3 Anatomy and Biomechanics of the Lateral and Medial Sides of the Knee and the Surgical Implications

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3.1 Introduction

Injuries to the collateral ligaments of the knee and their supporting structures pose unique challenges to orthopedic surgeons. In a recent population-based study of knee ligament injuries, the incidence per 100,000 person-years was reported to be 1147.1 for "nonsurgical" ligament injuries, 36.9 for anterior cruciate ligament injuries, and 9.1 for all other ligamentous knee injuries combined [1]. The majority of lateral knee injuries occur in combination with an injury to one or both of the cruciate ligaments [2, 3]. Unlike injuries to the lateral aspect of the knee, injuries to the medial knee are most commonly isolated and occur at a greater frequency. Among patients impacted by knee dislocations, a recent prospective review of multiligament injuries by Moatshe et al., which abided by the Schenk knee dislocation classification system, reported the most common combination of ligamentous damage to occur to three ligaments; KD III-M constituted 52.4% of the injuries and KD III-L comprised 28.1% [4].

During the last decade, the understanding of knee anatomy and biomechanics has expanded greatly. This is because of the development of methods to quantitatively assess anatomic structures and perform biomechanical testing. As a result, several surgical techniques have been developed along with radiographic techniques to assess postsurgical knee stability. This chapter will focus on the lateral and medial sides of the knee. The clinically relevant anatomy and biomechanics, along with anatomic-based surgical procedures, will be discussed.

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3.2 Anatomy

3.2.1 Lateral and Posterolateral Knee

The anatomy of the lateral and posterolateral region of the knee has been described in detail during the last few decades [3, 5–12]. Although the posterolateral corner (PLC) of the knee contains many structures, many investigators have reported that the main contributors to the static stabilization of this region of the knee are the fibular (lateral) collateral ligament (FCL), the popliteus tendon, and the popliteofibular ligament (PFL) (Fig. 3.1) [7]. In addition, recent literature has shown the characteristics of the anterolateral ligament (ALL) and the stabilizing features that this structure plays a role in for the biomechanics of the knee. The anatomy of these structures will be described in this section, with the associated biomechanics and surgical implications in the following sections.

3.2.1.1 Fibular Collateral Ligament

The FCL is approximately 70 mm in length with its femoral attachment slightly proximal and posterior to the lateral epicondyle and an average cross-sectional area of 0.48 cm^2 at the attachment site (see Fig. 3.1) [3, 7]. The distal FCL attachment is on the lateral aspect of the fibular head, with the center located in the anteroposterior plane at approximately two-fifths of the distance from the anterior edge of the fibular head. The average distance from the femoral attachment of the FCL to the popliteus tendon attachment is 18.5 mm, with the popliteus tendon located anteriorly and distally [7].

3.2.1.2 Popliteus Tendon

The midportion of the posteromedial tibia is the distal attachment of the popliteus muscle, which gives rise to the popliteus tendon [7]. The popliteus tendon courses around the posterolateral aspect of the lateral femoral condyle, becomes intra-articular, and attaches to the anterior portion

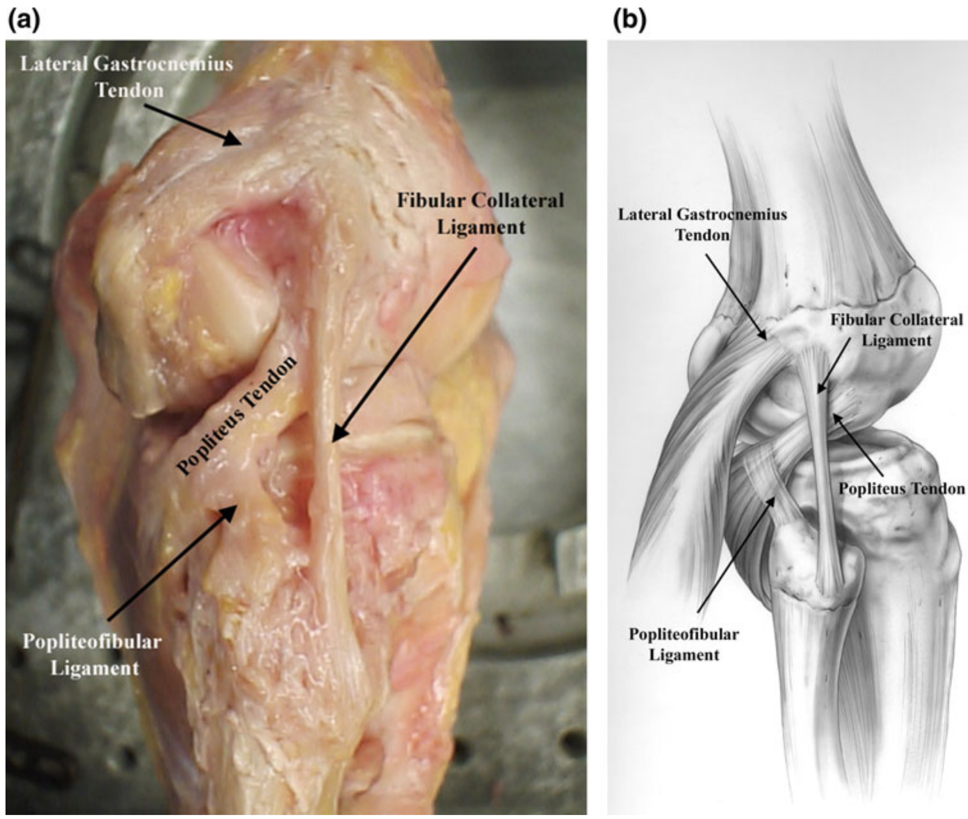

Fig. 3.1 *Right knee* **a** dissection and **b** illustration demonstrating the fibular collateral ligament, popliteofibular ligament, popliteus tendon, and lateral gastrocnemius tendon. Figure used with permission from LaPrade et al. [7], SAGE Publications

of the popliteus sulcus, deep to the FCL (see Fig. 3.1). The average length of the popliteus tendon when measured from its femoral attachment to the musculotendinous junction is 54.5 mm [7].

3.2.1.3 Popliteofibular Ligament

The PFL originates from the musculotendinous junction of the popliteus and consists of a smaller anterior and a larger posterior division [7]. The anterior division inserts on the anterior downslope of the medial aspect of the fibular styloid process; the posterior division inserts at the tip and posteromedial aspect of the fibular styloid process.

3.2.1.4 Anterolateral Ligament

The ALL is a ligament that is a thickening of the lateral joint capsule which comes under tension during internal rotation at 30° of knee flexion [13–15]. The femoral origin is located just posterior and proximal to the attachment of the FCL and the lateral femoral epicondyle, and its insertion is found on the anterolateral aspect of the tibia, just proximal and anterior to the anterior arm of the short head of the biceps femoris tibial attachment, approximately midway between the center of Gerdy's tubercle and the anterior margin of the fibular head [13]. The length of the ALL was calculated across multiple flexion angles between 0° and 90°, and was found to range between 36.8 and 41.6 mm, respectively [13].

3.2.2 Medial and Posteromedial Knee

The static supporting structures of the medial and posteromedial knee include one broad ligament and a series of capsular thickenings and tendinous attachments. This includes the superficial medial collateral ligament (sMCL), deep MCL, and posterior oblique ligament (POL) (Fig. 3.2). In the past, several authors have described the qualitative anatomy of this region of the knee [16–21]. Recently, detailed anatomical investigations have demonstrated the radiographic and quantitative surface anatomy of this region [22, 23].

3.2.2.1 Superficial Medial Collateral Ligament

The sMCL is the largest structure located over the medial aspect of the knee and consists of one femoral and two tibial attachments. Investigators have reported that the average femoral attachment is located 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle (Figs. 3.2 and 3.3). The proximal tibial attachment of the sMCL is fixed indirectly to bone via the anterior arm of the semimembranosus tendon. The majority of the broad-based distal bony tibial attachment forms a large portion of the floor of the pes anserine bursa [22].

3.2.2.2 Deep Medial Collateral Ligament

The deep MCL is a thickening of the medial joint capsule and is also referred to as the mid-third medial

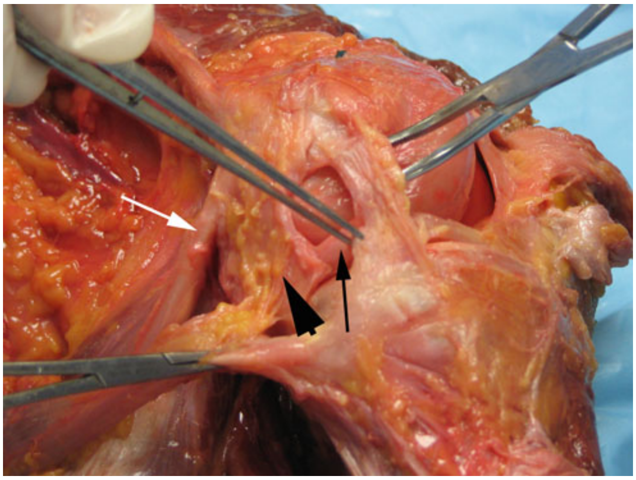

Fig. 3.2 A photograph of a dissection of the medial aspect of the *left knee* is shown. The meniscofemoral portion of the deep medial collateral ligament is seen elevated by the curved hemostat, and the meniscotibial portion is grasped by the forceps. The central arm of the posterior oblique ligament (*black arrowhead*) and the medial meniscus (*black arrow*) are also visualized. The semimembranosus tendon is grasped by the straight hemostat and the medial gastrocnemius tendon is also visualized (*white arrow*)

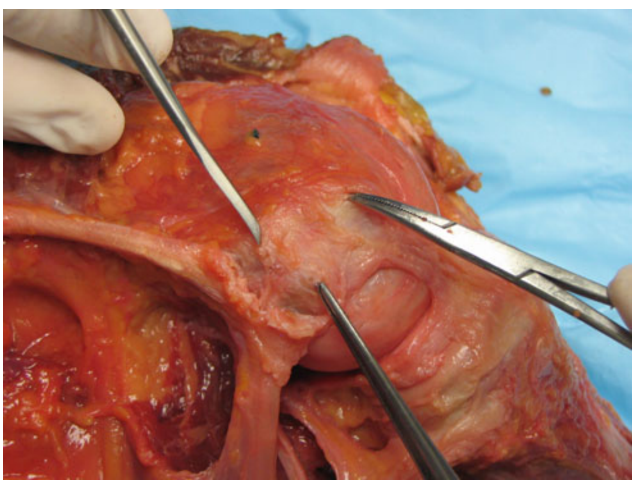

Fig. 3.3 A photograph of a dissection of the medial *left knee* demonstrating three main bony landmarks. The adductor tubercle is located posterosuperiorly (chisel), the gastrocnemius tubercle posteroinferiorly (Kocher), and the medial epicondyle anteriorly (curved hemostat)

capsular ligament [22]. Analogous to the aforementioned mid-third lateral capsular ligament, both consist of a meniscofemoral and meniscotibial component. The meniscotibial portion of the deep MCL is broader and shorter than the meniscofemoral portion and is attached slightly distal to the border of the medial tibial plateau articular cartilage (see Fig. 3.2) [22].

3.2.2.3 Posterior Oblique Ligament

Three fascial attachments from the distal aspect of the semimembranosus tendon make up the POL. These have been termed the superficial, central, and capsular arms [17, 22, 24]. The central arm is the most robust portion of the POL, and it is the main structural portion of the POL (see Fig. 3.2); proximally, it is merged with the posterior fibers of the sMCL and courses distally to the main semimembranosus tendon, acting as a fascial reinforcement of the posteromedial capsule. The femoral attachment of the POL, and hence the central arm, is on average 7.7 mm distal and 6.4 mm posterior to the adductor tubercle. The primary useful bony landmark for identifying the POL femoral attachment is the gastrocnemius tubercle, which is 1.4 mm proximal and 2.9 mm posterior to the POL (see Fig. 3.3). The superficial arm of the POL is a thin fascial expansion that courses posterior to the sMCL and blends distally with the tibial expansion of the semimembranosus. The capsular arm is a thin fascial expansion with multiple posteromedial knee soft tissue attachments [22].

3.3 Biomechanics

3.3.1 Lateral and Posterolateral Knee

A thorough appreciation of the anatomy of the posterolateral corner of the knee, as described above, aids in the understanding of the biomechanics of this region of the knee. The main static stabilizing structures of the posterolateral knee are the FCL, the popliteus tendon, and the PFL. The biomechanics and roles of these structures in the overall stability of the knee are discussed; the iliotibial band, biceps femoris, and lateral capsule are not specifically reviewed here.

3.3.1.1 Fibular Collateral Ligament

It has been reported that the FCL is a primary stabilizer to lateral joint opening [5, 16]. One study reported moderate anterolateral instability in the flexed knee with sectioning of the FCL, but noted stability to varus with the knee in extension [25]. It has also been reported that the FCL shares a role in stability against external rotation with the popliteus tendon, especially near full knee extension [6, 26].

3.3.1.2 Popliteus Tendon

The popliteus tendon, in combination with the other posterolateral structures, has an important role in restraining posterolateral motion of the knee [27]. Its role in stability specifically against external rotation has also been demonstrated [5, 6, 28, 29]. Upon sectioning of the popliteus tendon, LaPrade et al. found a significant increase in external rotation in addition to a small yet significant increase in internal rotation, varus angulation, and anterior translation motion relative to the intact state [30]. Anatomic reconstruction resulted in a reduction of the increased external rotation but failed to reestablish the stability in regards to the internal rotation, varus angulation, and anterior translation motion [30]. In addition, the popliteus complex has been shown to share posterior tibial loads with the posterior cruciate ligament (PCL) [31].

3.3.1.3 Popliteofibular Ligament

Some authors have questioned the importance of the PFL in the overall stability of knee. However, it has been reported that the PFL plays an important role in stability against varus and external rotation and contributes to overall PLC stability [32–34].

3.3.1.4 Anterolateral Ligament

During pull-to-failure testing, the ALL withstood an average maximum load of 175 N, with a stiffness of 20 N/mm; the mechanism of failure varied between midsubstance tear, detachments from its femoral origin, and complete detachments from its insertion upon the tibia accompanied by bony avulsions (Segond-type avulsion fracture) [13]. Additionally, the ALL is reported to provide rotatory stability to the knee, specifically as a secondary stabilizer throughout knee flexion during internal rotation torques and simulated pivot-shift tests in ACL deficient knees [35].

3.3.1.5 Cruciate Ligaments and the Posterolateral Corner

As described above, injuries to the PLC typically occur in combination with a cruciate ligament injury [2, 3]. As such, many investigators have analyzed the biomechanics and interdependence of the cruciate ligaments and the PLC. Increased forces in an anterior cruciate ligament (ACL) reconstruction graft have been reported in association with a deficient PLC [36]. Other studies have demonstrated a similar phenomenon for PCL grafts [37, 38]. Another study, which demonstrates the important relationship between the ACL and PLC, reported forces on the PLC increased by a factor of five in the ACL-deficient knee [39].

3.3.1.6 Objective Assessment of Lateral and Posterolateral Knee Biomechanics

The grading of injuries to the PLC structures has been defined to allow clinical assessment and comparison [40]. In order to objectively quantify the amount of lateral joint opening with varus stress, a radiographic technique was developed and tested by sequential sectioning in cadaveric knees [41]. An isolated grade III FCL injury resulted in an increase of 2.7 mm of lateral joint gapping at 20° of flexion when compared to the contralateral knee. A complete grade III PLC injury (FCL, popliteus tendon, and PFL) was associated with increased lateral joint gapping of 4 mm at 20° of flexion.

3.3.2 Medial and Posteromedial Knee

In addition to an expanding literature regarding the medial knee anatomy, the understanding of the biomechanics of the medial knee has also greatly increased recently. This understanding allows the surgeon to better appreciate injury mechanisms, clinical symptoms, and treatment options. Following is a summary of the main clinically relevant studies.

3.3.2.1 Superficial Medial Collateral Ligament

The sMCL is the primary restraint to valgus laxity of the knee [16, 42–44]. It has also been reported to be a primary medial knee restraint to external rotation of the tibia [45]. An interesting finding regarding tibial internal rotation was a reciprocal load response observed between the sMCL and the POL. This was characterized by an increased load on the sMCL with a corresponding decreased load on the POL as the knee moved from extension to flexion [46].

3.3.2.2 Deep Medial Collateral Ligament

The deep MCL, which consists of meniscofemoral and meniscotibial divisions, has been biomechanically evaluated for its role in valgus, external, and internal rotation stabilization of the knee. Sequential sectioning studies performed to study the function of the deep MCL have reported that it acts as a secondary restraint to valgus loads at the knee [45, 47, 48]. Furthermore, the deep MCL has been reported to provide resistance to external rotation at knee flexion angles of 30°–90°; however, this role was not demonstrated at full knee extension [45, 47].

3.3.2.3 Posterior Oblique Ligament

Biomechanically, the POL reinforces the posteromedial aspect of the capsule and has been reported to function as a stabilizer to valgus stress and internal rotation at less than 30° of knee flexion [16, 24, 46–49]. It should be noted that the primary valgus stability is provided by the proximal division of the sMCL and that the POL acts as a secondary stabilizer [20, 45, 49]. As mentioned above, the POL also functions in resisting tibial internal rotation laxity via its reciprocal load response with the sMCL.

3.3.2.4 Combined MCL–ACL Injuries

While the MCL is most frequently injured in isolation from cruciate ligaments, a common subtype of combined injuries is the MCL–ACL injury. This biomechanical relationship is important because of the treatment implications for these combined injuries. While the ACL and PCL provide primary stability to anterior and posterior tibial laxity, respectively, the medial knee structures serve as secondary stabilizers to motion in the sagittal plane [49–51]. It has been reported that a knee with a deficient ACL experiences forces on the MCL twice as great as when the ACL is intact [39]. In addition to reports of increased MCL forces in the ACL-deficient knee, investigators have also demonstrated that MCL deficiency leads to greater forces in a reconstructed ACL [52]. Investigators have also reported that the ACL-deficient knee with an absent sMCL has greater anterior translation at 90° than a knee with an intact sMCL; furthermore, if the sMCL, deep MCL, and POL are all sectioned, increased anterior translation occurs at all flexion angles [49].

3.3.2.5 Objective Assessment of Medial and Posteromedial Knee Biomechanics

The clinical exam and injury grading for patients with a suspected injury to the medial knee has been defined [40, 44, 53]. A radiographic technique has also been developed to objectively quantify the amount of medial joint line opening with valgus stress [54]. It was reported that an isolated grade III sMCL injury resulted in an increase of 3.2 mm of medial joint gapping at 20° of flexion when compared to the contralateral knee. A complete medial knee injury (sMCL, deep MCL, and POL) was associated with increased medial joint gapping of 6.5 and 9.8 mm at 0° and 20° of flexion, respectively.

3.4 Injury Assessment: Examination and Imaging

A careful history of the onset of symptoms, injury mechanism, prior injuries, and previous operative and nonoperative treatments should be obtained in all patients presenting with a complaint of knee instability and/or pain. A history of swelling, mechanical symptoms such as clicking or locking, and instability should be investigated. The type of instability should be determined by the patient's history; they may report difficulty on uneven ground, "giving way" (which suggests a patellofemoral source), or a side-to-side instability pattern. In addition, the presence of paresthesias in the peroneal nerve distribution and a footdrop may be reported. This information will guide the clinician in the physical examination and selection of imaging studies.

In the acute setting, the evaluation for a patient with a suspected multiple ligamentous knee injury should include inspection of distal pulses and an ankle–brachial index and/or computed tomography (CT) angiogram if indicated [55]. The examination for acute injuries (which may be limited by pain) and chronic injuries should include the external rotation recurvatum test, varus/valgus stress, Lachman, anterior–posterior drawer, pivot shift, posterolateral drawer, reverse pivot shift, and dial test at 30° and 90°.

Imaging should include standard anterior–posterior and lateral radiographs to assess for fractures. Varus and valgus stress radiographs, as described above, will add significant information and provide a quantitative measure of laxity and are strongly recommended [41, 54]. High-resolution magnetic resonance imaging will allow assessment of injury to individual structures of the lateral [56] and medial knee, femoral and tibial articular surfaces for bone bruises [2, 34], as well as intra-articular structures including cruciate ligaments, the medial and lateral menisci, and articular cartilage. Bilateral standing hip to ankle long-leg radiographs, especially in chronic injuries, are recommended to assess alignment and the possible need for an osteotomy to correct alignment [57, 58].

3.5 Treatment/Surgery

3.5.1 Lateral and Posterolateral Knee

It is well recognized that grade III PLC injuries do not heal and can lead to significant morbidity [59–62]. In a canine modeled study, the FCL, popliteus tendon, and PFL were sectioned, and provided a validation for the occurrence of grade III PLC injuries and their inability to heal. Additionally, early onset development of the medial compartment, indicating an early onset of osteoarthritis, was observed in the operative knees [63]. As such, it is recommended that these injuries are treated surgically in order to restore the function of this region of the knee and avoid potential for early development of osteoarthritis. Despite a general agreement on the need to treat these injuries, a consensus on the surgical technique does not yet exist.

In the past, reports of repairs of acute PLC injuries indicated good or fair outcomes in 88–100% of patients [64–66]. However, it must be noted that all patients in these series were immobilized in a cast for 6 weeks or longer postoperatively and validated subjective outcomes scores were not reported.

Reconstruction of the PLC has recently been emphasized due to inferior outcomes reported for primary repairs [61, 62, 67]. With the aim of reproducing the stabilizing function of the PLC structures, several nonanatomic reconstruction techniques have been described [68–73]. A trend toward anatomic reconstruction of the PLC is gaining popularity; our preferred treatments for grade III injuries to the FCL and posterolateral corner structures are based on biomechanically validated anatomic reconstructions [60, 74, 75]. A prospective case series of grade III PLC injuries compared the outcomes of repairs and reconstructions in regards to objective stability and subjective outcomes, with an improvement in both Cincinnati and IKDC subscores. The findings also suggested that injuries with acute repair of avulsed fractures, reconstruction of midsubstance tears, and concurrent reconstruction of any cruciate ligament tears resulted in significantly improved objective stability [76].

With the recent upsurge in literature encompassing the biomechanics of the ALL, treatment options remain a heavily controversial topic. A study by Nitri et al. reported a significant improvement in rotatory stability upon combined reconstruction of the ACL and ALL relative to only reconstructing the ACL [77]. This reduction in rotatory laxity of the knee was also reported beyond 30° of knee flexion in a study by Schon et al., but regardless of the fixation angle, a significant overconstraint of the knee was reported from this procedure [78]. Until further studies are performed, a reconstruction of the ALL using current standards is not advised due to this overconstraint and potential for early development of osteoarthritis.

An important distinction for our preferred surgical technique for lateral sided knee injuries depends on the timing of the surgery relative to the injury. In the treatment of acute injuries, often defined as surgery occurring within 3–6 weeks after injury, structures may be amenable for repair if there is a soft tissue or bony avulsion and tissue quality is adequate. However, a reconstruction may be required if there is poor tissue quality, midsubstance tears, or significant tissue retraction.

Fig. 3.4 An intraoperative photograph of a planned lateral hockey-stick-shaped skin incision is shown. This incision is utilized for exposure of lateral and posterolateral structures

3.5.1.1 Acute PLC Treatment

The process of patient positioning and preparation for surgery is the same for acute and chronic injuries. The patient is positioned supine on the operating table, and an examination under anesthesia is performed to confirm suspected pathology. A proximal thigh tourniquet is applied, and standard skin preparation and sterile draping is performed. For patients with concomitant intra-articular injuries, the arthroscopic assessment is delayed until the open dissection of the injured posterolateral structures is performed to minimize tissue distortion from fluid extravasation.

A standard hockey-stick-shaped incision is made over the posterolateral knee (Fig. 3.4) [3, 60, 74, 79]. This incision is continued down to the superficial layer of the iliotibial band. The incision is positioned more posteriorly in patients with a planned autogenous patellar tendon graft harvest for concurrent ACL reconstruction in order to maintain a minimum of 6 cm between the two incisions (Fig. 3.5). A stepwise assessment of structures with attachments to the fibula, femur, tibia, and lateral meniscus [6] is performed for full characterization of injuries. The long and short heads of the biceps femoris are identified, and a common peroneal nerve neurolysis is performed (Fig. 3.6). If avulsed from the fibular head, a tag stitch is placed in the distal aspect of the biceps tendon (Fig. 3.7).

The FCL distal attachment is assessed next via an incision into the biceps bursa, and a tag stitch is placed in the distal aspect of the ligament (Fig. 3.8). In order to assess the PFL, the region anterior to the common peroneal nerve is entered by blunt dissection. As mentioned, the posteromedial fibular styloid is the anatomic attachment site of the PFL. The musculotendinous junction of the popliteus tendon, where the proximomedial attachment of the PFL is located, is also assessed [7]. The femoral attachments are assessed next via a splitting incision through the superficial layer of the iliotibial band (Fig. 3.9). The incision is centered over the lateral epicondyle and extended distally to Gerdy's tubercle with a starting point approximately 6 cm proximal to the lateral epicondyle. By placing traction on the distal FCL, the proximal attachment of the FCL can be identified [7]. Next, the nearby popliteus tendon attachment in the anterior aspect of the popliteus sulcus is identified approximately 18.5 mm anterodistal to the FCL [7].

A standard arthroscopic assessment of the knee is performed following identification of all posterolateral knee structures and planning for repair and/or reconstruction. Specific assessment for injuries to lateral structures is performed including evaluation of gapping of the lateral compartment ("drive-through sign") and potential injuries to the coronary ligament and its attachment to the lateral meniscus posterior horn [80]. In addition, assessment of the integrity of the intra-articular portion of the popliteus tendon (Fig. 3.10), the popliteomeniscal fascicles, and the meniscofemoral portion of the posterior capsule is performed [55]. Concurrent meniscal tears are repaired when indicated; however, a partial meniscectomy is performed if tears are not

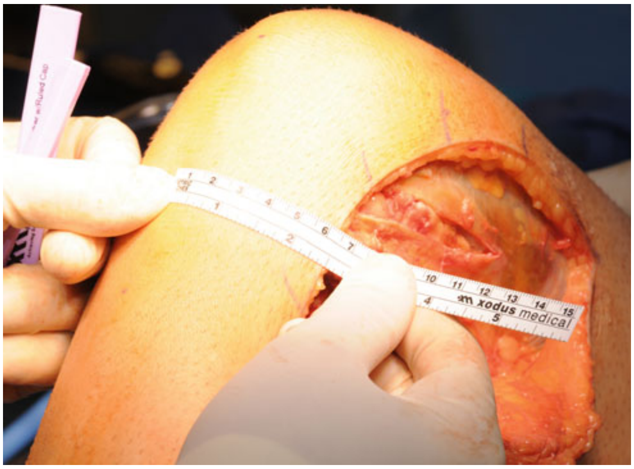

Fig. 3.5 An intraoperative photograph demonstrating a planned 6-cm skin bridge is shown. This technique is utilized for patients with a planned patellar tendon autograft harvest for anterior cruciate ligament reconstruction

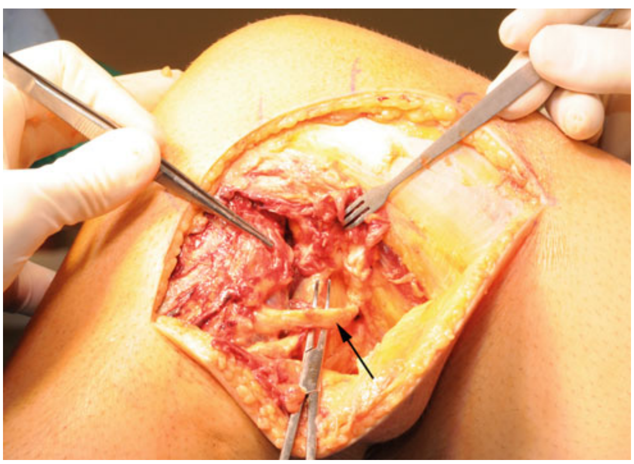

Fig. 3.6 An intraoperative photograph of the lateral side *left knee* is shown. The common peroneal nerve (*arrow*) is visualized following neurolysis

repairable. The cruciate ligaments are evaluated, and reconstructions are performed when indicated. The grafts are secured in their femoral tunnels, but fixation of cruciate ligament graft(s) in the tibial tunnel(s) is delayed until PLC femoral graft fixation is completed.

Following assessment of the PLC structures and treatment of intra-articular pathology, attention is focused on the treatment of the PLC injuries. As described above, a step-by-step approach to identification to these injuries is important; we follow a similar approach for the surgical treatment of these structures. Repair/reconstruction of structures is performed in the following order based on their attachment site: (1) femur, (2) lateral meniscus, (3) tibia, and (4) fibula. As discussed, the tear pattern is an important

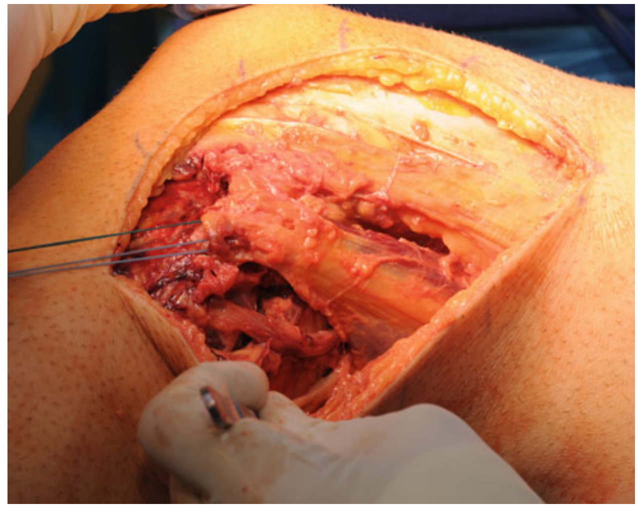

Fig. 3.7 An intraoperative photograph of the lateral side of the *left knee* is shown in a patient with an avulsion of the biceps femoris tendon. A tag stitch was placed in the distal aspect of the tendon to allow a proximal release and reapproximation to its distal attachment

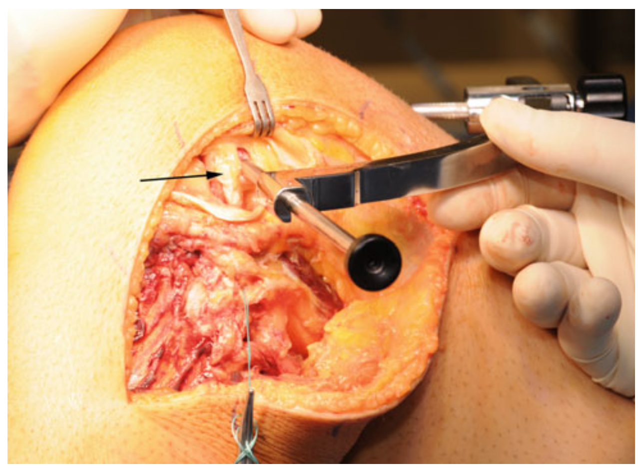

Fig. 3.8 An intraoperative photograph of the lateral side of the *left knee* is shown. A tag stitch was placed in the distal aspect of the fibular collateral ligament (FCL); the free end is wrapped around a curve hemostat, and traction is used to allow visualization of the femoral attachment of the FCL. A guide is utilized for FCL reconstruction; it is placed over the femoral attachment of the FCL for creation of the femoral tunnel. The intact popliteus tendon is also visualized (*arrow*)

consideration for the patient with an acute PLC injury. This issue should be addressed early in the procedure to allow adequate time for preparation of autogenous hamstring reconstruction grafts or allografts [60, 74].

A reconstruction of the FCL is planned for midsubstance tears and substantial intrasubstance stretch injuries [74, 75]. A recess procedure is planned for avulsions of the popliteus tendon if there is no obvious intrasubstance stretch injury and it can be reduced to its anatomic attachment in full knee extension [71, 81]. If evaluation of the popliteus tendon

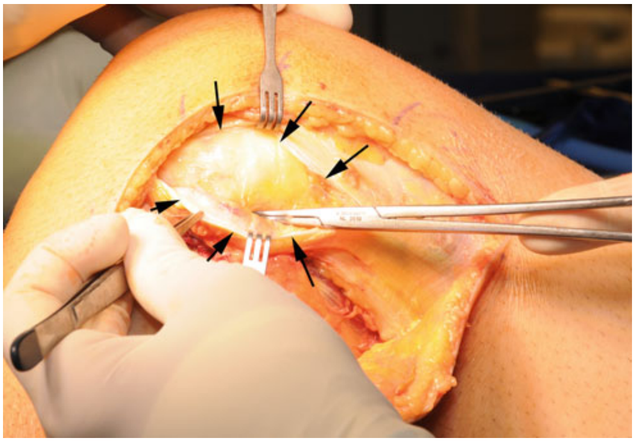

Fig. 3.9 An intraoperative photograph of a splitting incision of the iliotibial band is shown. The anterior and posterior borders (*arrows*) of the iliotibial band incision are retracted with surgical rakes

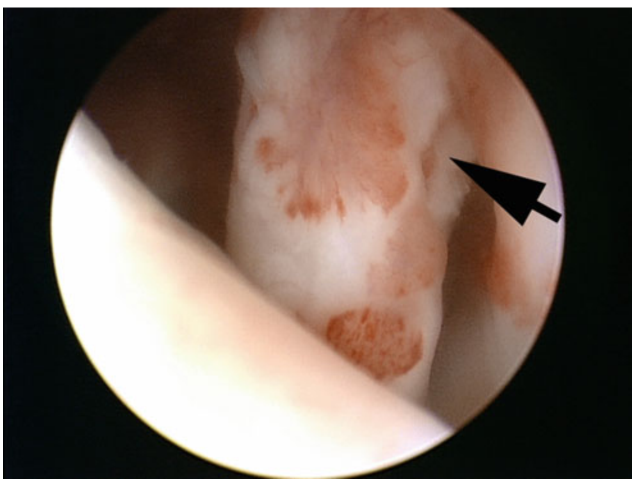

Fig. 3.10 An arthroscopic photograph of a torn popliteus tendon (*arrowhead*) is demonstrated

reveals a substantial intrasubstance stretch injury, midsubstance tear, or musculotendinous avulsion, a reconstruction of this structure is planned [29, 74]. Direct repairs of the PFL are performed on the knee with an intact popliteus tendon and when the PFL is avulsed from the fibular head and the tissue is amenable for approximation by suturing.

An anatomic reconstruction of the FCL or popliteus tendon is performed using an autogenous hamstring graft when one is torn in isolation from the other and is not amenable for repair [29, 82]. However, when these two structures are concurrently torn and nonrepairable, an anatomic PLC reconstruction is performed using an Achilles tendon allograft (Fig. 3.11) [60, 74]. Bone tunnels for reconstruction of either the FCL or popliteus tendon, or for all three main PLC structures are placed according to established anatomic reconstruction techniques [29, 60, 82]. When a full PLC reconstruction (i.e., FCL, popliteus tendon, PFL) is required for acute injuries due to tear pattern and tissue quality, the technique used is the same as described in detail in the following section on "*Chronic PLC Treatment*" [74, 83].

Next, avulsions of the popliteus tendon are repaired with a recess procedure providing that there is no apparent intrasubstance stretch injury and adequate tissue length is available to allow reapproximation with the knee in full extension (Fig. 3.12) [71, 81]. The femoral attachment site of the popliteus tendon is identified by previously described anatomic landmarks [7], and an eyelet-tipped pin centered on this site is drilled from lateral to medial. A 5-mm-diameter tunnel is overreamed to a depth of 1 cm. The tubularized native popliteus tendon is pulled into the tunnel by the passing sutures which are then tied over a button placed deep to the vastus medialis obliquus muscle.

Popliteomeniscal fascicle and coronary ligament tears from the lateral meniscus posterior horn are repaired with mattress sutures under direct vision. Suture anchors are used to repair tears of the superficial layer of the iliotibial band from Gerdy's tubercle as well as the meniscofemoral and meniscotibial (a bony or soft tissue Segond avulsion [56, 84]) portions of the mid-third lateral capsular ligament (Fig. 3.13).

Avulsions of the biceps femoris tendon are addressed by suture anchor repair to the anatomic attachment on the fibular head and styloid with the knee in full extension. Note that a proximal release of the long head of the biceps from adhesions and scar tissue may be required prior to repair if adequate length is not available. Failure to perform this maneuver may require knee immobilization in flexion until the repair has healed or may result in failure of the repair when the knee is placed into full extension.

In cases where either the FCL or popliteus tendon is still intact, a suture anchor repair of PFL tears from the fibular styloid is performed; however, a PFL reconstruction is performed for a nonrepairable PFL tear in patients with a concurrent FCL reconstruction and an intact popliteus tendon. The portion of the FCL graft that is passed out the posteromedial aspect of the fibular head reconstruction tunnel (as described below) is looped around the intact popliteus tendon at its musculotendinous junction, passed back laterally, and is sutured to itself.

Avulsions of the FCL from the fibular head are addressed next. This type of FCL injury is repaired using suture anchors if the native FCL has adequate length to allow anatomic fixation and there is no evidence of an intrasubstance stretch injury. Avulsion fractures of the fibular head (Fig. 3.14), also known as arcuate fractures [3, 85], are

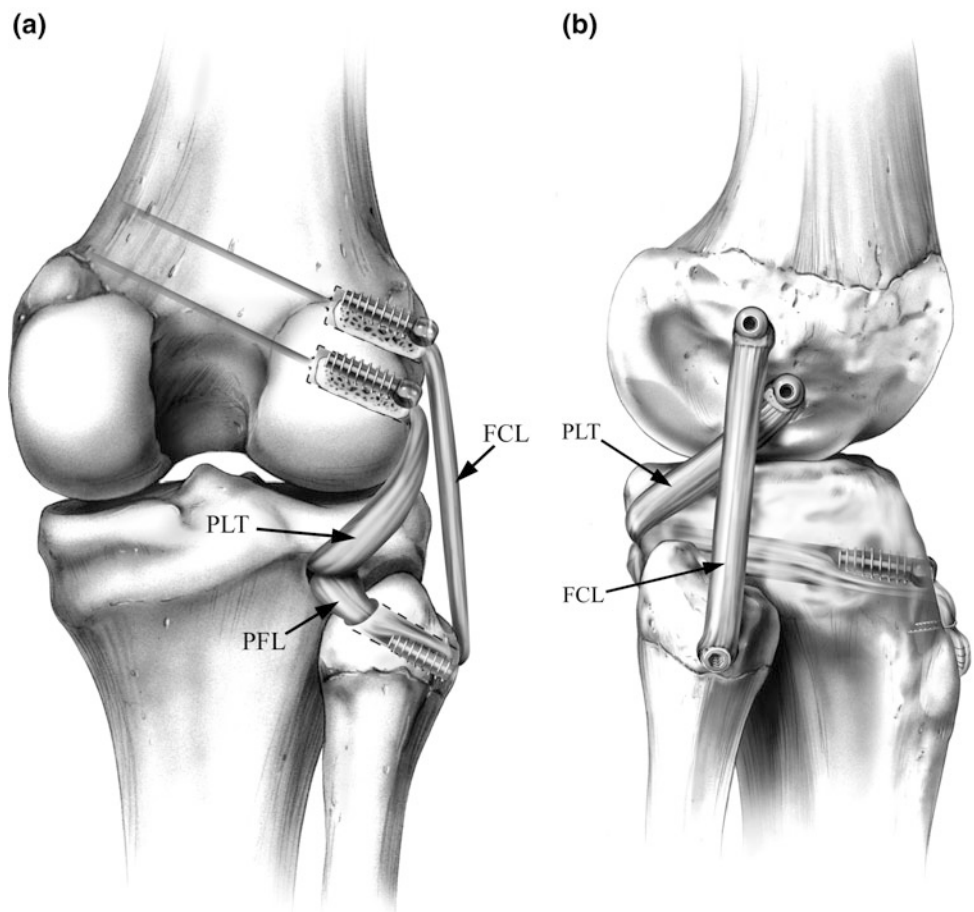

Fig. 3.11 An illustration of a **a** posterior view and **b** lateral view of an anatomic posterolateral corner reconstruction is shown. The two femoral tunnels with the fibular collateral ligament (FCL) and popliteus tendon (PLT) grafts with bone blocks and the interference screws are demonstrated. The tibial tunnel is demonstrated with the popliteus tendon (PLT) and popliteofibular ligament (PFL) grafts. Also depicted is the fibular tunnel with the associated FCL/PFL graft. Figure used with permission from LaPrade et al. [74], SAGE Publications

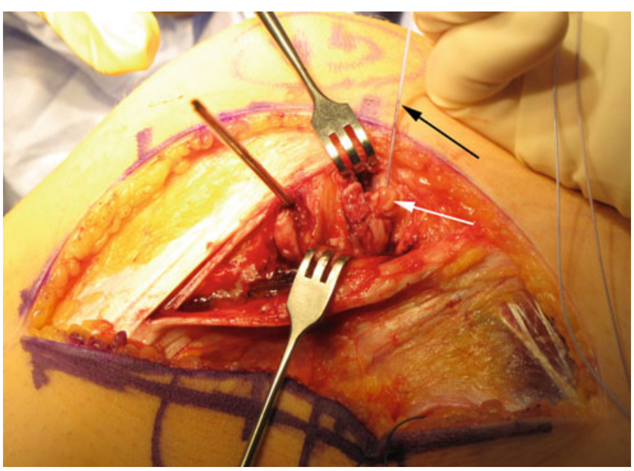

Fig. 3.12 An intraoperative *right knee* photograph is shown with a splitting incision of the iliotibial band for exposure of the femoral attachments of the fibular collateral ligament and popliteus tendon. The avulsed popliteus tendon (*white arrow*) and passing sutures (*black arrow*) are demonstrated. A pin is also visualized in the femoral tunnel for an FCL reconstruction

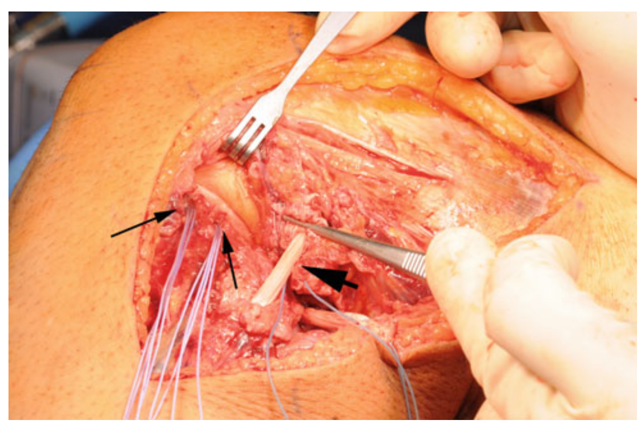

Fig. 3.13 An intraoperative photograph of a suture anchor repair (*arrows*) of a lateral capsule tear off tibia is shown. A fibular collateral ligament reconstruction graft is also visualized (*arrowhead*)

primarily repaired. A cerclage nonabsorbable #5 suture is placed through the proximal fracture fragment and into the common biceps tendon, and drill holes are placed 1 cm

Fig. 3.14 A *right knee* is visualized using magnetic resonance imaging to demonstrate an arcuate fracture of the fibular head (*arrow*)

distal to the fracture edge. The fracture is then reduced, and the sutures are tied with the knee in extension.

If a cruciate ligament reconstruction was required, tibial graft fixation can occur once the PLC grafts are secured in their femoral tunnels and the distal aspects are passed into their fibular and/or tibial tunnels. Graft fixation should occur in the following order: (1) PCL graft (to restore the central pivot of the knee), (2) PLC graft(s), and (3) ACL graft [60, 86]. As described, structures should be repaired such that the knee could be immobilized in extension without significant tension on the repair. Following repairs and graft fixation, an exam under anesthesia is performed to assure restoration of knee stability. Following repair/reconstruction of all structures, a “safe zone” arc of motion is determined by the surgeon to establish the range through which the knee may be moved postoperatively in physical therapy without compromising the repair.

3.5.1.2 Chronic PLC Treatment

While some structures may be amenable for repair in acute injuries, patients with chronic PLC injuries require a reconstruction of torn PLC structures. Following evaluation of bilateral long-leg radiographs and recovery from a proximal tibial opening wedge osteotomy if indicated, an anatomic PLC reconstruction is performed according to previously described biomechanically and clinically validated techniques [60, 74, 83].

Patient positioning, surgical approach, peroneal neurolysis, anatomic landmark identification, and arthroscopic evaluation (with assessment and treatment as indicated) are the same for the treatment of acute and chronic injuries. Following is a description of our preferred technique for reconstruction of the PLC utilizing four tunnels: one fibular, one tibial, and two femoral.

First, the fibular tunnel is created; a K-wire is drilled through the fibular head from the FCL attachment site to the PFL attachment site using a cannulated cruciate ligament tunnel-aiming device, and a 7-mm tunnel is overreamed (Fig. 3.15). While protecting the neurovascular bundle, the guide is then placed approximately 1 cm distal to the margin of the articular cartilage on the posterior popliteal tibial sulcus [87, 88]. A K-wire is drilled to this point from the flat spot slightly distal and medial to Gerdy’s tubercle [60], and the tibial tunnel is reamed to a 9-mm-diameter (Fig. 3.16).

Attention is then focused on femoral tunnel creation. The proximal FCL attachment and the insertion of the popliteus tendon are identified; the distance between the tunnel centers should average 18.5 mm as described above [7]. Using the same guide, a beath pin is drilled through each site (Fig. 3.17) in an anteromedial vector to exit the distal femur, and a 9-mm-diameter femoral tunnel is then reamed to a depth of 20 mm.

In order to minimize anesthesia and tourniquet time, graft preparation may be performed concurrently with tunnel creation. An Achilles tendon allograft, with length ≥ 23 cm, is split lengthwise to prepare two tendon grafts. The bone plugs are shaped to fit the above tunnel dimensions, and a #5 suture is used to tubularize the tendons. The grafts are pulled into their femoral tunnels (Fig. 3.17) with passing sutures, and the bone plugs are secured with 7×20-mm cannulated interference screws. The popliteus graft is passed distally

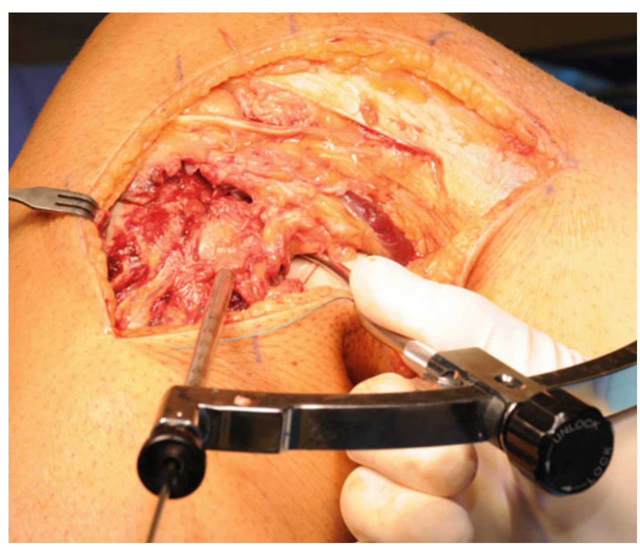

Fig. 3.15 An intraoperative photograph of a *left knee* is shown. A cannulated cruciate ligament tunnel-aiming device is used for placement of a K-wire through the fibular head

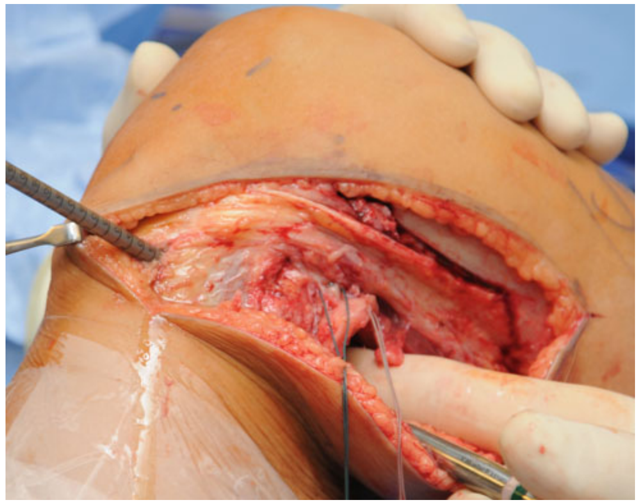

Fig. 3.16 An intraoperative photograph of a *left knee* is shown. A 9-mm reamer is used to create the tibial tunnel for a posterolateral corner reconstruction. Posteriorly, the neurovascular bundle is protected

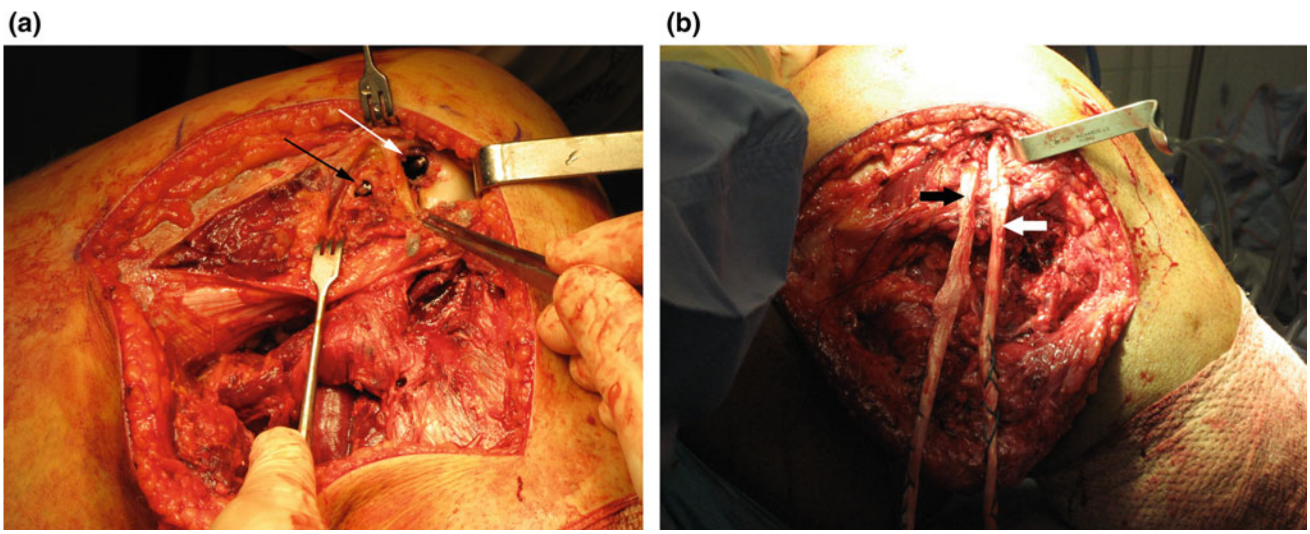

Fig. 3.17 Intraoperative photographs of a *right knee* posterolateral corner reconstruction are shown. **a** Eyelet pins are shown in the femoral attachment sites of the popliteus tendon (*white arrow*, reamed) and fibular collateral ligament (*black arrow*, not yet reamed). **b** The popliteus tendon (*white arrow*) and fibular collateral ligament (*black arrow*) allografts are shown in their femoral tunnels

through the popliteal hiatus along the anatomic path of the popliteus tendon and pulled anteriorly through the tibial tunnel. The interval deep to the superficial iliotibial band and the anterior arm of the biceps femoris long head is developed bluntly. The FCL/PFL graft is passed through this region and then through the fibular tunnel from lateral to posteromedial.

The knee is then cycled while the grafts are held tightly. The graft through the fibular tunnel is fixed using a 7-mm cannulated bioabsorbable interference screw with the knee in neutral rotation, a slight valgus stress, and flexed at 30°. After fixation in the fibular tunnel, the graft is passed anteriorly through the tibial tunnel. Using a 9-mm cannulated bioabsorbable interference screw, fixation of the grafts passing through the tibial tunnel is performed with anterior traction on the grafts, neutral rotation, and 60° of knee flexion. Supplemental fixation with a staple placed distal and medial to Gerdy's tubercle may be performed.

3.5.2 Medial and Posteromedial Knee

Most authors agree that an acute isolated MCL injury of any grade should be treated with a short period of rest with edema control and muscle reactivation followed by physical therapy for approximately 6 weeks. This is also recommended in patients with a combined ACL injury although it has been demonstrated that the loss of a functional ACL decreases the ability of the MCL to heal with nonoperative treatment [89]. However, the treatment for patients with bicruciate injuries and severe grade III medial knee injuries is less well defined; operative treatment when swelling decreases and tissues are amenable for medial knee repair with or without augmentation, and concurrent cruciate ligament reconstruction, is generally recommended for these injuries. Current literature shows that there is no significant difference between anatomic augmented repair and anatomic reconstructions. Even though both techniques fail to reproduce stability relative to the intact state, both are able to improve knee stability and significantly reduce medial joint gapping [90]. The nonoperative treatment for MCL injuries is well defined [91–96] and will not be discussed in detail.

While most patients treated nonoperatively ultimately heal their acute isolated medial knee injury, those that do not show signs of healing by approximately 6 weeks postinjury may require operative treatment. Valgus stability must be restored, whether nonoperatively or operatively, especially when combined with ACL reconstruction to minimize the risk of chronic instability and ACL graft failure. If tissues are of adequate quality for repair, a repair of the sMCL with augmentation using the semitendinosus may be performed to allow for early knee motion.

3.5.2.1 Surgical Technique

Our preferred surgical technique for severe nonrepairable acute injuries and chronic instability has been biomechanically validated and includes a reconstruction of the sMCL and POL using four tunnels and two separate grafts [97]. The patient is positioned supine on the operating table and an examination under anesthesia is performed to confirm ligamentous pathology. A proximal thigh tourniquet is applied and standard skin preparation and sterile draping is performed. For patients with concomitant intra-articular injuries, the arthroscopic assessment is delayed until the open dissection of the medial is performed to minimize tissue distortion from fluid extravasation.

The approach to the medial knee is made via an anteromedial incision from proximal, between the medial border of the patella anteriorly and the medial epicondyle posteriorly, to distal, over the pes anserine tendons (Fig. 3.18). The femoral attachment [22] of the sMCL is identified by blunt dissection.

If an autograft is preferred, the semitendinosus tendon is harvested next; however, a tibialis anterior allograft is frequently used by the authors due to the small size of the autogenous hamstrings. In preparation for autograft harvest, the gracilis and semitendinosus tendon attachments are identified by incising the anterior border of the sartorial fascia. A standard tendon harvester is used to harvest the semitendinosus tendon, and it is sectioned to create grafts of 16 and 12 cm for reconstruction of the sMCL and POL, respectively. The tendons are sized for 7-mm tunnels and tubularized with nonabsorbable suture at each end (Fig. 3.19).

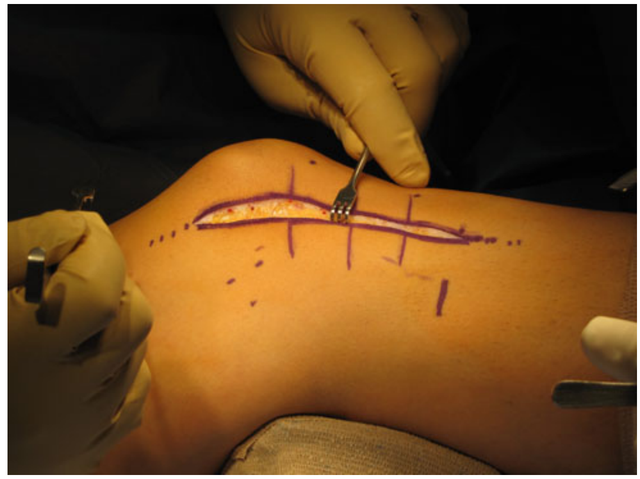

Fig. 3.18 An intraoperative photograph of the surgical approach to the medial knee is shown

In preparation for reconstruction, the sMCL and POL tibial attachments are identified [22, 97]. Utilizing anatomic landmarks, the femoral attachments of the sMCL and POL are further identified [23]. Once the femoral and tibial attachments of the sMCL and POL are identified, 30-mm-deep bone tunnels are prepared using a 7-mm cannulated drill to accommodate a 7-mm bioabsorbable interference screw (Fig. 3.20). In order to maintain screw and graft position during attachment of the interference screw, the distal edge of the tibial sMCL tunnel should be notched.

Graft placement and fixation occurs next, starting with the femoral tunnels. First, the 16-cm sMCL graft is recessed 25 mm into the femoral tunnels, and the sutures are pulled through the femur to the anterolateral thigh. Tension is placed on these sutures and the distal graft during interference screw fixation. The 12-cm POL graft is similarly recessed 25 mm in the femoral tunnel and fixed with the interference screw.

Following femoral graft fixation, final graft fixation in the tibial tunnels is performed. The sMCL graft is passed into the tibial tunnel, and tension is held with the anterolaterally exiting sutures. A varus moment is applied with the knee in neutral rotation and at 20° of flexion, and the sMCL graft is secured with the interference screw. The POL graft is then passed in a similar fashion and tensioned via traction on the anterolaterally exiting sutures in full knee extension. The interference screw is inserted with the knee in extension and neutral rotation during the application of a varus moment. Next, recreation of the two divisions of the tibial portion of the sMCL is performed utilizing a suture anchor placed

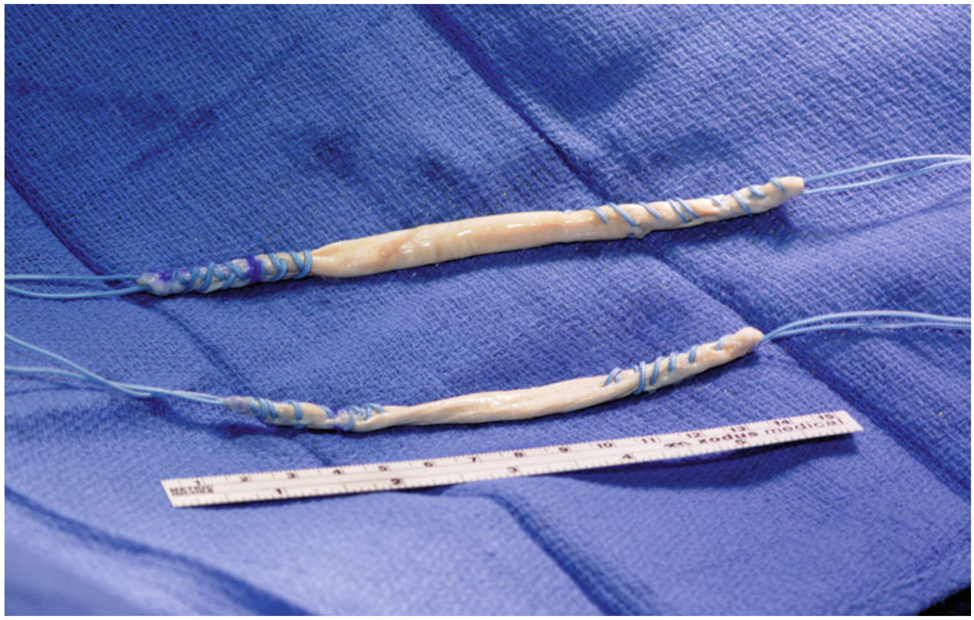

Fig. 3.19 A photograph of the 16- and 12-cm grafts for reconstruction of the superficial medial collateral ligament and posterior oblique ligament, respectively, is shown. The tendons are sized for 7-mm tunnels and tubularized with nonabsorbable suture at each end

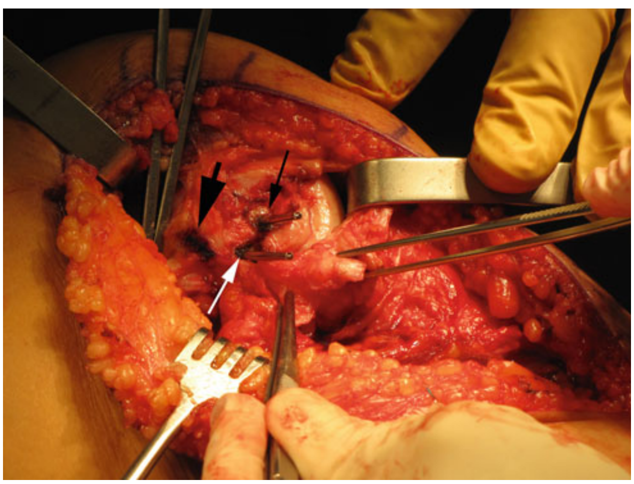

Fig. 3.20 An intraoperative photograph of the medial aspect of *left knee* is shown. The pins placed in the planned locations for the superficial medial collateral ligament (*black arrow*) and posterior oblique ligament (*white arrow*) tunnels are visible. Also, the location of the adductor tubercle is demonstrated (*arrowhead*)

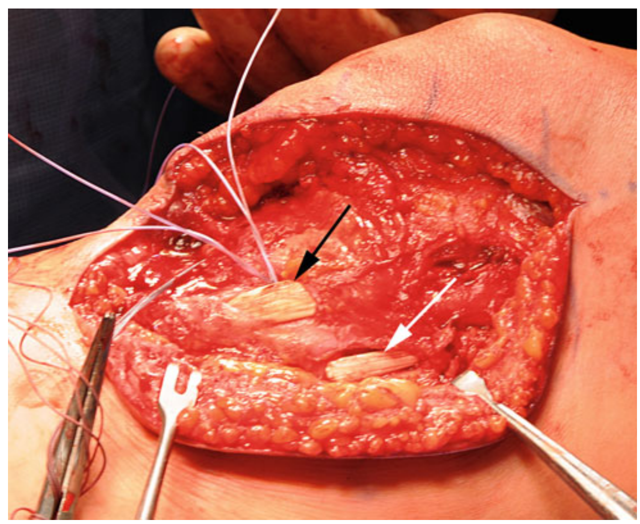

Fig. 3.21 An intraoperative photograph of the medial aspect of the *right knee* is shown. The superficial medial collateral ligament (*black arrow*) and posterior oblique ligament (*white arrow*) grafts are demonstrated

through the anterior arm of the semimembranosus, just distal to the joint line (Fig. 3.21).

3.5.3 Avoiding Tunnel Convergence

With greater injury to ligaments of the knee, tunnel convergence increases in occurrence and can potentially create obstacles during surgery and/or may reduce outcomes. This stems from the limited bone mass available in the proximal tibia and distal femur, leading to an increased risk of reconstruction graft failure from the potential damage to reconstruction grafts and the insufficient bone stock that may exist between the fixation and incorporation of the grafts [98]. When the POL tunnel was aimed at Gerdy's tubercle, a 66.7% tunnel convergence rate with the tibial PCL tunnel was repaired [99].

To address these potential complications, tibial tunnels for the reconstruction of the POL and sMCL should be directed 15 mm medial to Gerdy's tubercle and 30° distally, respectively [99]. Additionally, lateral femoral tunnels of the FCL and popliteus were found to be safe and avoid tunnel convergence with ACL tunnels if maintained in an angulation of 35°–40°, while medial femoral tunnels of the sMCL and POL likewise were safe if an angulation of 40° and 20°, respectively, were directed in the axial and coronal planes to avoid PCL reconstruction tunnels [99].

3.6 Immediate Postoperative Period

Patients are placed on self-controlled intravenous analgesia for up to the first 24 h after surgery and transitioned to oral narcotic medications. Our protocol is to place patients on enteric-coated aspirin, 325 mg daily, for 6 weeks for chemoprophylaxis against deep venous thrombosis. However, patients with a history of a deep venous thrombosis or coagulopathy are initiated on daily enoxaparin (Sanofi Aventis, Bridgewater, New Jersey) 40 mg subcutaneously for 4 weeks. Hourly ankle pumps are ordered, and intermittent compression devices are applied for 24 h postoperatively.

3.7 Rehabilitation

Postoperative rehabilitation is a crucial component of the treatment following surgical repair or reconstruction of lateral and medial knee injuries. In fact, preoperative knee rehabilitation has been advocated as an option to improve range of motion and increase quadriceps control [100]. This will also help to clarify postoperative restrictions and the required rehabilitation protocol for the patient. Postoperatively, the patient's knee is kept in full extension in an immobilizer for the first 2 weeks except when working on their "safe zone" range of knee motion. Patients are allowed to initiate weight bearing as tolerated at 6 weeks postoperatively. A full discussion of rehab protocol is beyond the scope of this text but has been described in detail in the lateral [100] and medial [17, 24, 91, 94, 96, 101, 102] knee literature.

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