Ligamentous Reconstruction of the Knee: What Orthopaedic Surgeons Want Radiologists to Know

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Abstract

Knee ligament injuries are common, and treatment methods are continually evolving. Accurate clinical diagnosis with imaging confirmation is critical to support appropriate treatment. Several imaging pearls allow for improved recognition of injuries. Stress radiographs may be obtained to quantify knee laxity. Magnetic resonance imaging allows assessment of the complex anatomy of the knee and has excellent sensitivity and specificity for many injuries.

Keywords
- ► knee ligaments
- ► stress radiographs
- ► anterior cruciate ligament
- ► posterior cruciate ligament
- ► medical collateral ligament
- ► posterolateral knee
- ► magnetic resonance imaging

Radiologists must understand key principles related to knee ligament injury and reconstruction, including the differentiation of acute from chronic injuries, and be familiar with normal and abnormal postoperative imaging findings. Optimization of outcomes for knee ligament injuries often depends on early intervention, the recognition of certain knee ligament tear patterns, such as posterolateral knee injuries or multiple ligament injuries, and the awareness of potentially subtle findings that can be important secondary signs of significant knee pathology.

Several key pearls are presented to improve diagnostic accuracy and avoid missed injuries that may have a critical impact on the treatment approach and overall outcome. For example, bucket-handle or meniscal root tears with multiple ligament injuries need to be recognized and treated acutely. Also, combined knee ligament injuries are more common than once thought. For example, $<$ 10% of posterior cruciate ligament (PCL) tears are isolated. Posterolateral knee injuries are challenging to identify on imaging and examination, although a medial compartment bone bruise is a secondary sign of injury to these structures.[1] The presence of an “intact” but previously injured PCL in a native knee or evidence of an “intact” cruciate ligament graft in a previously reconstructed knee does not guarantee functional stability; a careful physical examination and radiographic evaluation for joint subluxation in such patients with chronic injuries must be performed. In addition, previous ligament reconstruction graft-tunnel location and the presence of tunnel osteolysis (width $>$ 12 mm) are essential to recognize. Iatrogenic injuries, such as the presence of a meniscal root injury due to malpositioned cruciate ligament tunnels, also need to be identified.

We present a review of key anatomy and biomechanical principles concurrently with a discussion of imaging

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Table 1 Pearls for imaging findings identified radiographs or magnetic resonance imaging in patients with knee ligament injuries

Finding	Diagnostic or treatment significance
Anterior cruciate ligament	
Anterior tibial translation on lateral knee radiograph	Possible ACL insufficiency in chronic or reconstructed setting
ALL injury in the setting of ACL tear	Potential residual rotational instability and possible ACL graft failure if ALL tear not addressed
Lateral compartment bone bruise	Probable acute ACL tear
ACL tear and knee effusion without lateral compartment bone bruises	Chronic ACL tear may be present; evaluate for presence of acute meniscus tear
Posterior cruciate ligament	
Posterior tibial translation on lateral knee radiograph	Possible PCL insufficiency in chronic or reconstructed setting
"Normal"-appearing PCL on MRI in a patient with a chronic injury and a pseudo-Lachman on examination	PCL tear, healed with residual PCL laxity; kneeling stress radiographs recommended to quantify laxity
PCL tear	Associated PLC injury in up to 70% of patients
PCL tibial avulsion fracture	May include posterior meniscal root attachments
Lateral/Posterolateral knee	
Medial compartment bone bruise on MRI	FCL/PLC tear, medial meniscus "ramp" lesion (meniscocapsular separation)
Popliteus muscle belly edema	Possible popliteus tendon tear or stretch injury
Arcuate fracture or biceps tendon avulsion	Possible entrapment of common peroneal nerve; acute treatment allows careful neurolysis and restoration of biceps tendon attachment
Medial/Posteromedial knee	
PMC injury in the setting of ACL/PCL tear	ACL/PCL graft failure if PMC injury is not addressed
Medial ligament injury seen on multiple consecutive coronal sections from anterior to posterior	Complete medial injury including sMCL, deep MCL, and POL and may have gapping in full extension with valgus stress and significantly decreased healing ability
Distal MCL tear	Relatively poor blood supply compared with proximal tears and lower chance of healing
Superficial MCL distal tears displaced superficial to the pes tendons	Low likelihood of healing
Commonly associated meniscal injuries	
Ghost sign or meniscal extrusion	Posterior meniscal root tear
Meniscocapsular separation ("ramp lesion")	Increased stress on ACL graft and possible failure
Meniscal radial tear	Altered contact mechanics and possibly amenable for surgical repair
Double-PCL sign	Bucket-handle meniscus tear necessitating urgent orthopaedic evaluation

Abbreviations: ACL, anterior cruciate ligament; ALL, anterolateral ligament; FCL, fibular collateral ligament; MCL, medial collateral ligament; MRI, magnetic resonance imaging; PCL, posterior cruciate ligament; PLC, posterolateral corner; PMC, posteromedial corner; POL, posterior oblique ligament.

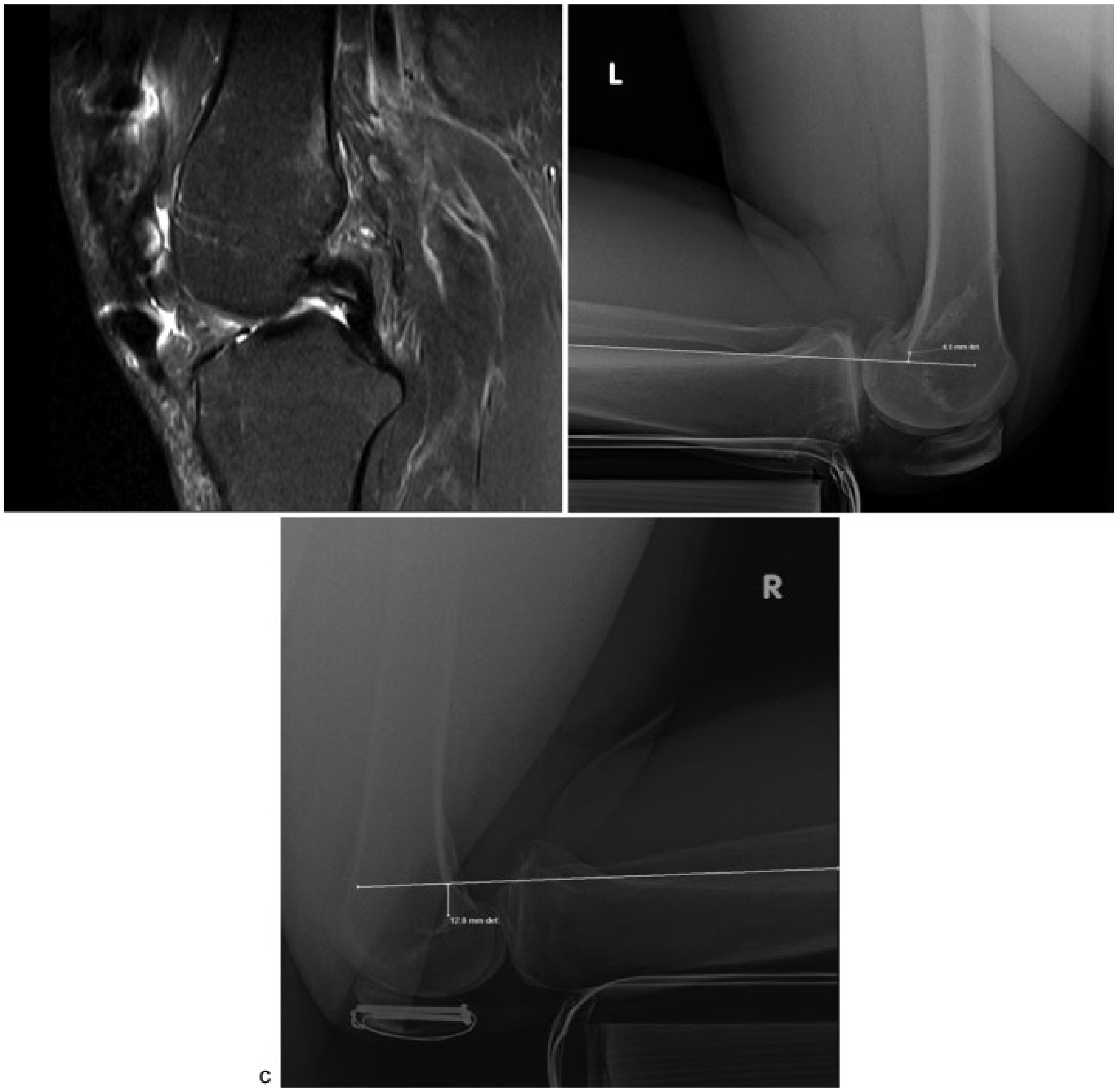
modalities and key findings. Selected case examples are incorporated and diagnostic pearls are listed.

Role of Imaging in the Preoperative Setting

Radiographs and magnetic resonance imaging (MRI) are the most frequently requested examinations for the evaluation of knee ligament injuries. Computed tomography is generally reserved acutely for the characterization of displaced fractures involving the articular surfaces and chronically to assess tunnel positioning for cruciate ligament reconstruction and whether tunnel osteolysis (widening) is present.

Plain Radiographs

Anteroposterior (AP), lateral, and patellofemoral sunrise view radiographs should be obtained in all patients. The AP view may identify a fibular head (arcuate) fracture[2] due to a biceps tendon, fibular collateral ligament (FCL), and/or popliteofibular ligament bony avulsion or a Segond fracture[3] associated with disruption of the anterolateral structure tibial



a b c

Fig. 1 (**a**) Right knee magnetic resonance imaging (MRI) sagittal section in a patient with posterior laxity and a reportedly "normal" posterior cruciate ligament (PCL) on MRI. (**b**) Left and (**c**) right knee posterior stress radiographs are shown in this patient with a 16.9 mm increased posterior tibial translation, consistent with PCL insufficiency.

attachments (and classically associated with an anterior cruciate ligament [ACL] tear).[4] The lateral knee radiograph may reveal anterior or posterior tibial subluxation in patients with ACL or PCL injuries, respectively (►**Table 1**). Additional radiographs should be obtained if clinically indicated including weight-bearing long-leg views to assess alignment and the mechanical axis, and Rosenberg views[5] to evaluate for joint space narrowing.

Stress Radiographs

Stress radiography is a "functional" imaging tool that provides an objective assessment of knee ligament injury, especially in the setting of an equivocal physical examination or magnetic resonance imaging (MRI). Stress radiographs should be obtained in patients with suspected or confirmed multiligamentous injury, preoperatively and at regular intervals postoperatively.

Posterior Stress Radiographs

Kneeling bilateral posterior stress radiographs at 90 degrees of knee flexion are a reproducible method for quantifying laxity in the setting of a PCL injury (►**Fig. 1**).[6,7] Compared with the contralateral uninjured knee, increased translation of 5 to 12 mm is usually present with an isolated complete PCL tear, whereas $>$ 12 mm is usually indicative of a combined posterolateral corner (PLC) or posteromedial corner (PMC) injury.[6] These measurements assume a normal posterior tibial slope of 9 degrees; in patients with a decreased, tibial slope, both posterior tibial translation and clinical symptoms are often increased.

Varus Stress Radiographs

A quantitative assessment of lateral compartment gapping is performed using bilateral varus stress radiographs at 20 degrees of knee flexion.[8] An isolated complete FCL injury

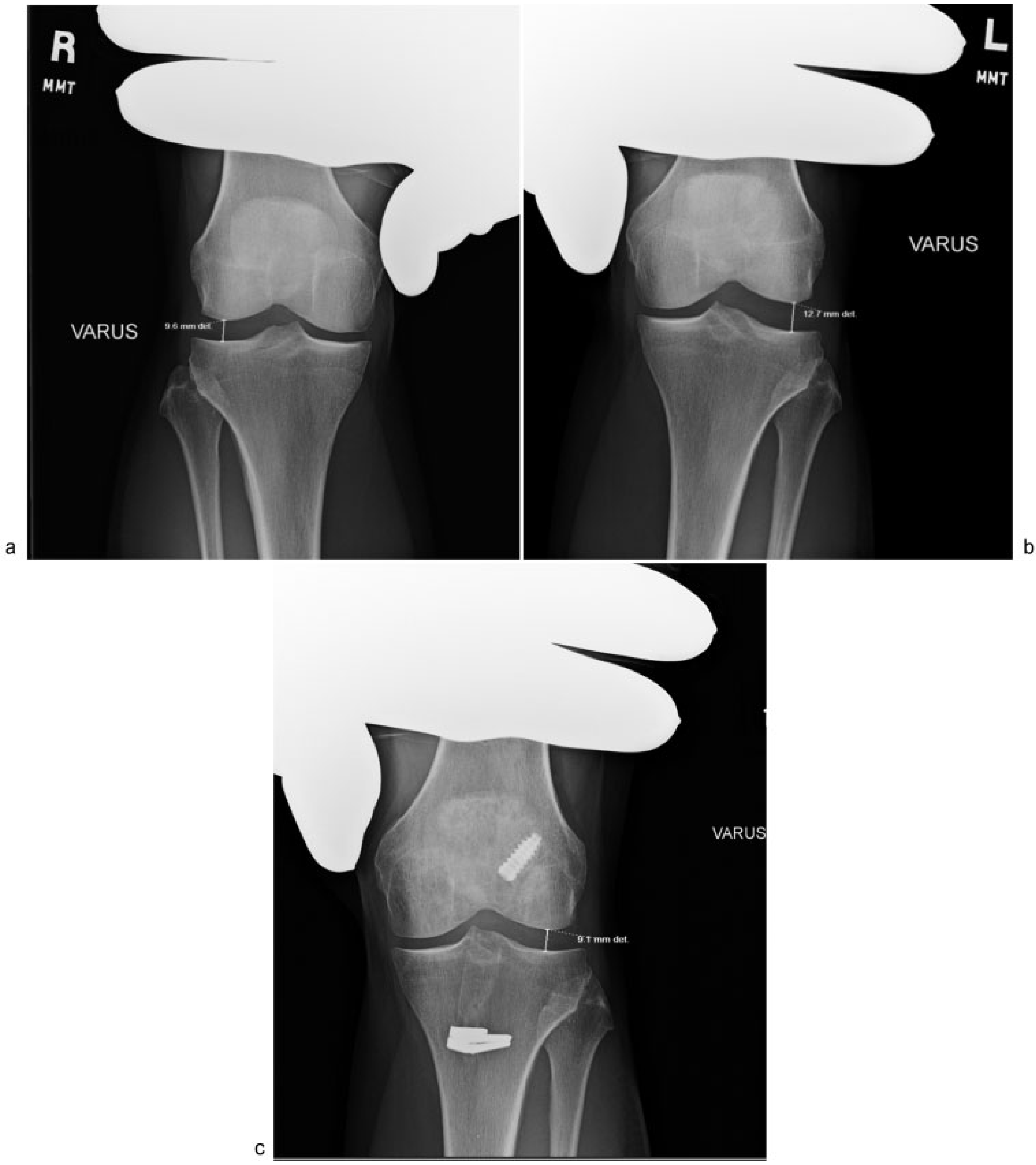


Fig. 2 Preoperative (**a**) right (uninjured) and (**b**) left (injured) varus stress radiographs of a patient with a 3.1 mm increased opening, consistent with a complete fibular collateral ligament (FCL) tear. (**c**) Postoperative left knee varus stress radiograph is shown, demonstrating restoration of normal stability following reconstruction of the anterior cruciate ligament and FCL.

has been reported to result in 2.7 mm of increased lateral compartment gapping, and a complete PLC injury results in 4.0 mm of increased gapping compared with the contralateral normal knee (►**Fig. 2**).

Valgus Stress Radiographs

A quantitative assessment of medial compartment gapping is performed using bilateral valgus stress radiographs at 20 degrees of knee flexion.[9] A complete superficial medial collateral ligament (sMCL) tear has been reported to result in 3.2 mm of increased medial compartment gapping, and a complete medial knee injury (sMCL, deep MCL, and posterior oblique ligament [POL]) results in 9.8 mm of increased gapping compared with the normal contralateral knee (►**Fig. 3**).

Magnetic Resonance Imaging

A detailed quantitative characterization of the anatomy of the ACL (►**Fig. 4**),[10] PCL (►**Fig. 5**),[11] medial knee (►**Fig. 6**),[12] and the lateral knee (►**Fig. 7**)[4,13] has been performed.

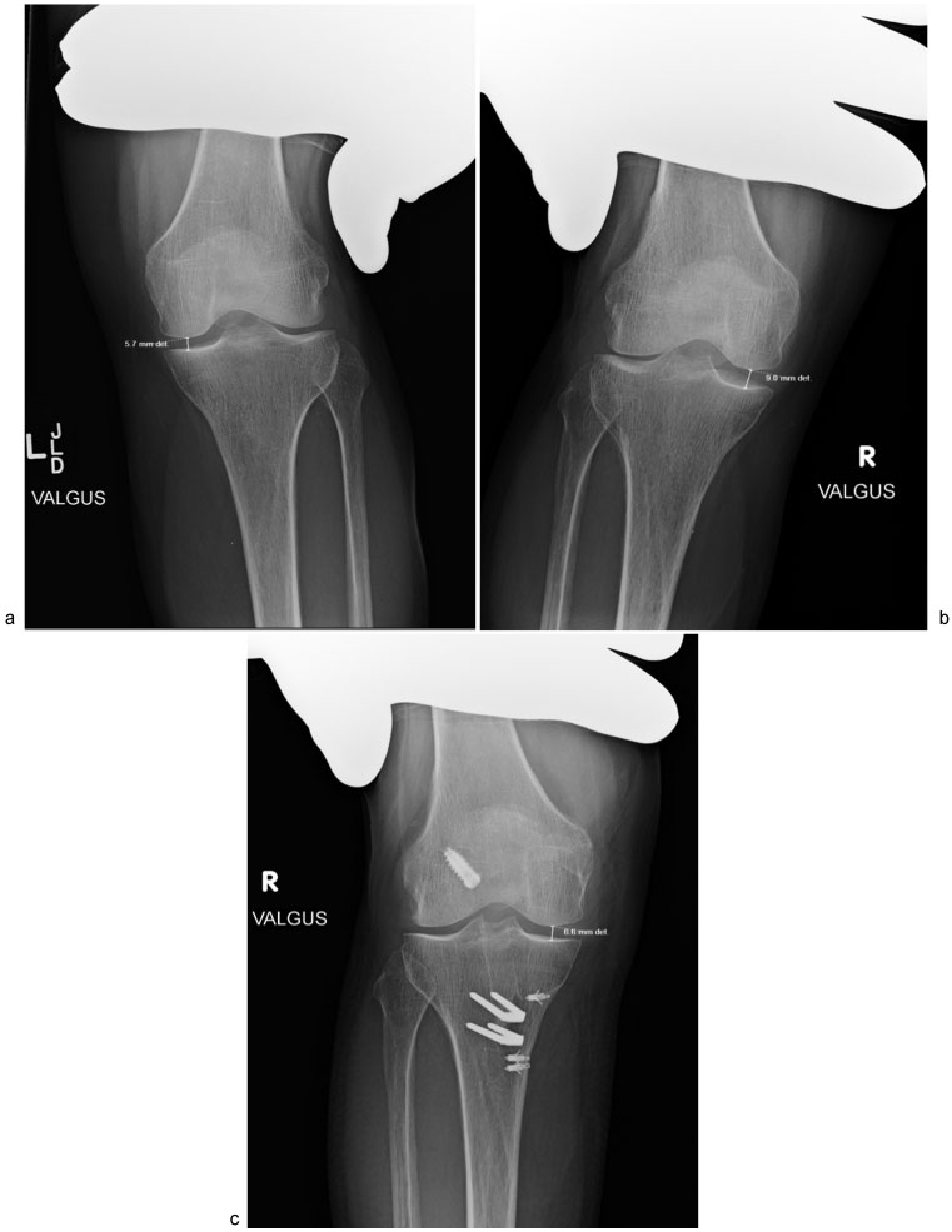


Fig. 3 Preoperative (**a**) left (uninjured) and (**b**) right (injured) valgus stress radiographs of a patient with a 3.3 mm increased opening, consistent with a complete medial collateral ligament (MCL) tear. (**c**) Postoperative right knee varus stress radiograph is shown, demonstrating restoration of normal stability following reconstruction of the anterior cruciate ligament and MCL.

An appreciation of the origin, insertion, and fiber orientation of the most important knee structures allows for further prediction of each structure's biomechanical role, and most importantly aids the radiologist in image interpretation.

A systematic evaluation of key anatomy on MRI is essential to avoid overlooking associated injuries that may necessitate an alternative treatment plan and referral to an orthopaedic surgeon with expertise in treating complex

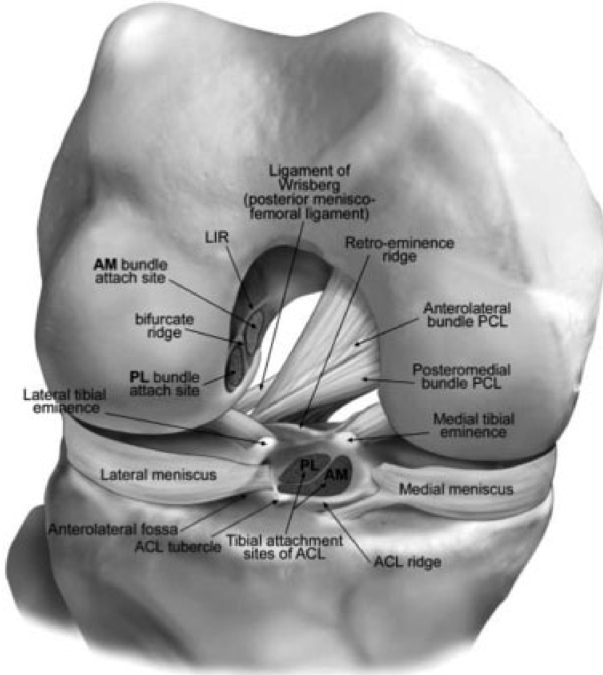


Fig. 4 Right knee illustration demonstrating tibial and femoral landmarks including anterior cruciate ligament (ACL) attachment sites. AM, anteromedial bundle; LIR, lateral intercondylar ridge; PCL, posterior cruciate ligament; PL, posterolateral bundle. Reproduced with permission from Ziegler et al.[10]

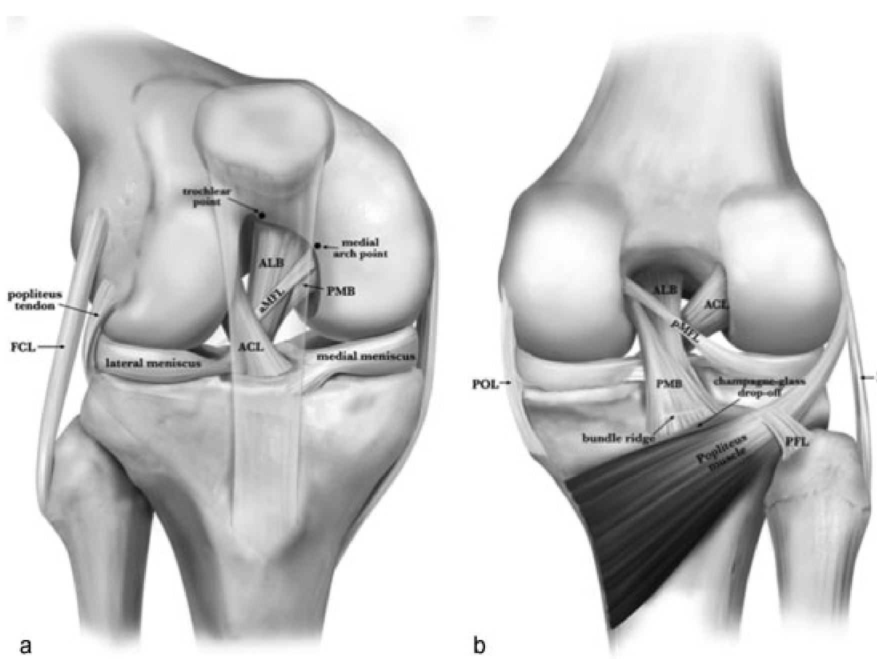


Fig. 5 Illustration of the (**a**) anterior and (**b**) posterior aspects of a right knee, demonstrating the posterior cruciate ligament (PCL) attachment sites adjacent to the articular cartilage on the femur and posterior to the meniscal roots on the tibia. Anatomical landmarks are shown. ACL, anterior cruciate ligament; ALB, anterolateral bundle; aMFL, anterior meniscofemoral ligament; FCL, fibular collateral ligament; PFL, popliteal-fibular ligament; PMB, posteromedial bundle; pMFL, posterior meniscofemoral ligament; POL, posterior oblique ligament. Reproduced with permission from Kennedy NI, Wijdicks CA, Goldsmith MT, et al. Kinematic analysis of the posterior cruciate ligament. Part 1: The individual and collective function of the anterolateral and posteromedial bundles. Am J Sports Med 2013;41(12):2828–2838.

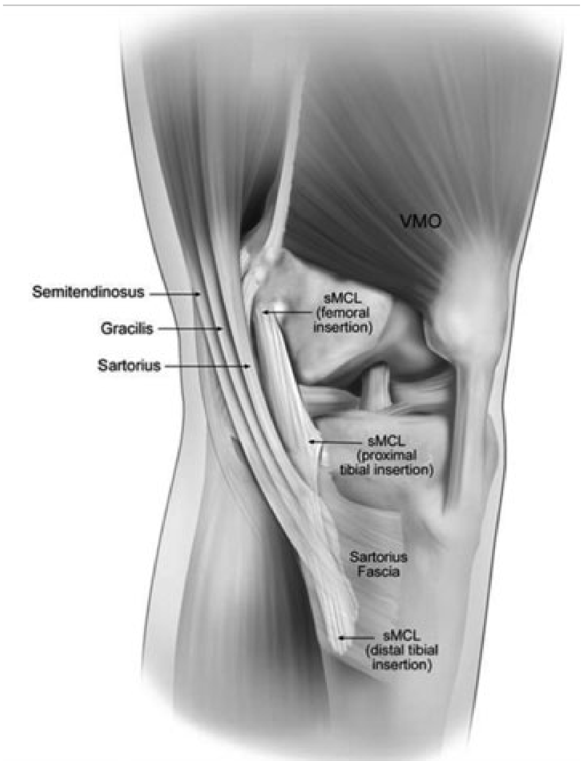


Fig. 6 Illustration of the anteromedial aspect of a left knee, demonstrating the femoral and tibial attachments of the superficial medial collateral ligament (sMCL). Not shown are the deep MCL and posterior oblique ligament. VMO, vastus medialis obliquus muscle. Reproduced with permission from Wijdicks CA, Michalski MP, Rasmussen MT, et al. Superficial medial collateral ligament anatomic augmented repair versus anatomic reconstruction: an in vitro biomechanical analysis. Am J Sports Med 2013;41(12):2858–2866.

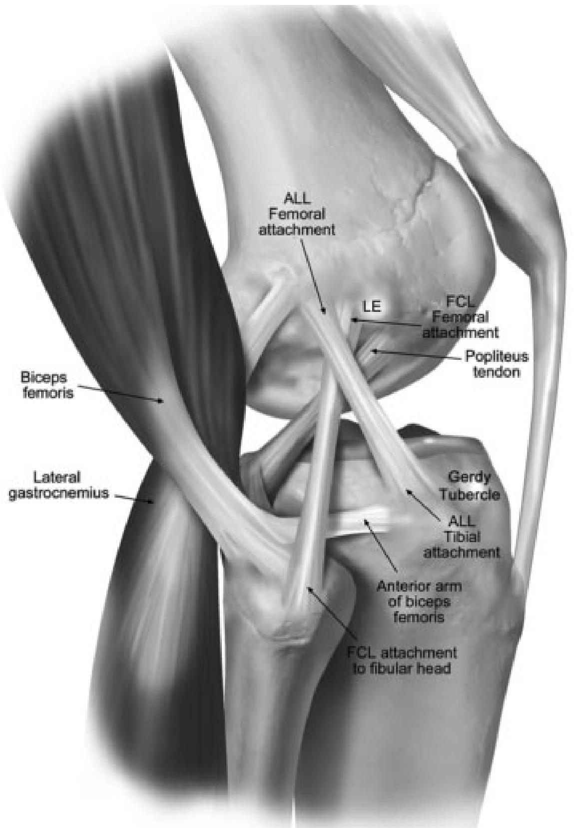


Fig. 7 Illustration of the lateral aspect of a right knee, demonstrating the attachment sites of the principal structures of the lateral knee (iliotibial band and non-ALL-related capsule removed). ALL, anterolateral ligament; FCL, fibular collateral ligament; LE, lateral epicondyle. Reproduced with permission from Kennedy et al.[4]

injuries. If the MRI is equivocal, correlation should be performed with both the clinical examination *and* stress radiographs.

Anterior Cruciate Ligament

Loss of fiber integrity with edema is characteristic of ACL tears, along with classic lateral compartment bone bruises.[14,15] The lateral meniscus is more commonly injured in acute ACL tears, and the medial meniscus is more commonly injured in patients with chronic ACL tears due to its role as a secondary stabilizer against anterior tibial translation.[16] Patients with chronic ACL tears often do not present to a clinician until a displaced meniscus tear has occurred, resulting in subsequent pain, effusion, instability, and a locked knee. In these cases, it is important to search for a displaced bucket-handle tear of the meniscus because it is considered a relative surgical emergency, and surgical consultation should be performed as quickly as possible to maximize the chances that the tear can be repaired.

Posterior Cruciate Ligament

Improved anatomical and biomechanical characterization of the PCL has advanced treatment of these injuries, and PCL tears are increasingly being treated with reconstruction. Acute PCL tears may be directly identified on MRI due to an avulsion or a midsubstance rupture. In the setting of a PCL injury, special scrutiny should be given to the PLC because these structures are frequently injured in combination.[17] Unlike complete ACL tears, the PCL has the ability to “heal” on MRI,[18] although a chronic healed PCL tear on MRI may be nonfunctional (►**Fig. 1**). PCL stress radiographs should be obtained for all chronic PCL tears when there is any concern of subluxation on the imaging studies or on clinical examination to determine objectively the functional status of the PCL.

Lateral Knee/Posterolateral Corner

Historically, the PLC was referred to as “the dark side of the knee,” although awareness of its function and anatomy has improved during the last decade.[19] Injury to this region occurs in combination with other knee ligament tears in nearly 75% of patients.[20] The three main stabilizers of the PLC are the FCL, popliteus tendon, and the popliteofibular ligament (PFL). The MRI appearance of normal and injured structures has been comprehensively reported,[21] and inclusion of these structures in the search pattern when reviewing a knee MRI is crucial, especially in the setting of an already identified ACL or PCL injury. Recognition of PLC injuries in the

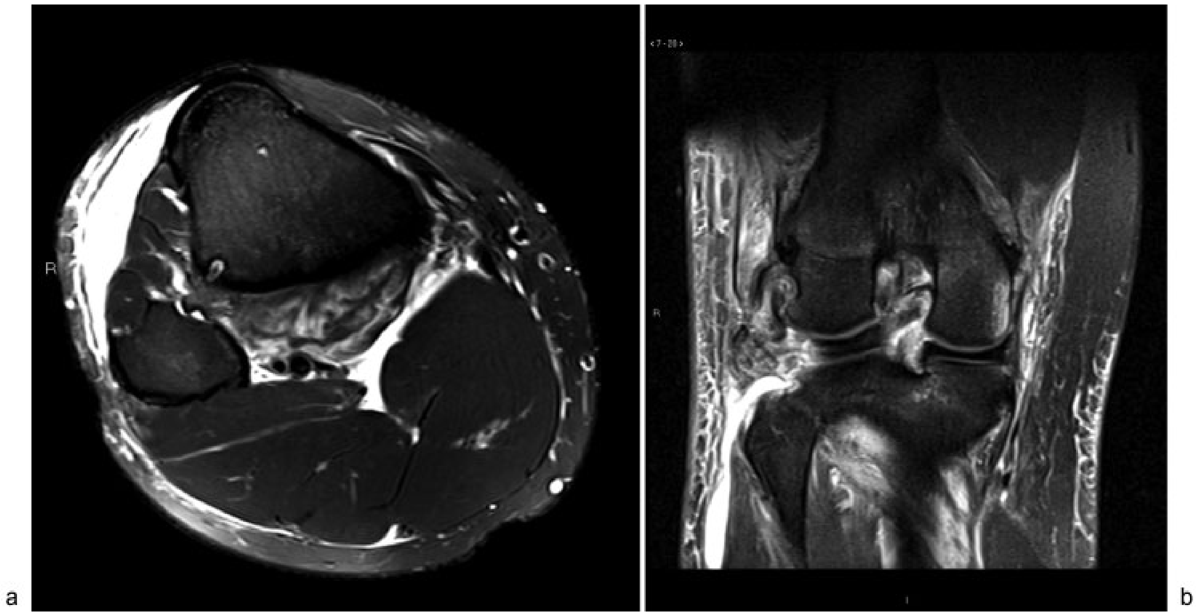


Fig. 8 (**a**) Axial and (**b**) coronal magnetic resonance imaging (MRI) of a patient with a multi-ligament knee injury including a complete posterolateral corner injury. The axial MRI demonstrates popliteus muscle edema, in contrast to normal-appearing medial and lateral gastrocnemius muscles. The coronal MRI demonstrates heterogeneous signal of the popliteus tendon at its femoral attachment site, along with substantial edema in the lateral tissues and complete avulsion of the soft tissue structures off the fibular head.

acute setting is crucial because treatment within 3 weeks of injury is associated with improved outcomes.[20] Isolated PLC injuries may occur, and edema about these structures along with a medial compartment bone bruise should raise suspicion of a PLC injury. This should be suggested to the referring provider.[1]

The FCL may sustain a midsubstance stretch injury or avulsion from the femur or fibula, and these findings should prompt a search for other injuries including the popliteus tendon complex and cruciate ligaments. Identifying a popliteus tendon avulsion or intrasubstance stretch injury can be challenging; a useful secondary sign of a popliteus tendon tear is edema of the

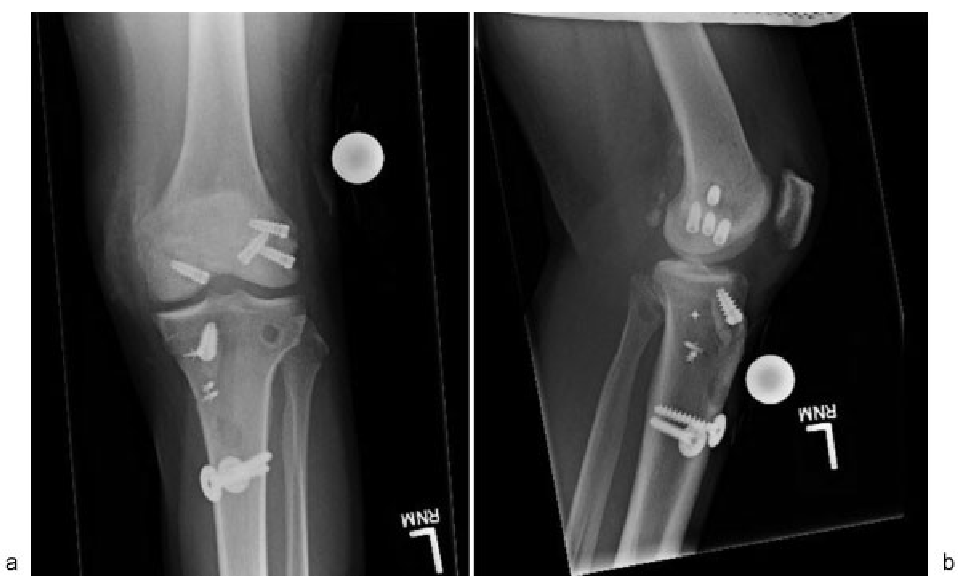


Fig. 9 Postoperative (**a**) anteroposterior and (**b**) lateral radiographs in a patient who sustained a knee dislocation and underwent acute anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL), and posterolateral corner (PLC) reconstruction. Metallic (titanium) interference screws are visualized in the lateral femoral condyle (ACL ×1, PLC ×2), tibial plateau (ACL ×1), and medial femoral condyle (Achilles tendon allograft for anterolateral bundle of the PCL). Suture anchors used for fixation of the superficial MCL reconstruction with autologous semitendinosus and gracilis tendons are visualized in the medial tibia. Two screw-washer devices are visualized in the anterior tibia for fixation of the double-bundle PCL reconstruction grafts. Bone tunnels with radiolucent bioabsorbable interference screws are located in the medial femoral condyle (PCL posteromedial bundle graft), fibular head (FCL graft), and lateral tibia (PLC grafts).

Fig. 10 (**a**) Anteroposterior and (**b**) lateral radiographs of a referral patient with two prior failed anterior cruciate ligament reconstructions (primary hamstring autograft, revision hamstring allograft). Substantial tunnel osteolysis is visualized in the femoral and tibial tunnels. Extracortical buttons are visualized at the lateral femur and anteromedial tibia (two buttons had been inserted at each location due to the primary and revision procedures).

muscle belly on axial fluid-sensitive sequences (►**Fig. 8**). The biceps femoris tendon may be avulsed from the fibular head with a soft tissue or bony injury, and this injury should be characterized on MRI. It is important to recognize that the formerly termed "arcuate ligament" is not a distinct structure but rather describes a group of structures attached to the posteromedial aspect of the fibular head and styloid consisting of the PFL, the fabellofibular ligament, and the capsular arm of the short head of the biceps femoris.[19] Thus it is recommended that the imprecise term "arcuate ligament" be avoided in describing this region, and rather the injuries to distinct structures should be identified.

Medial Knee/Posteromedial Corner

The components of the medial knee, including the entire PMC, should be part of the MRI search pattern, especially in the setting of an ACL and/or PCL injury. If present, associated injuries generally dominate the clinical presentation and may overshadow the injured PMC. The MCL complex includes the superficial MCL, the meniscofemoral and meniscotibial portions of the deep MCL, and the POL. Isolated partial MCL tears, and those combined with ACL tears, are often able to heal with nonsurgical treatment. Several tear patterns are associated with a lower healing potential (►**Table 1**). The failure to address an overlooked medial knee injury during surgical management of other injuries can lead to valgus instability and eventual failure of the other reconstructed knee ligaments.

Anterolateral Corner of the Knee

Increased attention has recently focused on the anterolateral corner of the knee, and soft tissue and osseous abnormalities have been described.[22] Helito et al evaluated 88 knees with an ACL tear with a visible anterolateral ligament (ALL) on MRI; an ALL injury was identified in 33 patients.[23] Most demonstrated proximal lesions, ~ 20% demonstrated distal lesions alone, and a small subset had a Segond fracture. Importantly, the presence of an unaddressed ALL injury in the setting of ACL reconstruction was theorized to contribute to residual rotatory laxity.[24] However, the potential role of the ALL in contributing to anterolateral knee rotatory instability is still being debated and investigated.[25–27]

Surgical Treatment and Implications for Radiologists

Several clinical studies have verified that complete knee ligament tears, especially involving the ACL and PLC, often fail to heal with nonsurgical treatment. The surgical treatment has evolved over the last 3 decades from direct repair, to nonanatomical reconstruction, and ultimately anatomical reconstruction with autografts or allografts.

Table 2 Surgical indications for grade III (complete) knee ligament injuries

Ligament injury	Tear type and recommended treatment
ACL	Reconstruction for grade III tears. Repair for bony avulsions from the tibia in pediatric or young adult patients
PCL	Reconstruction for grade III tears with combined injury (i.e., bicruciate, collateral) or repair of bony tibial avulsion fractures
PLC	Reconstruction of grade III injuries and repair of displaced bony avulsions and retracted soft tissue avulsions of the biceps femoris.
MCL	Generally, nonsurgical treatment is performed for isolated grade III injuries. If combined with an ACL tear, may attempt initial nonsurgical treatment. Tibial-based MCL tears are less likely to heal without residual laxity when treated nonsurgically, and reconstruction is recommended.
Multi-ligament	Surgical treatment with reconstruction of cruciate ligaments and reconstruction of collateral/corner injuries. Early intervention is associated with improved outcomes. Staged treatment is associated with higher failure rates.

Abbreviations: ACL, anterior cruciate ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament; PLC, posterolateral corner.

Multiple graft types and fixation devices are used. Ipsilateral knee autografts, including bone-patellar tendon-bone and hamstring tendons, are commonly used for reconstruction grafts in young patients. Allografts are usually reserved for older patients and those with multiple ligament injuries.

Fixation devices can be grouped based on the location and device type. Interference screws may be used with bone plugs or soft tissue grafts and may be metallic or a radiolucent composite material (►**Fig. 9**). Alternatively, the graft may be docked in a tunnel with extracortical fixation (i.e., a suture button) (►**Fig. 10**). Another fixation option includes surgical staples or screw-washer devices adjacent to the nonarticular tunnel aperture (►**Fig. 9**). Suture anchors may also be utilized for a soft tissue repair or ligament reconstruction (►**Fig. 9**). Awareness of these fixation options is important for evaluation of postoperative imaging characteristics and potential complications such as loss of fixation with interference screws or inadequate deployment of extracortical buttons.

Senior Author's Preferred Surgical Techniques

The intent of this section is not to serve as a technical manual for surgical treatment but rather to describe surgical indications (►**Table 2**) as well as key aspects of commonly used techniques and potential postoperative imaging findings (►**Table 3**). Full surgical technique details are available in the specifically referenced articles (e.g., tunnel size, knee fixation angle, order of graft fixation). Importantly, the native anatomy guides the desired tunnel locations, and a thorough understanding of the native anatomy is important for a review of postoperative imaging.

Anterior Cruciate Ligament Reconstruction

Reconstruction of the ACL is performed with a patellar tendon autograft. Anatomical femoral and tibial tunnels[10] are created, and the graft is generally secured with titanium interference screws in the femur and tibia (►**Fig. 9**). The femoral tunnel should be positioned distal to the Blumensaat line on lateral radiographs,[28] and the tibial tunnel should be adjacent to the anterior root attachment of the lateral meniscus on axial MRI sections (►**Fig. 4**). Staples may be utilized to secure the bone plug in a trough in cases of graft-tunnel mismatch; occasionally one prong of the staple may skive along the tibial shaft, which has no implications for the clinical outcome.

Posterior Cruciate Ligament Reconstruction

An arthroscopic-assisted double-bundle PCL reconstruction recreates the anterolateral bundle (ALB) with an Achilles tendon allograft and the posteromedial bundle (PMB) with a

Table 3 Postoperative radiographic and magnetic resonance imaging pearls

Finding	Possible clinical scenario
Femoral and/or tibial tunnel widening on radiographs or MRI	Compromised integrity with graft tears that may require a two-stage revision with tunnel bone grafting followed by ligament reconstruction
Anteriorly placed PCL reconstruction tibial tunnel	Iatrogenic injury to the meniscal root(s)
Arthrofibrosis	Limited motion and terminal extension
Graft impingement	Ligamentous laxity or instability and early failure; cyclops lesion
Subluxation on radiograph or MRI	May indicate graft laxity; stress radiographs should be obtained to quantify laxity

Abbreviations: MRI, magnetic resonance imaging; PCL, posterior cruciate ligament.

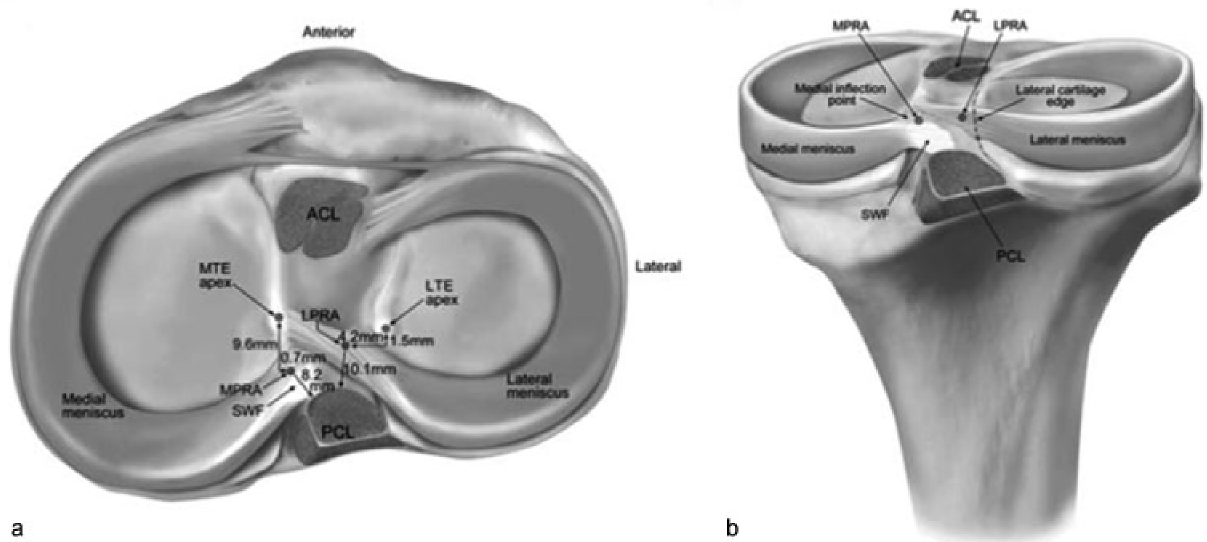


Fig. 11 (**a**) Superior and (**b**) posterior illustrations of the posterior meniscal roots demonstrating the arthroscopically pertinent anatomy and proximity to the posterior cruciate ligament (PCL) tibial attachment (right knee). ACL, anterior cruciate ligament bundle attachments; LPRA, lateral meniscus posterior root attachment; LTE, lateral tibial eminence; MPRA, medial meniscus posterior root attachment; MTE, medial tibial eminence; PCL, posterior cruciate ligament bundle attachments; SWF, shiny white fibers of posterior horn of medial meniscus. Reproduced with permission from Johannsen AM, Civitarese DM, Padalecki JR, Goldsmith MT, Wijdicks CA, LaPrade RF. Qualitative and quantitative anatomic analysis of the posterior root attachments of the medial and lateral menisci. Am J Sports Med 2012;40(10):2342–2347.

tibialis anterior allograft. Bony landmarks are used to create two closed-socket tunnels at the anatomical femoral attachments of the native ligament.[11] Fixation of the ALB graft and PMB grafts are performed with a titanium interference screw and a bioabsorbable screw, respectively. Two femoral tunnels and a single tibial tunnel are necessary. Both grafts are passed through a single tibial tunnel located on the lower half of the PCL facet, with the posterior aperture located ~ 6 to 7 mm proximal to the champagne glass drop-off on the posterior tibia (►**Fig. 11**).[11] Tibial graft fixation is performed with a screw-washer device (►**Fig. 9**). Tunnels placed on the anterior half of the PCL facet may disrupt the meniscal root attachments (►**Fig. 11**).

Lateral Knee/Posterolateral Corner

Depending on the physical examination and imaging findings, an FCL reconstruction or a complete PLC reconstruction may be indicated. These techniques are anatomically based and biomechanically validated, and successful outcomes have been reported.[20,29,30] Patients with chronic PLC injuries need long-leg alignment radiographs to evaluate for varus alignment and may first need to undergo a high tibial osteotomy as an index procedure to avoid premature PLC graft failure.[29,31]

A split Achilles tendon allograft is utilized for a complete PLC reconstruction.[20,29,32] Two femoral tunnels and single fibular and tibial tunnels are created at the ligament anatomical attachment. Grafts with bone plugs are secured with titanium interference screws, and bioabsorbable screws are used for soft tissue fixation (►**Fig. 9**).

Reconstruction of the FCL without a complete PLC reconstruction is performed with a semitendinosus autograft or allograft.[30,33] The previously described FCL anatomical landmarks and tunnel locations are again utilized, and the graft is secured with bioabsorbable interference screws with a valgus force applied in 20 degrees of knee flexion.

In acute and subacute injuries, biceps tendon soft tissue avulsions off the fibular head are repaired with suture anchors, and arcuate fibular head fractures are reduced and repaired with nonabsorbable sutures passed through drill holes because the bone quality is frequently not sufficient for screw fixation. Lateral capsular injuries are also repaired with suture anchors.[20]

Medial Knee/Posteromedial Corner

Valgus instability is treated with an sMCL reconstruction in patients with multi-ligament injuries or persistent laxity after appropriate nonsurgical treatment. Complete medial knee injuries with increased internal rotation laxity may also necessitate repair or reconstruction of the POL.[12,34] A semitendinosus and gracilis tendon autograft are used for reconstruction of the sMCL.[35] Patients with chronic medial knee injuries need long-leg alignment radiographs to evaluate for valgus alignment, and they may need to undergo a distal femoral osteotomy as an index procedure to avoid premature PMC graft failure.[31]

Anterolateral Corner of the Knee

Reconstruction of the "ALL" via a free graft (i.e., ALL reconstruction) or a lateral extra-articular tenodesis (LET) procedure with a strip of the iliotibial band and left attached to the Gerdy tubercle may be indicated in some patients with a high-grade pivot shift in spite of anatomical ACL reconstruction and in patients with a history of multiple revisions for graft failure. Multiple LET procedures[36] and ALL reconstruction procedures[37,38] have been described and are currently being used in carefully selected patients. Further research is necessary prior to widespread adoption of this procedure.

Multi-ligament Knee Injuries

Due to biomechanical and clinical evidence of increased failures associated with staged surgical treatment, the current preferred treatment for multi-ligament knee injuries is a single-stage reconstruction of all complete ligament tears.[20,39,40] Thus initial recognition of all associated ligament injuries is essential. The anatomical and technical principles guiding reconstruction of isolated ligament injuries, as just described, are also applied to multi-ligament patterns (►**Table 2**).

Role of Imaging in the Postoperative Setting

Postoperative imaging may include standard radiographs, stress radiographs, and MRI. Standard radiographs allow for the assessment of both reconstruction tunnel and fixation device location. Stress radiographs are routinely obtained at the 6-month interval and to allow for objective assessment of the restoration of normal stability. MRI is usually only obtained in the setting of a traumatic reinjury or atraumatic laxity. ►**Table 3** presents the key findings and associated pearls.

Standard Radiographs

Postoperative AP and lateral radiographs are obtained at early follow-up (e.g., 1–2 weeks) for patients with a ligament reconstruction. In some cases interference screw prominence or subsidence and inadequate deployment of extracortical buttons may be identified. Radiographs of patients with remote reconstruction of the ACL may demonstrate tunnel osteolysis (►**Fig. 10**) and require clinical correlation with graft function.

Stress Radiographs

Posterior (►**Fig. 1**), varus (►**Fig. 2**), and valgus (►**Fig. 3**) stress radiographs allow for the objective assessment of ligament reconstruction outcomes with comparison of laxity on side-to-side measurements. The aim of a ligament reconstruction is restoration of normal stability without residual side-to-side differences.

Magnetic Resonance Imaging

Similar to standard radiographs, MRI allows for the identification of tunnel location and fixation devices, and complications such as tunnel osteolysis (►**Fig. 10**) and iatrogenic injury (e.g., posterior meniscal root injuries in PCL reconstruction). Traumatic graft failure may also be identified in patients who sustain a reinjury.

In the setting of ACL reconstructions, specific attention should be paid to the course of the reconstruction graft fibers, the presence of arthrofibrosis, graft signal, and the presence of joint subluxation. Arthrofibrosis and a cyclops lesion can lead to restricted motion, and the presence on MRI should be reported. It is important to recognize the anatomical attachment sites of the ACL because it is the most commonly reconstructed knee ligament, and nonanatomical reconstruction remains the most common cause of graft failure.[41]

Graft signal properties change with time in the postoperative period, and they typically show low signal immediately after reconstruction, which can last up to 4 months. During revascularization and resynovialization (4–12 months), the graft is typically intermediate in signal on all sequences. The graft typically returns to low signal after 12 months.[42] Concern for graft integrity on MRI should prompt recommendation for clinical correlation and the use of stress radiographs.

Anterior subluxation of the lateral tibial plateau relative to the distal femur on sagittal MRI sections suggests a lax or nonfunctional ACL graft. The complications following PCL reconstruction are similar to those of ACL reconstruction, and posteromedial tibial subluxation may be identified on sagittal MRI sections in patients with a PCL reconstruction. An intact graft is not equal to a functional graft, and careful scrutiny for subluxation on radiographs or MRI is warranted.

MRI following complex reconstructions may have a variety of appearances. Reviewing the operative note and possible discussion of the case with the referring surgeon may improve diagnostic utility.

Conclusion

The use of advanced imaging techniques, including stress radiographs and MRI, has significantly improved the care of patients with complex knee injuries. To take full advantage of such technology, practitioners must be aware of secondary imaging findings, particularly those on MRI, that raise suspicion for a multi-ligament knee injury. Although orthopaedic surgeons are usually comfortable with interpretation of routine imaging, the referring clinician may not understand the complexity of an injury, and comprehensive reporting of all injured structures is especially important (►**Table 4**). This will support appropriate triage and provide the surgeon an opportunity to perform complex PLC, PMC, and ALL reconstructions combined with the primary ligament surgery

Table 4 Key considerations of imaging interpretation in the setting of knee ligament injuries

• Describe acute versus chronic injuries, complete versus partial tears
• Specify the ligament tear location (i.e., intrasubstance, femoral/tibial/fibular based)
• Report anatomical locations of soft tissue disruption or edema
• Maintain vigilance to avoid overlooking potential associated injuries: meniscal root or ramp lesions, osteochondral fractures, musculotendinous injuries (e.g., patellar tendon rupture, biceps avulsion)

(generally ACL or PCL), thereby improving long-term knee stability and graft functionality.

Collaboration between orthopaedic sports medicine surgeons and musculoskeletal radiologists improves patient care and is supported by an enhanced understanding of complex knee anatomy and arthroscopic and open surgical injury findings. Sustained partnerships will encourage continued advancement of imaging techniques and support timely intervention for patients through acute identification and treatment of knee injuries, ultimately supporting optimal patient outcomes.

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