteus muscle are usually combined with injuries to other knee structures.[13] Brown and colleagues,[54] in their MRI analysis of popliteus injuries (n = 24), reported combined injuries in 92% of cases, with involvement of its muscular portion in 96% of patients. Associated injuries included ACL (17%) or PCL (29%) tears, combined medial (46%) or lateral (25%) meniscal injuries, and medial (8%) or lateral (4%) collateral ligament lesions. Bone bruises or fractures were reported in 33% of patients. Popliteus muscle injuries are best evaluated on the axial and coronal planes (**Fig. 4**), and diagnosis of abnormalities on MR imaging plays a fundamental role in the diagnosis of an injury to the popliteus muscle because of the difficulty in assessing this structure at arthroscopy.[53,62]

Popliteofibular ligament

Visualization and assessment of the popliteofibular ligament can be challenging on MRI. Standard imaging planes (coronal, sagittal, and axial) may depict the structure, but visualization is not always optimal because of its oblique orientation and the delicate nature of the structure; coronal and sagittal planes are in our practice the most useful planes for assessment (**Fig. 5**). Some advocate the use of a coronal oblique plane, oriented parallel to the direction of the popliteus tendon, with one study showing visualization of the popliteofibular tendon improving from 8% to 53% of the knees.[63] Another study compared coronal oblique fat-saturated T2 with isotropic three-dimensional water excitation double-echo steady state (WE-DESS) sequences. The latter sequence improved the identification of the popliteofibular ligament from 71% to 91% of cases.[64]

Injuries to the popliteofibular ligament consist of ligamentous disruption, avulsion from the fibular insertion, partial tearing, and intrasubstance degeneration in the form of signal alteration within the tendon.[53] Surgical reconstruction of a disrupted popliteofibular ligament has been found to be beneficial in patients with posterolateral external rotatory instability of the knee.[65]

Arcuate ligament

The variable presence and subtlety of the arcuate ligament makes assessment difficult[24,66] and makes recognizing injuries of the arcuate ligament complex a challenging proposition. The anatomy of the arcuate ligament is debated[39] and can be considered a thickening of the posterolateral capsule. On sagittal images, the arcuate ligament is best identified on images on which the popliteus tendon and fibular tip are both visualized. The straight limb of the arcuate can be found superficial to the popliteus tendon as a delicate linear low-signal structure attaching to the fibular tip (**Fig. 6**). Dedicated imaging of the PLC in the coronal oblique plane may significantly improve visualization of the arcuate ligament, with an increase from 10% to 46% reported by Yu and colleagues[63] compared with standard coronal imaging.

Increased signal at the level of the posterolateral capsule on fat-saturated fluid-sensitive images should raise concern for capsular disruption and the possibility of associated injury or tear of the arcuate ligament (**Fig. 7**).[53] Injury to the posterolateral capsule has been suggested as one reason why PLC injuries can occasionally present without a significant knee joint effusion.[67] Baker and coworkers[68] operated on 13 patients with acute PCL injuries and posterolateral instability of the knee, identifying tears of the arcuate ligament complex in all 13. Their results suggest that surgical repair of the arcuate ligament complex improves patient outcome in PCL injuries with posterolateral instability,[68] emphasizing the importance of evaluating this structure on preoperative imaging.

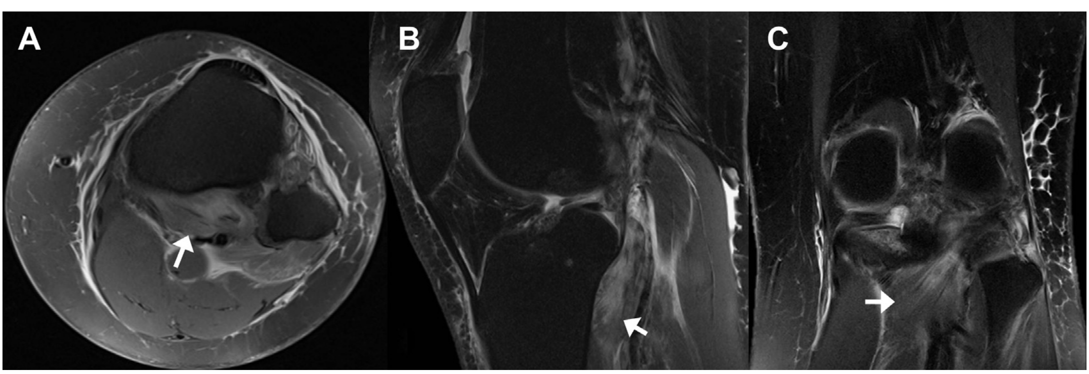

Fig. 4. Axial (*A*), sagittal (*B*), and coronal (*C*) PD FS images show a strain (grade II lesion) at the level of the myotendinous junction of popliteus (*white arrows*) and extensive circumferential soft tissue edema.

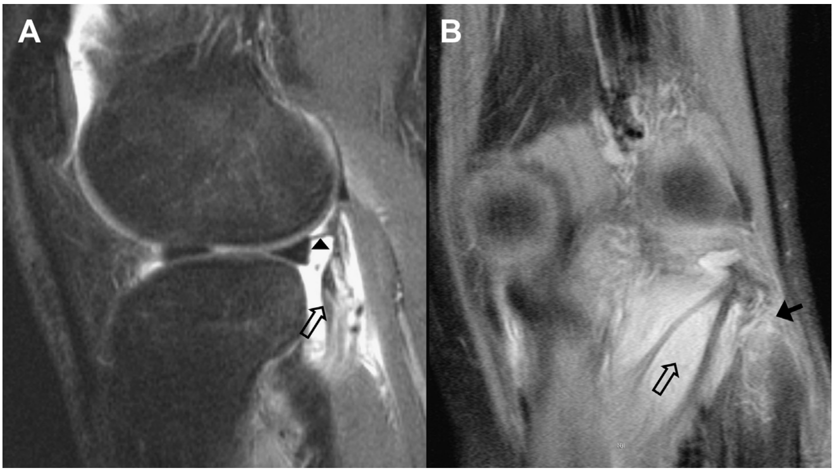

Fig. 5. Sagittal (*A*) and coronal (*B*) T2 FS images show diffuse edema at the level of the PLC and surrounding the myotendinous junction of popliteus compatible with a high-grade strain (*open arrows*). A partial tear of the popliteofibular ligament is present (*black arrow*). The posterosuperior popliteomeniscal fascicle is intact (*black arrowhead*).

Fabellofibular ligament

The fabellofibular ligament is best visualized on MRI in the coronal plane and is located posteriorly to the lateral collateral ligament and at the far posterior tip of the fibular styloid.[12] Yu and colleagues[63] compared visualization of the fabellofibular ligament in the coronal oblique plane with the standard coronal plane imaging and reported an increase in visualization from 34% to 48% on coronal oblique images. The fabellofibular ligament was seen in only 4% in the sagittal plane. Injuries of the fabellofibular ligament include degeneration, tearing and avulsion from the fibular tip (see **Fig. 7**). Avulsion of the fabellofibular ligament can be associated with an avulsive injury of the direct arm of the short head of the biceps femoris tendon.[5,14,53] The inferior lateral genicular artery is a branch of the popliteal artery, which can be used as an anatomic landmark in evaluating the fabellofibular ligament, as it passes around the posterior joint capsule laterally, running anterior to the fabellofibular ligament and posterior to the popliteofibular ligament.[39]

Soft tissue Segond injury (lateral meniscotibial capsular injury)

The soft tissue Segond injury is a soft-tissue avulsion injury described by LaPrade and colleagues,[12] consisting of disruption of the conjoined tibial attachment of the anterior arm of

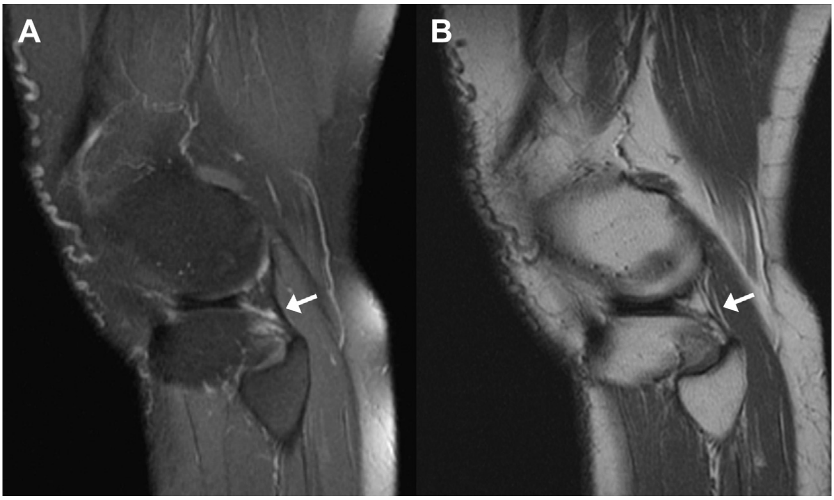

Fig. 6. Sagittal proton density images with (*A*) and without fat saturation (*B*) show an intact arcuate ligament (lateral limb) (*arrows*).

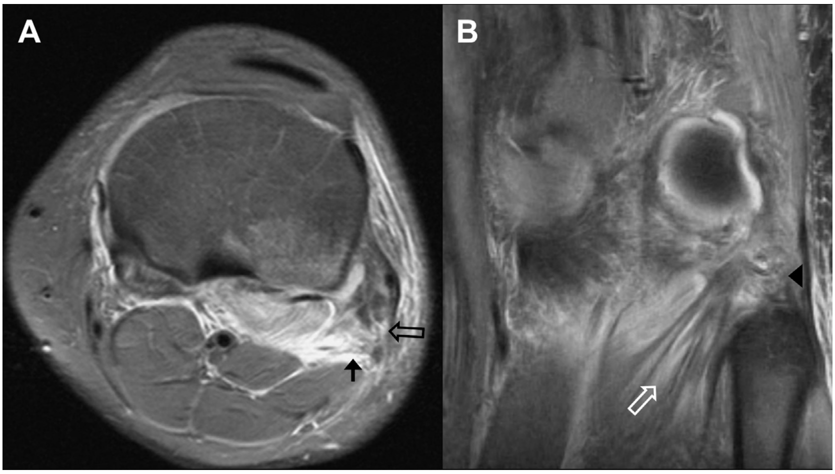

Fig. 7. Axial (*A*) and coronal (*B*) PD FS images show edema in the expected location of the arcuate (*black arrow*) and fabellofibular (*open black arrow* and *black arrowhead*) ligaments, without clearly identified ligaments suggesting injury of these structures. There is also high T2 signal within the muscle belly and around the myotendinous junction of the popliteus compatible with a grade II strain (*open white arrow*).

the short head of the biceps femoris muscle and the meniscotibial portion of the midthird lateral capsular ligament, with associated proximal retraction or thickening (see **Fig. 3**; **Fig. 8**).

Myotendinous injuries of the lateral head of gastrocnemius

The proximal myotendinous portion of the lateral gastrocnemius muscle is commonly not included in the classic list of the specific anatomic structures composing the PLC.[8] However, different factors determine its participation in knee stability provided by the posterolateral corner structures. Based on several anatomic relationships, it is clear that this structure serves as an important secondary dynamic stabilizer of the PLC. This is supported by its involvement in accommodating the fabella (or its cartilaginous equivalent) with its attachment to the fabellofibular ligament. Furthermore, the lateral gastrocnemius reinforces the meniscofemoral capsule and is firmly attached to the lateral femoral condyle at the level of the supracondylar process. Clinically, the stabilizing role of the lateral gastrocnemius is recognized in PLC reconstruction, including advancement procedures.[4,69]

Injuries to the gastrocnemius muscle usually involve the distal myotendinous junction of the medial gastrocnemius (tennis leg).[70] Although primary injuries of the lateral gastrocnemius are rare, the lateral gastrocnemius should be evaluated carefully in cases of posterolateral corner injury because of the secondary stabilizing role of this structure. The lateral gastrocnemius is usually best seen on sagittal images.[12,15,53]

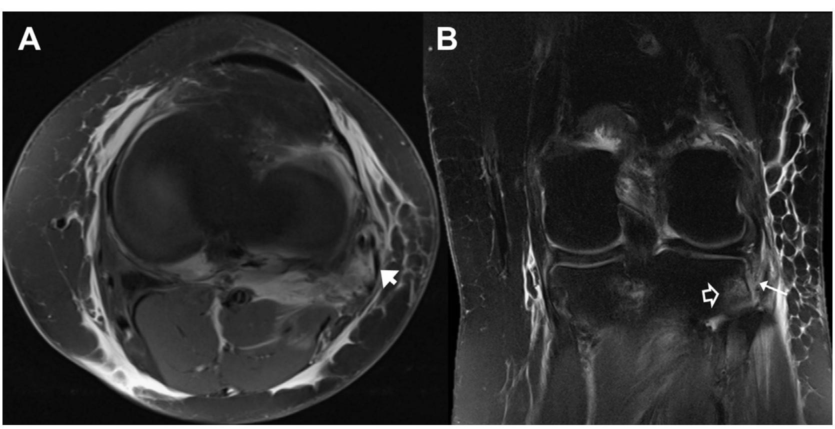

Fig. 8. Axial (*A*) and coronal (*B*) PD FS images show a distal biceps femoris tendon injury (*short white arrow*) and an avulsion of the lateral meniscotibial ligament (*white arrow*) with subjacent bone marrow edema (*open white arrow*), falling in the spectrum of a soft tissue Segond injury.

Osseous Alterations Associated with Posterolateral Injuries

Arcuate fracture

This injury is an avulsion fracture at the level of the fibular head (**Fig. 9**). If a pattern of diffuse fibular head edema is present at MRI examination, the injury usually involves the distal lateral collateral ligament insertion and the distal insertion of the biceps femoris tendon to the fibula (LCL and BFT distally form the conjoint tendon). When edema is localized at the medial aspect of the fibular head, the arcuate ligament or popliteofibular insertions are usually involved. Plain films (arcuate sign) and computed tomography (CT) show the bony avulsion at the fibular tip; MRI has a role in depicting ligamentous injuries.[15,71,72] The authors advocate the presence of fibular edema at the level of the fibular head on MRI as a diagnostic clue. In their MRI evaluation of 19 knees presenting with an arcuate sign at conventional radiographic examination, Juhng and colleagues,[71] reported a tear of the posterolateral capsule in 67% of the cases and an injury to the cruciate ligaments in 89% (16 knees) of the cases: 9 knees with a combined ACL and PCL injury, 4 knees with isolated ACL, and 3 knees with isolated PCL injuries. A bone bruise or fracture was present in all cases, with 50% showing an anteromedial femoral condyle bone bruise and 28% showing the same feature at the anteromedial tibia. A meniscal tear was present on the medial or lateral side in 28% and 22% of the cases, respectively. An injury of the popliteus muscle was evident in 33% of the cases, and all patients had a joint effusion. Huang and coworkers,[72] in their MRI evaluation of 13 knees presenting with an arcuate sign on plain film, found that in 85% of the patients the avulsed bony fragment from the fibula originated either from the attachment of the popliteofibular ligament or the attachment of the popliteofibular, arcuate, and fabellofibular ligaments at the posterosuperior aspect of the fibular styloid process. All patients presented with both PCL and medial collateral ligament (MCL) injury, but no ACL injuries were reported. A popliteus tendon tear was present only in one case, and 77% of the cases had an injury to the arcuate ligament complex, although integrity of the arcuate, popliteofibular, and fabellofibular ligaments could not be fully assessed. The medial meniscus was injured in 38% of the knees and the lateral meniscus in 46%, with arthroscopic confirmation. Bone marrow edema was present in 38% of the patients (anterior lateral tibial plateau, medial tibial plateau, lateral femoral condyle, medial femoral condyle, patella, posterior tibial plateau and fibular head).[72]

Segond fracture

First described in 1879 by Dr Segond,[73] this injury is classically described as a bony avulsion at the tibial attachment of the midthird lateral capsular ligament (**Fig. 10**).[10,12,14,74,75] The midthird lateral capsular ligament is a thickening of the lateral joint capsule that attaches to the lateral femoral condyle and lateral tibia with capsular attachments to the lateral meniscus. It is the lateral equivalent of the deep medial collateral ligament.[21] Its tibial attachment is just posterior to Gerdy's tubercle.[14] The avulsion may also involve the anterior arm of the short head of the biceps femoris that joins the midthird lateral capsular ligament at the tibial insertion. Different studies found its association with ACL injuries, meniscal tears, and damage to the PLC structures. Dietz and colleagues,[76] in a study on 20 knees, reported a concomitant ACL injury (confirmed at arthroscopy

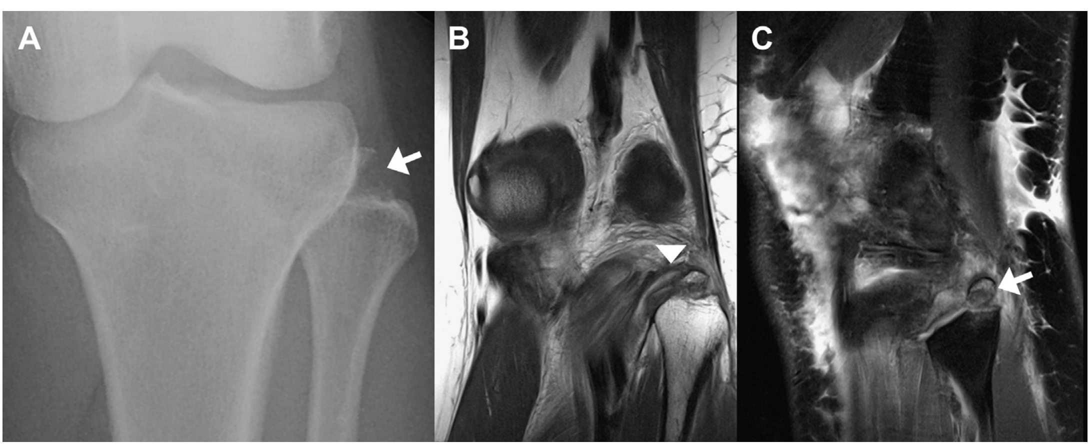

Fig. 9. Frontal radiograph (*A*) coronal PD weighted (*B*) and sagittal T2-weighted FS images (*C*) show an arcuate avulsion fracture (*white arrows*) displaced toward the popliteofibular ligament (*white arrowhead*).

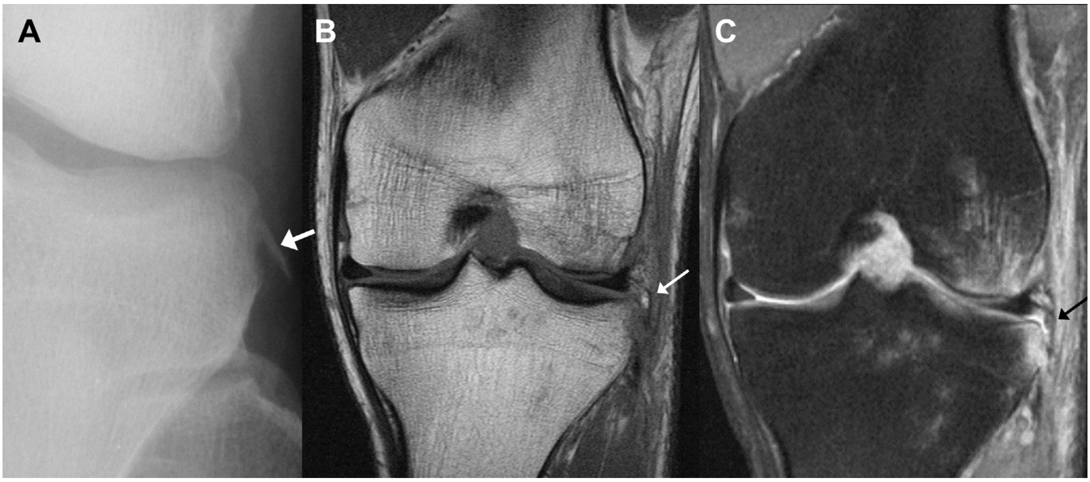

Fig. 10. Frontal radiograph (*A*) coronal T1 (*B*) and coronal T2-weighted FS (*C*) images show a displaced Segond fracture (*white and black arrows*) with surrounding soft tissue and marrow edema.

or physical examination) in 75% of the cases, whereas Goldman and colleagues,[77] in their study on 9 knees, reported an associated ACL injury in 100% of their patients with arthrographic and surgical confirmation. Campos and colleagues[78] suggested the involvement of the iliotibial band and the anterior oblique band of the lateral collateral ligament as important factors in the pathogenesis of the Segond fracture. In their patient population (n = 17) they reported an association with ACL injuries (94%), bone contusions (82%), meniscal tears (53%), PLC injuries (35%), MCL tears (35%), and popliteus tendon injuries (23%).

Anteromedial femoral bone bruise

The presence of a bone bruise in the anterior aspect of the medial femoral condyle on MRI has been associated with PLC knee injuries in the literature (**Fig. 11**). Ross and colleagues[67] reported a bone contusion in the anterior aspect of the medial femoral condyle in 100% of the knees presenting with a complete lateral complex injury (grade III), although their study was small, only containing 6 patients. Varus force and knee hyperextension are commonly involved, both considered common mechanisms of PLC injuries. Therefore, if an anteromedial femoral condylar bone bruise is present on MRI, it is a diagnostic clue that requires a careful evaluation of the PLC complex.

Avulsion of Gerdy's tubercle

The iliotibial band inserts into Gerdy's tubercle on the lateral tibia, and its avulsion can be seen in conjunction with PLC injuries. Isolated injuries

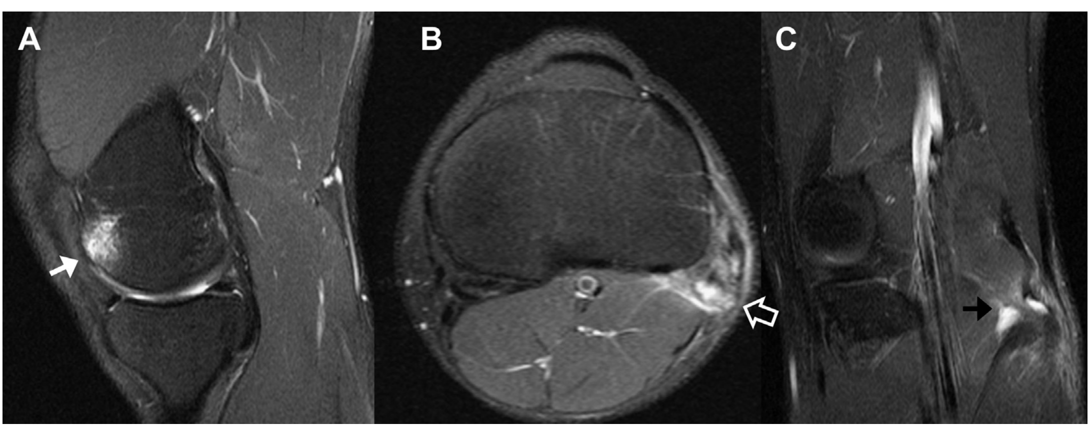

Fig. 11. Sagittal T2-weighted FS image (*A*) shows edema in the anteromedial aspect of the medial femoral condyle (*white arrow*). Axial (*B*) and coronal (*C*) PD FS images from the same patient show edema in the posterolateral corner with high-grade tear of the LCL at the fibular attachment (*open white arrow*), and a high-grade injury of the plantaris muscle (*black arrow*).

of the iliotibial band are infrequent. Ross and colleagues,[67] reported an avulsed iliotibial band in 50% of the knees (6 knees) presenting with a PLC complex injury. Hayes and colleagues[79] developed a mechanism-based classification of complex knee injuries (100 cases) based on patterns of bone marrow edema and ligament injuries seen on MRI and recognized 10 patterns, with injuries based on pure varus force accounting for just 1% (medial tibia and femoral condyle "coup-contrecoup" impactions with ITB and LCL injuries).

This mechanism is rarely seen because varus positioning is normally associated with an internally rotated flexed knee,[79] and additional structures beyond the iliotibial band are usually involved, with concomitant ACL lesions commonly present.[13,80] In their evaluation of avulsion fractures of the lateral femoral condyle in children, Sferopoulos and colleagues[81] reported 2 cases of avulsive fracture of the Gerdy's tubercle. Both of these were sport-related injuries from a direct blow to the medial aspect of the knee while playing football. MRI (**Fig. 12**), CT, and plain radiographs are all able to demonstrate this injury.[81]

Fracture of tibial plateau rim (anterior aspect of the medial plateau)

Fractures of the peripheral anterior margin of the medial tibial plateau have been associated with PLC injuries, and their presence is a useful indicator to raise awareness of a potential PLC injury. Bennett and colleagues[82] evaluated 16 patients with clinically suspected posterolateral corner injuries using MRI and found a tibial plateau fracture in 35%; of these, 83% were at the level of the anterior rim of the medial tibial plateau.

Components of the *Posterolateral Corner Complex*	Suggested Imaging Planes for MR Visualization
Lateral collateral ligament	Axial and coronal
Lateral coronary ligament	Coronal
Arcuate ligament	Sagittal
Popliteus myotendinous unit	Axial
Popliteofibular ligament	Coronal, *coronal oblique*[a] and sagittal
Fabellofibular ligament	Coronal and *coronal oblique*[a]
Lateral joint capsule	Axial and coronal

[a] Dedicated imaging plane usually not included in routine MRI protocols.

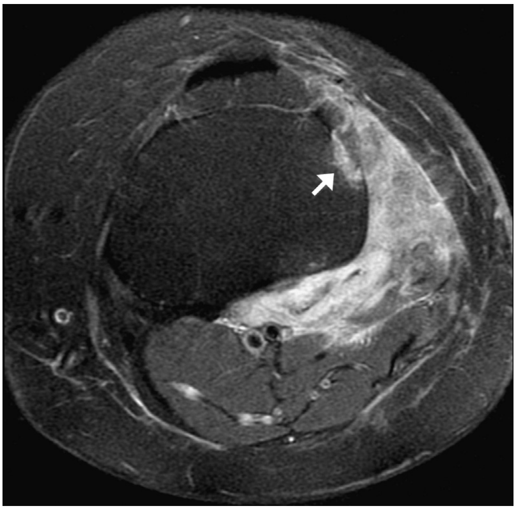

Fig. 12. Axial T2 FS image shows bone marrow edema localized at the level of Gerdy's tubercle (*white arrow*) consistent with an avulsive injury, with extensive edema around the PLC and lateral aspect of the knee.

POSTEROMEDIAL CORNER OF THE KNEE

Anatomy, Biomechanics, and Mechanism of Injuries to the Posteromedial

In 1979, Warren and Marshall[9] introduced the concept of a three-layer approach in the evaluation of the medial supporting structures of the knee, dividing those structures in a *superficial layer (I)*, *intermediate layer (II)*, and *capsule proper (III)* (see **Fig. 2**). In their original description, the superficial layer consists of fascial extensions, made by the deep (crural) fascia that invests the sartorius muscle. Posteriorly, it consists of a thin fascial sheet overlying the 2 heads of the gastrocnemius and the popliteal fossa structures. Serving as a support structure to muscle bellies and neurovascular structures in the popliteal region, it may be reinforced by fascial fibers originating from the sartorius, vastus medialis, and fascia at the level of the popliteal fossa. Anteriorly, layer I connects to layer II to form the medial patellar retinaculum. A fatty tissue layer lies between the superficial layer and the structures deep to it. Anteriorly and distally, the superficial layer joins the tibial periosteum at the level of the sartorius muscle insertion. The gracilis and semitendinosus muscles can be identified more distally as distinct structures with layer I lying superficial and layer II deep to them. The intermediate layer consists of the fibers of the MCL, also called the superficial medial collateral ligament or tibial collateral ligament. At the level of the posteromedial aspect of the knee, the intermediate layer (II) joins the capsule proper (III) and the tendon sheath of the semimembranosus muscle, forming the posteromedial corner pouch surrounding the medial femoral condyle (see **Fig. 2**).[9,83–85] The capsule proper, the deepest of the 3 layers, attaches to the medial meniscus and to the articular margins. Anatomic descriptions of the medial side of the knee describe the MCL as having an anterior vertical component and a posterior oblique component (see **Fig. 1**).[86] The vertical anterior portion measures 1.5 cm in width and 10–11 cm in length, attaching proximally to the medial femoral epicondyle about 5 cm above the joint line, and attaching distally to the medial aspect of the tibial metadiaphysis around 6–7 cm below the joint line. Its distal attachment lies deep to the semitendinosus and gracilis tendons.[83,85,87,88] The intermediate layer (II) and the deeper capsule proper (III) unite posteriorly with the anterior margin of the superficial MCL and the PMC of the knee. The posterior portion of the MCL originates at the proximal attachment of the medial collateral ligament and extends distally in a posterior oblique fashion (at 25° with respect to the anterior vertical portion) to reach the posteromedial aspect of the knee, forming an envelope about the semimembranosus tendon.[88] The posterior oblique portion of the MCL gained its own discrete anatomic consideration in an article from Hughston and Eilers[89] describing the posterior oblique ligament (POL), introducing the concept of the posteromedial corner. To be more specific, the POL has its proximal origin at the adductor tubercle of the medial femoral condyle while the MCL proper (anterior portion) originates around 1 cm anterior and distal to it. The POL also attaches to the medial meniscus at the posteromedial corner of the knee while the superficial MCL does not. The POL comprises 3 arms: the central or tibial arm, attaching to the medial meniscus; the superior or capsular arm, attaching to the posterior joint capsule and proximal portion of the oblique popliteal ligament; and a distal arm, attaching both to the sheath of the semimembranosus tendon and distally to the tibial insertion of the semimembranosus.[89] The MCL includes a deep thickened component called the deep medial collateral ligament (or deep medial capsular ligament), divided into a meniscofemoral component proximally and a meniscotibial component distally. A bursa separates the deep and superficial fibers of the MCL.

The anatomic structures that comprise the PMC of the knee and participate in its function as a restraint to anteromedial rotary instability (AMRI) are the *distal semimembranosus myotendinous complex*, the *POL*, the *medial portion of the oblique popliteal ligament* (OPL), the *meniscotibial ligament* (distal portion of the deep MCL), and the *posterior horn of the medial meniscus*.[90,91]

The distal semimembranosus myotendinous complex consists of 5 distal insertional arms dividing at the level of the joint line: the direct (principal), capsular, anterior (tibial or reflected), inferior (popliteal) arms, and the OPL expansion.[92] The direct arm travels anteriorly and inserts just below the joint line at the tibial tubercle on the posterior aspect of the medial tibial condyle passing beneath the anterior arm. The anterior arm extends anteriorly, under the posterior oblique ligament to attach to the medial aspect of the proximal tibia just beneath the medial collateral ligament. The inferior arm travels more distally than the direct and anterior arms, passing beneath the POL and the MCL to attach just above the tibial attachment of the MCL. The capsular arm has a deep location and coalesces with the capsular portion of the oblique popliteal ligament. A sixth arm, inserting at the posterior third of the lateral meniscus, has been described in 43% of cases by Kim and colleagues.[93]

The OPL is a lateral extension of the semimembranosus tendon that surrounds the posteromedial joint capsule, extending in a superolateral oblique direction as the largest structure in the posterior knee. The OPL is therefore a component of both the PMC and PLC of the knee and contributes to the posterior joint stabilizers, forming part of the popliteal fossa (see **Fig. 1**; **Fig. 13**). LaPrade and colleagues[1] elegantly showed its anatomic relationships, describing it as a broad fascial band crossing the posterior aspect of the knee in an oblique direction. Medially, the OPL arises from the confluence of the lateral expansion of semimembranosus distally and the capsular arm of the POL proximally. Laterally, the OPL attaches to an osseous or cartilaginous fabella, to the meniscofemoral portion of the posterolateral joint capsule and the plantaris muscle. There is also a fibrous attachment to the lateral aspect of the PCL facet.

Flandry and Perry[94] have described the biomechanics of the medial supporting structures of the knee with emphasis to the posteromedial corner. With its 5 arms attaching to bone, capsule, medial meniscus, ligaments, and tendon sheaths, the semimembranosus muscle acts as the main dynamic stabilizer of the PMC. If a structure of the PMC fails, the semimembranosus muscle activates itself, eventually developing intrinsic muscle spasm and articular instability. When the semimembranosus muscle contracts, flexion and internal rotation occur, increasing tension in the adjacent ligaments and contributing to joint stability. The semimembranosus also produces traction on the posterior horn of the medial meniscus, reducing the incidence of meniscal injuries caused by compression of the medial femoral condyle. The semimembranosus muscle causes tension on the oblique popliteal

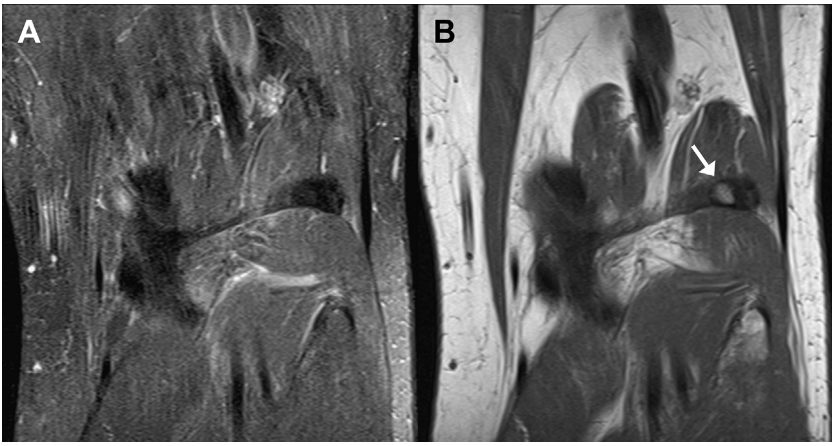

Fig. 13. Coronal FS PD (*A*) and non FS PD (*B*) images show the normal anatomy of the oblique popliteal ligament. Note its attachment to the fabella at the posterolateral aspect of the knee (*arrow*).

ligament and therefore participates in lateral capsular stability. The natural tendency of the POL is to be lax when the knee is flexed and tight when the knee extends. The above mechanism is therefore extremely important, because most knee injuries occur during knee flexion.[40,41] With respect to patterns of injury, patients with symptomatic AMRI almost always have involvement of the POL (99%), with the injury to the semimembranosus (70%) and peripheral meniscal detachment (30%) occurring less frequently.[90] When a grade III MCL injury is present, in conjunction with an anterior cruciate ligament (ACL) injury and medial meniscal tear, a specific pattern of injury has been described, the so-called *O'Donoghue's unhappy triad*.[95] The latter pattern of injury may be associated with PMC injuries. There is a strong association between PMC and ACL injuries,[90] and if those lesions do not occur together, usually an intact PMC compensates for the ACL deficiency to maintain stability. Combined PCL and MCL injuries are uncommon, and likewise a combination of PCL and lateral support structure injury is rare. Combined ACL-PCL injuries with medial supporting structure involvement occur with equal or greater frequency than on the contralateral side.[6,96–99] Usually an isolated MCL injury is treated conservatively, but the presence of a simultaneous posteromedial corner injury may require surgical intervention because of the potential for AMRI. An accurate evaluation of the PMC at imaging is imperative to guide the clinical and surgical management.

INJURIES TO THE POSTEROMEDIAL

Soft-tissue Injuries of the Posteromedial

Semimembranosus insertion injuries

Injuries to the distal semimembranosus insertion occur in up to 70% of posteromedial corner injuries[90] and include avulsion fracture at its tibial attachment, partial or complete tendon tears, and tendinosis (**Figs. 14** and **15**). Chan and colleagues[100] reviewed the radiographs and MRI studies of 10 patients with posteromedial tibial plateau injuries, including 5 fractures of the posteromedial tibial plateau and 5 distal semimembranosus insertional injuries, and found an ACL tear in 100% of patients.

Avulsion fractures usually occur at the insertion of the direct arm and may appear as a bone bruise with a fracture line on MRI examination. Partial tears and strains are common and usually involve the capsular arm. At MRI, partial tears and strains manifest as altered signal within an otherwise intact tendon. Complete tears of the semimembranosus, although uncommon, present as a discontinuity of the tendon itself, and are best seen on axial and sagittal images. Tendinosis caused by chronic stress is seen as thickening of the tendon insertion. If the capsular arm of the semimembranosus tendon is involved, signal alteration with eventual thickening may be seen at the level of the posterior medial capsular region, contiguous with the POL, and better seen on axial images.[91] The presence of fluid distending the joint capsule may facilitate evaluation of these deep structures. If fluid is absent, the capsular arm appears as a flat structure on the posterior aspect of the medial tibial plateau, indistinguishable from the nearby direct arm, in continuity anteriorly with the anterior arm and posteriorly with the OPL. The anterior arm is better seen on peripheral medial sagittal images, curving anteriorly with an almost horizontal course, and on coronal images as a round hypointense structure adjacent to the medial tibia, passing under the MCL. The direct arm is usually not visible on MRI. The inferior arm may be seen anteriorly as a low signal intensity structure that extends below the joint line.[92]

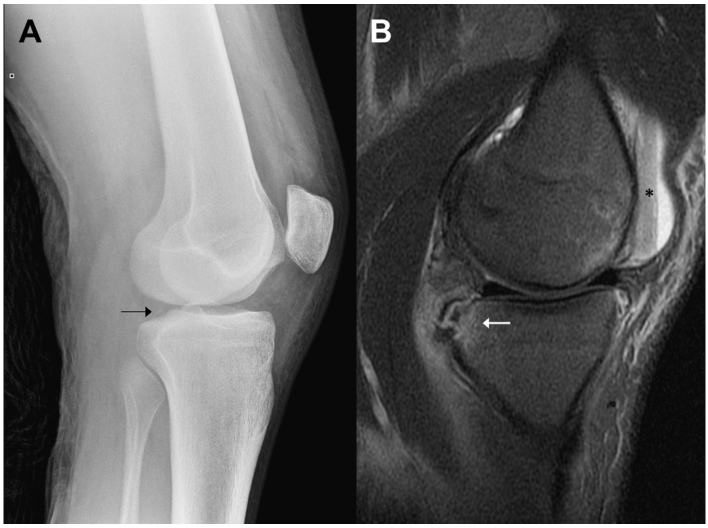

Fig. 14. Lateral radiograph (*A*) and sagittal T2-weighted MR with fat saturation (*B*) show an insertional avulsion injury of the distal semimembranosus tendon, involving both the capsular and direct arms. Note the small bony avulsed fragment (*black arrow*) and resulting bone marrow edema (*white arrow*). A lipohemarthrosis is also evident as a sequela of knee trauma (*asterisk*).

Posterior oblique ligament (POL) injuries

As previously mentioned, POL injuries have been found in 99% of surgically treated patients presenting with medial-sided knee injuries and AMRI.[90] Wijdicks and colleagues[101] in their biomechanic cadaveric study on 24 knees, directly evaluated the changes in tensile forces of the POL in an injury state and its relation to the MCL. They applied a valgus and external rotation moment to the knee after sectioning the MCL (superficial and deep) and found a significant load increase to the POL compared with a knee with an intact MCL condition. This finding reinforces the concept that in cases of reconstruction or surgical repair, all injured medial knee structures should be restored to reproduce the force relationships between them. Petersen and colleagues,[102] in another kinematic cadaveric study on 10 knees, addressed the importance of the POL as a restraint to posterior tibial translation in PCL-deficient knees, therefore emphasizing the need to specifically evaluate it in cases of combined injuries to PMC structures and the PCL. House and colleagues,[91] recommended applying the same grading system used for medial collateral ligament injuries to POL injuries (grade I, microscopic tear; grade II, partial tear; grade III, complete tear). POL injuries comprise sprains, partial tears, and complete tears, and are best visualized on axial and coronal planes (**Fig. 16**).

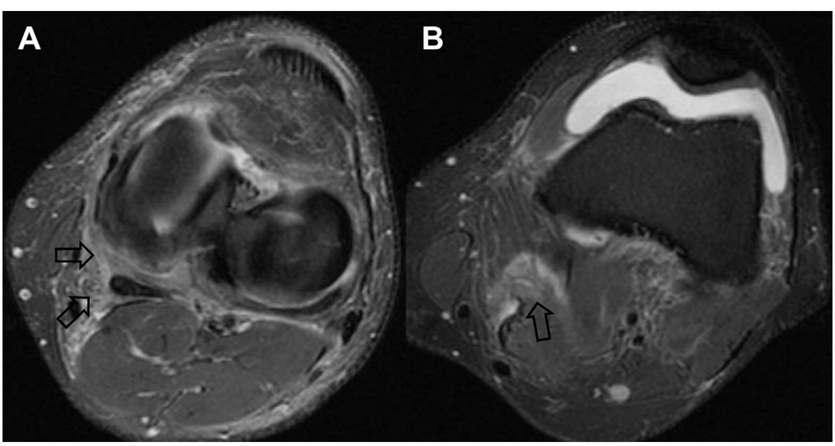

Fig. 15. Axial T2 FS images (*A, B*) show prominent edema within the myotendinous junction of the distal semimembranosus (*black open arrows*) consistent with a strain.

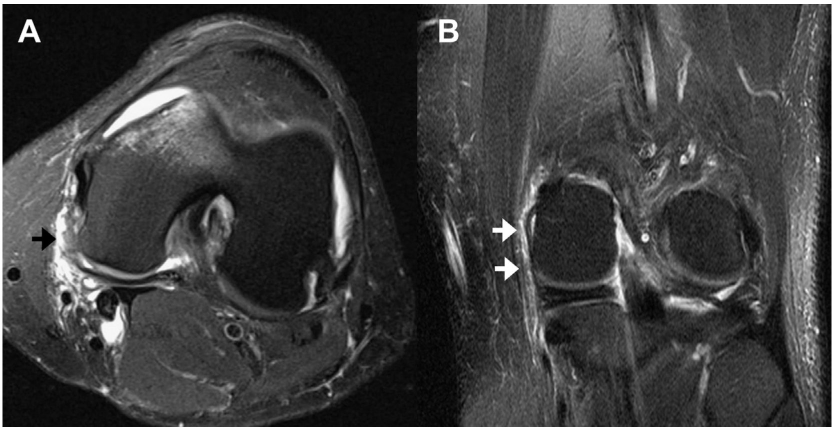

Fig. 16. Axial PD FS image (*A*) shows an irregular POL with surrounding edema consistent with disruption (*black arrow*). Coronal PD FS image (*B*) from a different patient shows an acute on chronic POL injury characterized by thickening of the ligament proximally and partial thickness tearing at femoral attachment with surrounding edema (*white arrows*).

Medial meniscocapsular lesions

The posterior third of the medial meniscus contributes to the dynamic stabilizing function of the PMC because of its intimate anatomic relations with the deep structures, which act as a restraint to posterior translation of the medial femoral condyle on the tibia. Its firm attachment to the tibia is important and guaranteed in part by the meniscotibial portion of the deep MCL. Meniscal instability may put the PMC under stress, therefore making it more prone to injury.[91] MRI can detect injuries to both the meniscotibial and meniscofemoral portions of the deep MCL, which can be seen as disruption, thickening, or bony avulsion. When a bony avulsion is appreciated at the level of the meniscotibial ligament insertion, the specific lesion is called a *reverse Segond fracture* (**Fig. 17**), which is associated with posterior cruciate ligament rupture.[66,103]

Injuries to the oblique popliteal ligament (OPL)

The OPL is the largest structure along the posterior aspect of the knee[1] (see **Figs. 1** and **13**), and its anatomic contribution to the PMC complex has been established. Morgan and colleagues[104] did an in vitro cadaveric study on 20 knees and defined the role of the OPL as the primary ligamentous restraint to knee hyperextension, describing its participation in genu recurvatum (knee hyperextension) development. The OPL should therefore be carefully assessed on MRI when evaluating the posteromedial corner of the knee.[1,104] On axial and sagittal planes, the OPL appears as a thin

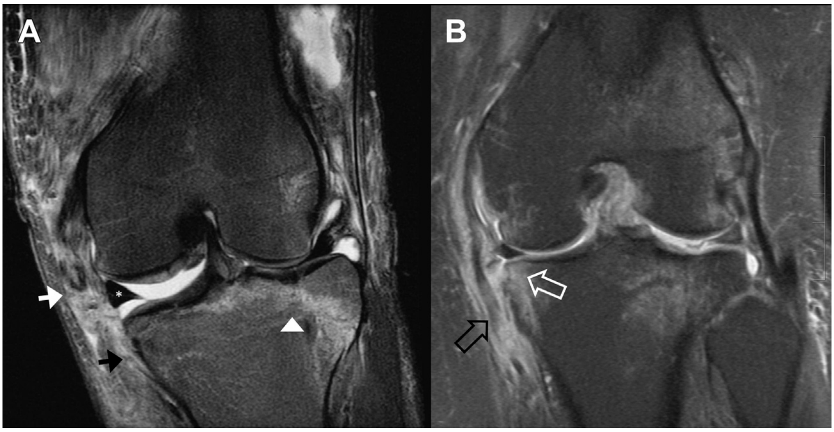

Fig. 17. Coronal PD FS image (*A*) shows disruption of the MCL at the distal midportion (*white arrow*) with associated injury of the meniscotibial fibers of the deep MCL (*black arrow*) and a floating medial meniscus (*asterisk*). An osteochondral impaction fracture of the lateral tibial plateau is also present (*white arrowhead*). Coronal PD FS image (*B*) from a different patient shows a meniscotibial avulsion fracture (Reverse Segond fracture) (*open white arrow*) and a disrupted MCL distally (*open black arrow*).

deep structure of low signal intensity, indistinguishable in most cases from the posterior capsule, but continuous with the semimembranosus tendon.[92] Injuries to the OPL may manifest as irregularity of this fascialike structure, with encircling edema in the deep posteromedial aspect of the knee. On axial imaging, this finding is appreciable on fluid-sensitive sequences at the level of the joint line.

Components of the *Posteromedial Corner Complex*	Suggested Imaging Planes for MRI Visualization
Distal semimembranosus myotendinous complex	Sagittal and axial
POL	Axial
OPL	Axial and sagittal
Meniscotibial ligament	Coronal
Posterior horn of medial meniscus	Sagittal

SUMMARY

The posterolateral and posteromedial corners of the knee represent challenging anatomic regions in musculoskeletal imaging. Plain films and CT are helpful in the assessment of osseous involvement. However, MRI is the imaging modality of choice because of its intrinsic ability to evaluate soft tissue structures, although ultrasound scan can be used as a complementary technique. High field strength MRI is becoming the standard in high-end musculoskeletal imaging services and will lead to future technologic advances that will enhance the visualization of even the most delicate anatomic components. The ability of the musculoskeletal radiologist to see more, demands a deeper understanding of complex anatomy and specific injury patterns, particularly in those anatomic areas in which anatomy does not follow classical imaging planes and is confined in a narrow space. The posterolateral and posteromedial corner of the knee fall into this category. The underestimation and misinterpretation of reporting injuries in these specific areas can result in a poor patient outcome. For example, chronic posterolateral instability for untreated PLC injuries[4,5] and valgus instability for PMC deficiencies[6] can cause reconstruction of the central supporting structures to fail long term. Therefore, a full appreciation of PMC and PLC structures is of primary importance in the MRI evaluation of the knee to generate a relevant, pertinent, and exhaustive report that will guide the clinical or surgical management of these patients and improve patient outcome.

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